MASTER

WATERPOWER '79

an international conference on small-scale hydropower

OCTOBER 1-3, 1979

PROCEEDINGS

ARMY CORPS OF ENGINEERS

U.S. DEPARTMENT OF ENERGY

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

CONF-791056--

DISCLAIMER

This book was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

WATERPOWER '79:

The First International Conference on Small-Scale Hydropower

CONFERENCE PROCEEDINGS

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

MGW

This publication contains the papers and addresses presented at Waterpower '79. The views represented here are not necessarily those of the U.S. Army Corps of Engineers, the U.S. Department of Energy, or other public and private entities with which the authors are associated.

FOREWORD

This volume contains the proceedings of "Waterpower '79: An International Conference on Small-Scale Hydropower," held in Washington, D.C., October 1-3, 1979. The subject of small-scale hydropower is a timely one, particularly in view of the interest in renewable energy resources and the need in the United States and in other countries to develop less reliance on fuel imports.

In the Fall of 1978 both the U.S. Army Corps of Engineers and the U.S. Department of Energy were independently developing plans for a 1979 Small-Scale Hydropower Conference. When this was discovered, the agencies joined forces, drawing upon existing staff and resources, for an even more effective effort in developing the Conference. In the initial phases of the Conference development, it was quickly determined that there were many separate efforts underway to advance the use of hydropower, such as:

(1) The Corps of Engineers was conducting the National Hydroelectric Power Resources Study authorized in Section 167 of the Water Resources Development Act of 1976. As outlined by Congress, the study objectives were comprehensive, ranging from an assessment of future sites and their power potential to analyses of social, legal, environmental, and institutional aspects of hydroelectric power development.

(2) In 1977, the U.S. Department of Energy began a Small-Hydro Development Program dealing with the commercialization of small-scale hydropower. The program was orgainzed into special studies, grants, demonstration projects, workshops and user documents..

(3) International interests in both the application of, and the potential for, small-scale hydropower was substantial. Developed countries wished to export equipment while developing countries wished to import these goods and services. The range of interest extends from financial institutions such as the World Bank to technical assistance provided by organizations such as A.I.D., in the U.S. Department of State, to a desire, in many countries, in Asia, Latin America, Africa, and the Middle East, for feasibility assessments.

(4) Several public and private organizations in the U.S. were conducting studies specifically to examine the feasibility of hydropower. These include the U.S. Department of Interior through the Water and Power Resources Service and the U.S. Water Resources Council through various River Basin Commissions, trade associations, universities, public and private laboratories, public and private utilities, U.S. and foreign manufacturers, state and local governments, entrepreneurs, A-E firms, special interest groups, and Congress.

The principal objective of the Conference was to provide a suitable information exchange forum for all of the organizations and individuals concerned about the future of hydroelectric power. This objective was accomplished by bringing together the diverse talents and insights of conference participants for discussion and exchange of ideas on the role of hydropower in meeting national and international energy needs.

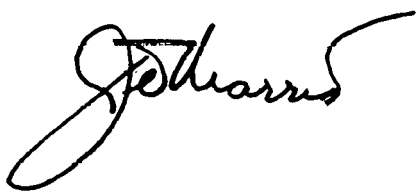
Several committees were formed for the purposes of planning and managing Waterpower '79. The major committee was the Steering Committee which provided overall guidance for planning the Conference. Members of

the Steering Committee were: Brigadier General Hugh Robinson, Chairman, Deputy Director, Civil Works, U.S. Army Corps of Engineers; James R. Hanchey, Acting Director, Institute for Water Resources, U.S. Army Corps of Engineers; Richard J. McDonald, Study Manager, National Hydropower Study (formerly Resource Manager for Hydroelectric Power, Department of Energy); and Alex Shawiko, Chief, Planning Division, Office of the Chief of Engineers, U.S. Army Corps of Engineers. Two additional committees were established: The Technical Program Committee, chaired by David Zoellner, Institute for Water Resources, U.S. Army Corps of Engineers and the Workshop Program Committee which was chaired by Margaret McClements Lambie, Small-Hydro Program Staff, U.S. Department of Energy.

This volume includes all of the technical papers presented at the Conference together with plenary presentations, executive, keynote and special addresses and summaries of the workshop sessions. All of the papers herein are published with the permission of the authors. Appendix A contains a hydropower glossary, Appendix B a listing of the technical session chairmen, Appendix C a listing of the exhibitors and Appendix D a listing of the authors.

The Assistant Secretary for Resource Applications, U.S. Department of Energy and his staff supported the endeavor from the beginning, and continued to lend assistance throughout the Conference. As Co-chairman of the Conference, I wish to acknowledge and express my genuine appreciation to the Department of Energy and the Corps of Engineers' conference planners, organizers, coordinators, and participants who contributed to the success of the Conference.

My thanks to everyone.



J. W. MORRIS
Lieutenant General, U.S.A.
Chief of Engineers

CONTENTS

Page

Foreword iii

Keynote Address:

Energy Policy
Jack H. Watson, Jr. 1

Executive Addresses:

The Potential of Hydropower
I.TG J. W. Morris 11
George S. McIsaac 17

Plenary Addresses:

Engineering Plenary Session
Norman M. Clapp 27

Policy Plenary Session
Georgiana Sheldon 33

Planning, Information and Methods
Alex P. Mercure 39

International Perspectives
Emil F. Musonyi 45

Special Plenary
Senator John A. Durkin 55

Special Panel Address
Peter Bourne 63

Closing Addresses:

The Future Role of Hydropower in the World Energy Context
Ellis Armstrong 69

Waterpower: An Agenda for the Eighties
Senator Mike Gravel 79

PRESENTATIONS

ENGINEERING

Page

Session 1 — Equipment

Small-Hydro Control and Operation
by *Howard A. Mayo, Jr.* 89
Development Concept for Kaplan-Tube Turbines
by *Otto Hartmann* 99
Small-Scale Hydro: The Use of Pumps as Turbines
by *John D. Lawrence* 108
Modernization of Hydroelectric Units
by *Grover F. Wachter* 116
The Ossberger Cross-Flow Turbines
by *F. W. E. Stapenhorst* 142

Session 2 — Redevelopment I

Redevelopment of Older Hydroelectric Generating Plants—A Three-Phase Approach by *Alfred G. Trott* 154
Small-Scale Hydroelectric Development at Existing Public Projects
by *Daniel E. Steiner* and *Albert R. Stritt* 157
Policy for Applying Small Hydro to a Utility System
by *Arthur E. Allen* 163
Hydropower Development at Water Supply Dams
by *Lewis E. Linzell* 169

Session 3 — Generation Systems

Energy Losses at Hydroelectric Powerplants
by *C. C. Purdy* 176
A Review of Induction Generators and Their Application to Small-Hydroelectric Powerplants by *John Slapp* and *Narain G. Hingorani* 185
Calculations of Circuit Breaker Closing Criteria for Synchronizing a Generator by *Robert W. Beckwith* 196
Package Electrical Equipment for Mini-Hydropower Stations by *Johan Bergseng, Hermann J. Besel, Friedrich Riezinger* and *Horst Butz* 202

Session 4 — Hydraulics and Hydrology

Practical Hydrology for Hydroplant Planning and Design
by *John H. Dixon* 210
Determination of Flow-Duration Curves at Ungaged Points in Regulated Streams by *Rickey Emmert* and *LeRoy F. Heitz* 218
Complexity of Hydraulic Problems in Low-Head Hydroelectric Developments by *Alexander B. Rudavsky* and *Sun-Quan Yuan* 226
Hydrologic Investigations for Hydroelectric Power
by *James G. Dalton* and *Gary M. Franc* 234

Page

Session 12 — New Ideas, Concepts and Technology I

Research and Development Needs for Alternative Approaches to Small Hydropower by *Edward J. Fritz* 260
Concepts for Small-Scale Hybrid Solar-Hydroelectric Powerplants by *R. Lewis French* and *K. Thomas Miller* 265
The Schneider Engine: Performance and Applications for Hydropower by *Daniel J. Schneider* and *Emory K. Damstrom* 273
The Need for and Application of Micro-Hydroelectric Technology by *Timothy J. Maloney* 302

Session 19 — Redevelopment II

Small-Scale Hydropower Application of Hydroelectric Mini Units by *H. Sattler* 306
Dam Safety — An Important Factor in Considering Small-Scale Hydropower at Existing Reservoirs by *Anthony R. Dolcimascolo* ... 317
Retired Hydropower Plant Sites in the United States by *Eugene A. Jarecki, Daniel R. McConnell* and *Ernest E. Sligh* 323
Minimizing Capital Cost in Small-Scale Hydro Development by *Malcolm R. Vanderburgh* and *David C. Willett* 333

Session 20 — Development and Operation Economics

A Basic Economic Comparison of Small-Scale Hydroelectric Busbar Costs by *James P. Searls* 342
Economic Evaluation of Small-Scale Hydropower Plants by *Alvin S. Goodman* and *Ruben S. Brown* 350
A Conceptual Economic Model of Small-Scale, Run-of-River Hydroelectric Facilities by *Donald W. Lystra* 361
Comparative Project Economics of Small-Scale Hydropower by *Kemal Satir* 368

Session 21 — New Ideas, Concepts, and Technology II

Identification of Hydroelectric Research in Support of Small and Large-Scale Developments by *Antonio Ferreira* 378
The Vertical Hydraulic Ram — A Low-Head, High-Flow Device for Power Development Design Outline for a 1000 kW Plant for a Six-Foot Head by *Hamilton Baird* 382
Hydroelectric Development, Without Dams, Reservoirs and Penstocks by *Phillip R. Hoffman* 388
Appropriate Technology in Hydropower by *Rene D. Tegtmeyer* 394

PLANNING, INFORMATION AND METHODS

Page

Session 7 — Social and Environmental Analyses I

Community and Social Impacts from Hydropower Development by *Shirlene Clemence* 404
Fish Passage and Small Hydroelectric Technology: A State-of-the-Art Review by *Milo C. Bell* and *Stephen G. Hildebrand* 411
Small-Scale Hydropower — An Opportunity for Historic Preservation by *William J. Novak* and *Richard T. Heiderstadt* 418

Session 8 — Planning for Development I

Low-Head Hydroelectric Evaluation and Inventory by *Nelson J. Jacobs* 424
Methodology for Conducting a Resource Assessment of Small-Scale Hydropower Potential by *Thomas E. Klock* 431
Screening Studies for Small-Scale Hydropower Potential by *Alexander C. George* 441
Interagency Coordination for Small Hydroelectric Power Development in Alaska by *Loran R. Baxter* and *Weldon A. Opp* ... 448

Session 9 — Case Studies and Demonstration Projects I

Feasibility Investigations of Five Low-Head Hydroelectric Projects Under Department of Energy Grant Programs by *James V. Williamson* and *A. Wayne Pietz*..... 452
Powerhouse Restoration at Hagley by *Lee DeHeer*..... 460
Idaho Falls Low-Head Hydroelectric Demonstration Project by *Pablo Chavez* 464

Session 15 — Social and Environmental Analyses II

Tapping the Boundless Resource to Solve Energy Problems by *Roger E. Hamlin* 486
Environmental Impact Assessment Methodology of Small-Scale Hydroelectric Projects by *Richard K. Carlisle* and *Donald W. Lystra*..... 492
Analysis of Environmental Impacts of Water Level Fluctuation in Reservoirs at Hydroelectric Sites by *Adam T. Szluha, James M. Loar, Ralph R. Turner,* and *Stephen G. Hildebrand*..... 498
Three-Agency Control for Co-Dependent Hydroelectric Facility by *Samuel E. Barnes*..... 504

Session 16 — Planning for Development II

Planning Small-Scale Hydropower Additions by *Darryl W. Davis* 520
Marketability of Low-Head Hydropower by *Stephen T. Lee, G. Paul Grimsrud, Man-Loong Chan, Eric Marsh, Glenn H. Masters, J. Randall Threadgill,* and *Abner W. Watts*..... 527

Page

Small-Scale Hydropower Development: How New Hampshire is Making It Happen by *Louis H. Klotz, Fred K. Manasse* and *David B. Master* 533
The Optimization of Civil Works Design for Small-Scale Hydropower Projects by *Kenneth R. Broome* and *Howard A. Mayo, Jr.* 539

Session 17 — Case Studies and Demonstration Projects II

The Annapolis Tidal Power Pilot Project by *G. C. Baker, E. M. Wilson, H. Miller, R. A. Gibson* and *M. Balls* 550
Case Study — Rollins Power Project: Bear River, California by *David C. Willer* 561
Case Study — Broadwater Dam Power Project: Missouri River, Montana by *Gordon E. Little* 568
Preliminary Feasibility Study for Hydropower at Brandon Road Lock and Dam by *Gerald J. Stadler* and *Brian Moentenich* 575

Session 18 — Planning for Development III

Study of Factors Affecting Feasibility of Low-Head Hydroelectric Generation by *Edmond R. Bates* 586
A River Basin Code and Mapping System for Hydropower Sites by *Eugene A. Jarecki* and *Thomas F. Papsidero* 591
An Engineering/Economic Model for Evaluation of Small-Scale Hydropower Feasibility by *Dilip R. Limaye, Thomas C. Hough* and *William Meroney* 597
Support Services for Small Hydroelectric Projects in North Carolina by *John L. Warren* 603

Session 22 — New Techniques and Projects

Potential Hydropower Development for Vertical Turbine-Spillway Combine by *W. Y. Chow* and *Alexander B. Rudavsky* 608
Small-Scale Hydro Simulation Program by *J. J. Mankauskas, Jr.* and *E. S. Wright* 617
Small-Scale Hydroelectric Generation and the Salt River Project by *Eugene J. Lauerman* 626
Weed Hydroelectric Development — A Small-Hydro Case Study by *James D. Calvert, Jr.* 633

POLICY

Page

Session 5 — Public and Private Finance

Policy Recommendations for Federal and State Governments to Ease Financial Constraints on Limited Resource Hydropower Developers by *J. Keen Holland* 646
Municipal Financing of Small-Scale Hydropower by *Larry Hobart* 652
The Financing of Small-Scale Hydropower by *George L. Tuttle* .. 657

Session 6 — Water: Management and Use

Development of a Small-Scale Hydroelectric Project: Policy and Political Considerations, Broadwater Dam, Montana by *Richard L. Bondy* 662
Federal Reserved Water Rights: Impact on Small-Scale Hydropower Development by *Gary J. Fisher* 667
Procedures for Evaluating National Economic Development (NED) Benefits from Federal Small-Scale Hydropower Projects by *James F. Johnson* 670
Overview of the National Hydropower Study: The Value, Potential, and Role of Hydropower as a Future Energy Source by *James R. Hanchey* 675

Session 13 — Environmental Issues and Impacts

The Department of Energy Environmental Subprogram Plan for Small Hydroelectric Development by *Stephen G. Hildebrand* and *George B. Grimes, Jr.* 682
Land Use and Small-Scale Hydropower: An Overview of Environmental Impacts and Institutional Responses by *Reuben C. Plantico* 688
Recent Congressional Action Affecting Small-Scale Hydropower by *Sarah J. Glazer* 693

Session 14 — Energy

An Analysis of Institutional, Economic and Environmental Restraints on Hydroelectric Development at Existing Dams by *Robert J. Taylor* 700
Private Financing of Small-Scale Hydro Projects by *Hugh W. McLeod* 708
Electricity Generation in Rural Areas: A Future for Small-Scale Hydro Projects by *William B. Telaar* 711
The Social Implications of Hydroelectric Energy by *John A. Waring* 715

Session 23 — Problems, Economics and Ideas

Small-Scale Hydropower Development in the West by *Alfred C. Ingersoll, Fred K. Manasse, J. Morley English,* and *David B. Master* 720
Problems in Evaluation of Federal Small-Hydro Projects by *Richard L. Mittlestadt* 727

INTERNATIONAL PERSPECTIVES

Page

Session 10 — Development Experiences

A Tale of Two Federal Systems: Canadian-American Law on Hydroelectric Development by *Peter W. Brown* 738
Small-Scale Hydropower Generation in Non-Oil-Producing Developing Nations: Some Policy Issues by *Franklin J. Ahimaz* . 743
Small Decentralized Hydropower for Developing Countries by *Kenneth Grover* 748
The Role of Small Hydroelectric Power Generation in the Energy Mix Development for the People's Republic of China by *Alexander A. Tseng, Deng Binli, Mao Wenshen,* and *Tu Zhaoxiang* 755

Session 11 — Technology

Modern Small-Scale Hydro Turbines by *Nils H. Rhmcke* 764
Small-Scale Hydropower: An Appropriate Technology for Less-Developed Countries by *Robert D. Kersten* 776
Micro-Hydro as an Appropriate Technology in Developing Countries by *Rupert J. Armstrong-Evans* 782
Small Hydro — A Viable Alternative Now by *John S. Gladwell* and *Calvin C. Warnick* 796

Page

WORKSHOP SUMMARIES

Workshop One
Financing and Marketing 805

Workshop Two
Planning 809

Workshop Three
Developing Policy/Legal Context 813

Workshop Four
Government Funding 815

Workshop Five
Licensing 821

Workshop Six
Engineering 823

Workshop Seven
Dam Inspection, Safety and Adequacy 827

Workshop Eight
Environmental Issues 829

APPENDICES

Appendix A: Glossary 837

Appendix B: Technical Paper Session and Workshop Chairmen 853

Appendix C: Exhibitors 861

Appendix D: Authors 867

KEYNOTE ADDRESS

Jack H. Watson, Jr.
White House Staff

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

THE ROLE OF SMALL-SCALE HYDROPOWER IN EMERGING ENERGY POLICY

KEYNOTE ADDRESS

Jack H. Watson, Jr.

Thank you General. I am very pleased and honored to welcome all of you to Washington, D.C.—those of you who are not working here regularly, and specifically to bring you the greetings of the President, who knows that I am here, and who, in fact, would like very much to be here himself. He'd like to be here really for a very simple reason and that is that there are few subjects which are more compellingly important to him and to the country; and, since I know that this is an international audience to the world, where the subject of energy, energy policy, and energy challenge is discussed. So, by a distinguished group of men and women such as this one gathered together to address with their wealth of experience, expertise, and talent on that subject, and what to do about it—it is the place where either the President or someone on his behalf ought to be, and I am glad to be the one here.

In the President's speech, or I should say speeches to the nation, both earlier this year in April and then significantly in July—on July 15 the Sunday night speech, July 16, his speech to the National Association of Counties, as many of you know, the President outlined many steps that he either has taken or thinks the country should be taking to reduce this nation's dependency on foreign oil. Let me comment on that very briefly, because I do not need to preach to this choir. The fact of the matter is that this country's dependency on imported oil is intolerable. It is a dependency which is economically weakening. For every million barrels of oil that flows into this country every day, we are importing inflation. Make no mistake about that. For every 10 billion dollars that flow out of this country, and literally 56 or 57 billion dollars will flow out this year alone to buy foreign oil, we are exporting jobs as we export those dollars. We are exporting American jobs. Without belaboring the fact, I shall simply say, understanding the presence not only of civilian but of military leadership in this room, and this conference as well, that a dependency of this sort, that we are in right now, with respect to imported oil, is also very threatening to our national security. For us to be so dependent day in and day out on a long thin grey line of tankers that stretch half way around the world bringing the necessary crude oil to these shores upon which virtually 50% of all our crude oil used, we depend upon to run our trucks and barges, to fire plants, to heat houses and commercial and industrial buildings. In fact, to move this country, it is a dependency which we cannot tolerate and it is a dependency about which the President has been speaking with a genuine sense of urgency, and a genuine call to arms virtually since coming into office.

When he called the energy crisis the moral equivalent of war $2^1/_2$ years ago in the Spring of 1977, scarcely 90 days after being inaugurated as President,

Mr. Watson is the President's Chief of Staff, The White House.

there were a lot of people who ignored the comment, there were others who ridiculed it. I think the events of the last 2½ years and particularly the events of this year—this summer where the country sprawled and felt first-hand the rising oil prices, gasoline prices, diesel fuel prices, long gasoline lines all over the country, point this out. We are in much less of a mood now either to ignore or to ridicule that characterization.

The President has said time and again with emphasis and force, that we must by 1990 be importing 8-1/2 million barrels of oil per day less than what we would be importing if we simply continued our level of 1977 imports. If we did that immediately, ladies and gentlemen, we would be importing by 1990 somewhere between 13 & 14 million barrels of oil a day, and the costs of that are incapable of estimating at this time. We expect that we will spend some 70 billion dollars next year for imported oil as we are spending some 55 or 56 this year.

The steps which the President has taken and the Congress has approved with the National Energy Act, for example, and specifically with the President's own decision to phase the decontrol of the price of domestic crude oil, have resulted, and will result in a savings of about 4 million barrels of oil a day. He outlined earlier this year—earlier this summer—a series of other steps that will peg down another 4-1/2 million barrels of oil a day, so that instead of 13 or 14 million barrels of oil imported by 1990 we should be importing,if we are serious and dedicated to the track which the President outlined and to which he calls us, about 4-1/2 million barrels—half of what we are doing right now.

If you ask what sort of proposals has the President outlined to get us there, this speech will not be long enough to include them all. I'll simply reference, in addition to phase-decontrolled domestic crude oil prices, his proposals about the Energy Security Corporation and the creation of an energy security trust fund, funded out of the Windfall Profits Tax which I expect will pass this month—the creation of an energy mobilization board, the fundamental purpose of which is to expedite the development of those vitally important alternative energy sources, synthetic fuels, unconventional gas, and others. He has already put into law, or is proposing, a broad ranging series of incentives, many of them in the tax code to the form of tax credit; many of them in the form of grants, loans, loan guarantees, low-interest rates, subsidies on development of various sorts for heavy oil, unconventional gas, oil-shale production, solar and others. He's proposed a solar bank. But, I don't want this morning to talk even more than I have already about the large-scale big-ticket items such as the synthetic fuels development program, which he proposes, and which I suspect many of you know about. The press and the public attention has been riveted on the big-ticket items—they are riveted on the Energy Security Corporation, on the synthetic fuel development proposal, on the 2-1/2 million barrels per day goal by 1990 that the President has signalled for the Synthetic Fuels Development Program.

I'd like to talk about something different which is just as important—and the pay-off just as great as those large-scale items. One area is energy conservation. There has not been a great deal of discussion yet, not nearly as much as there will be or ought to be about energy conservation, but make no mistake about one fact—and it's a fact—energy conservation is no catch phrase to be used for rhetorical purposes only—energy conservation is the

cheapest, quickest, most dramatic, most effective way for us to displace oil imports. This country depends on those imported barrels of oil to the tune of about 37-40% of our total energy consumption for the heating of our buildings, houses, apartments, and commercial buildings. The estimates vary considerably, based upon what assumptions you choose to make, but the pay-off in terms of increasing the energy efficiency of buildings in this country—weatherizing buildings for example, range from 1 million barrels a day up as high as 2-1/2 million barrels a day at a cost enormously cheaper than the development of synthetic fuels. Sophisticated folks have nodded their heads knowingly when people talked about ride-sharing,van-pooling, car-pooling. If this nation set its mind to an effective nationwide effort, to share rides, to take 1 person per car and expand it to 2-1/2 or 3 persons per car on an average, we could be saving by 1985, not 1990, some 500 thousand barrels of oil a day. That's a big pay-off—a pay-off that would cost us virtually nothing.

The utilities in this country are using about a million and a half barrels of oil a day to produce electricity. The President has said that by 1990 he wants those utility companies to be using half as much oil. He wants a massive concerted oil-to-coal switching effort, which will be saving us by 1990, if we hold to that track, 750,000 barrels of oil a day. Without giving you an elaboration, I'll simply enumerate the proposals like energy audit of both residence and commercial buildings requiring utility companies to do just that and then to follow-up on energy efficiency items at low-cost, long-range interest rates; requiring the states of the country—the 50 states—to set targets for gasoline consumption and ways to meet those targets. The President's proposal of an additional 16 billion dollars for public transportation, which as he said in New York last Tuesday, should put another 15 million passengers per day in public transportation by 1990, and save us hundreds of thousands of barrels of oil a day. One of the things this country is preoccupied with and has been for a long time—certainly all during my life—is the concept of the 10-strike. If you can't, in bowling terms, get a 10-strike, don't fool with it!! We are impatient with incremental things, we are impatient with the knowledge that we ought to have and that our experience teaches us, that there are very few 10-strikes to deal with the really big issues of the day—whether the issues are inflation or energy related—we have to do many things—many things—no one thing will suffice however grand. We have a kind of mega-solution syndrome, in a time where there aren't any mega-solutions. It's a syndrome from which we must escape.

I want to read a quote that I do not have committed to mind that demonstrates, I think, as well as I could possibly do myself, the President's own sense of how many things we need to do in the energy area of a dispersed nature—how many things must be done by local communities, at local initiatives for local pay off rather than from some one big central government force. Here's what he said last May in a speech that he gave in Des Moines, Iowa, "I can remember as a boy" he said, "growing up in rural America, what a wonderful change came over my family's life when electricity came to our farm. It was the biggest single event of my childhood" he said, "I can remember that our farm had a windmill to pump water, and we burned wood for fuel. We hadn't thought of solar energy then, or gasohol, but I know we would have used them gladly if we had. We would have thought of new energy ideas not as far-

fetched, but as far-sighted." He continued "Rural areas offer so many special opportunities—Harnessing our rushing streams, our forests, the gas we now flare off from coal mines, and our agricultural abundance. Those are also the best places to see the virtues of practical thought and local initiative. You begin to understand the value of individual effort and small-scale cooperative projects." Then he concluded by saying, "These virtues are not outmoded in a modern society, they are virtues that must lead us into the future. They show us the way to the security and to the self-sufficiency in energy that we have about lost."

Being President of a powerful, complicated, diverse fascinating nation is one of the great tasks that the world imposes on anyone. It is a task that consists of large parts and little ones—one of the things perhaps above all else that the President must do as part of this task right now in energy is to engage the imagination, and the ingenuity, and the participation of literally millions of Americans all over the country in this energy effort. We must break. We must shatter the conception that it can be done by massive programs—those programs have their parts to play to be sure, but in order for us to do what we must do, the kinds of things that you will be discussing here with small-scale hydroelectric power and others are essential. . . (That quote I just gave you was part of a speech that he gave at the Iowa County Commissioners Association in Des Moines, where he outlined a bunch of small-scale energy alternative solutions that we were pursuing, and are pursuing—one was an agreement involving the Department of Energy, Farmers Home Administration, the Economic Development Administration and Community Services Administration (CSA) to assist in the construction of up to 100 small-scale fuel alcohol plants all over the country—Gasohol plants). He also announced an agreement involving again the Department of Energy, Bureau of Reclamation, Economic Development Administration, Farmers Home Administration, Rural Electric Administration, Housing and Urban Development and CSA again to assist in the construction of 100 small-scale hydroelectric sites—generating sites—by 1981, and 300 of them by the end of 1985. He set aside a package of funding forces from all those agencies aggregating about 300 million dollars in 1980 and 1981 for the building of those 100 and then those 300 sites in the following years. I am pleased to say that since May, 900 sites have already been identified and nominated for assistance under the agreement, and the ones identified include about 440 which have already been referred to the Corps or to the Bureau of Reclamation and private engineers and on-site engineering and economic feasibility studies are underway. For those sites where economic and engineering feasibility studies have already been established, the owners and the project sponsors all over the country are already beginning to work with the Federal Development Agencies specifically to define the development package.

We are moving—we'll have those 100 sites and more by the end of 1981—I have no doubt about it—I think 300 sites by the end of 1985 is a modest goal. We should exceed it significantly. In New England, for example, I am informed by the Corps and others with whom we are working in the White House, that a six-stage hydroelectric-power working group composed of all the relevant Federal agencies as well as those from the states and industry are working to facilitate funding for the construction of hydro facilities in that part of the country where the dependency on oil, particularly for home heat-

ing, is so desperately high and where the costs of home heating fuel for this winter pose a great problem. We cannot move too fast. When the President made his trip down the Mississippi River on the Delta Queen, he announced that when he got back he would direct the Corps, the Bureau of Reclamation, and the Department of Energy to develop legislation that would authorize and facilitate construction of hydro facilities at Federal dams. That legislation has now been prepared and it will be introduced in the Congress within the next few days.

Let me give you a couple of facts so that you will have some context for the hydroelectric power situation that we face in this country. We estimate that the undeveloped hydroelectric potential at existing dams throughout this country is about 27,000 megawatts per year—that potential capacity is equivalent to about 140 million barrels of oil per year which in turn is enough to supply the electricity needs of about 8-1/2-9-1/2 million Americans. I am told by General Morris and General Robinson that as many as 5200 existing dams all over the country, virtually in every part of the country, could be economically converted to produce small-scale hydropower. We have been using hydropower in this country for almost a century. The first powerplant with a 200 watt generating capacity was built in 1882 at Appleton, Wisconsin. Since that time we have, as all of you know, built very large hydroelectric power dams on major rivers and they have been providing for years one of the cleanest and safest energy sources in the country. But as part of our mega-solution complex we stopped searching the small areas, we went only with the giants. And now today I am predicting I think, absolutely safely, that our attention has turned and will continue to turn to the small-scale effort. Why are small-scale hydroelectric power sites so attractive to us? There are a lot of reasons—they involve no new environmental impacts. Generally speaking, they are virtually non-polluting—they are using a renewable resource—flowing water—they are small and almost invariably can be aesthetically acceptable—even pleasing—the effects on stream ecology of small-scale hydro are very minor, sometimes even positive, which is not, as you know, necessarily true of the small-scale hydro. And the technology for the hydroplant is established. The available technology is there—although in this country, (I should footnote) we do not have that technology standardized and mass produced in the way that it is in some other countries like Great Britain—and we need to do that if we are going to proceed on a national scale. We must do that and part of the benefit which I hope will result from a conference and other conferences like this one will be an exchange of expertise and technical knowledge with respect to the standardization and mass production of that small-scale hydropower generation. The DOE has several other electric power programs which I will only mention—one of them has a 10 million dollar program in '79 and '80. Budget authorizes loans, feasibility studies, and related licensing for small-scale projects all over the country. We've got 160 feasibility studies and 80 licensing loans expected by the end of this fiscal year under that program—under a demonstration program DOE entered earlier this year into cost-sharing agreements totalling 4.2 million dollars in outright grants for construction of hydro facilities—again, throughout the country.

Since we have some friends from other countries, let me comment very briefly before I close, on the international aspect of this issue—this conference is important and useful, I think, because it provides the forum for new

ideas, experience and expertise exchange. It is important, useful, and timely because hydroelectric power is something that can be used all over the world, and the potential of which I am not expert enough to know but which I imagine to be enormous for all of us—I need not explain to this audience nor spend a moment further on the facts that energy is not just the United States' problem. It's a world problem. That supply of crude oil is running out for us all—not just the United States and in fact, the implication of a competition for a constantly diminishing supply of essential fuel among allies and friends—are not altogether positive implications—we need together in an internationally concerted effort to turn our attention and our resources, and our technology, and our ingenuity and our financial resources into the development of these alternative fuels—be they synthetic or renewable or whatever. As many of you know the U.S. is committed to cooperative energy development with other countries through the International Energy Development Program (OEDP) which was initiated in September of 1977, and DOE in this country is responsible for its overall management, with policy guidance from the Department of State. And among other things that program is facilitating the development of an energy plan in a host country by a joint team or teams of U.S. and host country specialists. We have already made assessments under this plan and program for Egypt and Peru and others are being initiated in Argentina, Portugal, South Korea and other countries. It is interesting to note and important, I think, that AID in this country—as well as the International Finance Community at large are recognizing increasingly the great potential for small-scale hydropower and they are expressing interests in participating in the implementation of projects identified in those assessments.

Please permit me a personal observation: dealing with the energy crisis, and I use that word advisedly, that confronts this country and the world is at the same moment a great opportunity and a great challenge. It is a great challenge because the energy crisis, the energy circumstances of this time, this day, this moment in history constitutes such a clear and unmistakable test of our will, our will as a people of the United States of America and to the visitors from foreign countries to the people of your own country as well. The energy challenge, I think, poses some very fundamental questions to us as a people running things on this planet right now. It poses questions about our capacities to respond to change, to discipline ourselves—that's particularly true of Americans—Can we do it? Will we do it? And without being dramatic, it poses fundamental questions about our capacity to be a generation of Americans and citizens of the world on the forward cutting edge of an era the outlines of which we can not and do not clearly perceive yet. We are that generation of people looking somewhat dimly into an energy era that's not yet formed. We are transitioning from a time of peace and plentiful crude oil to a time without it—and the challenges of that are great—I said it was a great opportunity as well. Why? It's an opportunity because it gives us a chance both in this country and across national borders to unite to do something in our common interest for a common purpose towards common goals of energy dependence and energy security. We talked, in the past, in this country of an energy independence. I don't think that is realistic. I think we must think in terms both in this country and in others of energy security because we have needed and will continue to need each other; but we must define those needs in the context of security. It's also a great opportunity—this energy crisis—

because it gives us a chance again as a people whether Americans or Britons or French or Africans or Indians or South Americans, to re-examine who we are and what we've got. What is important to us as societies—what we are capable of doing in terms of defining those societies in changing times. It gives us a chance to re-examine at a pivitol moment just exactly what kind of legacy we want to leave to our children and their children. It is my own personal view that we are equal both to the challenge and to the opportunity of this moment. But again, the simple fact of the matter is that time will tell that soon enough! Thank you very much.

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

EXECUTIVE ADDRESSES

Lt. General J. W. Morris
Chief of Engineers
U.S. Army Corps of Engineers

George S. McIsaac
Assistant Secretary
Resource Applications
U.S. Department of Energy

A NATIONAL ENERGY PERSPECTIVE

Lieutenant General John W. Morris

In spite of internal and external strife and economic peaks and valleys since 1776, the United States rolled into the halfway mark of this 20th century like an express train, sleek and on track. But a couple of disturbing things happened on the way to the 21st century: the cost of fuel and the price of gold escalated astronomically. Oil which we had always considered plentiful and cheap suddenly became scarce and expensive. And the price of gold on the international market reached $400 an ounce, a tenfold increase from the long established price of less than $40.

These two developments knocked many previous economic theories and conclusions into a cocked hat. Marginal gold mines which had been overlooked for decades suddenly became attractive to prospectors and investors alike. Hundreds of people are again panning for gold along our western rivers. Similarly, hydroelectric power development at many dam projects which had not been economically feasible in the past, suddenly became attractive investments.

Almost overnight the economic stability and national security of our country were threatened. The oil embargo demonstrated our crippling dependence on foreign oil as OPEC prices skyrocketed and the price of gasoline at the pump doubled. The urgency of accelerating domestic production of oil and full development of all other potential energy sources became a high national priority.

This international symposium will probe into the development of hydropower at small-scale dams, a significant untapped potential for additional electric energy here and throughout the world.

Our situation is not unlike that of Ruth in the Old Testament who gleaned barley after the reapers, or today's workers who glean the cotton or corn left behind by modern mechanical harvesting machines. Since 1900, we moved across the country from coast-to-coast like a giant machine harvesting the choice hydropower sites. We are now retracing our steps, gleaning the potential-power sites we overlooked before the escalating cost of fossil fuels, that made hydropower more competitive.

No rock should be left unturned in our search for alternatives to fossil fuels as sources of energy. Certainly we must take advantage of waterpower, much like the pioneers in the early days of our country. Their primitive waterwheels used flowing rivers and streams to power their factories, grind their corn, wheat and other grains. Likewise, our turbines and generators, large and small, should take maximum advantage of our waters to provide electricity for our homes, our farms and our industries.

I said that we must leave no rock unturned as we retrace our steps to glean all the possible untapped sources of hydropower. I will digress momentarily from the theme of this conference to assure you that in our search for small-

---

Lieutenant General Morris is Chief of Engineers, U.S. Army Corps of Engineers, Washington, D.C.

scale hydropower sites, we are not neglecting the full development of major hydropower sites.

Over the years the Corps had the foresight to develop hydropower projects with empty penstocks for future power development as it might become economically feasible. Last year alone the Corps added a dozen generating units at existing projects including five at Chief Joseph Dam on the Columbia River. We installed the remaining four units at Chief Joseph this year.

At Bonneville Dam on the Columbia River, which was the first major hydropower project built by the Corps of Engineers back in the late 1930's, we are building a second powerhouse which will more than double the rated electric capacity of that project. We are also planning construction of a second powerhouse at McNary Dam, also on the Columbia River.

Hydropower at Corps Projects Today

Today, the Corps of Engineers is the largest single producer of hydroelectric power in the United States.

It operates 67 projects housing 320 turbine-generator units with a total installed capacity of 18.6 million kilowatts. Last year these projects generated 87.2 billion kilowatt-hours of electric energy, or 31% of all the hydroelectric power produced in the United States. To produce that much power from the Nation's non-renewable sources would have required burning 36 million tons of coal, 818 billion cu. ft. of natural gas or 5.6 billion gallons of oil.

Potential Hydropower at Corps Projects

As we look at small-hydropower sites we are also exploiting the full potential at Corps projects.

There are nine Corps power projects under construction which will have an installed capacity of almost 4 million kW. Five power projects now in operation have authorized power additions. There are 16 power projects authorized, but not yet under construction. Nine existing power projects will require authorization to install additional units. Fifty existing projects have potential for installation of power-generating units. Finally, 35 potential projects not yet authorized have a power potential greater than the Corps current installed electric capacity.

The development of all of these potential sources of hydropower would more than triple the current generating capacity at Corps projects.

Taking Advantage Of Potential

What can be done to make the tripling of the Corps existing hydropower capacity a reality?

First of all, the high priority given by President Carter to national energy goals should facilitate and hopefully accelerate the realization of this potential.

The Corps of Engineers, on the other hand, is giving high-priority consideration to all actions which could accelerate the expansion of the installed electric capacity at existing or future Corps projects. Development of the hydropower potential at the 50 operational projects where power is not authorized is particularly attractive.

Pumped-storage projects increase the capacity of power generation. We will explore that potential vigorously. The Corps' De Gray Dam in Arkansas and Carters Dam in Georgia include operational pumped storage facilities. Two dams under construction in Missouri. (Clarence Cannon and Harry S. Truman) include pumped-storage facilities. As pumped storage is the only currently available large-scale means of storing electrical energy, it is an important part of the current national energy strategy.

We will study the feasibility of adding storage to increase power production at Corps projects with existing hydroelectric installations. We are currently raising the height of Chief Joseph Dam to accommodate a 10-ft raise in the lake level and installing 11 additional hydroelectric units which will double the electric capacity of the project to over 2 million kW.

We will study the feasibility of reallocating storage or modifying operating rules to increase power-output at existing power projects.

The Water Resources Development Act of 1976 also provides $10,000,000 for the Corps of Engineers to undertake feasibility studies of specific hydroelectric power installations at authorized projects that have a high potential for hydropower development.

On 23 August at Hannibal, Missouri, on his Delta Queen Cruise, President Carter announced that he was directing the Army Engineers "in conjunction with the Water and Power Resources Service (Formerly the Bureau of Reclamation), and the Department of Energy, to develop necessary legislation which would give those agencies clearer, simpler authority to exploit the energy potential of existing Federal projects without requiring them to go thru the full, protracted authorization process necessary for new-construction projects in cases where the addition of the necessary turbines is economically justified and would not have an adverse impact on the environment or on stream-flows."

National Hydroelectric Power Study

The Corps of Engineers is currently conducting a detailed assessment of the nation's hydroelectric resources as part of the National Hydroelectric Power Study authorized by Section 167 of the Water Resources Development Act of 1976 (P.L. 94-587). The study is designed to provide a current and comprehensive estimate of the potential for incremental or new generation at existing dams and other water resource projects, as well as for undeveloped sites in the United States.

The study objectives are:

(A) Analyze and define the nation's needs for hydroelectric power.
(B) Assess potential for increasing hydroelectric power.
(C) Determine feasibility of increasing hydroelectric generation by developing new sites, adding generation facilities to existing projects, and uprating existing hydropower systems.

(D) Analyze current institutional and policy-setting.
(E) Assess general environmental and socio-economic impacts.
(F) Recommend to Congress a national hydroelectric power development program including institutional and policy modifications to increase effectiveness of existing and future hydroelectric power developments.

The study has been divided into two major elements to accomplish these objectives. The first element includes a comprehensive assessment of hydropower resources across the nation, as well as the future demand for hydropower. The second element consists of studies to identify the socio-economic, environmental, institutional and other policy issues affecting hydropower developments, an assessment of their importance, and subsequent recommendations of policy modification to encourage a balanced use of the nation's water resources. The results of the two elements will be used to recommend regional and national plans for a hydropower development program.

The comprehensive assessment of hydropower resources was accomplished in successive stages. The initial data-base contained site information on approximately 50,000 existing dams from the Corps' National Dam Safety Inventory. Additional information added about 20,000 undeveloped hydropower sites to the initial inventory. The sites in the initial inventory without significant hydropower potential were screened out. About 17,000 sites were retained as a data-base for further investigations as a result of this screening.

To further refine the data-base, we used generalized costs data together with the generalized power values developed by the Federal Energy Regulatory Commission, both based on the optimistic estimates of capacity and energy from hydrologic data. These procedures served very well for screening the 17,000 sites so that approximately 5,000 sites will be retained for analysis in the National Hydropower Study.

A preliminary inventory of hydropower resources has been completed as part of the resource assessment. The Institute for Water Resources has prepared a series of regional reports based on data collected by the Corps of Engineers Divisions and Districts. The reports contain site-specific information on existing dams and potential sites that could accommodate new or increased hydropower development. Estimates of the regional and national potential for hydropower development are included in the reports.

When completed in 1981, it will be a blueprint for future planning and development of hydroelectric power in the United States.

Small-Scale Power Dams

President Carter's Energy Plan of 1977 specifically recognized the opportunity for redeveloping small-scale hydropower and directed the Corps of Engineers to estimate the hydropower potential at existing small dams in the country. This directive led to the Corps' preliminary 90-day hydropower study published in 1977 which was based on theoretical potentials for the river basins of the country, and did not include site-specific investigations.

We identified over 5,600 small-scale dams which are either generating power, or have the potential for incremental development. In addition, our study identified some 2,600 undeveloped sites with hydropower potential.

How big a piece of our national pie does the small-scale sources represent?

First of all, let's look at the big pie. The current total maximum potential conventional hydropower capacity at existing dams, both developed and undeveloped, is about 120 million kW. As of 1 January 1978, the developed conventional hydroelectric capacity in the United States totalled 59 million kW. An additional 10 million kW of pumped storage hydroelectric capacity had been installed.

In other words we have developed only 50% of the hydropower potential at existing dams.

Our 90-day study and Federal Power Commission compilations reveal that 50% of the untapped hydropower potential of this country is in small-scale hydropower projects, defined as dams less than 100 ft. in height, less than 10,000 acre-feet of reservoir storage capacity, and with a potential capacity less than 5,000 kW.

So, small-scale hydropower development, though less spectacular than its big brothers, is just as important as we seek to achieve our national energy goals.

We have been working closely with the Department of Energy as this jointly-sponsored symposium shows. We are developing the data-base on which a sound national hydropower development program can be planned and executed. The cooperation of many Federal, state and local interests is essential to the achievement of that goal.

The Corps of Engineers has the organization and capability to interface effectively with the private sector in the development of water resources, including hydropower. Its network of field offices reaches all sections of the country. The Corps is used to working effectively with state and local officials and individuals in its many programs involving planning, cost sharing, public participation and regulatory functions. Our track record for obtaining the cooperation of the public and private sector is a good one. I pledge the full cooperation of the Corps in the development of our total national hydropower potential.

Conclusion

In conclusion, I return to Ruth gleaning barley. According to the Old Testament, Ruth "gleaned in the field until evening and beat out what she had gleaned." We cannot afford to rest until our national energy objectives have been achieved.

Then and then only will our national security be assured.

Then and then only will our stewardship of our natural resource be responsive to the needs of future generations.

Then and then only, will we be able to face the future with confidence.

I am confident that, together, we are up to the challenge.

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

DEPARTMENT OF ENERGY'S HYDRO PROGRAM

George S. McIsaac

Jack Watson and General Morris already have persuaded you, I hope, of the Federal Government's commitment to small-hydro as well as given you an indication of some of the activities in which we are participating together. One of the most impressive aspects, to me at least, of this whole effort is the remarkable cooperation that has existed among the various participating Federal agencies, with state and local units and with the private sector. In light of the conflicts that sometimes occur in certain other areas of government activity, I think the small-hydro effort has been a model of cooperation.

What I would like to talk about today is the DOE program, the part we are playing in this effort. At the outset, I think it might be useful if I gave you some idea of how we feel about small-hydro in the context of the overall energy picture, which is, of course, our chief concern.

I am sure everyone here recognizes, that we as a nation, find ourselves in a very serious energy predicament for which there is no quick or easy short-term solution. Whatever we do about it is going to take time, a lot of money, substantial effort, sacrifice and whatever talent and ingenuity we can bring to the task.

Right now, the most urgent aspect of the energy problem is our over-dependence—I think of it as an addiction—to oil, particularly imported oil. And this addiction is draining our wealth, threatening our national security, and sapping our economic vitality. It is a major factor in the current double-digit inflation, as well as the rising unemployment. At least one major national and worldwide recession, the one in 1974, is directly attributable to it, and there is increasing speculation that it is about to cause another.

So our most immediate problem and first priority task is to reduce our dependence on oil as quickly as we can. There is no one single means of achieving that objective. There is no miracle cure or perfect substitute. We are, in fact, in a position where we must grasp every opportunity we find to reduce oil consumption and replace it with alternative sources of energy.

Conservation can and must play a major role. It is the cheapest, quickest and cleanest way to back away from foreign oil. But we cannot do it with conservation alone. We can eliminate a lot of waste, but we still must provide energy to support our industrial base and provide for the legitimate needs of our people. Thus, we must develop alternative sources of energy.

This is the context in which we view small-hydro. It is an available source of energy that has not been fully exploited. It offers the potential to back out some of the imported petroleum that is now sapping our national strength. It is reasonably economic, environmentally benign, and directly applicable to power generation. It is part of the solution.

I would like to describe briefly some of the key elements of the DOE hydro-program. Rather than merely recite a list of on-going efforts, I will group some of the more significant studies on a generic basis—according to the contributions they make to overcoming impediments to hydro development.

Mr. McIsaac is Assistant Secretary for Resource Applications, U.S. Department of Energy.

There are four impediments to the widespread use of small-scale hydro power. These are:

1. Lack of knowledge about the size, location and nature of the resource base;
2. Lack of understanding of the pricing aspects of small-scale hydro power,
3. Lack of proof, through actual demonstrations, that modern small-scale hydro technology works; and
4. Difficulty of transferring information to potential decision makers.

When I testified before Congress earlier this year, I had listed a fifth impediment, cumbersome licensing procedures. However, recent developments in the licensing process have overcome previous difficulties, as I shall mention later.

The first barrier to widespread small-hydro development is the general lack of understanding among decision makers about the size and locations of the resource base. DOE, along with other Federal, state, local and private entities is obtaining the information that is required. For example, we have contracted with the Applied Physics Laborabory (APL) of Johns Hopkins University for preparation of assessments of the institutional, economic and ecological impediments to development of small dams. APL has issued two reports on redevelopment of existing hydroelectric power dams. One of these addresses problems in redevelopment of such dams in New England.

The other concerns a comparable study of the Middle Atlantic States and the Ohio Valley. Right now, we are concluding a study of the southeastern states east of the Mississippi. And another assessment of interest is just being started by APL. This will be an appraisal of the influence of various incentives for obtaining increased power-on-line from hydro stations in the Pennsylvania-New Jersey-Maryland region. It will determine which of the various subsidy forms would be most effective in redevelopment of hydro facilities.

A complementary contract exists with the Energy Law Institute of the Franklin Pierce Law Center in Concord, New Hampshire. This work centers on the legal and institutional impediments to hydro development. Through both summary reports and case histories, Franklin Pierce Law Center is adding to our understanding of actions needed to expand the use of small-scale hydro.

The Corps of Engineers, as you have already heard, is completing its national assessment of the small-scale hydro resource. This will provide a more difinitive data-base of the magnitude and location of selected hydro resources on a national basis.

State planning groups in Washington, Oregon and Idaho conducted resource evaluations with DOE support. Similar information was developed by personnel in New York and Pennsylvania using state funds. All of these efforts are contributing to a better understanding of the extent of the nation's hydro resource.

The Water and Power Resources Services (formerly Bureau of Reclamation) has undertaken four studies for us. These assess the lower-practical limits for use of small-hydro facilities, the effect of small-asynchronous

generators in the power grids, standardization of intakes and outlets for small installations, and the marketability of small-scale hydropower in the United States. The standardization effort is under way in-house at the Bureau's Denver facility, while the other three elements are contracted.

This past July, we announced an engineering development program aimed at reducing the costs of small-hydro projects, and extending the technology to smaller water-flows. We have asked for proposals covering design, model testing, and economic feasibility assessment of innovative concepts to retrofit existing dams with electrical generating equipment and improve manufacturing processes and materials. We may be making five or more grants of up to $400,000 for appropriate proposals.

Finally, we have contracted with the National Conference of State Legislatures (NCSL) to assess how states can implement legislation enhancing the use of small-scale hydro systems. Through workshops and personal meetings, NCSL provides key-input information to interested state personnel. This enables the states to determine whether legislation is needed to promote the use of small-scale hydro, and what the content of such legislation should be.

A second barrier is the lack of understanding of the economics of power production from small-hydro facilities. The critical incentive for small-scale hydro development is the price the customer is willing to pay for the generated power. A utility interested in purchasing power from a redeveloped hydroelectric facility would want to know the comparative cost of hydro power to conventional generating capacity and how much fuel could be saved.

We do not yet know whether small-scale hydro project entrepreneurs will experience difficulties in raising capital funds. Yet we believe that investment in this energy option will prove to be sound. It is conceivable that we may observe instances of "protective investment," where capital funds are provided locally; so as to guarantee steady availability of energy for local industries, and thus protect investments made in those industries.

While economic analysis of small-scale hydro is still in it early stages, certain DOE efforts are contributing to improved understanding. Last year we awarded grants for undertaking feasibility studies for 54 small-hydro projects. Forty-six of these studies have been completed thus far. About half of these studies indicate sufficient financial feasibility to encourage the developer to undertake the project, or to proceed with more detailed evaluation.

The feasibility study-loan program was authorized under Title IV of the Public Utilities Regulatory Policies Act of 1978. In May, the DOE published proposed rules for loans for small-hydroelectric power project feasibility studies and related licensing.

The regulations establish the qualifications, criteria and procedures for obtaining a loan for the purpose of defraying up to 90 percent of the cost of a study to determine the feasibility fo undertaking a small-hydroelectric project at an existing dam, and for preparing applications for a necessary license or other required approval.

Ten million dollars appropriated for this feasibility loan-program for FY 1979, ten million dollars is budgeted for FY 1980, and additional funding will be sought for FY 1981. The program is expected to provide financing for approximately 400 feasibility studies and 200 licensing loans. Loans may be cancelled for those projects which are not technically or financally feasible.

The third barrier to small-scale hydro commercialization is ordinary skepticism. Decision makers need to have factual data if they are to be convinced of the benefits of small-scale hydro. Such data results from actual experience with operating systems. So we are providing this experience base through selected demonstrations of modern small-scale hydro applications.

Our initial demonstration project is at Idaho Falls, Idaho. It is scheduled to operate in late 1981 and will consist of three 8 megawatt bulb-turbines, generating electricity for the City of Idaho Falls. Over the 4-year design and construction period, the DOE cost share will be $7.3 million out of the total project cost of $43.6 million.

In June of 1978, DOE issued a Program Opportunity Notice calling for competitive proposals for cost-shared demonstrations. It required that a proposer had already made a feasibility assessment, had applied to the Federal Energy Regulatory Commission for a license, and that the Federal share of the total project cost be equal to or less than 25%. Based on our review, we selected seven proposals for immediate negotiation of contracts totaling about $4.2 million, representing an average cost to the government of about $600,000 each. The seven projects will provide about 18.5 MW of additional generating capacity in total.

This June, we issued a second solicitation for competitive demonstration proposals. Like the first, it pertains to projects at existing dams, and requires that a feasibility study has already been completed. This second competition will expand the potential coverage of dams, for there will be no height-limit on the hydraulic head. The maximum capacity limit of electricity generation for these projects has been increased from 15,000 kilowatts to 25,000 kilowatts. Federal cost-sharing will be no more than 15% or $2.5 million is anticipated for this competition. We expect that this round of demonstrations will provide a further refinement of our understanding of small-hydro economics.

The fourth impediment to hydro-utilization is simply the difficulty of transferring information. It is important that potential developers understand the technology, economics and opportunities for small-scale hydro.

We have successfully used workshops as a means of information transfer, and to improve our own knowledge of the state-of-the-art. The first workshop was held in Durham, New Hampshire in 1977. This was followed by regional workshops in Michigan and Idaho in 1978. The success of these meetings has led to many others across the country.

I should also mention that the hydro-program is supporting the preparation and publication of written documents to assist potential users. These include such items as technical handbooks, regulatory guidance and programmatic progress reports. These documents, plus the written record of the meetings, provide a valuable starting point for potential developers.

When I testified on behalf of the hydro-budget requested earlier this year, I included the cumbersome Federal licensing process in my summary of impediments to use of hydro power. However, new procedures developed by the Federal Energy Regulatory Commission have made a significant difference in the time and effort required to license small-hydro facilities. These changes serve to reduce the licensing time through use of short-form license procedures and fewer paperwork requirements. The effort by FERC has been impressive.

In conclusion, the success of the hydro-program to date has resulted from

the spirit of cooperation shown by all participants. Congress has established and supported the program, and has enacted legislation concerning its implementation. The Department of Energy and other agencies are using the money and resources provided by the Congress to extend the use of this resource. And the public, through individuals, and through business enterprise, is providing the ingenuity and the know-how to develop specific projects. I have no doubt, that this combination of interests will lead to realization of our goals for power-on-line through use of small-scale hydro.

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

PLENARY ADDRESSES

Norman M. Clapp
Former Administrator
Rural Electrification Administration
U.S. Department of Agriculture

Georgiana Sheldon
Commissioner
Federal Energy Regulatory Commission

Alex P. Mercure
Assistant Secretary
Rural Development
U.S. Department of Agriculture

Emil F. Mosonyi
Professor of Hydraulic Engineering
University of Karlsruhe
German Federal Republic

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

PLENARY SESSION

TOPIC: ENGINEERING

Chairman: Major General E. R. Heiberg III
Director of Civil Works
U.S. Army Corps of Engineers
20 Massachusetts Avenue, N.W.
Washington, D.C.

Panelists: Howard A. Mayo, Jr.
Manager, Marketing Development
Allis-Chalmers Corporation
York, Pennsylvania

David C. Willer
Manager, Water Resources
Tudor Engineering
Washington, D.C.

Robert H. Bruck
Chief, Electrical & Mechanical Branch
Engineering Division — Civil Works
U.S. Army Corps of Engineers
Washington, D.C.

William Love
Superintendent of Utilities
Vanceburg Light, Heat & Power Systems
Vanceburg, Kentucky

William S. Lawson
Director, Office of Technology
Assessment and Forecast
Patent Documentation Organization
Washington, D.C.

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

THE KEYNOTE IS PROGRESS

Norman M. Clapp

If I were to try to characterize this as a "keynote," I'd say the "keynote" is progress.

Two years ago I had the privilege of helping to open the workshop on low-head, small-hydro at Durham, N.H. At that time, small-hydro was still pretty much in the dreaming stage. The Army Corps of Engineers had just completed its 90-day study, Dick McDonald was there to report its findings, and the Congress had just appropriated 10 million dollars for demonstration projects and feasibility studies.

This was done on the initiative of people like Senator Durkin of New Hampshire and Congressman Ottinger of New York, and others. The significant thing, I think, was that it was done in the Congress. The initiative was originated in the Congress, rather than coming as part of the Executive Budget. This certainly seemed to reflect some significant grassroots interest, concern, and steam behind small-hydro (if I may mix a metaphor).

The feasibility studies were still in the offing, the demonstration projects were at that time limited to Idaho Falls. The two big questions before the group at Durham were: (1) what is the potential of small-hydro and (2), the bigger one, is it possibly feasible?

Today, just two years later, we have made considerable progress. It is the usual mixed-bag of good news and bad news. On the good news side, we have some new information from the Corps. I am not sure whether this has been published yet or not, but if it hasn't, it is due shortly. The preliminary figures in the public information file of the three-year study that the Corps has been doing on hydro potential indicate that the capacity potential, as well as the energy potential of the existing dams in the country, is about double what the 90-day study had indicated.

These preliminary figures are based on the actual examination of some 54,000 dams. Of this total, it was found that 5,424 sites—roughly 10 percent of the dams examined, were at least feasible in the technical sense of offering further hydroelectric-potential. The estimated additional capacity in these 5,424 sites has been preliminarily put at 94,636 megawatts. As I said, that is almost double the findings of the 90-day study two years ago. Furthermore, this total is broken-down into size categories. Of the 5,424 sites, 4,813 are classified between the potential capacities of 50 kilowatts and 15,000 kilowatts. The total capacity potential of this category is given as 5,455 megawatts; 166 sites, in the range of 15,000 to 25,000 kilowatts, are credited with the potential of 3,320 megawatts of additional capacity, and 445 dams over 25,000 kilowatts in size hold the bulk of the potential, namely, 85,859 megawatts. All of this, if it were developed, would be able to yield 223 billion kilowatt hours annually.

So, on potential, although these figures indicate that those small sites are still small, and although the big numbers in terms of capacity tend to rest with

---

Mr. Clapp is former Administrator of Rural Electrification Administration, U.S. Department of Agriculture, Washington, D.C.

the bigger dams, there is considerable encouragement in the size of the total potential available.

Now, we also have some further information on feasibility, which comes under the heading of "good news." The Department of Energy has already funded 54 feasibility studies. I do not vouch for the precise accuracy of my calculations, but I would say that roughly only 20 percent of those were definitely found to be infeasible. Another 20 percent were questionable, depending upon the resolution of certain contingencies. One of those contingencies is what kind of dam-user fees the Corps is going to charge. That leaves roughly 60 percent found to be feasible, even though many of them were were quite marginal as projects under current circumstances.

The general range of cost was $1,000 to $2,500 a kilowatt, which is no surprise. There were some extremes: one which indicates a cost of $600 a kilowatt, and one in Alaska with a cost of $6,000 per kilowatt.

On energy costs, the range was roughly between 20 and 45 mills, for the bulk of them. Again, there were extremes: one showed a projected energy cost of 6 mills and there was another that went as high as 232 mills.

There are now nine demonstration projects underway. For the coming year, there is an expanded program in sight. First of all, the National Energy Act authorized Federal loans of $110 million annually—$10 million for front-end money and $100 million for project development for each of three years, 1979-1981. Ten million is being appropriated—this time for loans, 90 percent loans—to fund feasibility studies and licensing costs.

The $100 million for project development, as authorized, has not been appropriated. However, the President has announced a program of Rural Energy Initiatives, which is now being implemented through a Memorandum of Understanding among five Federal agencies: the Rural Electrification Administration, the Farmers Home Administration, the Economic Development Administration, the Department of Housing and Urban Development, and the Community Services Administration. These agencies have agreed to put together a pool from their various lending resources, a fund of $300 million which, accidentally or deliberately, coincides with the $100 million authorized in the Energy Act annually for three years. The goal, as announced by the President, is to get 100 of these small-hydro projects at existing dams going by 1981, and 300 by 1985.

There is another group of demonstration-projects coming along—the PON-2, closed August 27. In this, eligibility for demonstration projects is somewhat different from the 1978 group. The head-height limitation of 20 meters has been eliminated, the eligible capacity has been raised to 25,000 kilowatts. I am told by the people at the Department of Energy that they expect to make the awards very soon.

There has already been a screening process underway at DOE, which, no doubt, can be related to the upcoming feasibility studies. However, this screening will not necessarily preclude other applications from being considered for feasibility study loans.

The five Federal agencies that are involved in the Memorandum of Understanding, and, I take it, other agencies as well, have been invited to suggest likely projects to the Department of Energy for examination. A procedure has been set-up whereby the DOE refers suggested projects to the Corps. The Corps will run them through their screening mill, decide which ones are

worth looking at further and which ones are not, and so advise the DOE. Those that are thus found worthy of further investigation will be given a "reconnaissance" type inspection by engineers from either the Water and Power Resources Service, (formerly Bureau of Reclamation), the Federal Energy Regulatory Commission, or the Corps. I am told that 500 suggested sites have already been sent to the Corps, plus another 104 that had previously been suggested for feasibility study in 1977. Another 400 have been more recently submitted. These still have to go through the initial screening process of the Corps.

There is also a new program opportunity notice, asking for submissions for innovative types of demonstration projects. These must relate to manufacturing process and materials cost reduction innovations. The closing date for these creative projects is October 10, 1979.

Out of all of this, it seems to me, there are certain things that are very encouraging. First of all, the momentum has built up. There is considerable and growing public and official interest in small-hydro development at existing dams. Small-hydro has an active place in the thinking of Federal officials today which it did not have two years ago. In fact, a goal has been set by the President when he announced that we ought to be striving to produce 20 percent of our energy requirements from renewable resources by the year 2000. Small-hydro will probably be one of the principal contributors to meeting that goal.

Power that costs 40 to 50 mills at one time would not have been very attractive. Today, the escalating cost of oil—and this gets into the bad news—is changing the reference framework of economic feasibility for hydropower. If the cost of oil for generation of electricity is going to run between four and six cents in the next two or three years—and perhaps even higher later—40-mill or 50-mill power from a hydro-project is a much more attractive proposition than it was even two or three years ago.

Other things are happening which have to do with economic feasibility. At lunch, General Heiberg handed me a circular put out by the National Hydro-Alliance, calling attention to some of the legislative proposals that have been introduced in the Congress. You will be interested to know that the proposal of Senator Nelson was adopted by the Finance Committee last week.

Let me mention some of the things that the Nelson proposal would do. First of all, it would provide a 20 percent tax credit on top of the normal 10 percent investment tax credit for small-hydro facilities. The credit would be available to the year 1985. The eligible projects would be limited to existing dams, and a capacity of 25,000 kilowatts or less. Investment in fish-ways and transmission facilities on site would qualify for the credit, as well as the turbine and whatever specific civil works might be involved. Furthermore, the bill would provide for accelerated depreciation. The asset life under existing regulaton in projects of this kind would normally be 40 to 60 years; the Nelson Amendment reduces it, on these particular projects, to 10 years for structures and 5 years for equipment. The Nelson Amendment would also preserve the tax-exempt status of state and municipal agencies on this type of project, even though more than 25 percent of the output of the project is marketed outside the present two-county limitation.

So, in conclusion, I believe it can now be said that small-hydroelectric development is not only an idea whose time has come, but is also a practical and feasible

energy development whose time has come. There are solid indications today that we are moving into a period when we will see some very tangible results from this long-neglected resource.

PLENARY SESSION

TOPIC: POLICY

Chairman: Brigadier General Hugh Robinson
Deputy Director
Civil Works, U.S. Army Corps of Engineers
20 Massachusetts Avenue, N.W.
Washington, D.C.

Panelists: Alex Radin
Executive Director
American Public Power Association
Washington, D.C.

Leo Eisel
Director
U.S. Water Resources Council
Washington, D.C.

Robert Smythe
Senior Staff Member, Natural Resources
President's Council on Environmental Quality
Washington, D.C.

The Honorable Lawrence F. Kramer
Mayor
Paterson, New Jersey

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

REVISED REGULATIONS FOR LICENSING REFORM

Georgiana Sheldon

Thank you Gen. Robinson. At the outset, let me tell you how delighted I am to be with you this afternoon. If I were not actually present at this gathering, I would not believe it happened.

Less than a decade ago a proposal to hold an International Conference of Small-Hydropower would have been considered a principal candidate for Senator Proxmire's Golden Fleece Award. But during the past decade, we Americans have succumbed to a lullaby—that we have abundant and low-cost energy supply. But in 1973 the Arab oil embargo and the subsequent OPEC ever-increasing prices for crude have rudely awakened us from our comfortable Alice in Wonderland world. Americans have awakened to face the reality of energy shortages, and possible economic strangulation because of them. As the world's leading industrial nation we are wholly dependent upon energy for our economic survival. The demise of our economic strength can only lead to the abdication of our political leadership of the free world. I do not believe that we will stand by quietly and watch our way of life destroyed. I do believe the time has come for difficult decisions and actions. We cannot afford the luxury of unwarranted delay and further procrastination. We must embark on a dynamic program to develop a viable energy supply. However, we must not repeat the mistakes of the past. We cannot afford to allow our future to be too dependent on one source of energy, be it coal, nuclear, solar or synfuel. This country must develop a comprehensive balance short-term and long-range program utilizing all of our sources of energy.

At this point in time, there can be no doubt that coal and nuclear energy, with appropriate safeguards, will be the centerpiece of our immediate future. However, any sound energy program must include rapid development of our renewable resources. And of course, the one we are to discuss this afternoon is hydroelectric power. Less we forget, in the mid 1930's hydroelectric power with a capacity of about 7800 megawatts comprised about 30 percent of the nation's total generating capacity. Although the relative contribution of hydro to the nation's capacity had decreased to nearly 11.2% in 1978, hydroelectric power has increased steadily to 59,000 megawatts as of January 1978. In 1977 the Corps of Engineers estimated our national hydropower-potential of 54,600 megawatts from existing dams. It is my understanding that revised COE data will show that potential even greater. Thus, by merely developing this potential we could double or triple the existing hydroelectric capacity. Clearly, small-scale hydropower can play a major role in a short-term solution of our energy needs. And it must be a vital part of our long-term energy program.

As a matter of national policy we must take immediate action to prevent the continued wanton waste of this renewable resource. The FERC, with whom I serve, has awakened to this responsibility. We have tried to answer the Presi-

---

Ms. Sheldon is Commissioner, Federal Energy Regulatory Commission, Department of Energy, Washington, D.C.

dent's call to streamline procedures. Recognizing that its procedures are among the barriers impeding the development of small-scale hydropower, the Commission commenced a multi-phase program designed to simplify and expedite our licensing process. In September of 1978 the FERC issued order #11 designed to simplify the licensing procedure for power-projects with a capacity under 1.5 megawatts. The simplified application lessens the descriptive information needed, reduces the details required on maps and drawings and revises the procedures for obtaining comments from the agencies. In January of 1978 we notified all major Federal agencies that comments would be solicited through public notice procedures only. This should lessen the time consumed in processing preliminary permit applications. In March of 1979 the Commission proposed new requirements simplifying the filing requirements relating to application amendments and cancellations of permits. The revised regulations will reduce the required filings from 9-4 substantive exhibits. These regulations will be considered soon by the Commission and should be finalized shortly. In April of 1979 we took another step in licensing reforms by proposing new regulations—streamlining procedures for all sites with existing dams. These regulations reduce application burdens to all proposed projects whatever the size or generation capacity, if installation does not require continuation of a new dam or substantial modification of an existing one. These regulations will reduce from 23 to 7 the number of exhibits required to be filed in an application. This also should be finalized shortly. In a final phase of the FERC licensing procedures, reform will apply to all projects with proposed capacity greater than 1.5 megawatts which must be constructed in its entirety. These revised regulations are in the early stages of drafting and probably will be not be ready till early next year. In addition to the FERC's actions to simplify licensing regulations and procedures, the Commission is undertaking actions of particular benefit to small-hydro projects. In April of 1979, in response to its newly granted discretionary power, the FERC issued new guidelines for exempting from the Federal Power Act, licensing requirements projects of 15 megawatts or less when located on man-made conduits for the primary purpose other than the generation of electric power. These guidelines will also be finished in the near future. In June 1979 we issued regulations defining qualifying cogenerators and small-power production facilities. Last week the Commission approved its proposed rule requiring the purchase of power from and the sale of power to qualifying co-generators and small-power production facilities by large electric facilities. These rules will relieve co-generators and small-power producers from the burden of Federal and state utility requirements. Of greater significance, these regulations should be the key to open the door for obtaining adequate financing for the development of small-hydro projects. The objective of the FERC's revised regulations is to simplify and clarify licensing requirements and procedures, to ease the burden of compliance and thus encourage hydro-development. However, let us face-up to the truth. A quick and painless authorization for proposed hydro-projects cannot be accomplished unilaterally by the FERC. At last count, some 17 different Federal statutes vested various Federal agencies with jurisdiction over at least some aspects of hydro-projects.

A successful program must involve the cooperation of other agencies, special interest groups and prospective licensees as well. State and Federal agencies must devise new processes of interagency coordination, so that re-

quired considerations are expeditiously carried out in the public interest. And then I might say, that the special interest groups themselves must discipline their reaction in opposition to all projects. It must evaluate the merits of each development and present recommendations in light of the ultimate benefits to the public interest. And finally, prospective licencees must face the reality that they are proposing to use a public resource and that entails certain obligations and responsibilities. It is the utilization of this public resource which brings into action governmental regulations and special interest groups. At an early stage, prospective licencees should avail themselves of the expertise of an agency staff to ascertain the requirements to be met and to obtain authorization. Moreover, the prospective licencee should immediately enter into a dialogue with special interest groups with regard to remedial or mitigative measures to be taken, which will eliminate opposition and shorten the licensing process All the efforts to breakdown the barriers impeding the development of small-scale hydropower will be for naught if we do not make the development economically attractive. Except for the feasibility loan program and some grants, both administered by the Department of Energy, at the present time, there are really no economic incentives for small-scale hydro comparable to those available to other sources of energy development. The economic scale and low-fossil fuel cost which has spawned the development of large-scale centralized power generation are fast disappearing. On the other hand, the economics of small-hydro electric generation plants looks better each day.

We must provide our free enterprise system with necessary inventives. I, therefore, applaud recent action last week, by the Senate Finance Committee under the leadership of Sen. Nelson and Sen. Packwood, which would provide a series of tax incentives, and rapid depreciation to encourage the development of small-scale hydropower at existing dam sites. The committee's action would do the following: First, it would increase the current 10% tax credit to 40% for investment in structures and equipment used to produce power at existing dams, and which have an installed capacity of 25,000 kW or less. Furthermore, the tax credit would be extended to cover the cost of constructing fish ladders where required by licenses. Second, it will allow small-hydro dam owners to write off the cost of depreciated facilities 4-5 times faster than under the current law. This would lead to faster recovery of capital investment and would alleviate the cash-flow problem from small developers with limited financing capability. Third, it would increase the curent 1.5% repair allowance to 4% thus permitting owners to take a higher annual deduction for repairs on small-hydro facilities. And fourth, it would provide special tax exemptions for state and municipal bonds used to finance hydro-facilities.

I am convinced that tax incentives such as these, when they are enacted by the Congress, could have significant effects upon the amount of power generated by small-scale hydro in the next decade. I am also convinced that conferences such as these with the exchanging of ideas can play a major role in developing the issues and shaping the policy of the future. Remember that no horse gets anywhere until he is harnessed. No steam power drives anything until it is confined. No Niagara is ever turned into light and power until it is focused, dedicated and disciplined, and I would ask all of you who are licencees, and all of you interested in this business to become focused, dedicated and disciplined. Our energy future will be brighter.

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

PLENARY SESSION

TOPIC: PLANNING, INFORMATION AND METHODS

Chairman: Mr. Stanley I. Weiss
Deputy Assistant Secretary for Utility and Industrial Applications
U.S. Department of Energy
1200 Pennsylvania Avenue, N.W.
Washington, D.C.

Panelists: Robert Cross
Administrator
Alaska Power Administration
Department of Energy
Juneau, Alaska

Ronald Corso
Deputy Director, Division of Licensed Projects
Federal Energy Regulatory Commission
Washington, D.C.

Dr. Jerry D. Priscolli
Senior Social Scientist
Institute for Water Resources
U.S. Army Corps of Engineers
Washington, D.C.

Mike Speer
Associate Director, Environment,
U.S. Fish and Wildlife Service
Department of the Interior
Washington, D.C.

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

RURAL POWER NEEDS

Alex Mercure

From the perspective of an Administrator in the Department of Agriculture, the importance of energy in rural development becomes clear. Financing the Rural Electrification Administration (REA) is obviously very crucial and has been extremely important since 1937 when President Roosevelt signed the Executive Order creating REA. There were many people who were skeptical about whether or not one could expand electricity to widely dispersed rural settings and to small communities. According to some of the veterans of that day—"People do not really need a great deal of electricity." Just in the past few years, there has been both a tremendous increase in the utilization of all sources of energy by America's agriculture, and a tremendous increase in growth in rural America in terms of small communities. According to demographers, small towns are now growing generally about twice as fast as our big cities. Even though there are still some rural counties that are declining, and some that are stagnant, about two-thirds to three-fourths of all rural counties are growing at about twice the rate of most urban populations. This is true of virtually every important region in the county. The Southeast for example, is about neck and neck with large cities and small towns. Those are important implications because this growth isn't due soley to population increases. There has been a tremendous diversification of location among America's industry and that brings with it demands for energy. REA is an important, though not exclusive, element of that demand. There are 1000 rural electric cooperatives out there providing electricity to many small communities.

In fact, many small communities today would still not have electricity (as in Alaska) were it not for the reasonable financing, and recognition of the unusual circumstances of small communities.

Introducing the background of REA is important, because in a sense small waterpower kinds of investments have similar kinds of problems. They are scattered, they don't produce large amounts of electricity at one time; but they do capitalize, on the inertia that exists in our streams and in the falling water. From the REA viewpoint, 5 MW of electricity can be as important to a small community as 500 MW of electricity can be to American electric power. More importantly, if the 10 million dollars that the Department of Energy (DOE) is spending on developing feasibility studies for 100-200 plants produces 5 MW of electricity per installation, and if 100 facilities are financed, then they will develop 500 MW of electricity. Based on what REA has been spending, 500 MW of electricity represents a 500,000,000 dollar loan—within a few million dollars—and in the future it's more give than take. That demonstrates how important it is to aggregate these diverse sources of energy. Waterpower fits into a category like another approach that REA is taking, together with Department of Energy. It's called coalbed gas. There is methane and natural gas

---

Mr. Mercure is Assistant Secretary for Rural Development, U.S. Department of Agriculture, Washington, D.C.

coming out of coalbeds on a constant and continuous basis, although none of these fields would produce a great deal more than perhaps 25 MW of electricity or its equivalent. The 100 best coalbed sites, therefore, would produce 2,500 MW of electricity, where as the Corps of Engineers has determined that potentially over 54,000 MW of electricity could be produced by existing dams.

Three years ago a study about REA turned out to be very controversial with the electrical cooperatives in this country, who perceived that REA was threatening to cut-off the lending power of the government. Our purpose, in the department, and REA's purpose was to try to determine just what the future was for the 1000 membership-owned electric co-ops in this country. The study determined that, by 1995, 27,000 MW of electricity would be needed at moderate rates of growth. Low-head hydro could, therefore, conceivably produce all of the energy needed by electric co-op systems in this country to 1995.

There appears to be a reluctance among REA personnel and other people around the country, to deal with 5 MW or 15 MW facilities. It is important to think about what small units aggregated and dispersed in this country may accomplish. This would be easy to do in the case of the rural electric systems. They are like small community municipally-owned utilities. It is not difficult to integrate small quantities of electricity, particularly if it's baseload, into the transmission system that those electric cooperatives already have. But more importantly, it reduces the operating costs. In Morrisville, Vermont, there is one low-head hydro facility that has been operating since 1921. Although there have been dismantled as many units as there are in existence today producing 2 MW of electricity at peak, even more could be developed.

There are existing facilities, irrigation-diversion dams and others, that have the potential for retrofit. Units ranging from less than 1 MW, to large units in erosion-control dams that have constant water-flow could produce some very significant amounts of energy.

It often seems that there is hesitation to take the steps in what is called "new technology" which, as it turns out, since 1921 is rather conventional. There still exists a hesitation to follow through on what is calculated in very simple terms to be important contributions to the energy picture of this country. Low-head hydro is only one of many solutions. There is a tremendous variety of relatively small contributions of energy that can be made in this country,—relatively small individual contributions that can be made in conservation, but when added up can contribute a great deal. It appears that over 300,000 MW of electricity will be needed over the next 10 years in this country—54,000 MW of electricity that can be generated in existing dams represents 1/6 of that power, with no more difficulty than has been experienced with coal-fire generating plants. There are other situations which are important. It appears in looking at the coalbed gas issue, that the Northeast doesn't have any coal and very little natural gas, but it does have water. Some theorists have suggested that development in the Northeastern part of the country, in the last 100 years or so is directly attributable to relatively low-cost and readily available electricity that came from hydropower. That may not provide the energy that utility people think is an important element of our consideration. There are important areas, such as New England, and Alaska, where electricity is being produced at 37¢ per kWh. Diesel fuel has to be barged up rivers to

small villages to small electricity generating plants. Either hydropower or wind or a variety of other small-scale alternatives could reduce the operating costs for that one village, and improve the economic life of that village, theoretically speaking.

The President has announced rural initiatives related to energy. He has also announced a number of other rural initiatives—health, transportation, water, sewage, and programs for housing for the aged. Several agencies have joined together to provide a simpler way for communities that deal with the Federal government. The first of these was the rural health initiatives. The intention was to provide primary medical facilities, that is clinics mostly, in communities that were seriously underserved. A commitment was made to 300 such clinics—figuring that 50 might be built the first year. HEW, Housing, Department of Labor, and CSA worked together, and before the year was out, 70 clinics were financed and others under construction. Although, there is nothing that innovative with low-head hydro, it is something which is tremendously beneficial to the country—capitalizing on wasted energy that's now going downstream. It's the technical innovation people who are going to make it possible.

Currently REA is putting together an effort to finance their cooperatives. It is not clear that plants with 1000 MW or 500 MW capacity are needed. What may be needed are small units of growth of 20 and 25 MW. Over a 10 year period that begins to add-up. Arrangements are being conducted with co-ops and with investor-owned utilities to try to aggregate the kind of use and demand for large plants. We are saying to our co-ops "before you come with an application, look around and find out what other choices are available to you, that require less than half a billion dollars or a billion dollars." The response has been impressive. In North Dakota there are farmers growing sunflower seed. REA was asked to guarantee a processing plant to extract the oil from sunflowers. A deal was eventually consumated between a private company who was going to handle the marketing—and with the General Manager of an electric co-op. Heat bypassing the cooling towers would be used to extract the oil from the sunflower seed. The Economic Development Administration also participated by giving REA $20,000 to do a feasibility study. The study revealed that sunflower seed hulls have about 1500 Btu more than the equivalent weight of lignite coal, which is what the primary fuel was. Estimates showed a savings of 180 tons of coal a day by burning the sunflower seed hulls which came out of the processing. To guarantee the processing plant would cost 23 million dollars. What was not known at that time, though, is that the amount of energy captured would take 36,000 4 MW low-head hydro operations to produce. This figure is now being used to discount the 4 or 5 MW capacity. The point is that we cannot afford to waste on either end of our energy-use cycle. There is a need to capture what is now being wasted, and to capitalize on the resources which nature has provided. REA is committed to move ahead with this to the extent of its capabilities, and we hope we can depend upon the Corps of Engineers and the Department of Energy for their help.

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

PLENARY SESSION

TOPIC: INTERNATIONAL PERSPECTIVES

Chairman: Mr. Holsey G. Handyside
Acting Principal Deputy
Assistant Secretary
Office of International Affairs
U.S. Department of Energy
1200 Pennsylvania Avenue, N.W.
Washington, D.C.

Panelists: Charles Weiss
Science Advisor to the World Bank
Washington, D.C.

Alan B. Jacobs
Director, Energy Office
Agency for International Development
Washington, D.C.

Francis X. Gannon
Advisor to Secretary General
Organization of American States
Washington, D.C.

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

RECENT TRENDS IN WATERPOWER DEVELOPMENT AND PUMPED STORAGE

Emil F. Mosonyi

It is an extremely great pleasure for me to speak on a subject—which has been my pet topic for almost 50 years—at this very important conference, before this highly qualified audience. First of all, I have to express my sincere gratitude for your honoring invitation. I am devoted to hydropower; it is a most exciting professional subject, for without any exaggeration, we may say that implementation of hydropower-projects requires the broadest application of several disciplines of engineering.

However, since my time is limited, I shall not be able to cover the whole of this very broad topic and, therefore, I have to restrict myself to a few selected aspects, which indicate up-to-date development and recent trends in hydropower all over the world.

As an introduction to the nucleus of my presentation, I would like to clarify some questions or even misconceptions. During the last decades we could hear the remark or sentence from even professional people that the time was up for waterpower development. Such statements, often declared by responsible personalities, slowed down and sometimes unjustly stopped progress in this field. Immediately after the end of the second World War, there were opinions predicting such a fast development of nuclear-power generation, one had to expect that hydroelectric stations, and also other conventional powerplants will be soon repressed in the competition.

I am firmly convinced that we already arrived in the time which later will be called the nuclear age in the history of mankind, however, I am also convinced that in the transitional phase—and it still may last many years— the conventional resources of energy, including waterpower, will still remain of paramount importance in covering power demands.

We have to admit, naturally, that in the rivalry between power producers, temporary economic situations and several achievements attained in thermal and nuclear technology during the last decades, made problematical the competitive utilization of waterpower resources.

The main arguments against the further utilization of conventional hydropower resources in the last decades were as follows:

1. The comet-like appearance and successful development of nuclear power production
2. The high specific investment costs of waterpower plants.
3. The much longer construction time of hydropower stations, which means a disadvantageous "freezing" of the capital invested.
4. The progressive increase of power demand which could be satisfied only by large coal-fed thermal or nuclear plants to be equipped with high-capacity machines and to be constructed in a fairly short time.

Dr. Mosonyi is Professor of Hydraulic Engineering, University of Karlsruhe, Federal Republic of Germany.

5. The construction of new-type thermal stations supplied by "very cheap" oil being available abundantly.

Furthermore, it was a general opinion that in the future program of waterpower development one has to content oneself with less advantageous powersites after having already harnessed the most favorable resources.

Naturally, the above argumentation cannot be accepted. Therefore, I would like to enumerate and discuss the most important factors which on the one hand render possible the contest for waterpower—thus indicating the trends of its development—and on the other hand explain the role of hydroenergy in the power supply.

I do not intend to answer the above arguments in order, but rather I would like to present to you a brief survey on developments of the last decades and already recognizable future trends which may undoubtedly help to put a stop to some delusions misjudging hydropower generations. One argument has not to be answered at all: I hope I do not need to give you a comment on the "very cheap and inexhaustible oil."

I am aware of the fact that this symposium is focusing exclusively on small-scale hydropower plants, however, I am of the opinion that in an introduction to international development the entire range should be briefly shown, since undoubtedly a narrow interrelation between scientific and technological aspects of large and small structures in every field of engineering can be experienced. (e.g. your successful moon flight improved my refrigerator and my pocket computer.)

I have to apologize that I am philosophing, but I am always afraid that according to the general inclination to a pendulum-like progress, we may bagatellize something important in the middle when turning away from the giants and focusing on the dwarfs only. Therefore, I would like to call your kind attention to the typical low-head hydropower possibilities, even when they exceed the arbitrary chosen limits of "small-scale." In the world, in many countries, not only the small-scale dam powerplants, but also the typical low-head, run-of-river stations to be located on low-gradient, plain-land streams will gain importance. That is the reason that I will begin my presentation with such examples.

Let us commence with the foundation of the structures. In several cases the difficult and complex task for the civil engineer is to find out the adequate solution for the foundation because of two reasons:

1. The foundation is a very expensive portion of the structure.
2. Unsolved seepage and soil conditions involve high-risks on stability or require an unacceptable overdesign.

Application and extension of research in soil and rock mechanics contribute to considerable reduction of investment, to shortening of construction time and to increased stability.

Utmost delicate problems arise with the foundation of high-capacity run-of-river plants in pervious alluvial stretches of large streams. Several new ideas have been successfully applied in the practice in the last decades. For example, the foundation of the Fessenheim Powerhouse has been carried out under the protection of a watertight trough previously created in the subsoil

by means of trenching and a dense network of grouting. Various alternatives of this procedure have been applied on the Grand Canal d'Alsace bypassing the Rhine River. On fissured rock the thickness of the concrete bottom slab can considerably be reduced by applying efficient uplift relief systems.

In all stages of building hydro-powerplants, the process has been accelerated remarkably, so that in several cases hydropower remains competitive with thermal-power in this respect, too.

In particular this refers to the speed of three construction phases:

- Foundation and tunneling works.
- Further the machine assembling at site.
- Prefabrication.

An example is the Iffezheim Powerplant on the Rhine River which was completed within 3-1/2 years.

A stimulus for waterpower utilization was the economic advantage of the underground layout of the station. Improved techniques in tunneling, lining, sealing and in reinforcing of caverns, pressure tunnels and shafts gives more and more preference to underground projects.

I very much regret that limited time does not permit me to show you a few very instructive examples of high-capacity underground projects in Canada, Austria, Sweden, Norway, Italy, and Switzerland. I am thinking of the Soverzene Plant in Italy, viz a comparison of an open-air and underground variant. Finally, because of several, but mainly economic advantages, the underground solution had been selected for implementation. There has been remarkable progress in excavation dimensions for power-caverns, illustrated by European examples. The storage-power stations serve either to balance the fluctuating natural-flow or they take an important part in delivering peak-power. The dam-power stations supplied from huge reservoirs produce the energy in most cases on such a low price, that they will not have any competitor for a long time.

The impressive 220 meter high Glen Canyon Arch Dam, Colorado, USA, creates a reservoir of 32 milliard cubic meters of storage capacity. The powerhouse capacity is 1000 MW. The second largest man-made lake as regards storage capacity is created by the Kariba Dam. It is not easy—even for professional people—to grasp what this 180 milliard cubic meters of water means.

With the Figure, I would like to try to give you an imagination. A small canal suitable for padding, connecting the Earth with the Sun could be filled-up with water from the Kariba Reservoir (150 million kM long); or a medium size naviagble double-path waterway reaching the Moon could be filled-up from the same. As already mentioned, one factor has been, in general, recognized to be an actual disadvantage of the hydropower in its ability to compete. It is the fact that in the first time of utilization the best possibilities have been chosen. In some regions, and especially in a great part of Europe, this may have happened, but considering our entire globe this statement does not hold true at all.

When studying available waterpower resources, we come to the conclusion that still many river stretches and dam-sites can be selected which have not been realized before, as offering the chance for economic implementation of

large hydropower plants or multipurpose schemes. It should be borne in mind that from the economically feasible hydropower potential of our globe, i.e. from the round 4 million megawatts, not much more than about 10 percent has been utilized up to the present.

Who would have dared to think of the complete utilization of the big streams crossing plain lands in the first period of development! That seemed to be a task technically insoluble or at least uneconomical at that time for the following reasons:

- Difficulties in foundation,
- The consequences of backwater, and
- Lack of suitable solutions for gate constructions and for low-head turbines of high capacity.

Within the scope of this lecture it is naturally impossible to present the very instructive examples of the integrated utilization of the Tennessee River in the USA, the St. Lawrence canalization in Canada, the Rhine and Rhone canalization in Europe, and the Volga River in the USSR.

Next, let's consider the utilization scheme of the Danube River, partly completed. (from among the 48 plants included in the scheme, 20 stations are already in operation.) Low-capacity, small-scale plants on the upmost stretch of the Danube are in operation, under construction and in planning. It is interesting to study the progress in the degree of utilization with run-of-river plants. The harnessing of the Rhine shows a typical example. This evolution can be characterized by the duration period of the plant discharge capacity drawn versus the time of commissioning of the plant. In the pioneer phase of low-head development this value was about 300 days or 82% ; when I studied, my professor taught us the thumb rule of 182 days or 50% ; at the present—on basis of economic consideration—we select the plant discharge capacity even as high as 90 to 55 days duration (25 to 15%).

The technical progress has rendered possible the building of hydropower plants of extremely high capacity. This fact has also its advantageous effect on the energy production costs. The table refers to a few conventional and to a few pumped-storage plants.

Hand-in-hand with this development there was also a remarkable increase in machine capacity. While some forty years ago a 50,000 kW unit has been looked at as an especially large machine, today with a few stations the unit-power of 500,000 kW has been exceeded.

It is very interesting to follow the evolution of the turbine types and the change in their range of application. In the last decades the propeller-type of turbines penetrated into the head-range of the Francis machines, while the Francis turbines are recently used for higher-heads than earlier, so they occupy the lower-part of the head-range having been pertained earlier to the Pelton wheels.

For low-heads up to the last decades only the conventional solution of the Kaplan turbine was accepted as the most advantageous solution when medium or high-rate flows had to be utilized, respectively, when medium or high-capacity units have to be constructed. It is evident that this, in some cases, is not apt for economic solutions of a small plant, because of the required deep foundation. Two examples for the conventional turbine setting can be shown:

1. Powerhouse equipped with fixed-blade propeller machines (e.g. Wheeler plant, Tennessee),
2. Powerhouse equipped with adjustable-blade machines (e.g. Ryburg-Schworstadt, Rhine, Switzerland).

The latter is called Kaplan turbine in spite of the fact that both types were invented by V. Kaplan.

For very low-heads, the tubular Kaplan turbine proved to be a very favorable machine type, even for high capacities. I would like to show four characteristical types of it:

1. The first illustrates the ring-generator type of generating unit. Aggregates of this type have been installed in typical low-head, low-capacity submerged powerhouses at first in the thirties, and some of them are still in operation. (e.g. Rott-Freilassing Powerhouse, Salach River, Federal Republic of Germany).
2. The second shows a bulb-type Kaplan unit which has been developed about in the last 30 years, and is appreciated as a very suitable machine for utilizing low-heads. (e.g. Iffezheim plant, Rhine River, German-French border).
3. The third type is the improved ring-generator unit having been designed in the last years and proposed for installation as both, low-size and high-capacity machines.
4. The fourth type of low-head unit is the so-called tube unit, which is suitable both for low-size and high-capacity developments, an example designed and constructed by the Allis-Chalmers Turbine Manufacturing Company (so-called STRAFLO machines).

Finally, I would like to call your attention to the problems which may arise on densely navigated rivers, when a sudden load rejection at high-capacity hydropower stations occur. The vessels, the river banks and even the structures themselves may be endangered by the surges generated due to the sudden closure of the turbines. It would be very instructive to discuss the measures and devices which have been invented in order to eliminate or at least to diminish surge waves, however, the time being at my disposal does not allow me to explain more details of this very important topic.

It became obvious from the energy crisis, and consequently from several presentations at this conference that—after a certain recession—an accelerated utilization of hydropower resources is necessitated. In my opinion, simultaneously several aspects have to be considered to achieve a fast and successful progress in this field. Besides scientific and technological problems which are discussed in other sections and in the workshops of this symposium, the following objectives have to be appreciated:

1. In order to obtain reliable power-generation costs a true allocation of investment is required in cases when the hydropower plant is part of a multi-purpose scheme. (The hidden subventioning of other objectives is misleading about the real value of hydropower.)
2. A realistic assumption concerning the lifetime of structures and equipment of hydropower plants is strongly recommended.

3. An up-to-date assessment of the plant discharge capacity is required.
4. The planning should not be based on the present situation. In some cases a trend analysis can be recommended.
5. The requirements on exploration, studies and especially on feasibility studies should be in conformity—with other words in a reasonable balance—with the economic and human value of the project. (It has no sense if a feasibility study costs more than the construction of the small-size plant.)
6. Midget plants do not require sophisticated equipment. (Please do not forget that also in technology and engineering sciences exist fashion, similarly to the fashion with the hats of the ladies. Believe me, I can prove it!)
7. Every effort has to be made to reduce planning and construction time. The old Romans used to say: "Bis dat qui cito dat" (twice gives he, who fast gives.)
8. Planning, design, construction and operation of hydropower should not be neglected in engineering education.
9. The decision-making with the competent authorities should be accelerated, if possible.

I hope I shall not be accused of an overstatement, if I say—when regarding the whole world, that we can speak about a renaissance of hydropower. In my opinion, this epoque will last at least a few more decades and will necessitate further intensive research, technological improvements and a broad international co-operation, and a continuation of discussions on a sound hydropower philosophy.

HIGH-CAPACITY PUMPED STORAGE SCHEMES

Country	Plant	Unit Number	MW	Plant capacity MW	Head m
Australia	Murray	10	119	1190	521
France	Revin	4	165	660	245
FR Germay	Wehr	4	250	1000	625
Italy	Chiotas-Piastra	8	150	1200	1018
Japan	Shintakase	4	336	1344	241
Luxembourg	Vianden	9	100	1100	280
		1	200		
Rumania	Lotru	3	170	510	809
Spain	Villarino	4	540	540	382
UK	Dinorwic	6	300	1000	530
USA	Cornwall	8	260	2080	320
Yugoslavia	Bajina Basta	2	300	600	600

HIGH-CAPACITY CONVENTIONAL WATER POWER PLANTS

Name	River	Country(ies)	Plant capacity MW
Itaipu	Parana	Brasil-Paraguay	12.600
Krasnoyarsk	Yenisei	USSR	6.000
Churchill Falls	Churchill	Canada	5.225
Grand Coulee III	Columbia	USA	3.600
Yacyreta	Parana	Argentina-Paraguay	4.000

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

SPECIAL PLENARY

Senator John A. Durkin
United States Senate

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

HYDROELECTRIC POWER AND ENERGY-EFFICIENT RESPONSIBILITIES

Senator John A. Durkin

Thank you General. And thank you for such a warm welcome. It was a couple of years ago, as early as 1977, that the Senate created for the first time the Senate Energy Committee. Energy responsibilities had been scattered all over the landscape. I remember the first meeting of the Senate Energy Committee where I raised the possibility of pursuing the retrofitting of existing dams with small-scale hydro technology. There was as much laughter in the room as there was for the General's joke. People looked at me like I had been the recipient of too much solar energy. But we've come a long way since then in a very short time. To think that one or two people, Congressman Ottinger in the House and myself in the Senate, started pushing hydropower and today, about 2½ years later, we have this number of people coming from all over the country, and we're host to almost a score from foreign countries to discuss the potential of hydroelectric power. This shows that this country as well as the rest of the world is taking our energy problems seriously.

Last summer when our gas lines were long and our gas supply was short, I used to hear people in New Hampshire joke in their frustration that Detroit ought to build a car that could run on water. For in New Hampshire, New England and throughout the Nation, water is often seen as an inexpensive and inexhaustible resource; the antithesis of the prohibitively high-priced and precariously undependable OPEC oil. Our rivers and streams flow freely through our backyards, invulnerable to foreign embargos and the politics of energy. Water, water is indeed everywhere and it is about time we begin to tap its tremendous potential power.

In my area of the country, New England, water power generated the growth of industry and commerce for almost 150 years; from colonial days to the middle of this century. The first water-powered sawmill and gristmill were built in New England in 1783. Following this, water was used to power small industires, such as textiles, shoes, furniture, and machine tools.

Despite this impressive record, over the past thirty to forty years water power has been neglected as a cost-saving, safe, sensible energy source for the country. The Federal Power Commission estimated that, in New England alone, in the past three decades over 200 small hydroelectric plants have been abandoned. As the cost for home heating oil in New Hampshire fast approaches a dollar a gallon, it is high time we channel the potential energy savings flowing by our river banks into our savings banks.

It is important to remember that the principal reason for the demise of hydroelectricity was not due to the arrival of a more effective energy source instead it was because a cheaper source had come on the market. I am referring, of course, to oil. It seems inconceivable today that oil, with its dollar a gallon price tag and its tenuous supply line, could have at one time replaced water as

---

Senator Durkin represents the State of New Hampshire in the U.S. Senate. He is also Chairman, Subcommittee on Energy Conservation and Supply, and member, Senate Committee on Energy and Natural Resources.

a primary energy source. But at the time that oil burst onto the scene, America was committed to a bigger and better policy, and large scale oil burning operations quickly made small scale low-head hydro facilities obsolete.

The utility companies were also quick to claim that large new oil-reliant plants were eligible for depreciation tax write-offs, while productive hydropower facilities were not. This financial incentive could have easily been eliminated through a revision of the tax code. Hydropower's success became its handicap; as hydro facilities outlasted the tax code terms for depreciation allowances.

In any case, the tides are turning, and hydropower is making waves again as a viable and valuable renewable resource. We must encourage continuing efforts to rediscover small, decentralized power facilities which can provide an increasing part of our energy needs. No one contends, of course, that water power can provide all our energy needs. However, it certainly can displace a great deal of imported oil now used to generate power, providing cheaper and more dependable energy which in turn would give homeowners and businesses alike some much needed energy and economic relief.

The Federal Power Commission has estimated that if only 10% of the nearly 50,000 small dams are even partially developed for electrical generation, the energy savings would be the equivalent of 180 million barrels of oil every year. In New Hampshire alone, there are hundreds of existing dams which could be equipped to generate power. One study estimates that more than 2,000 Megawatts of electricity could be gained in New England through conversion of existing dam facilities. To put these numbers in perspective, a 5,000 Kilowatt (thousand watt) hydropower facility could provide the energy needs of several thousand families.

We don't have to look far to see the tangible benefits of hydropower either. Just one example is a restored hydro facility in Franklin, Massachusetts, which is now capable of producing 300 kilowatts an hour; this plant alone saves the equivalent of a quarter of a million gallons of oil a year.

In addition to existing facilities, hydro power sites are being constructed and studied in many towns in my home state of New Hampshire. A hydroelectric facility in Nashua, New Hampshire, is planned to supply energy for the Public Library, Arts and Science Center, High School, police station, and public works garage. A conservative estimate is that this facility could reduce Nashua's tax rate by $2.40 per $1,000. The Brown Paper Company recently received funding from the Department of Energy for a water power construction demonstration facility at the Sawmill Dam Redevelopment Project in Berlin.

For oil-dependent New Hampshire and New England, hydropower represents an immediately available alternative energy source. It is clean, renewable and low-cost, and will produce tremendous oil savings for energy consumers in New Hampshire and New England. By retrofitting existing small dams in New England with new, efficient turbines to generate electricity, our region could save 22 million barrels of oil a year, or nearly $400,000,000. These small scale facilities can be put into operation at lower capital costs per unit and will produce energy at lower production costs per unit than new large generating plants.

By in large the cost for hydroelectric plants is a one time upfront expense. And as the price for fossil fuels continues to rise while supplies continue to plummet, water power increasingly becomes an inflation-proof energy resource for the future. The faster we make the conversion the more quickly we can reap the benefits of its savings.

As I mentioned earlier, while no single alternative energy resource is dependable enough to supply all our energy in the future, it is equally true that traditional fossil fuels can no longer be relied upon by the utility companies to meet our energy demands. The major power suppliers must utilize a balanced program of alternative resources which will complement presently tapped sources.

To speed up the conversion to hydro facilities, I introduced and succeeded in getting legislation passed which provides up to $300 million in Federal loans guarantees to cover 75% of the project costs for hydroelectric installations at existing dams. An additional $200 million was recently added to this bill. I also successfully fought for passage of legislation to provide $30 million in direct loans over 3 years for feasibility studies of sites for new projects. A number of studies are already under way by the Army Corps of Engineers. Feasibility studies are the costliest and riskiest component in the process of converting existing dams to water power generation. These loans will provide a needed impetus for developing these important facilities.

While I am pleased that this program is initiating the long overdue development and construction of hydro facilities, I am generally highly skeptical of the Federal government's ability to quickly implement such an important and far-ranging program. Had Thomas Edison been forced to submit to a series of bureaucratic feasibility studies we might well be without a light bulb today.

The beauty of low-head hydro is that it brings a decentralized approach to addressing our energy problem which in part has been created by the large, concentrated, multi-national conglomerates. It takes simple sound common sense to keep the administration, development, and commercialization of a water power program on as local a level as possible.

To illustrate why a local approach is the more expeditious path to follow, I can only point to the problems we have encountered in implementing the Public Utility Regulatory Practices Act (PURPA) which was originally designed to make small-scale power sources cost competitive with the large utility companies.

PURPA, as you may know, requires the major utility companies to purchase power from small-scale facilities at a fair rate. It is also supposed to streamline the licensing and regulatory procedures for small-scale power operations. And finally, it includes an essential provision which allows small-scale power owners access, at a fair price, to the utility companies' power lines.

Just about a year ago New Hampshire drafted similar legislation modeled in part after PURPA. New Hampshire has gone ahead and enacted their law while the Federal regulations are still floundering in deliberations. Simply stated a local approach is a faster approach.

This is not to say that the Federal government should do nothing. One step that we can take will greatly speed up the development of hydro is to exempt

small-scale development, up to 25 Megawatts, from the expensive, cumbersome, and by in large, non-applicable FERC regulations. Unnecessary Federal regulations stand as the biggest roadblock to extensive hydroelectric development. The Federal government can also offer Federal loans to state bonding agencies to aid municipalities in the construction of everything related to low-head hydro, from dam construction, to turbines, to fish ladders. Additionally, Federal legislation could offer tax credits to businesses for buying their energy from small-scale sources. This credit would be terminated after a few years, but in the meantime, it would provide a much needed market for small-scale power while giving business some welcomed energy and economic relief.

The bottom line is that water power can save consumers and businesses money while providing a clean, renewable, and non-polluting form of energy which will help make our region more self-reliant and independent. The Federal government can aid states and municipalities in implementing small-scale hydro facilities but it should, as much as possible, delegate the final authority to the states for the development and commercialization of low-head hydro. Water power is an energy source which can no longer be ignored, and I will continue doing everything possible in the U.S. Senate to encourage the widespread development and use of this important energy source.

I urge you here today to use your influence and join me in this effort.

Thank you.

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

SPECIAL PANEL ADDRESS

Peter Bourne

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

UNITED NATIONS INTEREST IN WATER

Peter Bourne

What I have to say very briefly this morning is not directed specifically at the issue of hydropower, but more generally about the current emphasis and focus on water issues in the U.N. system. As many of you probably know, in 1977 the U.N. held an International Water Conference in Mar del Plata, Argentina, a conference which I think in many ways proved to be vastly more successful than many people in the U.N. system anticipated, and also more successful than many of the people in the participating countries had anticipated. A great deal of enthusiasm was generated and it also became clear the very high priority that many countries, particularly in the developing world, attached to water resources. Growing out of the conference were a number of resolutions and recommendations to the U.N. General Assembly including one that a period of 10 years be set aside to focus on water resources, with, among other things, the specific objective of providing clear drinking water for everybody in the world by 1990. That particular resolution was passed by the U.N. last year and the period 1981 through 1990 is now what will be known as the "Water Decade" and will be one of a series of similar special emphasis periods that you may be familiar with such as the "International Year of the Child" and a number of other areas, that the U.N. have tried to emphasize in a special kind of way and give special priority to.

The U.N. "Water Decade" itself will be formally launched at the General Assembly next year probably some time in November while the General Assembly is in session. A full day of the General Assembly's time will be devoted to launching the Decade and it is hoped that at that time a good deal of attention could be focused on the issue of water resources and that top-level government representatives from throughout the world hopefully will participate in that initiating day.

In the period between now and then, the U.N. system is in a planning phase for the Decade and we're attempting to do something which is somewhat unique for most government systems as well, which is to take all of the fragmented parts of the U.N. system that have some interest in water and to put them together in what we are optimistically describing as Cooperative Action for the "Water Decade." This involves getting representatives of all of the various U.N. agencies ranging from the World Meterological Organization to the World Health Organization, UNICEF, United Nations Development Program, UNESCO, and several others to work together collaboratively. We plan to divide the responsibilities, hopefully getting people to give their time so that we can plan the Decade with the maximum degree of effectiveness with each agency taking responsibility for the area where it has the greatest expertise, and working together as part of the overall plan for the U.N. system. In preparation for the Decade we are asking each participating country (eventually every country in the world) to prepare some kind of general overview of water resources and their long-range plan in looking toward what they would

---

Dr. Bourne is Assistant Secretary General and Coordinator, United Nations Water Decade, New York.

anticipate doing during the 10 years of the Decade. We are also asking each country to establish a National Action Committee, at the ministerial level made up of those ministers who have the most direct involvement in the water area. That Committee will be established under the direction of the Head of State or Head of Government to develop a specific and very detailed action plan over the next several years, as to how water resources could be better planned and how the goals of the decade would be met by the end of the year 1990. In preparation for the Decade, the U.N. system is primarily involved in assisting governments with technical advice and helping them to prepare the plan and organizing their National Action Committee. At the country level there is an individual known as the resident representative of the U.N. Essentially, that individual is the Secretary General's Ambassador in each country. He represents the U.N. overall, even though there may be representatives from FAO, WHO, and other individual agencies. He is the key-man and he has been designated as having overall responsibility for coordinating the efforts of the U.N. system in supporting the government in planning for the "Water Decade." At the same time, being the key-person in relating to the government itself, he will try to get a high-level of interest and enthusiasm.

We are very committed to trying to get the developed nations to place a high priority on this program. The U.S. government has made a commitment of 2.5 billion dollars over the 10 years, essentially 250 million dollars a year. This, of course, depends on the willingness of the Congress year-by-year to support that commitment, but this is the general pledge that has been made. Similarly, a number of other donor countries, particularly the West Germans and the Swedes have made very enthusiastic verbal commitments at this point, as to their interest in the Decade. In addition, we anticipate the World Bank will play a major role in helping to develop programs in connection with the Decade.

We had one meeting of the major donors last November. We anticipate having another one this year, and we hope a point will be reached where some kind of mechanism, developed whereby countries can develop a comprehensive national plan for dealing with their water resources, and particularly for providing clean drinking water. And if the plan is detailed and comprehensive enough we hope to be able to broker that plan with the donor group and have either all or part of it picked-up by the various donor countries or multilateral donor agencies. In this way we hope to establish some kind of mechanism that hopefully will be more effective than some of the programs in the past, which by and large have been hit and miss efforts where there has been no coordinated effort to take a carefully prepared country plan and match it with the specific interest of the various donor agencies.

During the period - now a little over 6 months - that I have been coordinating the "Water Decade" activities, the primary activity that I have been involved in is traveling to various countries to try to stimulate interest in the Decade. One of the things that has been quite striking to me is the very high degree of enthusiasm that there is for the Decade, particularly in the many developing countries. I think perhaps, the urgency of the development of water resources is not appreciated by certainly the general public in this country as far as the many developing nations is concerned. In many developing nations, water is increasingly the No. 1 priority; and in most countries water and energy are at the top of the list of all national priorities. In most countries

I've gone to, there has been enthusiastic commitment, very great eagerness to participate in the Decade -and many countries are very well along in developing national action plans, establishing National Action Committees, and having people at the ministerial level already very vigorously working toward the success of the Decade. The problems that we encounter are the ones that are true not only in every government, but particularly true in developing countries. The problem is fragmentation in many even small-developing countries, water resource issues are divided up often between a dozen or more ministries in terms of their responsibilities, many of whom never normally get together to plan their activities. Trying to get people together and getting them to talk for the first time is a problem that is certainly not unique in developing countries in terms of fragmentation of government activities. We also find that in many instances, although there may be a shortage of technical expertise, the problem that is really lacking in developing countries is the lack of management skills more than technical skills. Very often the ability to lay out a comprehensive long-range plan to look at management problems, to look at options, to make decisions, and to do management by objective, is the more difficult problem that many developing countries face. We find that in many instances providing managers, economists, even political scientists, often are more important than providing people with specific technical water expertise.

In summary, just let me say, I think that the "Water Decade," although it's still in it's embryonic stage, is going to be a very important vehicle in focusing interest on the whole area of water. I think that it is going to raise the awareness of this issue in a very intense way on a global basis. I think it's going to make many people in policy-making positions, in many countries, look at the potential that water has to offer in its variety of manifestations, and I think that we can look forward to the "Water Decade" as promoting this entire field in every aspect that we are interested in.

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

CLOSING ADDRESSES

Ellis Armstrong
U.S. Representative
World Energy Conference

Senator Mike Gravel
United States Senate

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

THE FUTURE ROLE OF HYDROPOWER IN THE WORLD ENERGY CONTEXT

Ellis L. Armstrong

This has been, and still is, a productive conference. The speakers, the technical seminars, the workshops, the exhibits have all contributed to a better understanding of the potential, and the problems, of developing small-scale hydropower. The potential is promising, but as with most things, there is no magic. Accomplishment takes work, effort and time. The challenges for development to occur become more difficult and more widespread as we have more people. And this is a fact that no fantasy or wistful thinking is going to change; more and more people are coming down the road.

The challenge is for all of us to more realistically face-up-to the fundamental problems of mankind in order to meet the needs of the growing numbers of people in our world. Meeting the needs of people, both in the developed and the undeveloping countries, basically involves energy, water, and food; interrelationships are varied and complex. For instance, in the more affluent countries where food supplies seem assured, at least for the present, the emphasis is directed toward a fuller life, including increased services and cultural activity in an unpolluted quality environment. This requires greater energy from cleaner sources, and better management and control of water. In the developing countries, the emphasis is on adequate food, goods and services that reduce risks to life, and improve human conditions, so that life is less arduous and more worthwhile. Worldwide, all are striving toward individual betterment, justice, harmony, and peace; these goals require economic growth and improvement, and this requires increased use of energy and better and increased utilization of water.

Hydropower Development

Hydropower has a key-role in meeting these needs by providing a clean, continually renewable, energy source; as well as providing assistance with control of water for improved and assured food production, reduced damage from floods and droughts, improved municipal water supplies, and in some arid areas, at least, a more productive and useful environment for man as well as wildlife.

Man's utilization of waterpower to help him adapt his environment to make it more compatible to his survival goes back to at least 4000 BC when it was utilized by the "hydraulic states" for irrigation and for military purposes. Mechanization of waterpower appears to have developed about 1500 BC, primarily for raising water to a higher level and a waterwheel of sorts appeared

---

Dr. Armstrong was Chairman, United States National Committee, World Energy Conference 1972-74, Chairman, Hydraulic Resources Task Force, World Energy Conference Conservation Commission 1975-79; U.S. Commissioner of Reclamation 1969-73; is presently water and energy consulting engineer, Salt Lake City, Utah.

about 200 BC. By 1000 AD waterpowered-grist mills were quite common; for instance, in 1086 AD it is recorded that there were 5,624 water mills in Southeastern England, serving 3,000 communities.

The use of waterpower moved along with and contributed to the advance of industrialization and was the source of energy, other than man and animal muscle-power and wind, until the advent of the steam engine in the forepart of the 19th Century. It launched the industrial age around the world, and with the advent of electricity in the 1880s, its importance increased, even though steampower had overtaken it in amount of energy produced.

Today hydropower provides 23% of the electric-power worldwide, with only about 17% of that considered developable now being utilized. These figures come from the studies of the Conservation Commission of the World Energy Conference, which indicated that the hydropower considered likely to be developed, is about 2.2 million megawatts installed capacity with a yearly productive potential of nearly 10 million gigawatt hours of energy. This is equal to approximately 40 million barrels of oil per day burned in a heat-powerplant.

Hydropower Advantages

While the amount of energy produced and the potential are impressive, hydropower is of much greater importance because of the following reasons:

1. It is a non-consumptive generator of energy, utilizing a clean resource, continually renewable by the energy of the sun which creates and sustains the hydrological cycle.
2. It is essentially non-polluting and no heat is released.
3. The generation of hydropower requires some type of water control, ranging up to full control of the discharge from a watershed, thus it is an important part of the multipurpose utilization of water resources and reduces the potential of destruction from floods. Water out of control is mankind's most destructive force. With storage facilities, floodwaters are retained and better utilized for food production; for river regulation improving navigation, fish and wildlife, and recreational potential; for municipal use and better control of wastewaters; and the destructive force of flood flows, as well as the energy of normal flows, is harnessed to provide electrical energy for man's use.
4. It is a reliable energy source within the hydrological limitations of the site. The relative simplicity of hydraulic machinery makes energy instantly available as needed. As no heat is involved, equipment has a long life, and malfunctioning is rare.
5. It can be made available in small installations at remote areas of developing countries with relatively simple technology, and can be a catalyst in developing other resources and creating opportunities for improving human conditions, as has been demonstrated in the past.
6. Its reliability and flexibility of operation, including fast startup and shutdown time in response to rapid changes in demand,

makes it an especially valuable part of a large-electrical system, increasing the overall economy, efficiency, and reliability of the entire system.

7. It has excellent peaking-power capability, for the reasons outlined above. Storage of energy by pump storage systems is the most economical and trouble-free method available to date for large-scale use. While about four units of energy input is required for three units of output, the input is low-cost energy and the output is high-value energy meeting peak-loads. Even so, in a large electrical system, the alternative for peak-loads may be the utilization of old and relatively inefficient thermal units; in these instances the use of pump storage can result in overall savings of energy. In flat topography areas, all underground pump-storage facilities have potential.
8. Its technology is well developed and proven, with efficiencies of turbines now as high as 95% . Units ranging from a few kilowatts up to 700,000 kilowatts are in operation, and while the equipment must be adapted to the specific site for greatest efficiency, full reliance can be placed on performance expectations.
9. With changes occurring in river basin hydrology, great potential exists at present powerhouses and at dams without hydro-installations for hydro-production with minimum capital or energy costs. Also improvements in turbine and generator efficiency makes upgrading of many present equipment installations especially attractive.
10. Hydropower facilities have a long life; dams and control works will generally perform for a century or more with little maintenance required.
11. As no fuel is required, and heat is not involved, operating costs are low for hydropower. Because of this and the long life of the facilities, a hydropower installation is essentially inflation-proof.
12. Hydropower-development makes maximum use of local materials and labor, and thus compared to heat-power facilities, usually is much more appropriate in developing country programs.
13. A vast quantity of hydropower remains to be utilized, especially in the developing countries, which on the average have developed less than 7% of their potential; in some countries it is less than 2% .
14. The economic feasibility of hydropower is improving, compared to other energy sources which use finite fuels. With more realistic methodology of economic evaluation, including full recognition of the value of non-use of depletable resources; of not being dependent upon fuel resources controlled by others; and of a non-pulluting generator of energy; hydropower becomes increasingly attractive.

World Energy Fundamentals

In addition to these items concerning the advantages and the value of hydropower, there are some additional basic fundamentals from the world

energy standpoint that make necessary full consideration and action in developing the hydropower potential. First let us consider the number of people now on our one-world and the growth expected in the next 40 years.

We now number 4.3 billion; by the year 2020, barring catastrophe, we will likely number 8 or 9 billion. The OECD countries, which include Western Europe, North America, Japan, Australia, and New Zealand, now total about 18% of the world total, and by 2020 will only be 10%; the centrally planned countries, which include USSR, China, and their satellites, now comprise nearly one-third of the worlds population, but by 2020 will be one-fourth of the total; the developing countries now are about one-half of the total and by 2020 will comprise 65% of the worlds people.

These latter 5 or 6 billion people of 2020, with their rising expectations for a better life, and their desperate struggles for improvement, must be a major factor in considering energy programs; otherwise chaos looms ahead.

With today's transportation system, no place on earth is more than a day away from any other place; and with our satellites, we are in instant pictorial communication with almost every spot on earth. These factors present a great hope for the dissemination of knowledge and appropriate technology that will enable basic natural resources to be developed for the good-of-man all over the world. They also support and improve our understanding and appreciation of each other's problems. Basically we are all pretty much alike, with our concerns, dreams and hopes for the future, especially for our children and grandchildren. These are basic concerns which motivate people everywhere on earth. And the development and utilization of energy is essential to enable dreams to come true.

World Energy Conference Studies

Deeply concerned with the conflicting information and data regarding, energy, which had reached the stage where no one believed any one anymore, the World Energy Conference formally launched its Conservation Commission Study in 1975. The charge was to determine as objectively and factually as possible, the energy resources of the world; investigate ways improvements in development and utilization of these resources could be accomplished; assess possibilities of substituting other energy resources for oil; evaluate the probable extent conservation measures could reduce energy demands; and then determine what the energy needs worldwide would most likely be, and the ways they could be met. The World Energy Conference is an organization of 76 nations, organized in the 1920s and dedicated to the efficient and effective peaceful use of energy for the betterment of mankind worldwide. The Conservation Commission, including the study reviewers totaled 80 members, and in addition large-task forces were formulated in the areas of oil, coal, natural gas, nuclear, hydraulic, unconventional resources (such as solar, biomass, wind, geothermal, waves), conservation, and energy demands. These included people we considered the most knowledgeable in the world.

The studies have now been completed and the results published. (The publications are listed at the end of this paper). The publications, I believe, present the first fully comprehensive, objective, authoritative analysis of the world's energy resources and the demands for the next four decades. The message is not "doomsday", but it does emphasize that time is running out,

and that resolute action on long-range programs to develop and more effectively utilize the world's energy resources must be aggressively instigated now.

Even back in 1971 at the First National Energy Forum, which was organized by the United States National Committee of the World Energy Conference, and which I keynoted, I pointed out that really all that had to be understood was how to add and subtract; that the energy demands and the energy resources being used clearly indicated we were in trouble. This theme has dominated the discussions of each National Energy Forum held each year since. This alone demonstrates the great difficulty of focusing on a problem due to crash 10 or 15 years ahead, and this is especially true in our affluent and comfortable societies.

Our energy crisis has developed from our dependence on oil, which now provides about half of our total worldwide energy use. This shows that total physical worldwide capability of oil production without political constraints otherwise putting a ceiling on the amount being produced. This indicates the potential production will peak out at about 85 million barrels a day, ten years from now. The worldwide demand for oil, without political constraints, is likely to exceed the total production capability about 1990, as production capability drops off rather sharply to 40 or 50 million barrels a day. Of course there are uncertainties, but this represents the combined knowledge and judgement of some, at least, of the world's most informed and knowledgeable experts. The width of the band is considered to cover the uncertainties.

The data on this figure assumes construction of a nuclear and coal-fired plants at the rate planned; increase in efficiency in use of energy and in conservation to the extent that the economy is not greatly adversely affected; that other energy sources would continue to be developed; and that the price of oil would reach $20 per barrel by 1985. We're already at the $20 level generally, as this might move the break point ahead a year or two.

A large number of scenarios were intensively analyzed, but this represents what I believe is most likely to occur. Even with worldwide recession, the break point is only moved ahead about 10 years. Note that we are now using 60 million barrels of oil per day, which is at the upper edge of the oil demand curve. Not having enough other energy resources to fill the widening gap between demand and supply of oil, that is likely to occur in about 10 years, would be serious and threaten worldwide economic and social chaos. And in the United States it takes 10 years for a nuclear powerplant.

One other problem is illustrated by the curves. Note that the physical capability of producing oil is 15 to 20% more than the present oil demand, principally because of the additional production that Saudi Arabia could provide. This tends to give a false sense of security, and the option of depending upon imported oil to meet increasing needs for the next decade or so, is likely not to exist.

One more point — these curves represent the overall worldwide situation. Individual countries which greatly depend upon importing OPEC oil, are in much more vulnerable positions. Political stability is what we hope for in the OPEC countries, but you know the risk as well as I do. We, in the United States, now are dependent upon importing about half of our oil. You know what happened with a 3% shortfall and the long gas lines that developed as a result of the revolution in Iran and the following bureaucratic distribution problems. Many people in the long gas lines did not always display rational

behavior. A colleague of mine came up with this design of a car which he says is guaranteed to get you to the head of the next long gas line — that is, until too many others get the same model. And on a worldwide basis, weapons are available which are much more efficient, effective, and deadly than these guns. Think about that.

Many people fail to have a perspective of the magnitude of our energy problems. Worldwide, we are now using the equivalent of about 120 million barrels of oil per day, approximately half of which is oil. If this total were barrels of oil stacked on top of each other, they would extend into the sky a distance of about 100,000 miles; almost half way to the moon. And this is the amount of energy we are now using each and every day; thus slight-of-hand tricks, fantasy, whimsy magic, rock music, movie star rantings, emotions, or half-truth "naderitisms" are not going to be much help in reaching meaningful solutions or in determining viable options. It will take truth, facts, objective effort, and never ending hard work, and we must get with it.

The bottom line of the Conservation Commission study is essentially that we have the energy resources to meet the worldwide needs and that we generally have the technology and the capability. But we must get going now. While from a realistic standpoint, we must depend mainly on coal and nuclear energy resources for the next two decades or so to fill the gap created by oil and gas shortfalls, we must push the other energy resources also.

Hydropower Development Worldwide

Hydropower presents the many advantages that have been listed and thus development needs to be vigorously pushed. Several developing countries have extensive programs being planned, and the projects now under construction, especially in South America, are impressive. For instance, the largest powerplant in the world is now well along in construction at the Itapu Dam on the Parana River between Brazil and Paraguay. The first stage capacity is 12,600 megawatts; when completed the installed capacity will be 21,000 megawatts. Argentina is launching a program to construct about 50 hydropower plants by the year 2000 that will provide nearly 30,000 megawatts of installed capacity at an estimated cost of $53 billion in present dollars.

In 1975, China had a total of 60,000 small-scale hydropower plants in operation with an average capacity of 36 kilowatts. Plants of this size are important at the beginning of improvement of human conditions as they provide a few street lights, a light globe or two in each house in a village, and support small cottage-type industry. The development to date represents only 2½% of China's hydropower potential. China recognizes that much more development is required as they move further ahead in improving human conditions. Six dams with a combined capacity of 21,000 megawatts are now being actively planned; and the Three Gorges Dam on the Yangtze River, under study for 30 years and which has a potential capacity of 30,000 megawatts, is being programmed to follow.

There is no way following the "soft path" for energy to meet the needs of people; adopting such a course would mean we'll not be around very long. You see we must use and improve our technology for the continual growth in energy, so growth in economic activities will enable the needs of the growing

numbers of people to be met. With improved technology people are assets. Backing away from technology spells doomsday. Soon we'd have very little to go around except people; and we'd use what energy we did have to kill each other off; and our capability to do this is complete and frightening.

Remember, however, that both "soft" and "hard" sources of energy, and of energy conservation are needed, and both must be pushed. There is no easy way out of our dilemma.

This conference has focused on the importance of small-scale hydropower, especially in the United States, and has demonstrated its value even in the well developed countries. It has stressed the need to launch an aggressive program of small-scale development, as it represents a valuable neglected energy resource. The World Energy Conference Conservation Commission study concluded that the worldwide hydropower installations will increase about five times by 2020. The increase will be much less in the developed countries—for instance, it is expected the present 60,000 MW will be about double in the United States.

Many countries are carefully examining their energy resources and their energy needs, and determining the options they can consider to meet the needs. The United Nations and various world financing organizations are making similar studies. The U.S. Departments of Energy and State are assisting developing countries in making these determinations. For instance, last year joint task forces assessed energy resources and developed several alternate energy strategies to utilize these resources to meet the energy requirements in Egypt and in Peru; this year similar studies are being instigated in Argentina and Portugal. Others are planned. With this type of information available to a country's decision makers, and the worldwide situation delineated by the WEC Conservation Commission study, much more effective programs, both for an individual country and to better meet the worldwide problems, can be formulated. And in all these plans, hydropower plays a most important part.

Factors Affecting Hydropower Development

The workshops and technical sessions have defined and well delineated the many factors that affect hydropower, and have explored the ramifications. The present level of technology has been adequately discussed, and while it generally is well developed and proven, some improvements can still be expected. Most problems become quite-site specific, but generalizations can be helpful guides. I want to stress several factors that I consider particularly significant from a worldwide standpoint.

First, there no longer are single-purpose water resource development projects. In arid areas of the world, water is the controlling factor of present and future human activity, and even in humid areas, it is an essential resource that requires careful husbandry. Being a basic resource that has limitations and which acts upon and interacts with all man's activities, any utilization must consider the full range of impacts on economic and social activity, and on the environment.

The various requirements for uses of water in a specific development potential need to be carefully defined, reasonable priorities determined, with op-

timum overall ways to best meet the various needs formulated. Tradeoffs will be required, and they need to be as fully defined and delineated as possible. Some uses are complementary and some are conflicting. While part of the factors can be well defined, judgemental evaluations will be required. Knowledge, experience, balance, and sound understanding and perspective are necessary for optimum programs. Providing decision-makers with this calibre of qualifications in one of the biggest problems we face.

The energy management training program for developing countries, sponsored by U.S. Agency for International Development and being carried out by the State University of New York at Stony Brook, is an example of an effective approach to help solve this problem. We need many more of these types of activities if we are going to meet our worldwide needs. Whether we like it or not, we are all involved in, and will be affected by, the results of such programs.

Another problem worldwide is the methodology of economic evaluation being used to determine the feasibility of a hydropower project. The usual economic analyses doesn't adequately define the value of hydropower, and are often weighted against it as compared to other energy sources. Probable differences in inflation rates, and especially with the oil problems which have been discussed, are usually not considered. Neither are the values of utilizing a non-polluting, non-consumptive energy source.

The inflation-proof characteristics of hydropower demonstrate the additional capital costs that can be justified for a hydropower plant, over those for an oil-fired powerplant. While it is simplistic, it shows a need for formulating methods of economic analysis that recognize the inflation-proof value of hydropower. For example, if oil cost $20 per barrel at the time the oil-fired powerplant went into operation, and if financing could be obtained at 8% interest, you could equitably invest $3,400 more for a kilowatt of hydropower than that of an oil-fired plant. While many cost and benefit factors will be involved in a specific site, and they must be carefully determined and weighed in making that site decision, these curves show a good approximation of the comparative value of the hydropower.

Rarely does a hydropower project concern only a local area. Even small-scale developments can have wide effects. Most of the large developments remaining have international considerations. Irongate Dam being built cooperatively by Romania and Yugoslavia on the Danube is an example, as is the St. Lawrence hydropower development already accomplished by the United States and Canada. Both of these projects took years of negotiations for agreements to be reached so that the construction could proceed. Both are multipurpose in that navigation, river regulation, recreation, municipal water, fish and wildlife are all involved. The Itapu Project, which has been mentioned, is another outstanding example.

These projects and others similar, are top achievements in man's struggle to improve his environment by harnessing the forces and controlling in some degree the vagaries of nature. But most important to the future of mankind, it seems to me, is the demonstration that international, national, local, and individual interests can cooperate and can be coordinated for the common good. It shows how nations, states, and groups of men, with some differences in objectives, and sometimes conflict of interests, can pool their dreams and combine their efforts for mutual benefit. They show the way that most of the problems of this troubled world can be resolved.

In areas of the developing countries, such as those involved with the Congo and the Mekong Rivers, a major difficulty is equitably arriving at a division of the costs, benefits, responsibilities, and the construction and operation activities. Here is where seasoned and objective perspectives and judgements are required. The developed countries, perhaps acting through international organizations, such as the World Energy Conference, can provide a much needed service in helping resolve these problems. They are complex — technically, socially, politically, and economically — and there are no easy answers. Legal problems can become overwhelming and the best of legal talent may be required to untangle the snarls.

Environmental impacts of hydropower-development vary widely at the potential development sites around the world, and must be carefully determined and evaluated. Methodology for accomplishing this is now quite well developed. With this information, options can be better compared and weighed, and intelligent trade-offs determined; the positive effects can be strengthened and the adverse effects minimized and mitigated to the degree possible. The same is true with the social effects. But here again, there is need for balanced, knowledgeable, and objective evaluations and judgements. There are no shortcuts and there is no magic.

One more problem, which is worldwide, is that of developing an organizational structure that can function effectively in the area of energy and water. Of course, some of the smaller and more simple projects lend themselves to planning and development by the private sector and financing by private investors. However, for the optimum development of water and energy resources, even the simple projects will involve interface with Government organizations. Most of the large, complex projects will be planned, constructed, and operated by government direction, and with the hydropower features, at least, being closely correlated with the electric utility industry.

If we are going to meet the problems of the future, as well as the present, comprehensive planning carefully evaluating the full-range of factors in the entire system is mandatory. To accomplish this is difficult, and special interest piecemeal approaches no longer suffice. For instance, in the United States this last decade, Congress has passed about a dozen national legislative acts, primarily concerned with energy and environment, and each somewhat focused on a single problem or a group of closely related problems. Each piece of legislation has been basically for sound purposes. As some of the legislation is of necessity somewhat loosely written, the resulting volumes of detailed rules and regulations, sometimes with attempts to "cookbook" the widely varying physical, economic, and social conditions in our diverse country into "standard" treatment, the result has become a regulatory morass and a permit quagmire.

This has been further complicated by "no growth" extremists recognizing and exploiting a ready-made tool to accomplish their tunnel-visioned goal of stopping most everything.

As a result it is becoming increasingly difficult to move ahead, even with the most essential developments. This situation has at least partly developed from failure to consider the full-system of costs and benefits in planning projects in the past, and the failure to fully evaluate the ramifications of specific pieces of legislation in related areas of concern. Special effort needs to be made to organize agencies and conduct studies to minimize the problems

being encountered in the United States. This takes objective, competent professionalism of the highest order, and is a formidable challenge.

In summary, hydropower is an important part of the worldwide efforts to meet the energy needs of people. It presents many advantages that, with balanced, innovative, and competent planning and development, can be more fully realized. And it is high time that we settle down and get with it. Time is running out.

WATERPOWER: AN AGENDA FOR THE 80'S

Senator Mike Gravel

Unquestionably, ENERGY will be the most critical issue facing the United States Congress in the 1980's.

In the next decade this country will be faced with some difficult choices in determining the priorities for the development of energy.

The outlook for hydropower as an alternative energy source in the 1980's is integrally tied to the overall consideration and development of a comprehensive and effective energy policy for the Nation. In order to accurately access the future of waterpower in the next decade, it is necessary to understand and consider the current direction of this country's energy policies.

We do not have an effective energy policy today, primarily due to the fact that there continues to be widespread disagreement among the nation's leaders over the major long-term goals.

The Congress has come under severe criticism for not dealing with the Nation's energy future. Yet, in order to develop a comprehensive and effective national energy policy we must first arrive at a consensus as to the long-range goals and short-term objectives.

The so-called "windfall profits" tax is an example of this current misdirection. It is an effort to tax excess profits, when in fact there are no excess profits. What is actually being contemplated is a transfer of capital from the oil and gas industry to government to be recycled into various programs; aid to the poor, mass transit, and the development of a synfuels program to name but a few, a transfer of capital which is required to discover future energy supplies and develop new energy sources.

Over the past years, the return on capital investment for American oil companies has been about 10 percent. Oil company profits average only in the middle range of corporate profitability.

The cheap oil has been found. New oil sources are deep in the earth, or offshore, or in areas of difficult access like Alaska's North Slope.

The average cost of drilling has doubled in the 1970's, forcing the industry to invest more money to get the oil and gas our economy needs. To cripple future oil and gas exploration, with what is in effect a serverance tax, would put an even greater strain on the economy than already exists under the current artificial energy pricing system.

Government controls on the price of gas and oil have had an adverse effect on the productivity of the U.S. economy. The fundamental element in the development of any effective energy policy is a realistic pricing system. Natural gas and domestic oil prices are regulated at levels well below the market price. As a result, energy consumption in this country continues to rise while domestic production of oil and gas continues to decline.

Basic economics tells us that the goods and services a nation can provide are maximized when the price of each is equal to the marginal cost of acquir-

---

Senator Gravel represents Alaska in the U.S. Senate, and is Chairman, U.S. Senate Subcommittee on Water Resources, and is a member, Committee on Environment and Public Works.

ing it. Therefore, until the deregulation of oil and gas is initiated this nation will continue to ride the "Energy Merry-Go-Round."

If we are to reach any sort of efficiency in the use of energy in the near future, price controls on oil and gas must be removed. At present, there is no single energy source that can satisfy the World's ever increasing energy demands.

Recent events both at home and around the world dictate that we develop alternative energy sources. The fall of the Shah's government in Iran, the near catastrophic accident at Three Mile Island and the escalating cost of OPEC oil have drastically impacted our Nation's energy supply and threatens to send this country into a major recession.

In the short term we can not replace oil and natural gas as the major source of world energy. Oil and natural gas currently supply approximately 75 percent of our Nation's energy needs. By the year 2000 it is estimated that the World's energy demand will increase by 50 percent. Alternate energy sources must be developed to supplement and fill the void that will develop between supply and demand. If this country and the other nations of the world do not address this problem now we are sure to face economic turmoil in the 1980's.

The critical issue involved in the development of alternate sources of energy is its cost, both from a purely economic standpoint, as well as the non-monetary costs associated with the degradation of the natural environment, effect on public health and the potential loss of human life.

As we analyze our choices we find the development of hydropower, and in particular low-head hydropower, at the top of the list. The development of hydroelectric power has always been subject to the market. Hydropower provided the foundation for the industrial development of this Nation and continued to grow until the regulation of natural gas took hold in the early 1960's.

This abrogation of the marketplace caused the price of natural gas to stay at an artifically low-consistant level which caused a dislocation of hydroelectric power in the marketplace. The command decision by government to develop, subsidize, and promote the use of nuclear power, whose costs and risks have never been accurately accessed, only increased this dislocation.

We are now looking at a further abrogation of the marketplace by a proposed government financed effort to produce synthetic fuels. The more this porposal is examined, the worse it looks. It would produce relatively little fuel, at the highest price with considerable environmental damage likely, and at a maximum cost for bureaucratic overhead. If we are to solve our energy problems in the 1980's, it is essential that we let a free-market determine the proper economic time to bring on such programs as synthetic fuels.

When the government all but removed the liability on the manufacturers and distributors of nuclear energy it skewed that energy source in the marketplace. Even the government command inducement to this sector of energy has not been able to overcome the detrimental market effects latent in this non-market approach to the energy problem. As a result of the above and the public reaction to the received or real dangers there is little chance that nuclear power at this generational stage can move forward appreciably.

We now find viability of solar-power to be limited in application, with original-cost estimates proving to be highly optimistic, and at best we will only be able to supply 20 percent of our energy needs in the next century.

Coal-fired powerplants currently produce pollutants at levels known to

cause serious respiratory illnesses. In addition, acid precipitation in the Northeastern United States threatens enoromous environmental consequences, and of course the dialogue on the "greenhouse effect" continues unabated. Wind-power and geothermal energy are unknown quantities, any breakthrough in this field could be significant, at present it remains indeterminable.

Energy conservation initiatives are undermined by a totally unrealistic pricing system. In addition, realistic projections based on the existing pricing system, of the amount of energy that can reasonably be conserved in the next twenty years does not significantly impact on the projected demand by the year 2000.

Clearly, one of the more viable short-term alternative energy sources is hydroelectric power. The technology is well established, it is renewable and it is the cleanest practical source of energy available today.

In the United States today, hydropower provides approximately 13 percent of the Nation's total electric-power with an installed capacity of about 60,000 megawatts. In 1978, a Corps of Engineers study estimated the gross potential for low-head hydroelectric power in the United States to be over 300,000 megawatts, or 5 times the current installed capacity. However, approximately 90 percent of the total potential involves the development of new sites. Current programs deal primarily with the development of existing sites. If low-head hydroelectric power is to provide a significant reduction in our dependence on foreign oil, we must explore, analyze, and develop it to its fullest practical potential.

Support for the development of small-scale hydropower in the Congress if formidable. A number of bills have been introduced, both in the House and the Senate, proposing the accelerated development of small-scale hydroelectric power. Again, this legislation deals primarily with the development of existing sites.

In August, Senator Mark Hatfield and I were joined by several of our colleagues in introducing Senate Bill 1641, the Small-Hydroelectric Power Development Act of 1979. This bill will set-up a continuing authority for the Corps of Engineers to site, select, plan, design, and construct new low-head hydroelectric facilities. This authority is set-up on a turn-key basis with the non-Federal entity owning and operating each facility and agreeing to pay back 100 percent of the Federal cost of construction, plus interest over a fifty year period. Projects constructed under this act shall be limited to an installed capacity of twenty-five megawatts. As currently written each project is limited to a Federal cost of not more than $15,000,000 and a total program limitation of $75,000,000 annually.

Recent testimony before the U.S. Senate Water Resources Subcommittee has convinced me to amend the bill changing the project limitation to an appropriate dollar figure per installed kilowatt capacity and increasing the total program amount to a level which will allow greater flexibility. Most important, Senate Bill 1641 is designed specifically to provide small-low income communities with a source of renewable energy immune to rising oil prices. These projects will help provide such communities with a stable economic base for economic development in the 1980's.

In closing, I do not want to leave you with the impression that the development of low-head hydroelectric power, and in particular new-site develop-

ment, will proceed without obstacles. There are formidable barriers to the expeditious development of hydropower as an alternative energy source.

Licensing procedures for small-hydro sites must be streamlined. This will involve significant change in the level of cooperation forthcoming from Federal and state fish and game agencies. However, I believe if this is not accomplished in a spirit of cooperation, the Congress will legislate it. Tax incentives must be forthcoming if substantial development of small-hydropower is to become a reality.

Environmental opposition to hydroelectric power development has been significant in the past and any consideration of new sites will meet with similar opposition. Today, however, there is more than sufficient environmental law in place to protect this country's natural resources and ensure that the mistakes of the past are not repeated. If the environmental community is to continue to provide meaningful input in the next decade, they must present a reasonable system of priorities for the development of energy. Conservation alone will not provide the answer. It is no longer acceptable to oppose development across the board without presenting responsible alternatives. The signs are clear, Congress and the Nation will no longer put-up with this self-righteous, "All or Nothing Approach" to the environment.

These are but a few of the problems that Congress and the Nation will deal with in the 1980's if waterpower is to significantly contribute to this Nation's overall energy picture. For the long run we must continue to investigate, develop, and improve upon the potential of all viable forms of energy development. In the meantime, HYDROPOWER is our most practical solution for the 1980's.

The overwhelming benefit of hydroelectric power is yet to be realized, when these facilities are payed off, future generations will inherit a totally renewable low-cost source of energy, immune to the escalating cost of fossil fuels.

TECHNICAL PAPER PRESENTATIONS

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

ENGINEERING SESSIONS

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

Session One

ENGINEERING

Topic: Equipment

Chairman: Mr. George Smith
Manager, Hydrolectric Project
Idaho National Engineering Lab.
U.S. Department of Energy
Idaho Falls, Idaho 83401

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

PAGES 89 to 90

WERE INTENTIONALLY

LEFT BLANK

Turnip Check Plant

A somewhat different approach has been taken by the Imperial Irrigation District at their Turnip Check installation as shown in Figure A-1.3. In 1963 they installed a 570 horsepower TUBE turbine on their west side main canal. This outdoor-type, unattended unit utilizes a 16.5 foot (5M) drop at an irrigation control point. Tight shutoff is provided by a Tainter gate located in the canal upstream of the trash racks and concrete pipe serves as the intake penstock. With the adjustable runner blades, optimum hydraulic performance is obtained for varying seasonal-flow conditions. To stop the unit, the blades are moved to a flat or closed position. Control of the adjustable blades can be automatic from a head water-level float system or manual at the control cubicle. After the induction generator is connected to the line, the float control system maintains the designated water-level range by adjusting the runner blades to vary the flow through the turbine. The induction generator is rated 420 kW, 900 RPM (synchronous), 3 phase, 60 Hz, 480 volts.

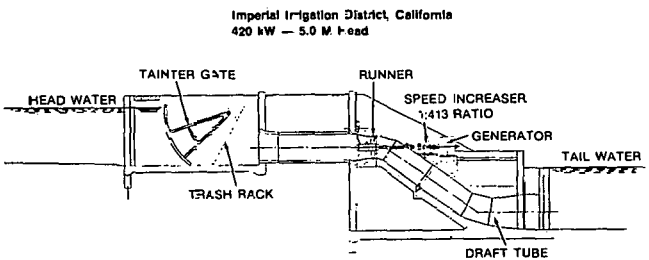
The unit is connected to the system by operation of a standard size 7 full voltage motor starter equipped with overload relays. This starter is backed up with time-delay line fuses. An auxiliary supply transformer, a watt-hour meter and a 9-point annunciator unit are also in the cubicle. In Figure A-1.4, the boxes at the left signify 8 adverse conditions, which would cause shutdown relay operation. Each of these plus generator overload will also actuate an annunciator drop. The plant has been operating successfully since 1964.

Synchronous Generators

The control system required for a synchronous generator is somewhat more complex than that necessary for induction generators. Situations under which synchronous generators are required include isolated operation, high capacity installations, applications where power-factor improvement is needed or desired and installations near or at the end of transmission lines. A synchronous generator has an advantage over an induction generator in being able to operate independently to supply the required voltage, frequency and kilowatts at the required load-power factor. Disadvantages of the synchronous generator are the insulated rotor winding and the necessity of using more complex controls. The conventional synchronizing equipment usually associated with synchronous generator installations and excitation systems has been simplified by the use of modern brushless exciters. A preview of some of the earlier installations will help to emphasize the changes that have developed during the last 15 years.

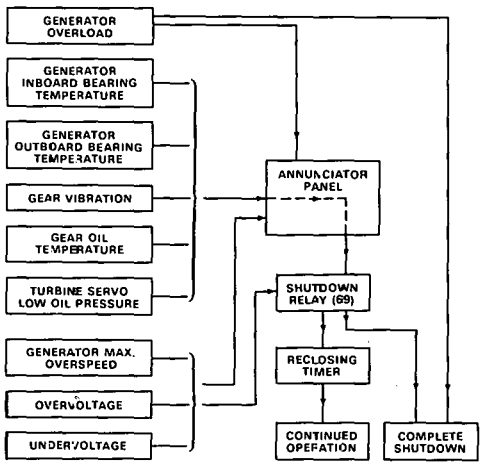
Stevens Point Plant

The first of the modern synchronous TUBE turbine units was installed in 1963 by Consolidated Papers Incorporated, located in Wisconsin Rapids, Wisconsin. Figure A-1.5 is a photograph of one end of the pulp mill with a drawing of the hydrogenerating unit superimposed. This turbine is rated 2800 horsepower when operating under a net effective head of 22 feet (6.7 M)



Irrigation water supplies are controlled by this adjustable blade TUBE unit. A high speed induction generator is driven through a single reduction gear unit. The tainter gate provides tight shut off. Blade control is automatic from a head water level controller. No power house was constructed.

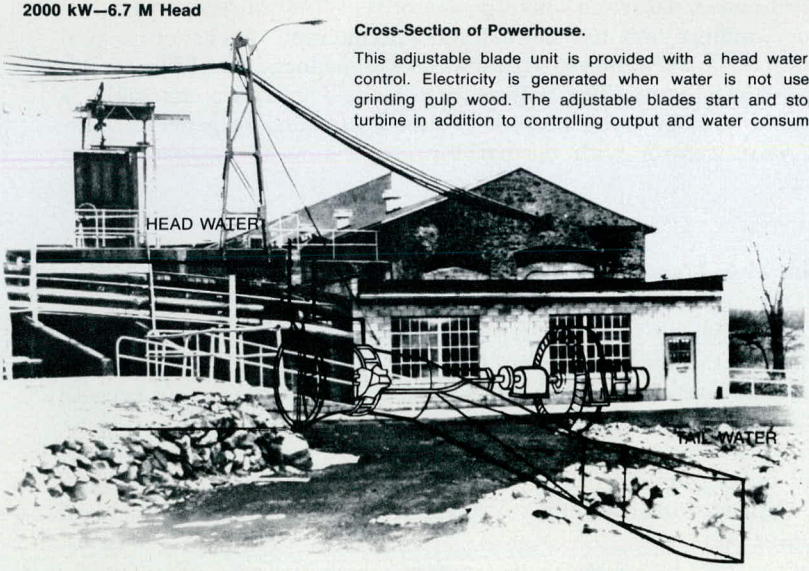
FIGURE A-1.3 Turnip Check



PROTECTIVE SCHEME insures safe operation of the unattended plant under a variety of adverse conditions.

FIGURE A-1.4 Turnip Check Scheme

Consolidated Papers, Inc., Wisconsin
2000 kW—6.7 M Head



Cross-Section of Powerhouse.

This adjustable blade unit is provided with a head water level control. Electricity is generated when water is not used for grinding pulp wood. The adjustable blades start and stop the turbine in addition to controlling output and water consumption.

FIGURE A-1.5 Wisconsin River Division

and is provided to generate electricity from the river flow when the pulp wood grinders are not in operation. The existing flumes at this plant had unit capacities ranging from 530 to 850 horsepower. This TUBE turbine unit intake is essentially the same width and depth as these smaller capacity installations. It provides more than 3 times the capacity of any of the adjacent flumes.

Startup is simple in that after the inlet valve is opened, the turbine blade angle is increased to "break-away" blade angle. Then the unit gradually accelerates to synchronous speed, at which time the breaker is closed. The unit is loaded by further increasing the blade angle to give desired output, or to match the automatic head water-level controller, which is normally used. Once on automatic control, the unit regulates head water level within a predetermined, adjustable range.

The direct-connected synchronous generator is of conventional design plus amortisseur windings and has normal short-circuit ratio. Excitation is provided from a static excitation system that uses a magnetic amplifier exciter and silicon-controller-rectifier voltage regulator. The entire assembly is mounted within a single cubicle. Another cubicle contains the generator, turbine and valve control with normal instrumentation for operation and paralleling.

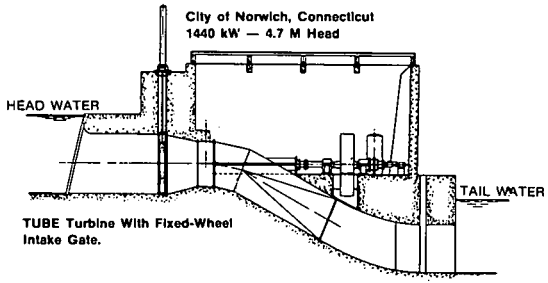
City of Norwich Plant

A very similar unit is shown in Figure A-1.6 which illustrates the low-head unit installed for the City of Norwich, Connecticut. This is the same size runner as is installed at the Consolidated Papers Plant in Wisconsin, but because the head is only 15.5 ft. (4.7 M) the unit is rated at 1999 horsepower, to be within the minor license requirements. The unit has a hydraulically-operated, fixed-wheel intake gate to provide tight closure during shutdown. The turbine is directly connected to an 1800 KVA synchronous generator and is used as a peaking unit.

This unit is tied into a municipal system which includes other hydroelectric units and a stream electric generating plant. In event of a major power failure within the system, it may be necessary to supply emergency power to start motor-driven pumps and auxiliaries essential for operation of the steam plant without outside power. This so called "black start" capability was not only designed into the City of Norwich installation, but has been also incorporated into the Great Northern Paper Company's Dolby installation in Millinocket, Maine.

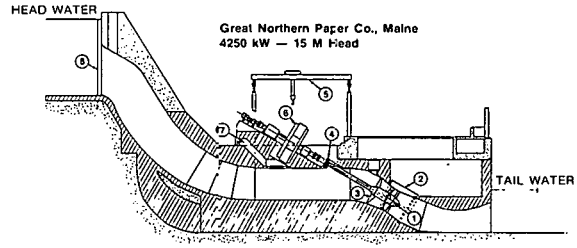
Dolby Plant

The Dolby TUBE turbine unit is shown in Figure A-1.7. Due to the higher head it was important to locate the turbine runner below tailwater in order to reduce the turbine size and cost. This also reduced the generator cost by providing a higher operating speed. Since the intake structure existed at a relatively high elevation it seemed most practical to install the generating unit shaft at an angle of 30 degrees with the turbine runner low, the generator high and the supply penstock brought in between. This also located the generator



Municipal hydro plant is designed for automatic remote control. Black start capability provides power for starting the local steam generating plant.

FIGURE A-1.6 Tenth Street Hydro Station



Inclined shaft accomodates locating TUBE unit runner below tail water elevation and generator substantially above. Moderr unit replaces a pair of old style horizontal Francis turbines.

1. RUNNER
2. OPENING IN TOP HALF OF DISCHARGE RING
3. FIXED INLET VANES
4. PACKING BOX
5. 22.7-MG (25-TON) CRANE
6. GENERATOR
7. COOLING AIR EXHAUST DUCT
8. INTAKE GATE

FIGURE A-1.7 Dolby

and its auxiliaries under the existing powerhouse crane. These two units are each rated 4250 kW when operating under a net of 48 ft. (14.6 M).

The starting and stopping procedures of these particular units is different due to the five runner blades which cannot be moved to a negative blade angle to provide zero rotation with the intake gate open. Even with the intake control gate open to its no-load position, the turbine runner can pass more water than the gate. In attempting to establish synchronous speed under these circumstances, the governor would call for a greater blade angle and the runner would pass even more water. Runner head would reduce and speed would decrease. During start-up, the governor is self-defeating. Starting and synchronizing, therefore, require a different approach.

Cornell Plant

Let us next take a look at these rather large units as shown here in Figure A-1.8. Each of these units is rated 11.1 MVA and are directly connected to 100 RPM synchronous generators. They were installed by Northern States Power Company in the Cornell Plant, formerly a paper mill built about 1910. This was a rather major redevelopment of the old powerplant with a very much simplified hydroelectric generating unit. In this case a hydraulically operated Tainter gate is used for startup and tight shutdown. The turbine is provided with both stationary guide vanes and fixed pitch propeller runner blades. Nothing is adjustable; therefore, there is only one point of operation for a given head. You will remember that the same was true with the small 100 kW Paint unit but these units have a substantially higher capacity.

There is no governor, and the starting and loading sequence is controlled by the Tainter gate and a speed switch. With head conditions at the site nearly constant, the no-load and full-load gate position were first calculated and then adjusted in the field. Actual synchronous operation is established by closing the generator-line switch and energizing the static exciter as has been done at the other projects previously described. Shutdown is achieved by closing the head gate to the no-load point, after which the machine and exciter breakers are automatically tripped. The gate then continues closing.

You will recognize that the degree of protection provided on machines of this size is somewhat greater than that provided on the similar but smaller Paint unit. As with all machinery, good judgement should be exercised in not only the degree of protection but the degree of refinement in the various engineering details required.

Conclusion

The historical background of small, low-head hydro developed over the last 20 years includes more than thirty TUBE turbine units. Their sizes range from a 30" (750 mm) diameter runner to eight 315' (8 m) diameter runners, the world's largest but not over 25 MW output. Control systems vary from the simple 100 kW induction unit to the more complex 25 MW units and a 10 MW unit in Canada which are of the Kaplan type.

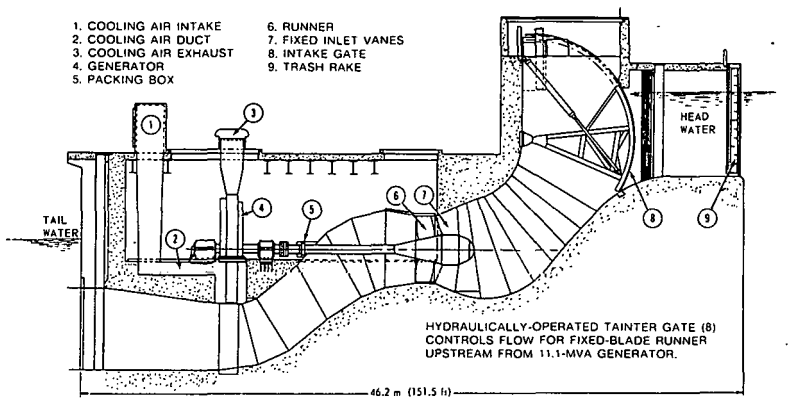


FIGURE A-1.8 Hydraulically Operated Tainter Gate

The challenge today is to provide a lower cost, therefore, simplified and standardized control system acceptable to both the powerplant developer and any system to which the power may be supplied. With the help of several Consulting Engineers, Utility Engineers and Control Component suppliers, I believe this has been accomplished based on the described projects. Refinements can, of course be added, within limits. Whether the added cost is justified becomes a site-specific evaluation.

DEVELOPMENT CONCEPT FOR KAPLAN TUBE-TURBINES

Otto Hartmann

Introduction

Low-head hydro is handicapped by the fact that large quantities of water must be handled for relatively little power. Dimensions are large and, consequently, civil construction and equipment expensive per unit of power.

If "small capacity" is added to "low-head" things get even worse. First cost limitations are at least as stringent as with large capacity installations. In addition, operation and maintenance are becoming a disproportionate heavy burden. If capacity falls below one megawatt, the cost of only one full-time employee may be critical for the plant economy. In developing countries the situation may be different, but not better; labor may be cheap, but skilled labor is scarce and precious. Automatic operation under normal conditions presents no problem, but a certain amount of maintenance, inspection, cleaning and repair work remains and should, if possible, not require special skills and equipment.

In conclusion, the ideal small, low-head plant should not only be of low first cost but also of simple design. It should be easily accessible in all critical parts, to enable the average mechanic to understand its function, detect faults and perform repairs. The ideal small low-head machine should be able to digest some debris in the water, to live on low maintenance and to survive even maltreatment without great damage. The low-head, small-capacity concept presented in this paper is an attempt towards these objectives.

The Basic Concept

Great effort has been expended towards cost reduction of low-head power plants. From the classical vertical-shaft Kaplan turbine with direct driven umbrella-type generator, still predominant in the upper low-head range, development has led to the "bulb", "tube" and "through-flow" axial turbines. Typical examples are shown in Figures A-2.1, A-2.2 and A-2.3.

Quite obviously, the "through-flow" arrangement leads to the minimum concrete volume. Present difficulties are the seals on the large diameter, and especially the support of the heavy "rim" generator by the turbine runner and bearings. The latter has prompted development of the "Straflo" turbine (Escher Wyss), where the generator rotor has its own bearings and only torque is transmitted from the turbine rotor to the generator rotor (Figure A-2.4).

The proposed design concept goes beyond the "Straflo" principle, as it conceives the following features:

Mr. Hartmann is Vice-President, Motor-Columbus Consulting Engineers, Inc., Baden, Switzerland.

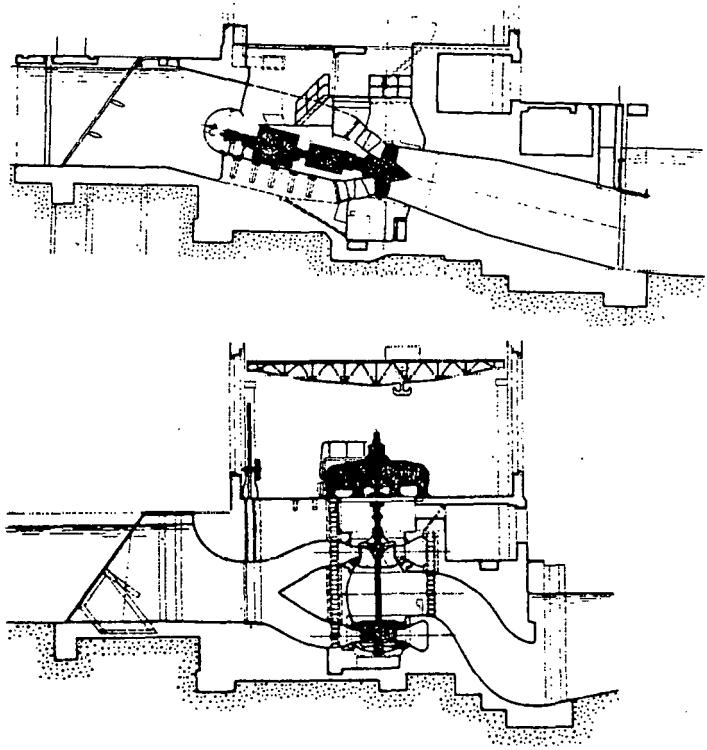


FIGURE A-2.1 Bulb Turbine "AUE" (1350 kW, head=4.4M) Replacing old Francis Turbine (below)

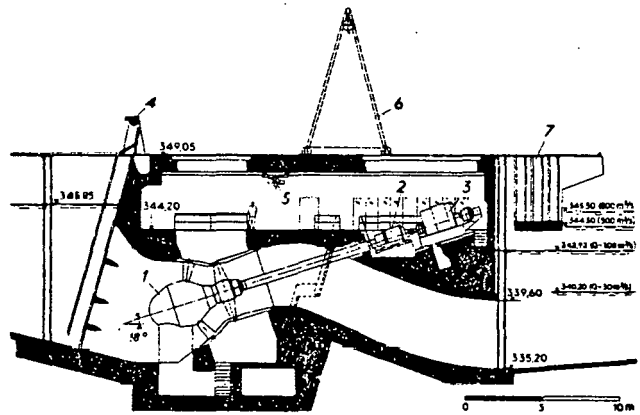


FIGURE A-2.2 Tubular Turbine "Kappelerhof" 2800 kW, head=5.15M

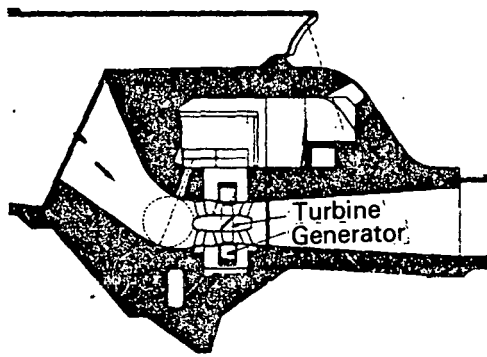
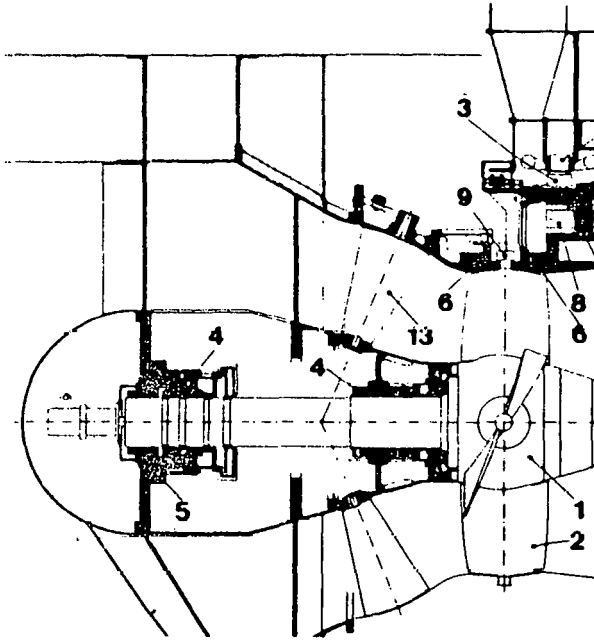
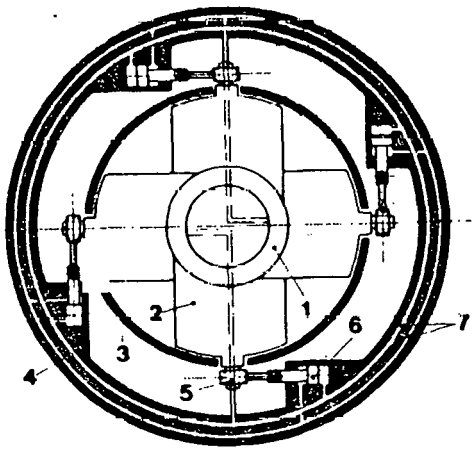


FIGURE A-2.3 Through-flow Turbine with "Rim" Generator



1 HUB
2 RUNNER BLADES
3 GENERATOR POLES
4 TURBINE RADIAL BEARING
5 TURBINE AXIAL BEARING
6 SEAL
7 GENERATOR RADIAL BEARING
8 GENERATOR AXIAL BEARING
9 TORQUE LINK
10 EMERGENCY BEARING
11 BRAKE
12 GENERATOR STATOR
13 GUIDE VANES



1 HUB
2 RUNNER BLADE
3 THROAT RING
4 GENERATOR ROTOR
5 TORQUE LINK
6 BALANCING PISTON

FIGURE A-2.4 "Straflo" Turbine with Separate Generator Bearings

- The turbine runner, together with the runner tube and central body (hub), would form one rotating assembly (rotor).
- If adjustable runner blades (Kaplan type) are used, the blades would be mounted in the rotor tube; the blade adjusting mechanism also arranged in the rotor tube, not in the hub.
- The complete bearing system is arranged on the outer rims of the rotor assembly. No central bearings would exist.
- The runner hub no longer has a mechanical function; it is merely a streamline continuation of the distributor hub but without mechanical connection to the latter.

For large machines the concept may offer development prospects: all essential parts are arranged in the dry, only the runner blades protruding into the water path. The hub, having lost its mechanical functions and the requirement to house the blade adjusting mechanism, can be reduced in diameter. This and the fact that bending stresses on the runner blades are reduced, may offer possibilities to achieve higher efficiencies and discharge rates. The major problem is the same as for the "Straflo" turbine-the bearing system. For small machines this difficulty may be overcome and additional advantages achieved by:

- Support of the rotor assembly on wheels (instead of bearings).
- A belt drive to connect the turbine rotor with the generator.

With these additional features, the design concept seems to offer a suitable solution for the small-capacity range up to several hundred kilowatts, in recognition of the main objectives: simple, rugged, cheap. As an example, a typical lay-out is shown in Figure A-2.5a and b and characteristic data are listed in Table A-2.1. Additional details are given below.

Rotor Assembly

The runner blades, central body (hub) and rotor tube form one rotating body. In case of fixed runner blades, the elements can be welded firmly together. Movable runner blades would be guided in the rotor tube and the central body held on stems on the inner end of the runner blades. Mounting of the runner blades on the outside reduces bending forces. Since the blade-adjusting mechanism is integrated in the rotor tube, the diameter of the central body can be reduced and consequently the discharge capacity of a given runner diameter increased.

As the runner tube rotates with the runner, there is no longer a gap between these elements and the need for exact machining to maintain such delicate gap is eliminated. This is obvious with fixed runner blades, but with movable runner blades the gap can be also avoided by discs welded onto the runner blade ends. Elimination of the runner gap also resolves the problem of gap cavitation and the danger of foreign matter (debris) plugging the gap.

The whole rotor assembly is held in place by bearings on the circumference of the runner tube. For large machines, hydrostatic bearings would be suitable similar to those developed for the "Straflo" turbine. This solution is, however, too complicated and expensive for small machines. Therefore, mounting of

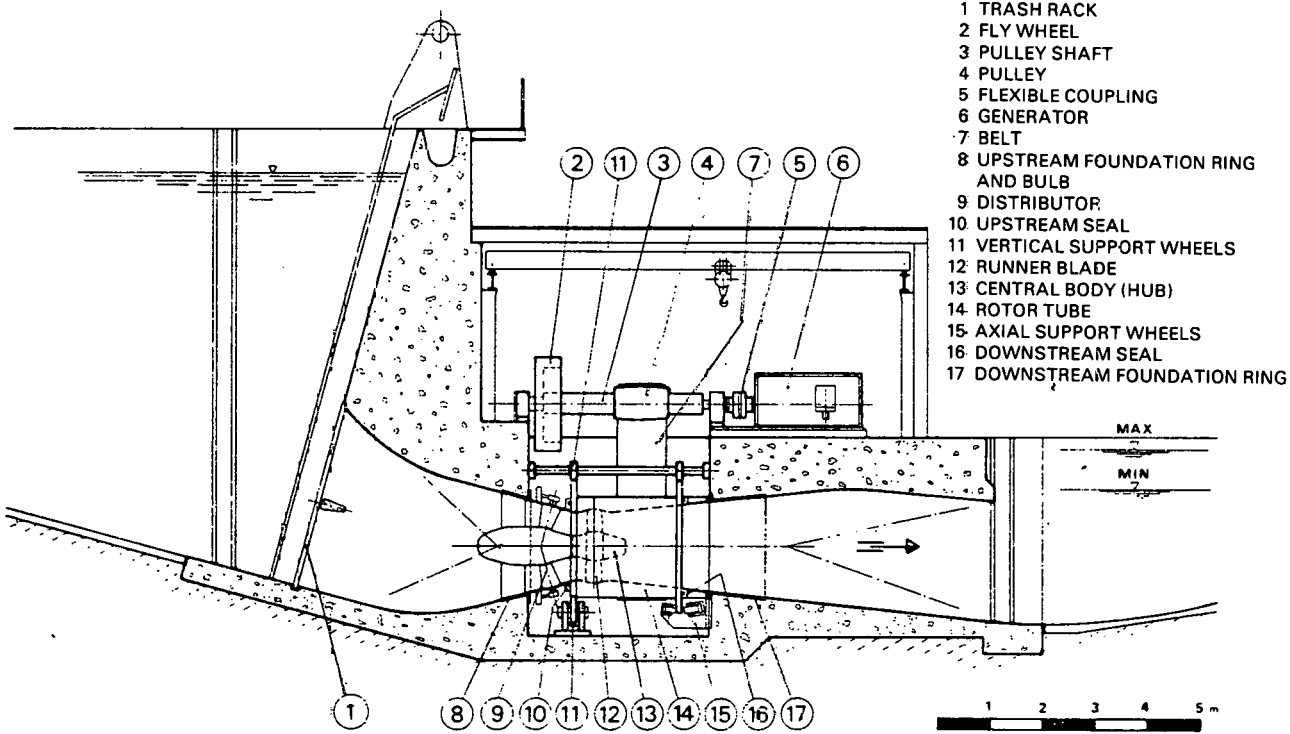
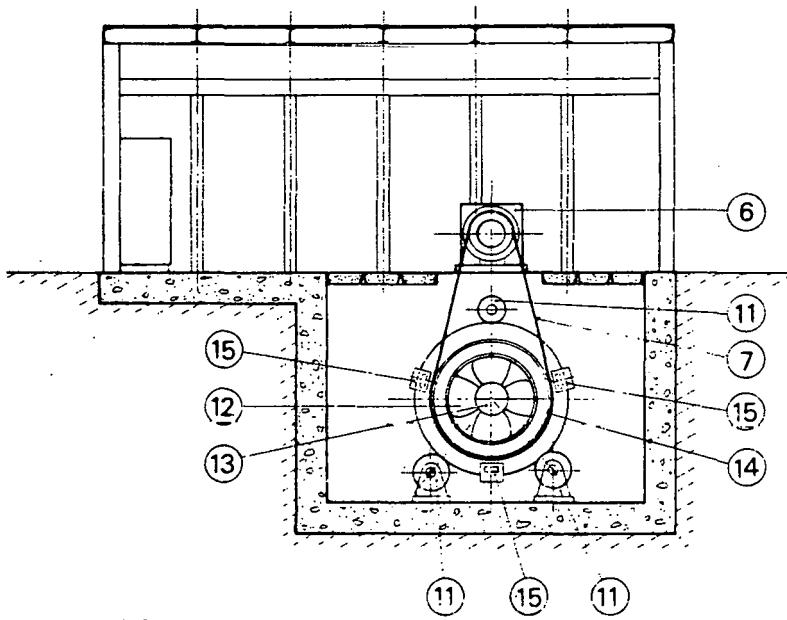


FIGURE A-2.5a Longitudinal Section



6 GENERATOR
7 BELT
11 VERTICAL SUPPORT WHEELS
12 RUNNER BLADE
13 CENTRAL BODY (HUB)
14 ROTOR TUBE
15 AXIAL SUPPORT WHEELS

FIGURE A-2.5b Cross-Section

Table A-2.1

Characteristic Data Layout
(See Figure A-2.5a and b)

Head 6 m (20 ft), Discharge 10 m³/ (335 cfs), Power 500 kW
Runner Dia 1.4 m (4'7"), Turbine speed 300 RPM,
Rotor tube dia 2.0 m (6'6.75"), Generator speed 900 RPM (60 Hz)
Pulley Dia. 0.67 m (2'2.25"); Generator speed 1 000 RPM (50 Hz)
Pulley Dia. 0.60 m (2'0"), Belt velocity 31.42 m/s (103 ft/sec)
Rim dia. 2.500 m (8'2.5"), Rolling velocity 39,27 m/s (128 ft/sec)
equal 141 km/h (88 MPH), Rotor assembly weight (incl. water)
approx. 11 tons

the runner on wheels is proposed. The weight and circumferential speed of small machines are similar to those of railroad vehicles. Simple lip seals can be applied for the circumferential seals on the upstream and downstream end of the rotor tube. Such seals have been in use on the straight-flow units in Germany for many years.

For the runner blade adjustment mechanical solutions appear more promising than oil hydraulic actuation which, in the absence of the central hub of the known Kaplan type design, would require pressure oil injection of the circumference of the rotor tube. Instead, actuation by electric motors fed through slip rings might be a possibility.

Generator Arrangement

Straight-flow units utilize special custom-designed generators that are arranged around the rotor rim. For small-capacity units the belt drive offers a simple and very cheap solution. Modern belt material would allow transmission of up to some 1,000 kW. With the belt drive, speed increase is accomplished very easily and the generator speed can be chosen (within limits) by variation of the pulley diameter. Cheap standard generators can be used instead of expensive custom-designed machines. The pulley-shaft would be carried in separate roller bearings and a flexible coupling used to avoid additional loading on the generator bearings. If necessary an additional fly-wheel can easily be attached on the pulley shaft.

The belt drive is not only virtually maintenance-free, it also permits the arrangement of the generator above tail-water level. Thus the generator is safe from incidental flooding of the turbine pit, an extremely important fail-safe feature.

Fabrication, Construction and Erection

The proposed design concept essentially utilizes components similar to those of present axial-flow designs. Development is required for the rotor

tube, the runner blade shape and runner blade adjusting mechanism and the support wheel system.

A marked advantage is achieved by the fact that the complete rotating body can be assembled in the manufacturing shop and in most cases shipped to site without dismantling small-capacity units. This allows a drastic reduction of site-erection work. All delicate assembly work of the rotor assembly, including balancing, can be completed in the shop.

The powerhouse civil construction is reduced in quantity and simplified. Complicated connections with the mechanical parts, bracings, access shafts, erection pits and the like are not required. Erection of the unit would essentially comprise the following steps:

- The complete distributor assembly including the upstream seal assembly is bolted to the upstream foundation ring and bulb.
- The downstream seal assembly is fixed to the downstream foundation ring.
- The complete rotor assembly is lowered onto the support wheels, which are then adjusted and the centricity checked.
- The upper and lower seals are shifted into place and fixed.
- Finally the pulley shaft is installed, connected to the generator and the belt applied.
- The installation of the generator can be completed simultaneously with and independent from the turbine erection.

Conclusions

The proposed concept of an axial through-flow turbine with rotating rotor tube assembly, with the runner blades held in the rotor tube, offers mechanical and hydraulic advantages. For small-capacity units especially, simplifications are achieved in the civil construction and erection.

- All essential parts can be inspected and are readily accessible for maintenance and repair without dewatering the machine.
- High-speed standard generators can be used with a simple belt drive step-up. The generator is arranged safely above flood level.
- The proposed concept utilizes simple mechanical components. Operation would be fully automatic. Maintenance and repair should not require greater skills than other agricultural machinery.
- It is hoped that this design concept will further the development of small low-head hydro.

SMALL-SCALE HYDRO: THE USE OF PUMPS AS TURBINES

John D. Lawrence

Introduction

Historically, scale diseconomies have rendered small hydroelectric developments in the 50 to 25,000 kW range unattractive to the major private and small public utilities alike. In the 1960's, many such existing plants were retired because maintenance and repair costs exceeded the costs of the then-available fuel-based alternatives. Traditionally, turbines and generators and their associated peripheral equipment and structures had been "custom designed" for each particular installation. This practice led to uneconomically high plant investment costs, and to a dearth of manufacturers of small-hydro units in the United States. The energy crisis, the resurgence of interest in small-hydro and the development of standard packaged units has now begun to reverse this trend.

Why then this interest in the use of pumps for hydroelectric generation when conventional turbines are available? There is no simple answer to this question, but interest in the use of pumps as turbines essentially to reduce costs has certainly been aroused. Yet, the technical and economic feasibility of the concept in small-hydro installations has not been fully established by any means. Nor has the relevant technology been developed to the point where the potential for its application can be readily determined for a given case. The objective of this paper is, therefore, to examine some aspects of the available technology and to identify at least some areas of its application which are worthy of more detailed study.

The availability of standard pumping equipment in the United States far outstrips that of hydroelectric turbine-generators. An attempt to develop low-cost, "off-the-shelf" generating equipment packages, utilizing standard pumps may well provide added stimulus to the competitive production of the appropriate units for small hydroelectric installations. The cost savings and shortened lead times which could result, will further stimulate small-hydro development and place hydroelectric generating facilities even more firmly within the reach of the small consumer-owned utility. Such packages would be designed for economic application in a nationally representative range of potential small-hydro installations. To achieve this end a comprehensive program of study is required to develop appropriate innovative and low-cost hydroelectric generation equipment packages incorporating pumps and appropriate generators for application at representative sites. Such a study should also examine the technical and economic merit of the use of these innovative hydropower plant packages in place of available conventional equipment.

Mr. Lawrence is Project Manager for Acres American Incorporated, Buffalo, New York.

The Technology

The use of standard pumping equipment as hydraulic turbines for power generation is not new. A number of pump manufacturers are known to have tested pumps in the turbine mode, usually for industrial power recovery applications. The use of pumps as turbines is currently also receiving much attention as a conservation measure in cooling water and other similar industrial applications. A 275 kW hydroelectric plant at Baker, Oregon, already makes use of a pump installation for power generation. At least one U.S. manufacturer is active in the modification of available pump units for use in hydroelectric applications.

For effective application of the concept, it is essential that the feasible limits of rating and head for such units be firmly established. Initial studies indicate that unit capacities of 100 to 1500 kW under heads of 10 to 25 feet are particularly appropriate. Fixed-blade propeller type machines will meet these requirements with diameters ranging from 36 to 72 inches and specific speeds from 120 to 175. These sizes correspond closely with a number of single-stage, single-suction centrifugal, mixed flow or axial flow (propeller) pumps, which are available "off-the-shelf."

Such pumps appear to be suitable for adaptation to turbine operation. Double-suction volute pumps may also be attractive but would probably require major casing modifications for acceptable operation as turbines. Preliminary assessments suggest that the concept is most likely to be competitive in the range-of-head and capacity currently served by standardized package turbine units, some examples of which are shown in Figure A-3.1. The applicable limits of head and unit size will also be influenced by the available national development potential. Inventories of hydroelectric resources currently being prepared by the Corps of Engineers and others provide an excellent basis for determination of these limits.

Although there is some evidence that many pump manufacturers possess proprietary test data, there is little or no published information dealing with the performance of pumps as turbines, particularly in regard to efficiency and cavitation potential. A method of selection of a pump to meet specific generating requirements when used as a turbine has been suggested by C.P. Kittredge (Table A-3.1.) This methodology, which is based on some model test data, does not appear to have been used in any practical applications. Using the Kittredge approach, pump characteristics relating head, brake horsepower, and efficiency with discharge can be converted to corresponding approximate characteristics in the turbine mode. Examples of estimated outputs from typical pumps are given in Table A-3.1. Peak pump efficiencies are usually in the 80 percent to 85 percent range. It is expected that the efficiency of a machine in the turbine mode will be less than in the pumping mode. Thus the peak turbine efficiency will probably be less than 80 percent. The efficiency will also drop off appreciably at heads and flows significantly different from rated conditions.

The turbine should therefore be designed to operate most efficiently at full load, eliminating the need for adjustable guide vanes. The unit can be controlled through the inlet works, whether this be an automatic head gate, a butterfly valve or a siphon arrangement. Although modulation of output is possible with gates or valves, the siphons operate only in an off or on mode. The guide

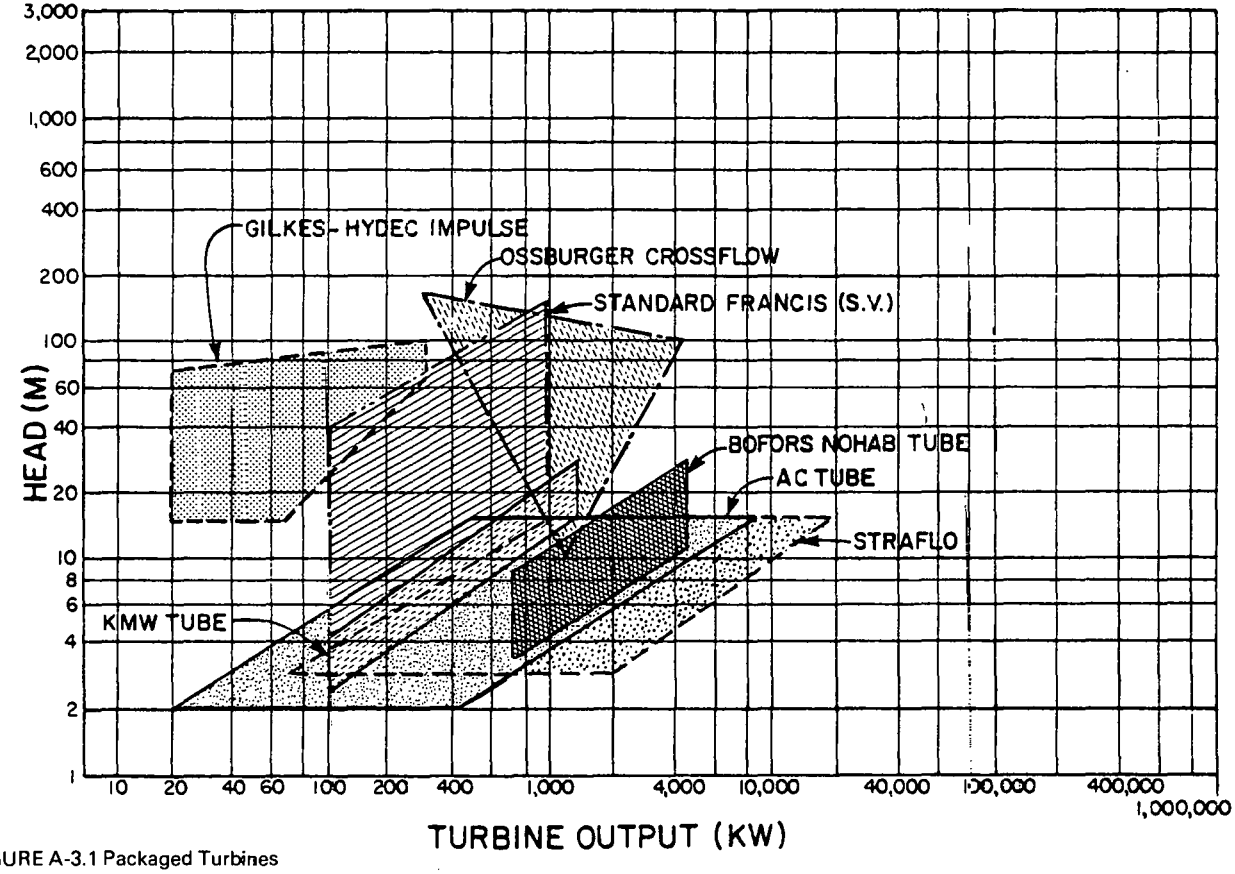


FIGURE A-3.1 Packaged Turbines

structure can consequently be made more rugged compared to movable guides to withstand ingestion of debris, with the important consequence that greater spacing of trashracks can be permitted. The maintenance of gate linkage will also not be required. Despite the apparent uniqueness of these concepts, the utility of this type of turbine equipment is not impaired significantly. The majority of the small powerplants in service in large electrical networks are in fact not regulated to a significant extent.

For power generation equipment, high-speed machines are not only economical in first cost, but also result in reduced gross weight of equipment compared to direct coupled low-speed generators. Thus the use of speed increasers, a concept already being applied in conventional packaged turbine-generation units, is also appropriate. The turbine-generator mechanical accessories, protection equipment, and controls can thus form an integrated preassembled road-transportable unit. Shop check-out of accessories and systems is facilitated, and mechanical aspects of field erection can be reduced to a minimum. In the size range contemplated at present, field assembly of units by mobile crane handling will be most appropriate. Major overhauls of the mechanical or electrical equipment would be completed by the same approach at infrequent intervals. As with packaged turbine-generators, powerplant economies result from reduced space requirements and the use of removable hatch-type roofs. Siphon intakes may also have application for existing developments. The inlet shroud may be positioned over an existing dam, rendering the extensive costs for a conventional underwater inlet works unnecessary.

Table A-3.1: PUMPS OPERATING AS TURBINES

	Pump Characteristics						Turbine Characteristics*			
	Diameter (in)									
Type	D	I	Head (ft)	Discharge (gpm)	BHP	Efficiency (%)	Head (ft)	Discharge (cfs)	Efficiency (%)	Output (kW)
C	30	35.5	110	36,000	1170	85	135	115	80	1410
M	42	48	36	58,000	600	88	68	216	78	1030
A	60	54	17.5	88,000	450	86	33	328	78	780

C: Centrifugal (Double-volute, single stage)
M: Mixed flow (Single-stage bowl)
A: Axial flow propeller (Single-stage bowl)
D: Discharge Diameter
I: Impeller Diameter

* At best efficiency, based on C.P. Kittredge: "Centrifugal Pumps Used as Hydraulic Turbines," Transactions of the ASME, January 1961.

The Economics

Rightly or wrongly, hydroelectric generation equipment is generally regarded as "expensive." Although very reliable and cheap to run, a hydro facility is highly capital intensive and relatively expensive to construct. Any attempt to reduce this initial cost will therefore be beneficial. Pumping equipment, on the other hand, is generally regarded as relatively "inexpensive," or at least *less* expensive, but also less efficient. But does efficiency matter that much in a small-hydro installation? Although loss of efficiency in a hydro plant will tend to increase the energy costs, reduced costs for capacity may well compensate. Net energy cost will still remain relatively constant over the life of the project. Continued escalation in fuel costs over a 30-year life render the equivalent energy costs of thermal generation alternatives significantly greater in many cases. Consideration of levelized energy costs on such a basis would often still favor the hydro alternative, which in fact, will probably have a considerably longer life. (See Figure A-3.2.)

Although several manufacturing companies in the United States and Canada are currently producing small units of less than 1000 kW in capacity, relatively few have the capability of manufacturing these in the 1000 to 5000kW range. Quoted costs of such units are somewhat variable, depending on the manufacturer, the size and type of unit, the required range of duty, etc. Recent (1978) examples of standard Francis, propeller, bulb or tube-type turbine-generator costs, for heads of 15 to 60 feet and unit capacities from 500 to 5000 kW, range from $250 to $900 per kW. (See Figure A-3.3.) The pumps listed in Table A-3.1 range in price from $60 to $120/kW FOB U.S. factory which is competitive with similarly sized hydraulic turbines.

Economic evaluations are, therefore, necessary for a given installation to establish the economic merit of using pumps as turbines. These evaluations should further seek to identify the region of application within which the use of pumps as turbines is economically attractive in comparison with conventional equipment. For this purpose it will be necessary to develop cost estimates for a series of complete prototype package-plant designs incorporating the selected equipment combinations.

The estimated power benefits of a particular prototype-plant design may be based on nationally representative power values. Due account should be taken of plant capacity factors for the selected representative installations and potential restrictions on operation of unregulated pump-generator units in the development of average energy costs. Comparisons should be made for similarly sized installations using conventional packaged equipment installations, with or without regulation, as appropriate.

Development Prospects

The application of usage of pumps as turbines at a given site requires:

- Determination of available head and flow;
- Establishment of appropriate installed capacity;

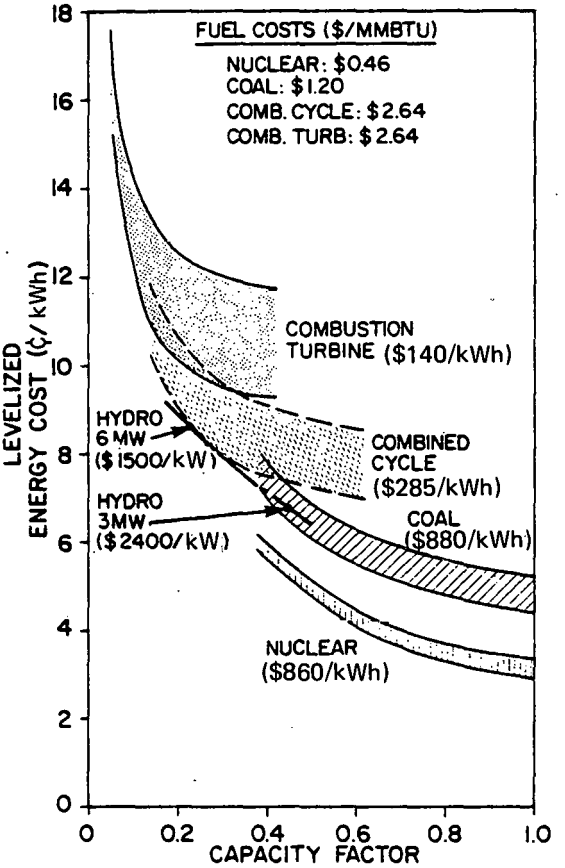


FIGURE A-3.2 Comparative Energy Costs

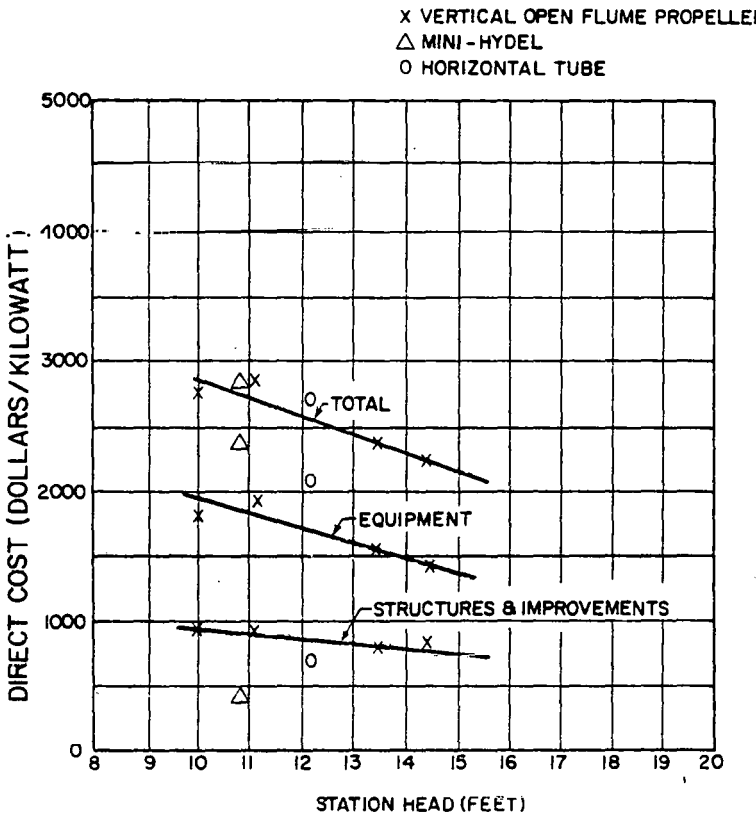


FIGURE A-3.3 Comparison of Powerhouse Direct Costs

- Selection of pump size and speed best suited to meet head, flow and capacity requirements when operated as a turbine;
- Selection of appropriate generating and other peripheral equipment;
- Consideration of plant structural design requirements;
- Preliminary estimation of development investment, operating and maintenance costs;
- Preliminary estimation of power and energy outputs and benefits therefrom.

Thus there is a need to establish broad categories of type and size of pump appropriate for use as turbines, and to obtain and evaluate the available manufacturers' test data to determine realistic turbine performance characteristics. Requirements for additional testing must also be determined. Pump type and size limitations should be established and categorized into appropriate groups within the constraints of plant head and capacity.

Manufacturers should be solicited to obtain any available test data for representative pumps. The selected units will essentially be operated in the proposed prototype plants without regulation. Performance characteristics will consequently be restricted in each case to a relatively narrow range of head and output corresponding to the range of highest efficiencies. Establishment of the actual characteristics of the machines when operated as turbines may be achieved by direct test results where possible. Where test data does not cover the appropriate head and capacity ranges, the principles of homologous model testing can be applied to extrapolate results.

The recognized turbine manufacturers have already initiated the production of packaged units and there are indications of interest from other sectors of industry in the potential market for such units. The Federal Government has also played a part in stimulating this interest by initiating several coordinated programs of small-hydro development geared to the needs of both the manufacturers and the utilities. There is clear evidence that both public and private utilities are keenly aware of the improving economics of small-hydroelectric developments. Conditions are now appropriate to warrant a full-scale research and development study into small units utilizing pumps and other such innovative design concepts for the numerous small-hydro sources which are available in the United States today. Should the technology be proven feasible, development of a series of hydroelectric powerplant equipment packages, using pumps of appropriate size, and suitable for rapid procurement and installation at relatively low cost, could be expected.

The program of research and development suggested in this paper is intended to investigate in depth several promising new concepts in the design of hydroelectric generating equipment with a view to accelerating the economic construction of small-hydro developments. The concepts to be studied will also be conducive to expansion of the available small turbine manufacturing capability in the United States. This in itself is likely to lead to reductions in equipment costs.

MODERNIZATION OF HYDROELECTRIC UNITS

Grover F. Wachter

One of the major challenges facing the engineers in this decade is the energy crisis, demanding solutions to overcome the ever increasing costs of power generation and facing the eventual depletion of the limited non-renewable natural resources. One of the renewable resources which has been used to harness power is water. In the last century, the art of developing large blocks of hydropower has been established creating a vast source of energy for our electrical needs. Tremendous strides have been made in the field of hydrodynamics developing and improving the equipment to meet our latest requirements. The initial concepts of using waterwheels, and later hydraulic turbines for driving grist mills has developed into vast hydro installations serving the load centers in our heavily populated and industrial areas.

In the early days, the primary objective was to develop power and utilize it through a techanical drive to the driven machinery. These drives consisted of ropes, belts, or some type of gear train. The early hydraulic generating units were of small size and their output seldom exceeded several hundred horsepower. While early turbine units were generally considered successful in their day, they are not considered as such in our time due to their comparatively large physical size and consequent high cost on a horsepower or kilowatt basis.

Today there are many existing hydrostations operating below their potential capability. The hydraulic units do not develop the maximum contribution to the power systems they are serving. Many of the hydroplants have been in operation over a long period of time. Their rated capacities may have been selected without allowance for changes that have occurred, such as closer regulation of the river flow due to storage reservoirs, new plants located either upstream or downstream, changes in peaking capacity value, and possibly other factors which today are evaluated into a modern hydroplant study. Water utilization and peaking capability are terms synonymous with our endeavors to derive the maximum benefits from our renewable water resources. Full utilization of modern hydraulic turbine design techniques becomes a key factor in not only new plant designs, but also in the modernization and upgrading of many of the existing hydro installations.

Upgrading existing hydrogenerating units has been accomplished on many units in the past two decades, but has become particularly attractive at the present time due to:

1. Continued escalating costs of new generating units.
2. Scarcity and high price of clean fuels.
3. Environmental considerations rendering many technically attractive sites unavailable for development.
4. The ever-growing regulatory requirements and delays associated with the development of new hydroelectric sites.

Mr. Wachter is Manager, Customer Service, Hydro-Turbine Division, Allis-Chalmers Corporation, York, Pennsylvania.

Many of the early hydro installations were developed for average flows to assure operation of the hydrogenerating units for a normal demand of an associated manufacturing facility. Today, where the hydroelectric unit will usually be interconnected with a large system, it may be more economical to select hydrounits for flows available for 20 to 30 percent of the time. This consideration results in a greater available flow than the sizing criteria for the units as originally installed, and hence an opportunity to up-grade the original generating equipment by installation of new turbine runners, construction of an addition to the existing hydroplant or installation of new generating units in the existing powerhouse.

Modern runner designs and turbine arrangements have been developed to permit additional ways of upgrading the performance of the older generating units. Abandoned hydrogenerating installations considered uneconomical for rehabilitation or modernization for the last 20 years are now being studied to utilize the available water resources.

Model laboratory testing of hydraulic turbines prior to 1915 was conducted to obtain performance efficiency and output. In the 1940's and 1950's, hydraulic laboratory testing was expanded to include cavitation tests which resulted in a significant improvement in the operation and maintenance of hydrogenerating units. Today hydraulic turbine manufacturers' hydraulic laboratories are available to study the increase in capacity and/or efficiency which may be derived from modernization programs. Additional studies can be made to define the cavitation characteristics for the proposed upgrading, thereby providing operating information to advance the design toward a relatively maintenance-free unit. Recent studies[1] of existing dams in the Northeastern United States indicate that about 10-20% of the existing dams, including those that already have hydro installations, are deserving a more serious look toward modernization or installation of new hydrogenerating units.

Several existing installations have been modernized and uprated in recent years. A review of a number of these installations provides an interesting documentation of improvement in the performance of the rehabilitated hydraulic turbines as compared to the original units. The scope of equipment modification will vary with each hydrogenerating unit modernization as indicated in the review of these completed hydrounit rehabilitations.

City of Orillia, Ontario, Canada

At their Swift Rapids Plant, the City of Orillia had operated for many years three horizontal units, each with a pair of Francis turbines mounted on draft chests. Each of the three units produced 2,120 horsepower (1,582 kilowatts) under a net head of 47 feet (14.3 meters). The use of conventional Francis or vertical propeller turbines to modernize this type plant provides only a limited increase in output. This problem was solved with the application of horizontal, adjustable blade, TUBE turbine units which suited the system requirements. Figure A-4.1 shows the original Francis turbine installation with a

[1] R. J. McDonald — *Estimate of National Hydroelectric Power Potential at Existing Dams* U.S. Army Corps of Engineers Institute for Water Resources, Report dated July 20, 1977.

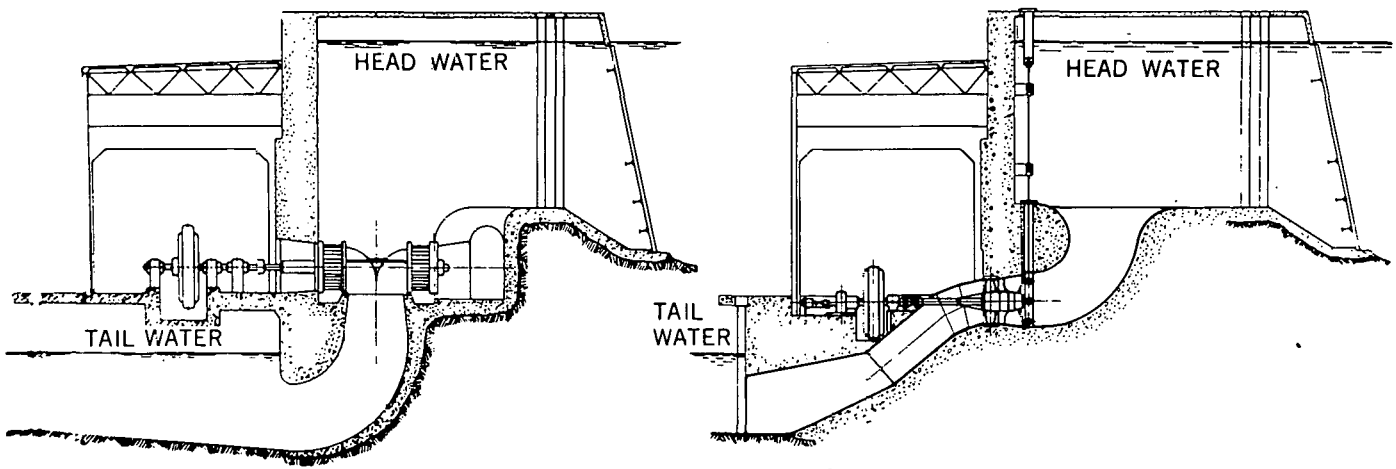


FIGURE A-4.1 Cross section of Swift Rapids Plant

draft chest and the arrangement of the modern, high capacity TUBE turbine unit.

Two high-capacity TUBE turbine units were installed by the City of Orillia to replace the original three horizontal units. Each unit is rated to develop 3,500 horsepower (2,611 kilowatts) under 47 feet (14.3 meters) net head. This represents a 65 percent increase in capacity over the original units, and was accomplished in the same physical space. The new units have a hydraulically operated fixed-wheel intake gate, which provides for tight shutoff and emergency closure. The adjustable runner blades are controlled by a governor so that in the event interconnections are disrupted, the frequency can be maintained.

The TUBE turbine provides an excellent opportunity for redevelopment of the typical paper mill installation, where one or more pair of runners discharge into draft chests. For such installations, the capacity per flume can frequently be doubled since the water passes through two minor bends as compared to the four 90 degree turns inherent with a draft chest with Francis runners.

Extremely low-head and small-capacity hydro units have been uneconomical for many years because of the high equipment and civil works costs. With economic evaluations rapidly changing due to the significant escalation in the price of oil and natural gas, low-head hydro generating units are now being developed. To encourage this development, hydro-equipment manufacturers have standardized the design of low-head, small-capacity type turbine units, thereby eliminating the high one time engineering costs for custom designing this type of unit. (See Figure A-4.2.) These units are predesigned for heads up to 50 feet (15.2 meters) and have capacities up to 5,000 kilowatts. The unit generally consists of an intake closure device such as a standard butterfly vavle or an intake gate, a tubular-type turbine with stationary guide vanes, runner with either fixed or adjustable blades, fabricated steel water passageway, hydraulic control unit, speed increaser, and either an induction or synchronous generator.

Alcoa-Yadkin Falls

The following example presents another type modernization and rehabilitation of a hydrounit in order to obtain increased capacity.

Yadkin, Inc., a subsidiary of the Aluminum Company of America, located in Pittsburgh, Pennsylvania, installed three Francis turbines at their Yadkin Falls Plant from 1917 to 1921. Each of the units was designed to develop 9,660 horsepower (7,206 kilowatts) under 48 feet (14.6 meters) net head when operating at 90 RPM. The power from this plant is used at Alcoa's extensive smelting facilities at Badin, North Carolina. The original generators produced 36 cycle current. One of the generators has been converted to 60 cycles.

A total of three hydroelectric plants on the Yadkin River serve the Badin smelting facilities. At approximately the same time that Alcoa decided to completely modernize the smelters, it also decided to build another hydroelectric station and to modernize the existing stations. The problems at the Yadkin Falls Plant were fourfold:

1. The 36 cycle current from units 2 and 3 could not be used in the rebuilt smelters. Conversion to 60 cycle was necessary.

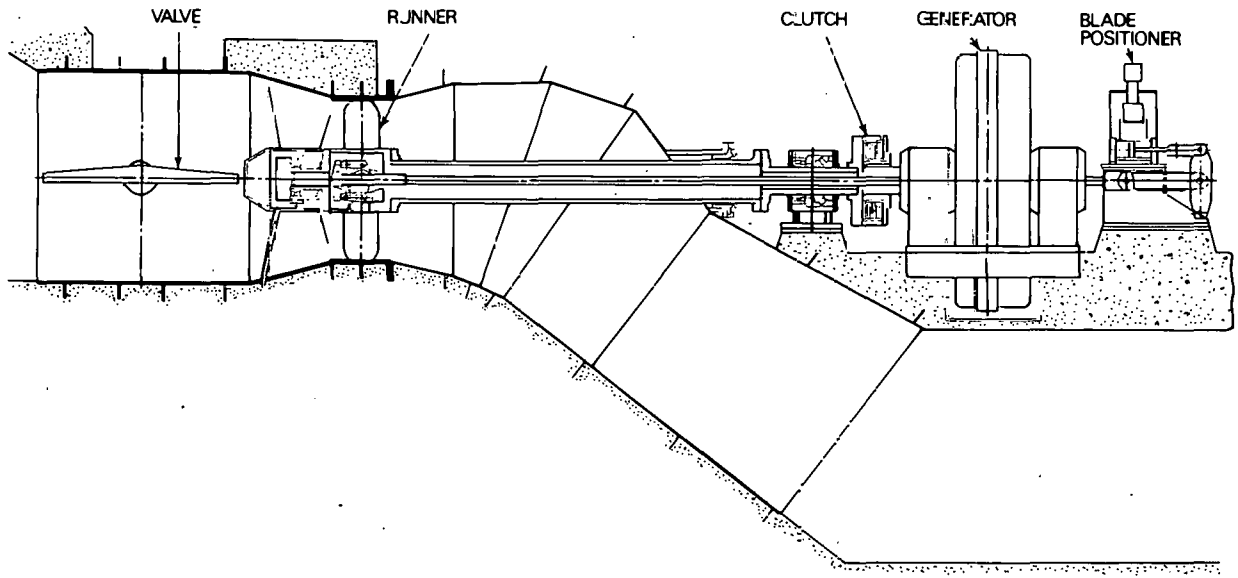


FIGURE A-4.2 Standardized Hydroelectric Generating Unit

2. Unit 3 had experienced considerable concrete growth throughout the years opening up large cracks from foundations to the powerhouse roof. The turbine and generator had been releveled to a point where no further releveling could be done. This entire problem had to be resolved.
3. The total discharge of the three Yadkin Falls turbines was less than any of the other stations on the river. To obtain an improved water balance on the river it was desirable to increase the discharge capability of the Yadkin Falls turbines rather than spilling water.
4. The increased capacity desired at the Yadkin Falls Plant was severely complicated by a desire to utilize the existing concrete semi-spiral casings and distributor centerline which yielded a draft head in excess of 20 feet (6.1 meters) on the old units.

Alcoa decided to go ahead with the rehabilitation of units 2 and 3 at Yadkin Falls in 1959. A mixed-flow,, fixed-blade propeller turbine was proposed for this rehabilitation complete with new stay ring, pit liner, wheel case with distributor parts and also including a new draft tube contour. The mixed-flow propeller turbines are each rated 15,000 horsepower (11,190 kilowatts) at full gate under 54 feet (16.5 meters) net head when operating at 128.6 FPM (55% greater capacity than the old Francis turbines). They will also develop 13,500 horsepower (10,070 kilowatts) at best efficiency versus 9,250 horsepower (6,900 kilowatts) for the old units (46% greater). In terms of specific speed, the eight-bladed mixed-flow turbine tends to fill a gap between Francis and axial-flow turbines. Because of its relatively large runner blade area and small conical hub, this runner design has good cavitation characteristics, permitting its use in modernization of existing hydraulic turbines which originally contained Francis turbines with runners located above tailwater levels by as much as 20 feet. Hydraulic model laboratory tests were performed for the Yadkin Falls mixed-flow turbine to check the performance and cavitation characteristics when operating under conditions homologous to those of the prototype units.

The modernized units at Yadkin Falls (See Figure A-4.3) were index tested shortly after installation to determine the relative performance of the unit. The results of these index tests showed that all of the anticipated horsepower increase was realized.

City of Seattle — Gorge Plant

In 1921, the City of Seattle purchased two units for the Gorge Powerhouse, each rated 27,500 horsepower (20,515 kilowatts) under 275 feet (83.8 meters) net head. Provisions were originally made for increasing the dam height thereby increasing the net head on the turbine to 325 feet (99.1 meters). Because of the increasing power demands in the Pacific Northwest in the 1950's, the City of Seattle decided in 1955 to raise the dam and obtain the increased head. This would provide 45,000 horsepower (33,5700 kilowatts) under 325 foot (99.1 meters) head instead of the original 37,500 horsepower (27,975 kilowatts). This represented an increase of 20% in capacity which was accomplished by slight modifications to the runner and wicket-gate

dimensions, using the existing turbine-inlet butterfly valve, spiral case and draft tubes.

The increased output desired from any hydraulic turbine when maintaining essentially the same tailwater elevations and turbine setting presents a challenge to the turbine manufacturer, especially when it is desired to use the existing draft tube and restrict the inherent increase in cavitation. In order to evaluate the performance and cavitation conditions, model laboratory tests were conducted for the Gorge Plant turbines whereby not only the proposed new turbine design was model tested, but also the original turbine, to provide a direct comparison between the old and the new units. Figure A-4.4 shows a cross section of the Gorge Plant hydraulic turbine before and after modernization.

U.S. Bureau of Reclamation — Hoover Powerplant

The Hoover Powerplant is located at Hoover Dam on the Colorado River about seven miles northeast of Boulder City, Nevada. The powerhouse forms a U-shaped structure with the base of the U across the river on the downstream toe of the dam and one side or wing on each bank of the river. The Arizona wing contains a total of nine hydrogenerating units designated A1 through A9, and the Nevada wing contains eight hydrogenerating units designated N1 through N8.

In 1970, the Bureau of Reclamation replaced four original Francis turbine runners installed in generating units N1 through N4. These units were originally placed in commercial operation in 1936 and 1937. Extensive weld repairs were required on several occasions to correct cavitation damage resulting in a general deterioration of the runners and a subsequent decision to replace the runners.

Specifications issued by the Bureau required a homologous model turbine equipped with replacement runners be constructed and tested on one of the four identical hydraulic turbines installed in the N1 to N4 positions at Hoover Powerplant. The results of the homologous model test were used to predict operating performance of the prototype units and confirm the guarantees of performance submitted with the replacement runner proposal.

Field index tests were made on August 4, 1969, before the new runners were installed and again on April 29, 1970, after replacement. The before-and-after tests shown in Figure A-4.5 illustrate the changes in relative performance of the turbines:

1. Peak efficiency with the replacement runners (Figure A-4.6) installed is 7.5 percent higher than the efficiency of the units with the original runners at the same net head.
2. The full-page power output with the replacement runners is 142,000 horsepower (105,930 kilowatts) at a net head of 500 feet (152.4 meters). This is an increase of 12.4 percent over the full-gate output of 127,000 horsepower (97,740 kilowatts) of the units with the original runners at the same net head.

A second phase of replacing runners in the Hoover Powerplant was begun in 1978 with the award of a contract by the U.S. Bureau of Reclamation to

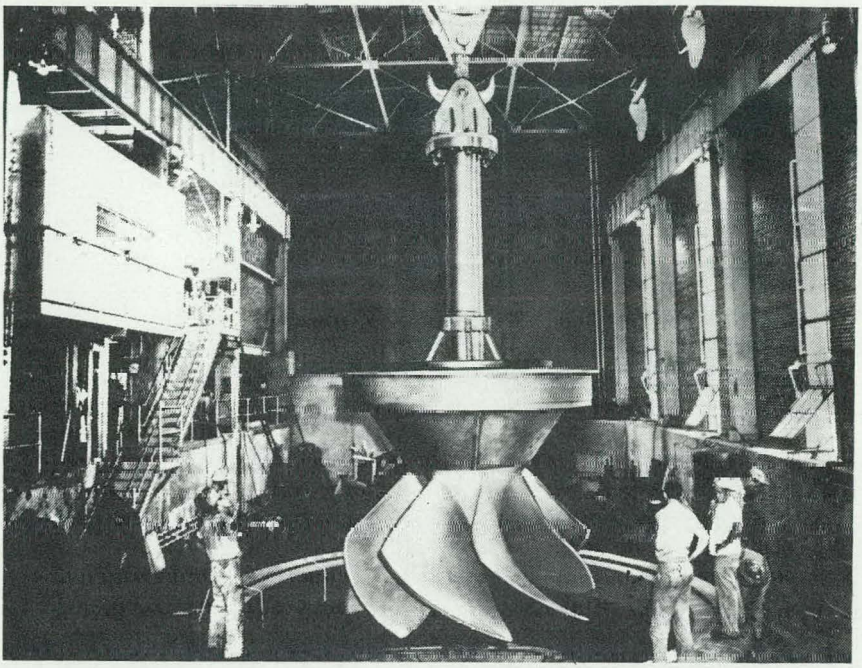


FIGURE A-4.3 —Installation of Head Cover and Runner Assembly for Yadkin Falls Plant

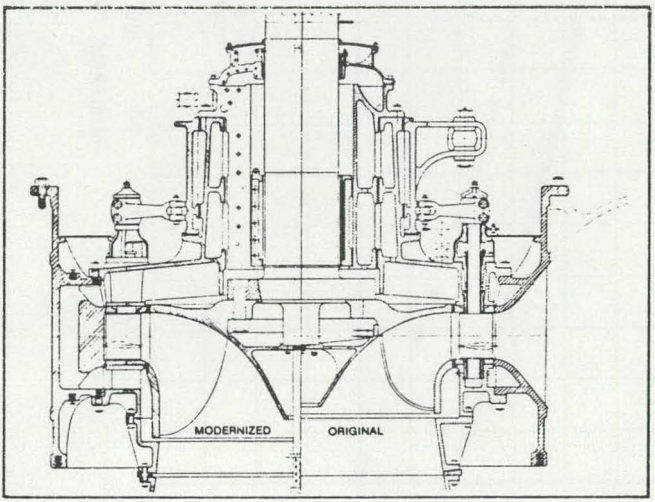


FIGURE A-4.4 Cross Section of Gorge Plant Hydraulic Turbine before and After Modernization

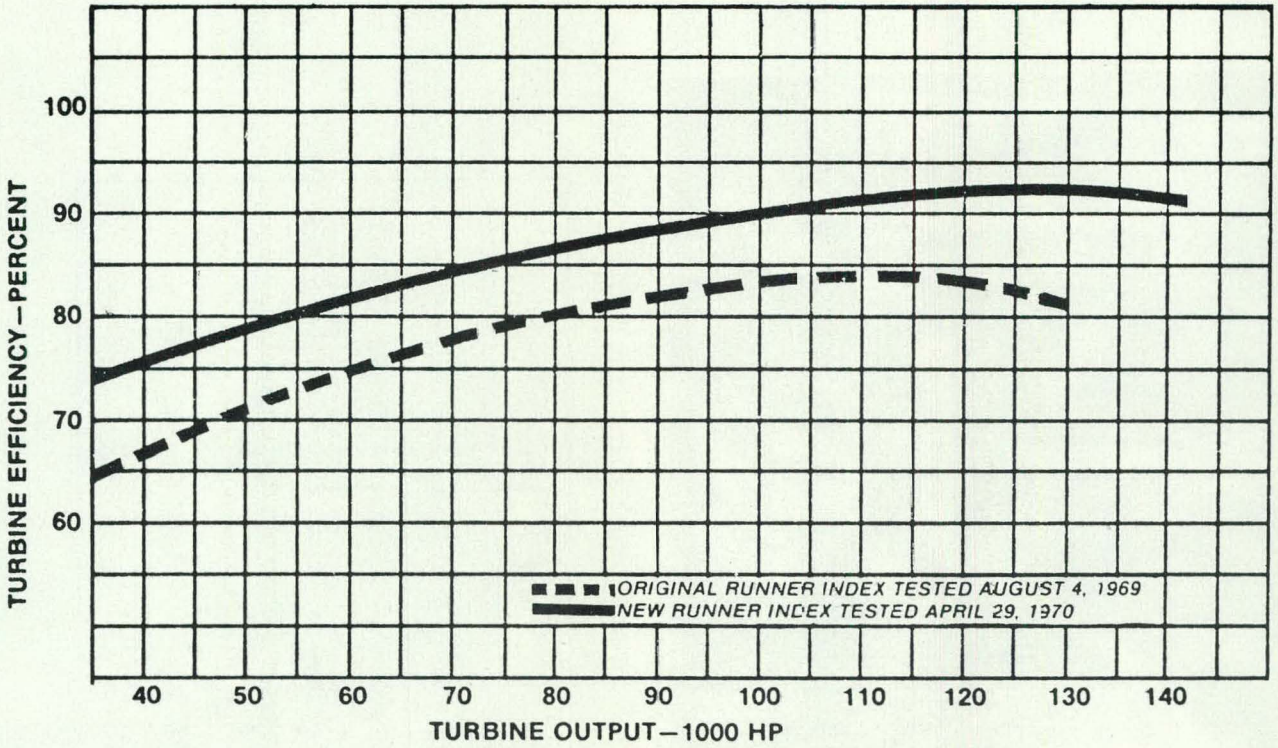


FIGURE A-4.5 Relative Change in Performance at Hoover Power Plant Units N1 to N4 with New Runners

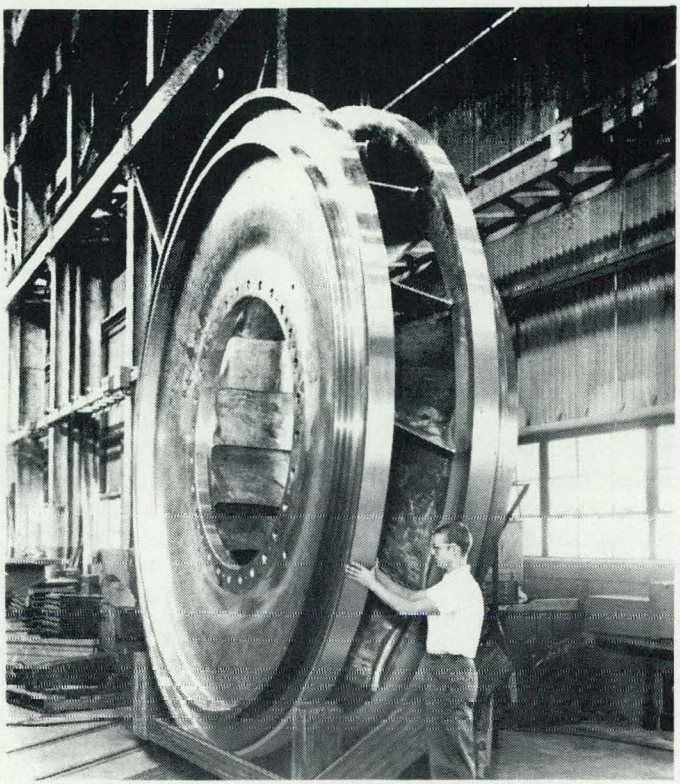


FIGURE A-4.6—One of the Replacement Stainless Steel Runners for Hoover Powerplant

design and manufacture five replacement case stainless steel runners with runner cones, and throat liners for Units A3 through A7. Units A3 and A4 have slightly smaller runners (124 inches or 3.150mm discharge diameter) than Units A5, A6 and A7 (133.625 inches or 3.39mm discharge diameter). Yet all five new replacement runners are designed to deliver not less than 157,300 horsepower (117.346 kilowatts) under 490 feet (149.4 meters) net head. This new rating represents a 37% increase in power over the original turbine rating of 115,000 horsepower (85,790 kilowatts). The Bureau of Reclamation required that two separate hydraulic model tests be conducted to verify the prototype guaranteed output because of the two different prototype runner sites. Table A-4.1 shows a summary of plants wherein an increase in output was achieved with new design and rehabilitated conventional hydraulic turbines.

Pump/Turbine Modernization

Early pump/turbine units, while relatively new in their application compared to the Francis and propeller turbines, are undergoing a modernization program with replacement of the original impeller/runners. The earliest of pump/turbine units had impeller/runners similar to centrifugal pump designs, with modifications to improve the hydraulic characteristics for the generating cycle. While homologous model laboratory studies were conducted on these early pump/turbine units to prove the design theories and check guaranteed hydraulic performance, the hydraulic characteristics of these early pump/turbine units was below achievements now being derived with modern pump/turbine designs.

The operating head and load range, both pumping and generating, is greater for pump/turbines than conventional hydro generating units. Part load operation in the generating cycle has become a major requirement for many of the pump/turbine units. Equipment manufacturers initially recommended operation in excess of 50% gate opening in the generating cycle to minimize vibration and other detrimental performance characteristics. There does exist today a demand for reevalution and consideration of a broader load operating range for pump/turbine units. Special research is being conducted to improve part load performance for pump/turbine when generating.

Significant improvement in hydraulic performance of pump/turbine units has been achieved in a relatively short span of twenty years. Recently constructed modern hydraulic laboratories are available to test designs of early pump/turbine units and compare their operating characteristics with that derived from modernized impeller/runners. The following two examples illustrate such modernization programs:

- Power Authority of the State of New York
- Lewiston Pump/Generating Plant

Twelve pump/turbine units are installed at the Lewiston Pump Generating Plant of the Power Authority of the State of New York. The units commenced operation in 1961 and are rated 28,000 horsepower (20,900 kilowatts) at 75

TABLE A-4.1

INCREASE IN OUTPUT ACHIEVED WITH NEW DESIGN AND REHABILITATED TURBINES

		Original Unit Capability				New Unit Capability				
Plantt	Owner	Year Installed	Head Feet (Meters)	Type & RPM	Output HP (kW)	Year Installed	Head Feet (Meters)	Type & RPM	Output HP (kW)	Increase in Output
Gorge	City of Seattle	1923	325 (99.1)	Fran. 257	37,500 (27,975)	1959	325 (99.1)	Fran. 257	45,000 (33,570)	20%
							Rehabilitation of Original Units			
Diablo	City of Seattle	1932	310 (94.5)	Fran. 171.5	83,000 (61,918)	1959	310 (94.5)	Fran. 171.5	108,500 (80,941)	30%
							Rehabilitation of Original Units			
Yadkin Falls	ALCOA	1917-1921	48 (14.6)	Fran. 90	9,660 (7,206)	1962	48 (14.6)	Prop. 128.6	12,900 (9,623)	34%
							Rehabilitation of Original Units			
Narrows - (Badin)	ALCOA	1915-1924	175 (53.3)	Fran. 156.5	29,500 (22,007)	1964	175 (53.3)	Fran. 163.6	36,000 (26,856)	22%
							Rehabilitation of Original Units			
Hoover Powerplant Units N1 - N4	U.S.B.R.	1936-1937	500 (152.4)	Fran. 180	127,000 (94,740)	1970	500 (152.4)	Fran. 180	142,000 (105,930)	12%
							Replacement of Original Runners			
Hoover Powerplant Units A3 - A4	U.S.B.R.	1950	490 (149.4)	Fran. 180	115,000 (85,790)	—	490 (149.4)	Fran. 200	157,300 (117,346)	37%
							Replacement of Original Runners			
Hoover Powerplant Units A5 - A7	U.S.B.R.	1940	490 (149.4)	Fran. 180	115,000 (85,790)	—	490 (149.4)	Fran. 180	157,300 (117,346)	37%
							Replacement of Original Runners			
Glendo Powerplant	U.S.B.R.	1958	115 (35.1)	Fran. 180	20,000 (14,920)	—	115 (35.1)	Fran. 180	22,000 (16,410)	10%
							Replacement of Original Runners			

feet (22.9 meters) net head, 112.5 RPM generating, and 3400 cfs (96.3 cms) at 85 feet (25.9 meters) pumping total dynamic head.

Normal pumping operations was originally established at 85 feet (25.9 meters) total dynamic head, with the maximum pumping head specified as 99 feet (30.2 meters). After the units had been designed for this operation and shop fabrication was underway, it was found necessary to raise the maximum water elevation in the upper reservoir by 10 feet (3.1 meters) without changing the elevation in the lower reservoir. It was too late by then to change the design of the pump/turbines for this increased pumping head of 109 feet (33.2 meters). Model tests showed that cavitation and rough operation increased at the higher pumping heads.

Each of the original twelve pump/turbine impeller/runners contained 70 square feet (6.50 square meters) of stainless steel for protection against cavitation. Nevertheless, after several years of operation, extensive repair of cavitation damage was required. Much of the repair area was located outside of the original stainless steel area. As a result of the extensive cavitation repairs, gradual deterioration of the impeller/runners resulted in the need for their replacement.

The Power Authority of the State of New York awarded a contract in 1977 to develop a new pump/turbine impeller/runner which would operate satisfactorily within the actual total pumping and generating head range. Model tests were performed on this new pump/turbine impeller/runner to not only determine its performance characteristics, but to analyze and visually inspect model cavitation tests, pressure fluctuations, velocity profiles, and other hydraulic characteristics. Successful results were achieved with these studies resulting in a subsequent contract to manufacture replacement impeller/runners homologous to the accepted model units. Figure A-4.7a and A-4.7b shows the improvement in pumping performance which has been derived with the new impeller/runners installed in the original wheel case.

The improved generating performance is shown in Figure A-4.8. Improved pump cavitation characteristics and stable operation have also been achieved with the replacement impeller/runners as shown in Figure A-4.9. The margin between plant sigma and critical sigma has been increased as a result of the increase in pump discharge over the entire pump head range.

The replacement impeller/runners will have the same inlet and discharge diameters as the original units, with only the vane (bucket) contour being modified. In accordance with specification requirements, 180 square feet (16.7 square meters) of stainless steel weld overlay is being applied to each impeller/runner. This added overlay plus the improved cavitation characteristics should result in a significant increase in the unit availability.

Cabin Creek Pumped Storage Plant, Public Service Company of Colorado

One of the earliest high-head pumped-storage plants constructed in the United States was the Cabin Creek Plant of the Public Service Company of Colorado. Each of the two units installed at this project are rated 223,000 horsepower (166,360 kilowatts) under 1,190 feet (362.7 meters) net head at 360 RPM. Operating as a pump, the units are rated to discharge 840 cubic feet

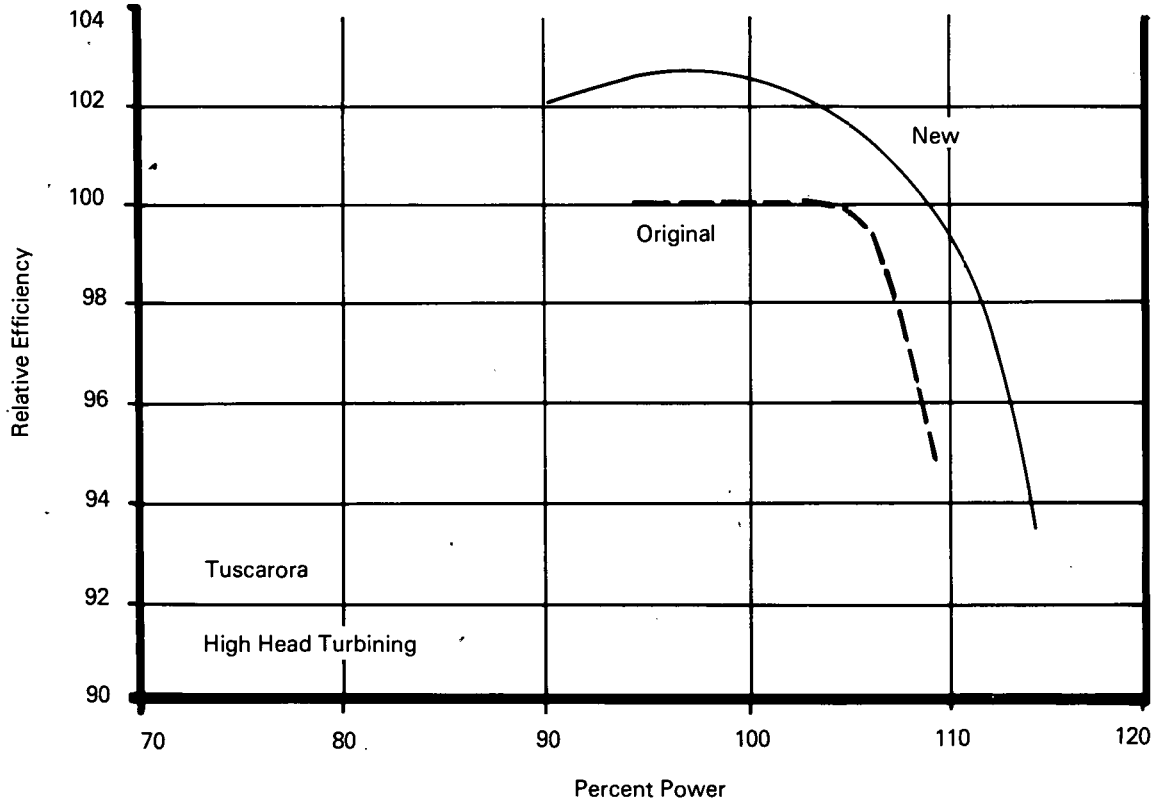


FIGURE A-4.7 a Improvement in Pumping Performance High-Head Turbining

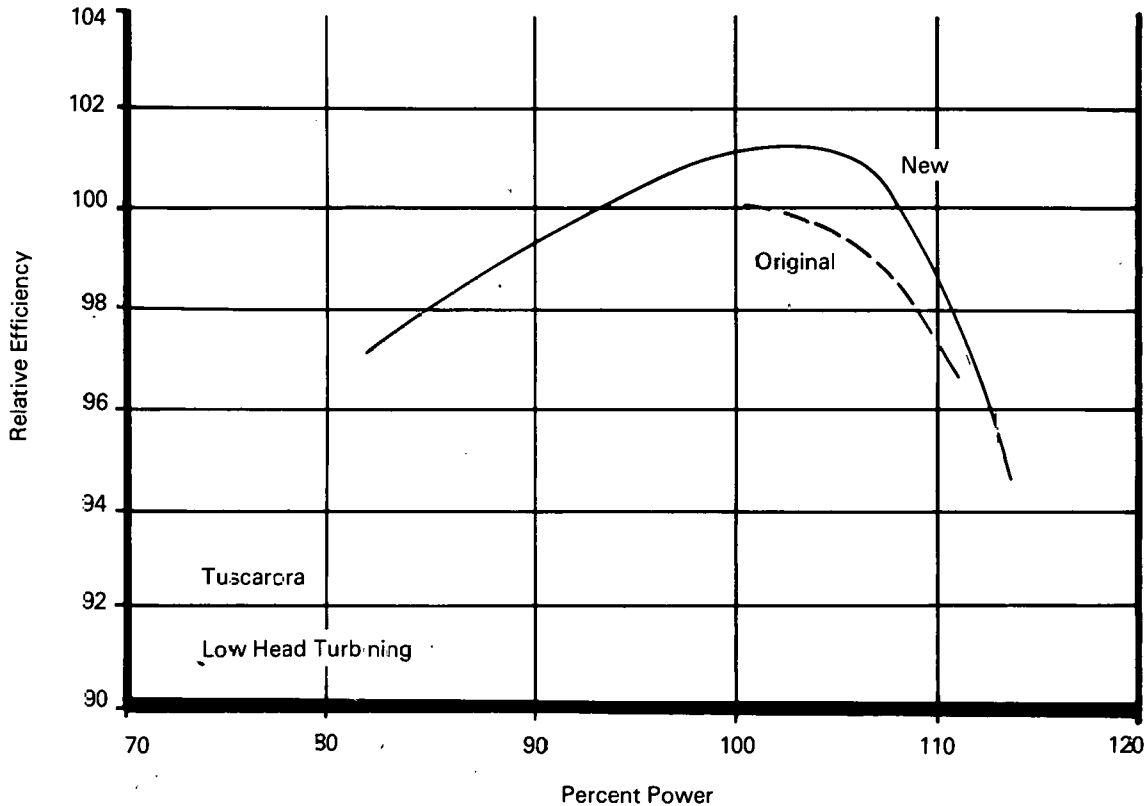


FIGURE A-4.7 b Improvement in Pumping Performance Low Head–Turbining

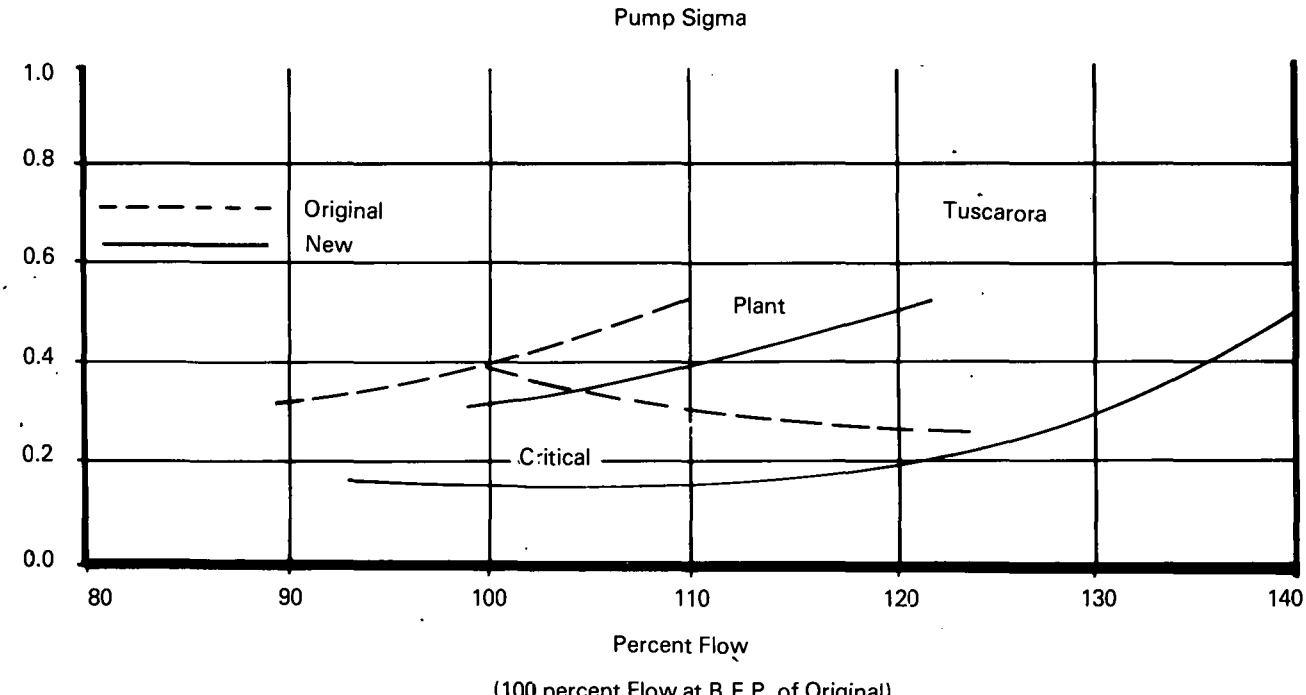


FIGURE A-4.8 Improved Generating Performance

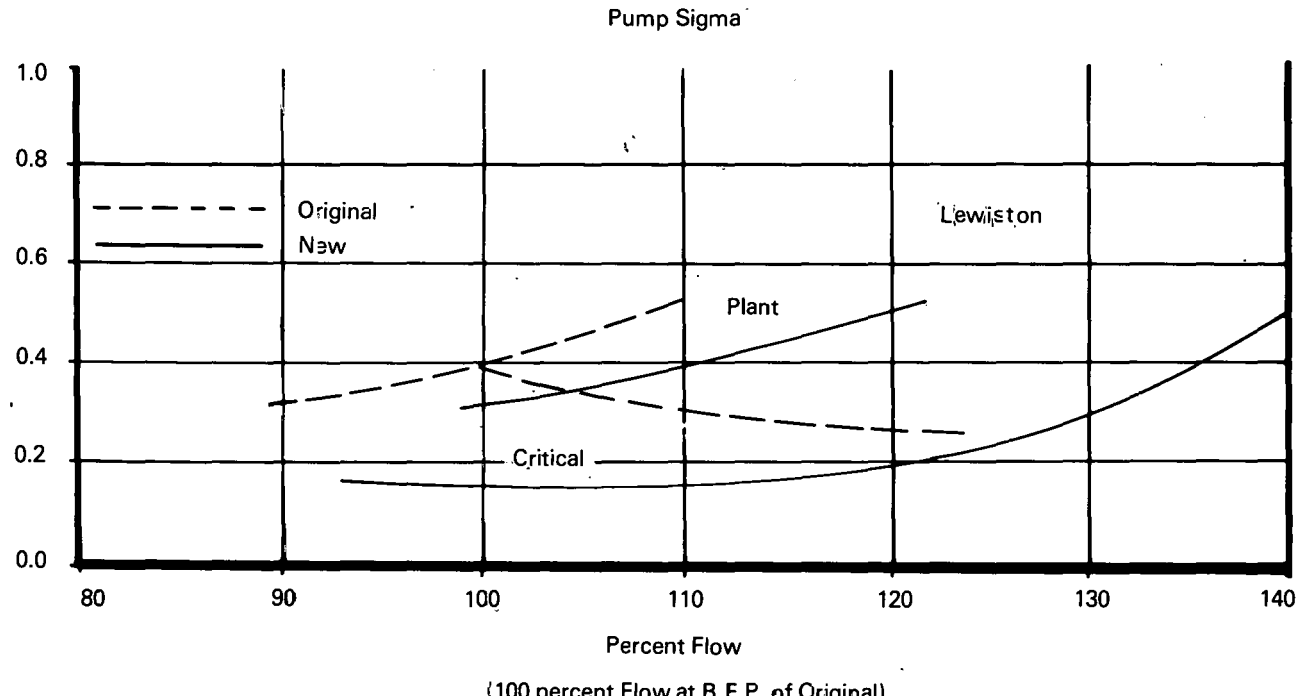


FIGURE A-4.9 Improved Generating Performance

per second (23.8 cubic meters per second) at 1238 feet (377.3 meters) total dynamic head.

The operation of these pump/turbines was selected to suit system load requirements. Six of the normal fourteen hours daily generating mode operation was spent at cpacities of fifty percent rated load or less. Generating at these low loads produced draft tube surging resulting in rough operation and vibration.

The original impeller/runners were made from solid cast steel ASTM A27, Grade 65-35, normally used for conventional hydraulic turbine runners. One-piece castings of the size and type used for this installation must be cast with realistic tolerances, hence the runner vane thickness at the turbine inlet edge was at the lower limit with resulting high stress levels. During the first several years of operation, cracks developed in the vane turbine-inlet edge at the crown and band. An in-place repair was performed on the impeller/runners by welding mild steel inserts of thicker material into the periphery of each vane. Pitting damage, due to cavitation, was also experienced with the mild steel runners.

Cracks again developed in the runner vanes which were attributed to localized shrinkage stresses due to the inability to properly stress relieve the many weld repair areas. Subsequent annual inspections indicated the need to repair by welding the cracks and pitting.

As a result of the gradual deterioration of the original impeller/runners, Public Service Company of Colorado decided to proceed with their replacement. Design studies and a model test program were undertaken to develop replacement impeller/runners having improved part-load operation when generating and also increase the margin between plant sigma and critical sigma. To reduce the effects of the generating whirl component in the vertical section of the draft tube immediately below the impeller/runner, a co-axial diffuser was designed and tested for installation in the existing draft tube. Model tests, when generating, were run with and without the co-axial diffuser, and with the new design impeller/runner. Figure A-4.10 shows a plot of draft tube dynamic pressure versus head for constant gate opening, without the co-axial diffuser installed in the draft tube. Figure A-4.11 shows a plot of the same characteristics with the co-axial diffuser. A comparison of the figures shows that the magnitude of the dynamic pressures have been significantly reduced when the co-axial diffuser is installed in the draft tube. In addition to the reduction in dynamic pressure in the draft tube, other improvements have been achieved with the replacement impeller/runners for the Cabin Creek Plant. These improvements include:

- Increased pumping efficiency.
- Flow stability at maximum pumping head.
- An increase in margin between plant sigma and pump critical sigma.
- Pump visual cavitation determined by observations through a plexiglas section in the model draft tube.
- Turbine part load efficiency.

The new replacement impeller/runners will be made from solid stainless steel, ASTM A296, Grade CA6NM, which offers greater strength and im-

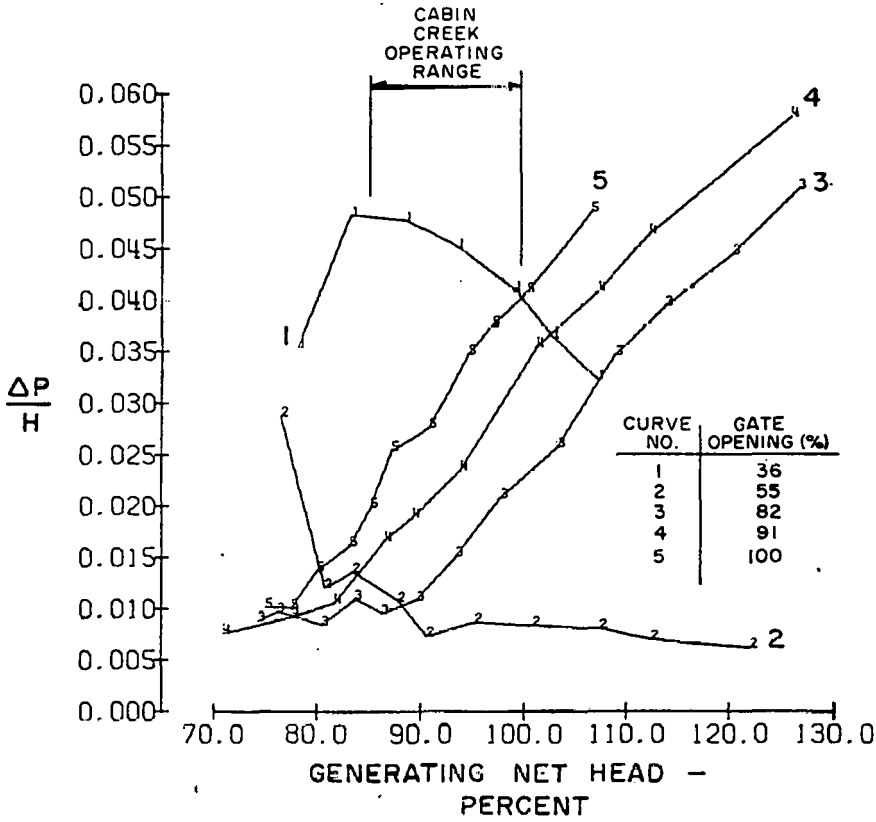


FIGURE A-4.10 Draft Tube Dynamic Pressure/Head vs. Generating Net Head - No Diffuser

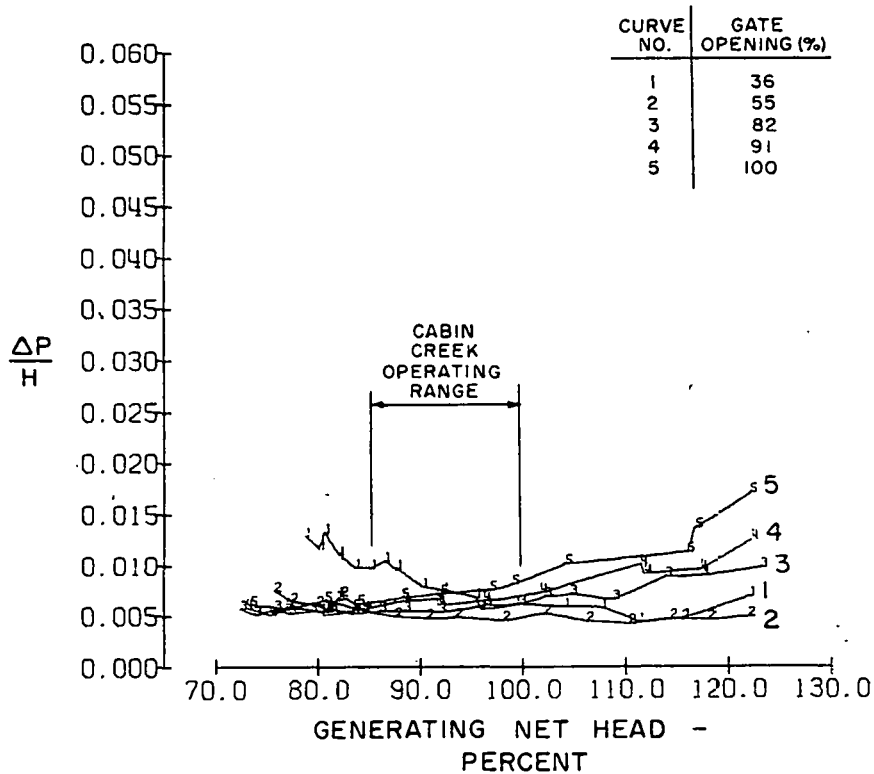


FIGURE A-4.11 Draft Tube Dynamic Pressure/Head vs. Generating Net Head — Diffuser

proved resistance to cavitation compared to the original mild steel impeller/runners. Early pump/turbine impeller/runner designs were based on each designer's interpretation of general design criteria for rotating hydraulic machinery. Some of the impeller/runner designs were derived from interpolation or extrapolation of past designs. Model tests were conducted to check the designs and provide model hydraulic performance for calculating prototype performance.

Present day pump/turbine, impeller/runners are designed combining knowledge gained from the traditional methods and experience with early units, as well as the use of modern computer programs.[2] This procedure is structured to be flexible in order to accept new information which will be of benefit in upgrading the hydraulic performance of new pump/turbines, as well as replacement impeller/runners for existing units.

Hydrogenerator Uprating

Improvements have also been accomplished with modernization of major hydrogenerators.[3] Capability does exist for uprating existing hydro generators for several reasons:

1. The mechanical parts and magnetic circuits, (with perhaps the exception of air and oil coolers), seals and bearings, for all practical purposes never wear out.
2. Coolers, seals and bearings are easily replaced.
3. The windings can be replaced with coils having insulation superior to the original.
4. The basic characteristics of the turbine and generator are such that these units can be used equally well for base or peaking service.
5. The application of modern technology usually will increase the machine efficiency as well as increase the capacity.

Uprating cannot be accomplished reliably by only rewinding the stator. If no ventilation modifications have been made on the original hydrogenerator, the original temperature tests can provide very useful information to be factored into the design of an uprated machine. However, from a loss standpoint, an older machine may have higher core and tooth loss as a result of aging of the silicon steel and interlaminar insulation. Therefore, if a substantial uprating is planned using the old stator core, new loss tests should be made because higher core loss will adversely influence the winding temperature.

The most common modification which results in a hydrogenerator uprating is the replacement of the stator winding and the use of the existing rotor winding and exciter. Because the field current will increase with load, the

---

[2] A. G. Mount, A. J. Stipanovic — *Development of Improved Francis Pump/Turbine Runner for Existing Installations* — The Joint ASME-CSME Applied Mechanics, Fluid Engineering and Bioengineering Conference, Niagara Falls, N.Y., June 18-20, 1979.

[3] P. S. Johrde — *Means and Limitations of Increasing Hydrogenerator Output* — IEEE/ASME Joint Power Generation Conference, San Diego, Calif., September 20, 1977.

capacity of the exciter may be exceeded. If such is the case, the rated power factor of the hydrogenerator may have to be increased or a new source of excitation must be obtained.

The new stator winding usually has the same number of turns per coil and the same number of parallel circuits as the original. The new insulation is normally superior to the old asphalt type, and is therefore designed to have a higher working stress in volts/mil. The redesign of a hydrogenerator to accomplish a desired uprating involves the matching of existing mechanical, electrical, and heat transfer capabilities with alternative modifications involving new technology.

The original rotor winding usually can stand the extra field current associated with an uprating. This is very fortunate because most rotor windings suffer little or no deterioration with time and are seldom replaced. Once the uprating is determined based on thermal limits of the windings, the new losses must be calculated and the original air coolers checked to determine if the additional loss can be absorbed by increasing water flow or additional coolers.

As in the hydraulic turbine uprating, it is necessary to review the mechanical design of the existing hydrogenerator. Items normally reviewed include the torsional stress in the shaft with the new rating, the rotor spider and its attachment to the shaft, and the effect of greater short circuit torque on the stator and foundation.

Economic Evaluation of a Hydrounit Up-Grading

The production of electric power to satisfy the load curves of large utility systems requires a large amount of capital to be invested. For hydroelectric plants the annual costs result from fixed charges on the initial capital investment. Running costs proportional to annual kWh generated are regarded as minimal, unlike a thermal plant which has large fuel operating costs. Major hydroelectric projects with favorable site conditions will today cost between $200/kW to $1000/kW (excluding transmission lines) depending primarily on project head and project capacity. In view of the rapid increase in the price of fuel oil in recent years, efforts are being exerted to reduce the importation of this high cost fuel and resort to other sources of power generation. At an oil equivalent of 600 kWh/bbl. the increased capacity of existing hydroplants, even of small capacity, will have a significant impact on reducing our oil importation. If a hydroplant were to operate for 10.5 months of the year, each kW of increased capacity would save 12.5 barrels of oil every year.

Energy costs will vary with the type of generating units operating to supply the load demands of a utility system. If a conventional hydrogenerating unit were down for maintenance, and spill was occurring, this lost generation on a diversified system can be considered as having to be replaced by a fuelled plant. It is the highest cost thermal unit, including interest, depreciation, and fuel costs, at any point in time which must be considered to determine total energy costs necessary to replace the lost hydrogenerating unit.

The economics of a typical hydrounit upgrading are rather straightforward, whereas the costs of typical large hydro developments include a dam and reservoir, tunnels, penstocks, a powerhouse, transmission lines, rights-of-

way, project licensing and more recently the cost of legal barriers in applying for a FERC license. The existing hydrounit upgrading costs would be subject to none of these. The costs for performing a hydrounit upgrading are normally limited to the cost of replacement runners, cost of rewinding a generator, associated electrical equipment upgrading, and field installation costs of the equipment.

When considering the economic justification of a hydrounit upgrading, the minimum expected life of 25 to 30 years should be considered. With the competition for available funds and manpower in any utility system, a return of the total investment in five to ten years, where the fuel costs and interest rates are reasonably predictable may be used to evaluate the proposed hydrounit upgrading.

The cost of a new oil fixed thermal is estimated to be more than $650/kW. With an assumed annual capital charge of 16 percent (interest plus depreciation), and a 75 percent plant factor, the calculated capacity value is:

$$\text{Capacity Value} = \frac{\text{Installed Cost X Capital Charge}}{\text{Hours of Plant Operation}}$$

$$\text{Capacity Value} = \frac{\$650/\text{kW X } 0.15}{8760 \text{ HR/YR X } 0.75} \text{ X } 1000$$

$$\text{Capacity Value} = 15 \text{ mils/kWh}$$

Based on an energy equivalent of 17 kWh/gal. of fuel oil, and an assumed oil cost of 60¢/gal., the fuel cost per kWh is 35 mils. Assuming operating, maintenance, and administration costs totaling 3% of the project cost, the fixed charges are:

$$\text{Fixed Charges} = \frac{\text{Installed Cost X O.M. \& A. Costs}}{\text{Hours of Plant Operation}}$$

$$\text{Fixed Charges} = \frac{\$650/\text{kW X } 0.03}{8760 \text{ HR/YR X } 0.75} \text{ X } 1000$$

$$\text{Fixed Charges} = 3 \text{ mils/kWh}$$

The total cost of a thermal-generating unit would therefore be the sum of the capacity value, fuel costs, and fixed charges or 53 mils/kWh. The economic value of new firm hydro capacity is therefore 53 mils/kWh, and for non-firm energy is equal to at least the cost of oil utilized to generate the equivalent electricity in an oil-fixed thermal unit, at approximately 35 mils/kWh. This is the generation which would be displaced if non-firm hydro capacity is produced. The amount which one could afford to invest in a hydrounit rehabilitation or upgrading and obtain a five-year payback can be approximated using the following approach:

ANNUAL CHARGE PER DOLLAR OF PROJECT COST

	MILS
1. Principal and Interest* (5 years @ 10%)	264
2. Operating and Maintenance (1.5%)	15
3. Administration and Miscellaneous (1.5%)	15
TOTAL	294

$$\text{*Annual Payment} = \text{Project Cost} \times \frac{i}{1 - (1 + i)^{-n}}$$

Where i = Interest Rate

n = Number of Years

$$\text{Annual Payment} = \frac{\$1.00}{1 - (1 + .10)^{-5}} \times \frac{.10}{} \times 1000$$

Annual Payment = 264 mils

The charge per kWh for each dollar of project cost assuming 60% operation is:

$$\frac{294 \text{ mils}}{8760 \text{ HR/YR} \times 0.60} = 0.056 \text{ mils/kWh}$$

The target cost for non-firm power of a five-year payback would then be:

$$\frac{35 \text{ mils (alternative fuel cost)}}{0.056 \text{ mils/kWh (cost of renovated hydro unit)}} = \$625/\text{kW}$$

If a 10-year payback was assumed instead of the five years, the annual principal and interest charge per dollar of project cost would reduce from 264 mils to 163 mils, and the amount one could spend would be $950/kW assuming no inflation in fuel costs. Assuming that fuel prices increase at 10% per year, the target cost for a five year payback increases from $625/kW to $800/kW, and for a ten-year payback it increases from $950/kW to $1520/kW.

As an example, the U.S. Bureau of Reclamation purchased two replacement runners of solid stainless steel in 1979 for the Glendo Powerplant. The cost of the two replacement runners was $459,000. The increased capacity derived from each of the replacement runners was 1500 kW, or a cost equivalent of $153/kW. With an alternative power cost of 35 mils per kWh, the U.S. Bureau of Reclamation could spend up to $625/kW on $1,875,000 to upgrade this two-unit plant and obtain a five-year payback on their investment. Assuming the cost of oil increases at the rate of 10% per year, they could afford to pay $800/kW or $2,400,000 to obtain the 3000 kW increased plant capacity.

Figure 4-A.12
Hydraulic Turbine Customer Information Sheet

CUSTOMER:

PLANT NAME:

TYPE AND SETTING OF TURBINE: HORIZONTAL / VERTICAL

UNIT NUMBER:

ORIGINAL TURBINE MANUFACTURER:

SHOP ORDER/SERIAL NUMBER:

TURBINE NAMEPLATE RATING: OUTPUT HP/KW
HEAD FT/METERS
SPEED RPM

OPERATING CHARACTERISTICS:

	% OF MAX. GA OPEN'G.	% OF THE TIME	GENERATOR OUTPUT (KW)	FLOW CFS/M³/S
FULL LOAD	100			
BEST EFFICIENCY				
PART GATE		100		

NET HEAD OR HEAD WATER ELEVATIONS*	FEET/METERS	% OF THE TIME	CORRESPONDING MINIMUM TAILWATER ELEVATION* FEET/METERS
MAXIMUM			
NORMAL			
MINIMUM		100	

*VALUES ABOVE MEAN SEA LEVEL OR RELATIVE TO DISTRIBUTOR/SHAFT CENTERLINE (FOR HOR. UNITS)

TURBINE DISTRIBUTOR/SHAFT CENTERLINE (FOR HORIZONTAL UNITS)
ELEVATION ABOVE MEAN SEA LEVEL: FEET/METERS

CAVITATION REPAIRS:

FREQUENCY OF REPAIR: YEARS

SEVERITY OF DAMAGE:

HIGH
NORMAL
MINOR

INDICATE IF ANY CHANGE IN PERFORMANCE OVER THE LAST 10 YEARS WAS OBSERVED

YES/NO

MAINTENANCE RECORD:

While some replacement runner economic evaluations may not stand on their own merits based on increased capacity, there may exist a deterioration or degradation of the original runner material which should be considered along with the increased capacity when evaluating the merits of replacing the existing hydraulic turbine runners.

Modernization Studies

Modernization of existing hydroelectric units requires careful studies by experienced hydraulic turbine and generator designers. In planning for any such modernization program, it is important to initially begin with studies of the hydraulic turbine to determine its capability for increased capacity or efficiency. Since there is relatively little consistency in design of the older turbine water passageways, it has been difficult to establish a consistent trend of what may be achieved from a modernization program. Individual studies are required for each installation, and sufficient data should be submitted to the hydraulic turbine manufacturer to perform reliable modernization studies. Figure A-4.12 outlines typical data desired for such studies. In addition to this technical data, powerhouse general arrangement and turbine distributor section drawings, if available, would be helpful.

Conclusion

There exists in many of today's operating hydro installations, the opportunity to increase the capacity and/or energy by applying technological advances in hydro equipment design of the past 20 to 30 years. Units that have operated for over half a century are being rehabilitated to provide additional energy at costs that can be economically justified. Although the contribution to our nation's increasing energy requirements from modernization of existing hydrogenerating units may be a small percentage of our total energy requirements, it certainly is a step in the right direction.

OSSBERGER CROSS-FLOW TURBINES

F. W. E. Stapenhorst

I would like to thank the Department of Energy and the Army Corps of Engineers for inviting me to address the seminar on the subject of the cross-flow turbine.

I believe that the selection of the suitable turbines and other equipment is gaining in importance as the many small-scale hydro projects are approaching the on-going stage.

We all know that for the last few decades, small-scale hydro equipment has been neglected by practically all turbine manufacturers. The industry has concentrated on even bigger turbines with higher and higher efficiency. Probably the best example of this is the Grand Coulee Project. Canadian G.E. and U.S. Allis-Chalmers designed and furnished turbines in the range of one million hp each. There was just no thought and no demand for small-scale hydro. The few that were sold were scaled-down units supplied in the U.S.A. by Leffel and Allis-Chalmers and other manufacturers in Europe - small turbines such as Francis, Bulb, Propeller and other units. Members of this conference are now aware that Allis-Chalmers have now revamped their TUBE turbine. They would also know of Leffel's types of small turbines.

The only turbine company excluding itself from the race for bigger and bigger turbines is the Ossberger Turbine Company in West Germany. This Company has always concentrated on small turbines, with all their engineering, design and development being applied to small-scale hydro. It is not unreasonable, therefore, to consider this company as the world leader in small-hydro with several thousand of their units operating in many countries.

The type of turbine Mr. Ossberger selected for this production is of the impulse type. It is named the "cross-flow" turbine because the water physically crosses the runner twice. The cross-flow principle was invented by Mr. Michell, an Australian engineer, at the turn of the century. It was further developed by an Hungarian engineer, Professor Banki, who is responsible for its popularity at the time.

The real push came when Ossberger acquired the patent rights for the cross-flow turbine and concentrated on perfecting its design, construction and manufacture. The principle of the cross-flow wheel has not changed since its conception by Mr. Michell. Water in today's cross-flow turbine is directed through a rectangular jet to a cylindrical runner. The main characteristic of the cross-flow runner is that the water passes the runner blades twice - first from the outside towards the center, and then after crossing the open center, from the inside outward.

This cross-flow of the water in its secondary action outward cleans the runner blades of any debris, ice and other foreign matter which enters the turbine. A further feature of today's cross-flow turbine is its capability to efficiently cope with heads as low as three feet and all the way up to heads of

---

Mr. Stapenhorst is President of F. W. E. Stapenhorst Inc., and President of Tyton Seal, Inc. of Pointe Claire, Quebec, Canada.

several hundred feet. No other type of turbine available today covers such wide range-of-heads.

The most important property of the Ossberger cross-flow turbine which makes it particularly suitable for small run-of-the-stream operation is its flat efficiency curve over a wide range-of-flow. You will see that its efficiency stays very high even at a 15 percent of rated flow, where Francis would, in fact, not produce any power.

To accommodate high variation in flow, the Ossberger turbine guide vane is split into two sections. One section covers one-third and the other section two-thirds of the runner. At maximum flow both sections are open. At medium flow the two-thirds section is open with the small section closed. At minimum flow only the small section is open. The Ossberger Cross-flow Turbine therefore, will easily out-perform all other types of turbines at widely fluctuating flows. The only other turbines that come close to this performance are those with adjustable blades which generally adds considerably to the price of the turbine. Our type of turbine can also accommodate head fluctuations of about plus/minus 20 percent.

With the total concentration upon the development and its perfection, the Ossberger Cross-flow Turbine has become probably the most practical turbine in its range in the world today. Today's cross-flow turbine has only two moving parts, i.e. its runner and its guide vane.

The multi-bladed runner is made of cold drawn steel. Each runner is precision dynamically balanced prior to its assembly into the housing. The bearings of the runner are standard roller bearings available at any bearing supplier throughout the world. The guide vane bearings are of white metal type and a spare set of bearings is maintained by us in North America for each turbine sold in the U.S.A. The shaft-seal packing is also standard and is obtainable from any packing manufacturer throughout the world.

The turbine is supplied with an intake transition piece between the penstock and the turbine. This is generally round, to fit the end of the penstock and formed into a rectangular shape to be bolted to the turbine housing. The low-head turbines are usually supplied with a draft tube of a rectangular configureation to fit the turbine housing to which it is bolted with its outlet end of round section.

A semi-modularized design has been developed for the various diameter runners. This means that the turbines for each size runner differ only in the length of the runner and in the diameter of the shaft. This feature is not only reflected in the price of the turbine, but also permits speedy deliveries since most other parts are standard.

The guide vane is so designed that it can eliminate a valve at the penstock at low-head installations. With the guide vane closed, the turbine housing can be opened permitting inspection of the runner - an operation which takes only a few hours.

The draft tube is either straight or elbow shaped. With a maximum vertical length of 12 feet, selection of suitable turbine elevation is made easy without loss of operating head.

The turbine is generally supplied completely assembled mounted to a frame. This frame is bolted to the floor with the draft tube and the transition piece bolted to the assembly at installation. All the cross-flow turbine actually requires is a strong floor with a hole in it. Installation is done in a matter of

days. There are no parts imbedded in the concrete. The turbine is coupled to a speed increaser, in most cases consisting of standard parts, and to a horizontal shaft generator of standard design.

The use of standard locally-available equipment drastically reduces the cost of hardware when compared to other units, especially those with vertical shafts sensitive thrust bearings, wicket gates and other parts requiring regular maintenance.

Participants of this Conference should know that we are at present importing the turbine only, acquiring other components in the U.S.A. This generally results in a foreign content of less than 15% of a project. Also, Ossberger has expressed its interest in building a plant in the U.S.A. for the manufacture of their cross-flow turbines, once the demand for small-scale hydro warrants the investment.

In many cases, small plants would be feeding into the large grid of a large utility. This allows the use of induction or asynchronous type of generation which makes the equipment even more economical and simple. This system would eliminate a speed governor for the turbine and the generator is an ordinary induction motor which draws excitation for the grid and is driven at a slightly higher speed than the synchronous speed.

The control for these units has been developed by Ossberger. It is a simple and reliable piece of equipment named Ossberger Regulator. Start and stop of the turbine is fully automatic, using photocells and integrated circuitry which can be programmed to include control of the water level of the reservoir to within a couple of inches. This equipment will permit the units to automatically operate when water is available, or save the water for use during peaking hours. For synchronous applications, a standard speed governor, such as the Woodward Type UG, is used.

The manufacturing program of the Ossberger Cross-Flow Turbine presently includes runners to a diameter of maximum 1250 mm with typical data as follows:

At 10 feet	265 hp	- 285 cfs
20 feet	666 hp	- 353 cfs
30 feet	838 hp	- 300 cfs
55 feet	1700 hp	- 325 cfs

Other Ossberger Cross-Flow units are suitable for heads up to 700 feet and outputs to 5000 hp.

If more water is available and larger installations are required, the cross-flow turbines are ideally suited to be put up in multiples. In some cases, two turbines can be coupled to one generator via a suitable speed increaser. The features of the Ossberger Cross-Flow Turbine can be summarized: simplicity, reliability, and performance combined with low-cost civil works, as well as, extremely little maintenance.

I hope my remarks have contributed to this Conference and that they will help participants in their selection of the most suitable turbine type for their particular application. Some members of this Conference may remember my announcement at the University of Idaho Conference in early June 1978, that we were planning a demonstration plant in the State of New York. I am pleased to announce today that our plans have materialized. We obtained the

licence from FERC in March this year. With the constantly increasing prices caused by inflation during the long time of front activities, we are particularly happy that the Department of Energy has taken an interest in our demonstration project.

Immediately after receiving our contract with the Department for a contribution in the amount of $245,000.00, we commenced the rehabilitation of the Goodyear Lake Generating Station in the State of New York. The station is situated on Highway 28, just North of its junction with Highway 7 near Oneonta. We will be installing two Ossberger Cross-Flow Turbines for a total maximum consumption of 700 cfs and output of about 1400 kW. With the greatly varying flows available to us, we will generate about 7.5 mill. kWh yearly.

The installation is asynchronous feeding into the grid of the New York State Electric and Gas Corporation. Our generating station will operate entirely automatically, including the control of the water level in the lake. Complete information about all phases of this project will be made available to the Department of Energy. Visitors are welcome to the site at any time. We plan to be on line early 1980 with an official opening date to be announced. This event is planned to take place in the Spring 1980.

Meanwhile, we are happy to note that additional projects of a similar nature are on the move or about to move. This is no doubt due to the tireless work of FERC in respect to licenses. Mr. Corso has become so active that he reminds me of a travelling salesman, only he is peddling licenses without getting a commission. His appearances and valuable help are found everywhere.

The Department of Energy with their ever deeper involvement and growing experience are already offering endless assistance in feasibilities and planning in all aspects of even more projects. I am certain that with the continuing efforts of everyone, many badly needed small-scale hydro stations will soon come on line.

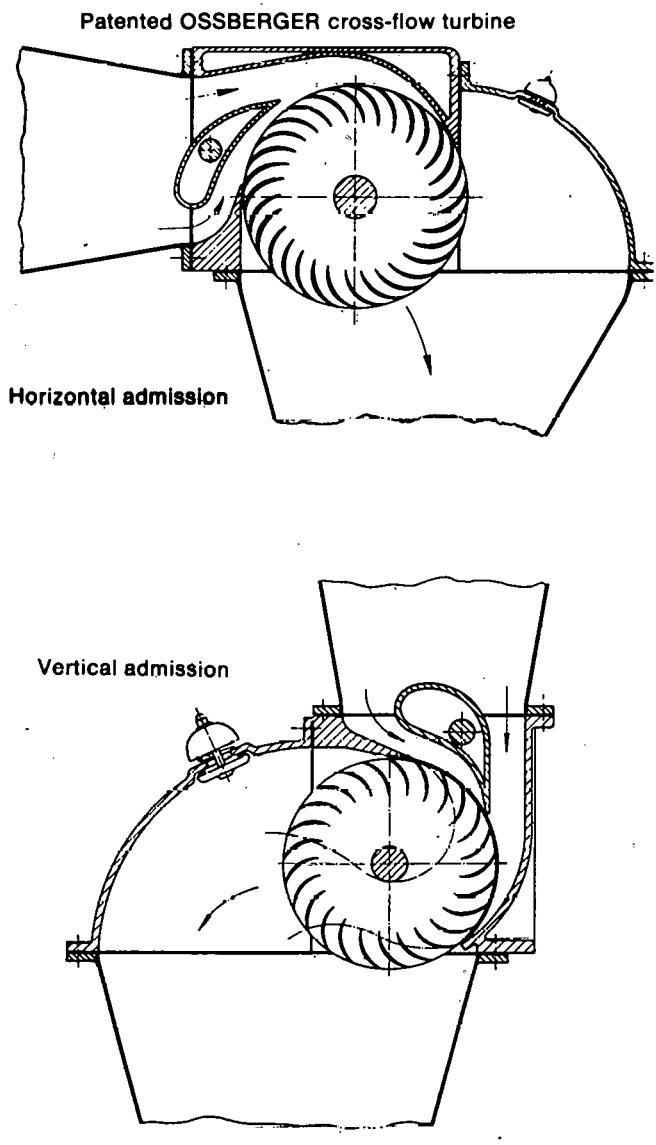


FIGURE A-5.1 Cross section of patented Ossberger cross flow turbine

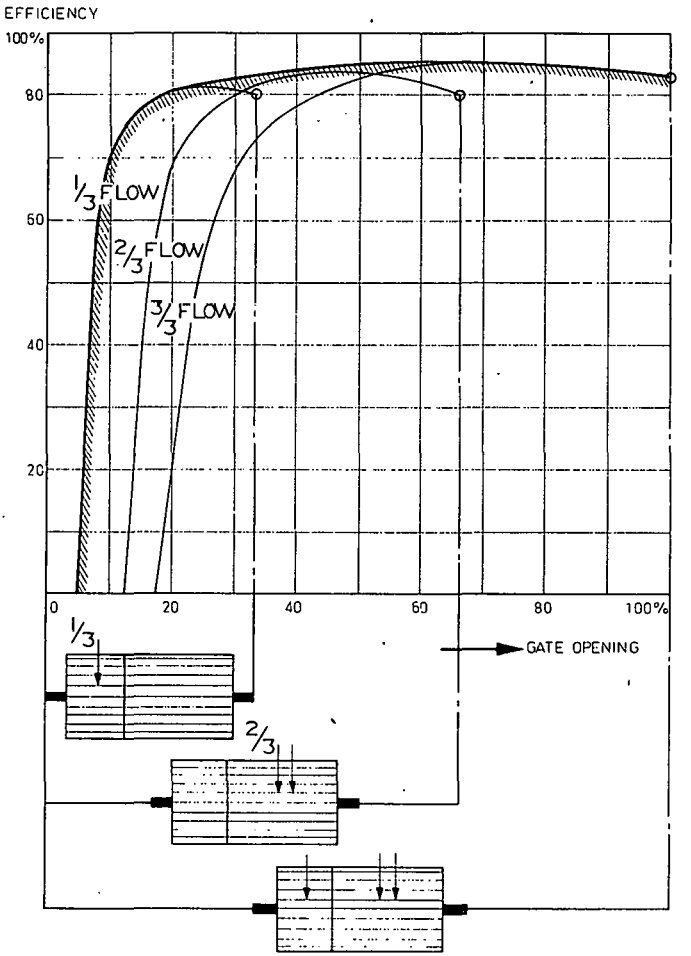


FIGURE A-5.2 Efficiency Curve – Ossberger Cross flow turbine

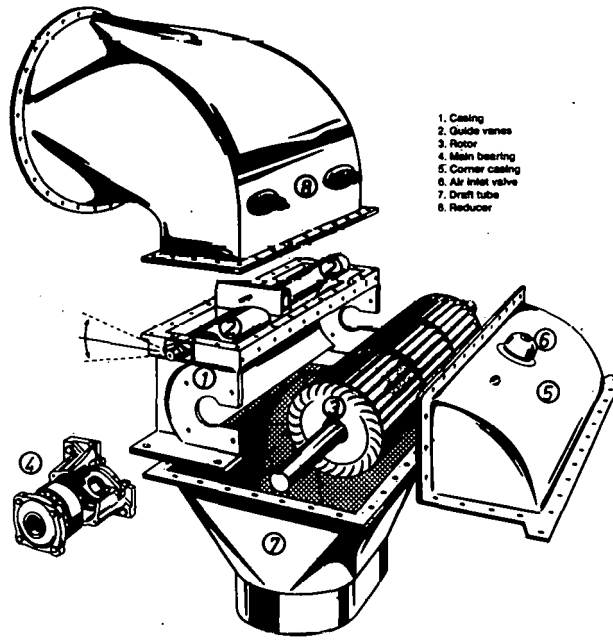


FIGURE A-5.3 Exploded view of Cross Flow Turbine

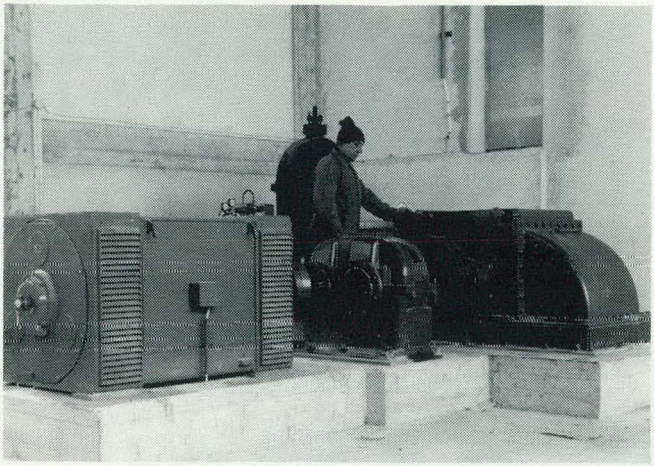


FIGURE A-5.4 Mounted Turbine

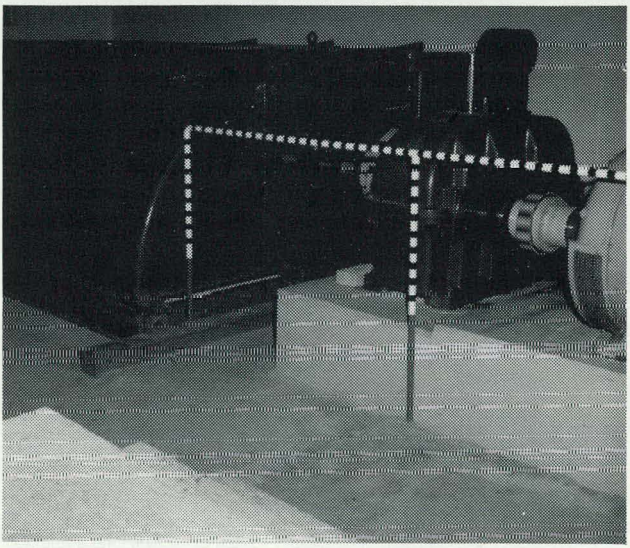


FIGURE A-5.5 Cross Flow Unit

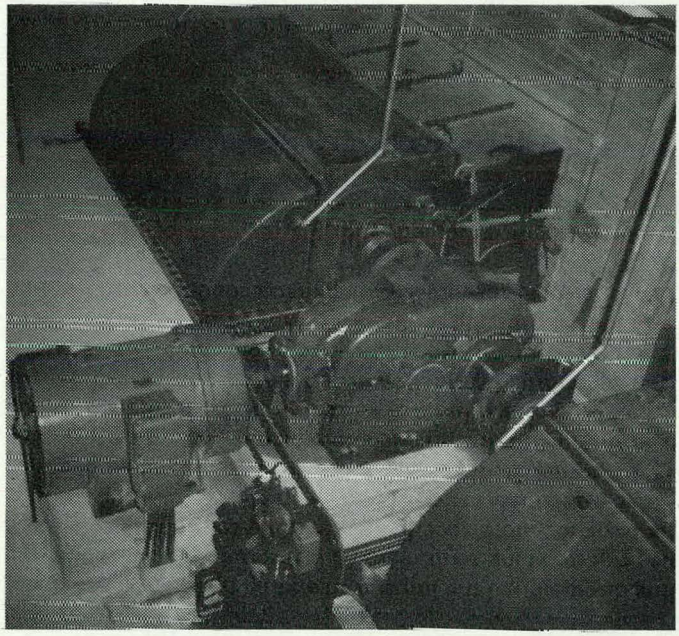


FIGURE A-5.6 Coupled Turbines

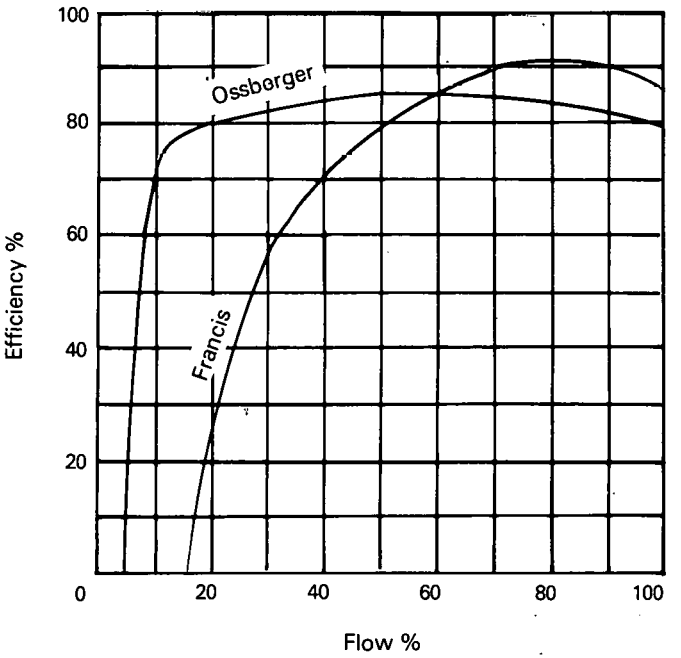


FIGURE A-5.7 Efficiency Curve of an Ossberger Turbine

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

Session Two

ENGINEERING

Topic: Redevelopment I

Chairman: Mr. J. Gavin Warnock
Vice President and General Manager
Acres American, Inc.
Clark Building
Columbia, Maryland 21044

REDEVELOPMENT OF OLDER HYDROELECTRIC GENERATING PLANTS: A THREE-PHASE APPROACH

Alfred G. Trott

There is a growing interest in the possibilities of restoring and upgrading many of the old and inefficient hydroelectric generating plants existing in many parts of this country, specifically in the East, Middle West and also in the Northwest. There are many factors responsible for this impetus: (1) The rising cost of fossil fuel, (2) Regenerable nature of hydroelectric generation and (3) A virtual non-polluting source of energy that would satisfy even the environmentalists.

Many of these old hydroplants, because of their low-generating capabilities have been sold or leased by utilities to small industries, such as paper mills, and to municipalities. Some of these plants have been donated outright to municipalities specifically for the recreational facilities derived from the reservoirs. Those plants that have been retained by the utilities have continued operating even though equipment in place is increasingly difficult to replace.

Recently, however, some manufacturers have developed turbine and generating equipment which can be adapted admirably to the upgrading of these old and inefficient hydroplants. An example is a device called a tube turbine, which consists basically of a tube with an inlet valve or gate, with the turbine mounted within the tube and the turbine shaft projecting out approximately horizontally through the tube and connected to a small geared generator. This equipment is smaller compared to the original and, therefore, can be installed within most of the old hydro powerhouses. With some ingenuity, similar equipment can be designed and fabricated that would replace the old existing equipment, and at the same time be considerably more efficient.

To restore and upgrade old inefficient hydroplants requires thorough investigation of the problems and difficulties involved. In order to resolve these problems and difficulties in an orderly and cost-effective manner, Power Design Services, Inc. (PDS) recommends a planned three-phase approach. This approach affords the client/owner an opportunity to make an appraisal and to decide on further project commitment at the conclusion of each phase.

The three-phase approach to the investigation of hydroplant restoration and uprating are:

Phase I - Site Information
Phase II - Feasibility and Economic Evaluation
Phase III - Engineering and Design

During Phase I, it is necessary to obtain site related information including: hydrology, hydraulics, existing structural data, and special hydraulics condi-

---

Mr. Trott is a hydraulic projects engineer - Power Design Services, Inc., Lombard, Illinois

tions. Hydrological data, applicable when the plant was first built, may no longer prevail. Vast areas originally covered with vegetation may now be paved, or have been built up into residential, commercial, or industrial developments. The many roads now in existence may also have modified the drainage area. All these point to the necessity to check and verify all existing records and, if necessary, make new surveys. Therefore, updated hydrological data, including watershed, runoff, precipitation, and extreme events should be collected, as well as any other hydrologic data needed for evaluation of the proposed design. If these data are not available, information on the closest rain gauges and stream gauges should be used.

The hydraulics data to be obtained should contain all of the river information, including cross sections, backwater curves, sedimentation, icing, vegetation, flood plains, and any other available data. If these data are not available, the closest gauge and information point should be established.

As to the special problems of sedimentation, icing, detritus, and debris, the available data should be provided in terms of data on samples, classification into a suspended or bedload material, sieve analysis, plasticity index, and any other data generally related and identified in soil mechanics. Biological data (i.e., fish species) and requirements for preservation of the biological life should also be obtained. In this respect, the specific requirements of Federal and state EPA and other interested agencies should also be investigated.

Existing structural data should be obtained on spillway, powerhouses, fish ladders, bypass facilities, gates, and any structural component parts which influence the hydraulic behavior of the stream under operation, maintenance, emergency, and flooding conditions. These data which should be available in design or "as-built" drawings should be field inspected and verified. In addition, drawings on turbines, draft tubes, and existing mechanical and electrical equipment, as well as all associated instruments which could be utilized, should also be reviewed and inspected.

Special hydraulic conditions, if they exist, should also be defined. For example, sluicing locations may be dictated by hydraulic appurtenances inherent to certain industries located in the area. Navigation requirements, if applicable, must meet the Corps of Engineers' specifications. Other aspects of special significance in hydraulics should be considered.

Also from a hydraulic point of view, photographs of both the upstream and downstream reaches of the river should be obtained as far as is practicable. Of particular importance are the special features of flood plain, curvatures, deposition patterns, vegetation, forest locations, over-growth patterns close to the dam, erosion patterns, and materials (e.g., gravel deposits in part of the system, sedimentation, islands, etc.). Photographs of the downstream portion of the river should include special definition concerning possible control points. This is particularly important for determination of energy dissipation. If the spillway is operating, pictures of the operation, as well as erosional and historical pictures related to flooding, are of importance. Photographs of the spillway, turbine house, and gates should be taken from several viewpoints so that a good orientation can be established to permit later evaluation.

Phase II builds on the information gathered during Phase I and implements feasibility and economic evaluation. Specifically, a determination must be made as to the extent of repair necessary to the existing dam structure and equipment. An investigation to determine modifications required to achieve

maximum capability is then made. Finally, preliminary arrangement drawings and equipment lists are prepared to complete the feasibility and economic evaluation.

Based on the results of Phase II investigation, the decision may be made to either terminate the project or proceed with Phase III, which is the engineering and design activities. It should be noted that concurrent with Phase I and Phase II, the owner may, with assistance from environmental consultants, initiate applicable licensing and permit actions, as well as the environmental impact report. These activities will continue into Phase III. Also, during Phase III, the hydraulic model testing is performed to verify the design prior to the start of actual construction.

It is necessary to model test certain aspects of a hydroplant system where problem areas of the planned layouts have been indicated by analytical methods or by visual inspections. This holds especially true for existing conveying structures that are to be used again. Model testing can indicate problem areas that were not originally contemplated. Modeling costs are minimal, compared to the possible loss in generating capacity, and problems cannot be rectified without excessive costs and delays.

One very important aspect of this type of project is financing. To convince a client that one or more old inefficient hydroplants has the feasibility of being restored or upgraded is a formidable task. The client has to meet a strict budget and does not have the easily obtainable capital to invest in an old plant that does not appreciably increase its system capacity. However, the client is interested in those opportunities in which there are definite technical feasibility and economic advantages. The three-phase approach provides a means for minimizing financial commitments until the owner/utility is convinced that the project is technically and economically viable.

In conclusion, in today's tight energy climate, many of the existing old, low-head, inefficient hydroelectric generating plants can be restored and upgraded and made economically viable. Clients are generally receptive to discuss these low-head hydroplant restoration projects, and they can be convinced at least to undertake a study, if a planned approach which minimizes the risk and financial exposure is proposed.

SMALL-SCALE HYDROELECTRIC DEVELOPMENT AT EXISTING PUBLIC PROJECTS

Daneil E. Steiner and Albert R. Stritt

Formulation of economically viable and socially acceptable plans for development of small-scale hydro at existing public projects presents an opportunity for innovative design and operational concepts. During this process, the planning and design team must recognize that the ultimate client for hydroelectric development at public projects is the broad public interest. In general, our clients' requirements are complex and often vaguely defined. This paper presents the authors' point of view for defining and pursuing the public interest objective in terms of several key parameters.

These parameters are:

- Cost-effective design of hydroelectric appurtenances with particular emphasis on hydraulic conveyance facilities.
- Functional and operational constraints on hydroelectric additions to multiple purpose projects.
- An analysis of existing and projected regional electric supply and demand characteristics.
- A reordering of traditional economic objectives to emphasize conservation, and,
- Opportunities to match seasonal variations in reservoir operation requirements with variations in electric supply and demand characteristics.

The data base for the illustrations and quantitative evaluations presented in this paper include published information of the East Central Area Reliability Coordination Agreement (ECAR) and data evolving from preliminary studies of small scale hydroelectric additions to 20 multiple purpose reservoirs within both the Ohio River Basin and the ECAR area. These 20 multiple purpose reservoirs encompass a variety of drainage and head conditions, types of dams and appurtences, and project purposes.

Most multiple-purpose dams in the Ohio River Basin and many other areas of the country fall into two categories of dam types and hydraulic conveyances. These are:

- Concrete gravity dams with multiple sluiceways, and
- Earth and rock fill dams with tunnels or cut and cover conduits.

Typically, sluiceways at concrete gravity dams are located within spillway overflow sections. Tunnels and conduits are generally sized to pass 10-year flood flows and have upstream control structures. Within this general frame-

Mr. Steiner is responsible for the Hydroelectric Power Program, Flood Control Program and Multiple Purpose Planning Studies, and Mr. Stritt is Project Manager, Plan Formulation Branch, Ohio River Basin, U.S. Army Corps of Engineers, Ohio River Division, Cincinnati, Ohio.

work, retro-fitting hydroelectric facilities requires site investigations to achieve design concepts and cost estimates of reasonable dependability. Site-specific design concepts are particularly important at an early stage of small-hydro investigations because the costs of tailraces, conveyances, and extraordinary powerhouse site development can easily exceed the costs of powerhouses and switchyards. In this context, economic and financial feasibility may hinge upon identifying a safe and cost-effective conveyance system.

Existing outlet facilities are the most obvious and, potentially, the least expensive conveyance alternative. However, tunnels and cut and cover conduits with controls at the upstream end may not be designed for withstanding the full hydrostatic head created by the addition of a downstream powerhouse. Concrete lined tunnels may be most adaptable to hydro additions and cut and cover conduits may be suitable at projects with moderate heads. Where existing conduits cannot withstand anticipated increased stresses, installation of steel liners or other physical reinforcement should be considered. Where the hydraulic capacity of conduits substantially exceeds anticipated turbine releases, an upstream powerhouse which utilizes the existing conduit as the tailrace may prove to be cost-effective.

If existing outlet facilities cannot be modified to serve as hydraulic conveyance facilities, new facilities must be considered. A relatively high-cost alternative is to construct a tunnel through one of the dam's abutments. Another alternative is tunneling through the dam itself. Vertical drilling through a concrete section warrants consideration; however, excavating a tunnel through an existing earth or rockfill dam presents major safety problems and generally should not be considered. As an alternative to tunneling, use of a siphon conduit may be most cost-effective in some instances.

Based on preliminary evaluation of 20 projects, variations in estimated development costs can be related to design head and the type of hydraulic conveyance system used to develop power. With few exceptions, cost variations attributable to conveyance concepts were far more significant than variations associated with design head. A summary of preliminary findings follows.

- Downstream powerhouse development with existing facilities would include steel liners for existing conduits and a bifurcation system at the existing stilling basin. Total hydro-development costs for this concept ranged for $1,400 to $1,800 per kW.
- Construction of new outlet works would be accomplished by tunneling through an abutment as dictated by site layout and foundation conditions. Total development costs ranged from $1,400 to $2,200 per kW
- Using existing conduits as tailraces generally would involve excavation of a power chamber just downstream of the intake transition. The chamber would be constructed on one side of the tunnel to facilitate installation of the turbine and generator. Total development costs for this concept ranged from $650 to $1,000 per kW.

While a preliminary evaluation of 20 projects is not a conclusive data base, the information presented on the attached table clearly suggests that max-

imizing use of existing facilities can significantly reduce power development costs.

An additional requirement of the planning process is to define the functional and operational constraints on potential hydroelectric additions to existing public projects. As a general statement, vital project services such as flood control, water supply and base flow stabilization cannot be compromised to marginal performance levels. Also, public utilization and environmental values of project lands and water cannot be significantly disrupted or degraded on a long-term basis. This general statement provides framework criteria for identification of potential trade-offs at individual projects.

A careful evaluation of potentially acceptable trade-offs in existing project services provides a basis for a continuing formulation process. This formulative process must address the central issue which is - are potential trade-offs of existing services warranted by the resulting increased energy output? Answering this question requires determination of public benefits resulting from hydroelectric developments. In this regard, attention must be directed to defining key characteristics of regional electric requirements.

The East Central Area Reliability Coordination Agreement (ECAR), physically overlaps much of the Ohio River Basin, thus providing an appropriate basis for defining regional electric power characteristics. ECAR covers all or significant portions of eight states from Michigan to Virginia and Maryland to Indiana, and encompasses 19 major electric utility systems and 370 other electric utilities. ECAR's 1977 generation capacity and demand were 77 and 60 GW, respectively. Projected peak-demand approaches 100 GW by 1987.

Over 80 percent of ECAR's current generating capacity is from coal-fired facilities. Oil and gas-fired facilities comprise 11 percent of capacity with hydro and nuclear comprising 4 and 3 percent, respectively. Current oil consumption is about 30 million barrels annually. Projections based upon 1978 conditions indicate a 30 percent increase in annual oil consumption by 1987. ECAR exhibits distinct daily and annual load variations. Daily load variations are typical of national patterns. Annual load variations result in distinct summer (July-August) and winter (December-January) peak loads of about equal magnitude.

The preceding discussion of the impacts of adding hydroelectric to existing projects and the projected long-term regional utilization of oil for electric supply suggests the basis for more specifically defining regional public interest. In particular, these assessments suggest that hydroelectric additions to public projects should be formulated and operated to displace oil and gas-fired energy sources to the maximum practicable extent.

The objective of displacing oil-and-gas-fired electric energy sources results in a reordering of economic formulation criteria. Maximization of beneficial hydroelectric energy output must receive priority emphasis over traditional economic criteria for maximizing net return on investment. With this objective, conservation of critical resources rather than economic gain dominates the formulation process.

Matching hydroelectric development with the regional formulation objective of displacing oil and gas entails careful examination of potential regimes for operating hydroelectric facilities. Potential operational regimes can be categorized as run-of-river, peaking or intermediate. Run-of-river type opera-

tion, with limited pondage and plant factors in the range of 75 percent, has the least impact on existing project functions and operational regimes, but also is least effective in displacing oil and gas. Base load type run-of-river operations only warrant serious consideration where extreme year-round constraints on pool and flow fluctuations occur.

Conversely, operation of hydro facilities during periods of peak demand is most effective in displacing gas and oil, but also results in the greatest impact upon existing project services. Peaking operation with plant factors in the range of 25 percent requires substantial pondage and can result in significant daily fluctuation of lake levels and downstream flows. In the Ohio Basin, impacts of lake and stream-flow fluctuations are greatest during the late spring spawning and incubation period of native fishery and during the summer when public use of project waters is most intense. While tolerance to lake and stream flow fluctuations varies from project to project and measures to ameliorate adverse impacts are possible in some instances, introduction of a year-around peaking regime at an existing project has little likelihood of public acceptance.

The disadvantages of run-of-river and peaking type hydro regimes and seasonal variation in restraints on lake and stream-flow fluctuations suggest that an intermediate operational regime, which varies seasonally, warrants serious consideration. With seasonal variations, a peaking mode of operation would generally be acceptable from October to April when biological and public use constraints are least significant. Installed capacity would be based upon the peaking mode of operation. Capacity, which could not be regularly utilized during the late spring and summer, could be called upon for short term periods of extraordinary demand or unplanned outages. Under these conditions, all installed hydro capacity would be a component of regional capacity margins.

The implications of alternative operational regimes are illustrated in a preliminary manner on the attached exhibit. For 20 representative small hydro projects, installed capacity would average about 1.5 MW per project at a 75 percent plant factor and increase to about 12 MW per project at a 25 percent plant factor. Annual energy output would increase from an average of about 9 GWH per project to about 28 GWH per project. Total net increase in energy output would be about 370 GWH. At a 25 percent plant factor, gross energy output is still a small component of regional requirements, but impacts warrant consideration in terms of potential annual oil displacement of almost 1,000,000 barrels.

Since physical and environmental restraints would proclude year-around peaking operations, seasonal variation in hydro regimes would reduce savings of oil. Preliminary evaluations of 20 representative projects suggest that an annual oil displacement of 720,000 barrels would be the maximum attainable savings. This would result in an average savings of 36,000 barrels per project. Obviously, 36,000 barrels of oil is of no particular regional significance. However, the initial stages of the National Hydro Study has resulted in the identification of about 550 potential small-scale hydro projects within the Ohio River Basin. Development of one third of these projects could provide for an annual savings of 3,000,000 barrels of oil. These aggregate annual savings of oil are equivalent to a regionally significant 30 percent of projected increases in oil consumption by ECAR utilities over the next ten years.

TABLE B-2.1

PRELIMINARY DATA - SMALL-HYDRO POTENTIAL
REPRESENTATIVE MULTIPLE PURPOSE RESERVOIRS

SITE	BASE DATA		CONCEPTUAL DEVELOPMENT PLAN					ALTERNATIVE PLANT FACTORS			
								75 Percent		25 Percent	
I.D. NO.	Drainage Area (Sq.Mi.)	Range In Head (Ft.)	Capacity (MW)	Energy (GWH)	Plant Factor (%)	Design Concept (1)	Cost ($/kW)	(MW)	(GWH)	(MW)	(GWH)
OH27	237	141-104	4.0	12.1	35	A	1550	0.4	2.6	7.6	16.6
OH29	342	151-97	5.9	16.4	32	A	1400	0.5	3.3	11.8	25.8
IN17	379	150-83	5.4	14.3	30	B	1450	1.1	7.2	7.5	16.4
KY55	826	96-68	12.7	37.5	34	B	1400	1.6	10.5	27.5	60.2
IN05	553	96-45	4.9	13.9	32	B	1800	0.6	3.9	9.7	21,2
IN04	809	102-48	7.9	22.3	32	B	1800	1.2	7.9	15.2	33.3
IN02	295	85-36	2.4	6.7	32	A	1800	0.2	1.3	4.6	10.1
KY07	682	102-58	13.8	38.9	32	B	1700	1.4	9.2	25.0	54.7
KY12	454	70-30	3.8	11.3	34	A	1900	0.6	3.9	6.6	14.5
KY11	703	124-60	6.3	20.0	36	A	2150	1.2	7.9	11.6	25.4
KY27	408	68-37	3.7	10.9	34	A	1700	0.6	3.9	9.0	19.7
KY94	395	84	4.5	15.3	39	C	900	0.7	4.6	9.9	21.7
VA33	221	193-177	5.7	21.9	44	C	800	1.2	7.9	14.0	30.7
OH75	573	48-38	6.3	11.8	21	C	1000	0.7	4.6	5.1	11.2
OH69	742	31-28	1.6	7.3	52	A	1600	0.8	5.3	6.5	14.2
OH70	1,379	29	6.6	17.9	31	A	2050	0.6	3.9	8.2	17.9
WV49	540	148	14.8	56.7	44	C	650	4.7	30.9	18.9	72.8
PA09	434	110-31	15.0	45.0	34	A	1600	6.1	40.1	21.0	46.0
PA01	1,351	70-30	7.0	26.5	43	A	1900	3.4	22.3	13.2	29.0
PA11	589	25-19	3.0	10.0	38	A	1600	0.8	5.2	5.1	11.3

1 A - New tunnel and powerhouse. B - Existing tunnel/conduit with downstream powerhouse.
C - Power chamber at upstream end of existing tunnel/conduit.

To sum up, current national oil consumption for electric energy production is about 1.5 million barrels a day. New hydro development and modification of existing hydro regimes could be a major factor in reducing this consumption. Reduced oil consumption should be the primary objective for hydro development at public projects. This objective should be pursued at all projects regardless of size. In pursuing this objective for small-scale hydro, careful consideration should be given to:

- Effective use of existing appurtenances to minimize hydro development costs.
- Defining the limits of potential trade-offs of existing project services, and
- Seasonal variations in hydro operation regimes to maximize savings of oil within physical and environmental restraints.

POLICY FOR APPLYING SMALL HYDRO TO A UTILITY SYSTEM

Arthur E. Allen

Hydroelectric plants that will be built under the current impetus for such plants may in some instances be built for individual loads, but usually they will either be part of the electric utility system of their area, or their energy production will affect demand on the electric utility system. For the national economic welfare, it is essential that the utmost benefit be obtained from all energy that is produced. Therefore, hydroplants, large or small, should be analyzed relative to the electric utility system in their area. This paper briefly discusses general principles and an example.

General Background

The power system of the United States consists basically of approximately 500,000 MW of thermal generation and 72,000 MW of hydroelectric generation, including pumped-storage. The Pacific Northwest contains about 30% of the hydro and still is basically a hydro system. Elsewhere, the predominant generation is thermal and the Pacific Northwest will gradually become so in the future.

Load factors in the United States are relatively high. The national annual average load factor is 61%. Regionally, annual load factors range between 54% and 67%. For shorter periods, load factors are higher. Monthly load factors in the region having 67% annual load factor range from 69% to 79%. In one region having 55% annual load factor, monthly load factors range from 64% to 77%. The pattern of high monthly load factors prevails throughout the nation.

Weekly load factors are higher than monthly, usually by about 4% or 5%. Daily load factors are about 3% higher than weekly. The calendar week, Monday through Sunday, is the basic planning period for utility operation. Customer load is lighter on Sundays than on other days and Saturday load usually is intermediate between Sunday and the other days. Load pattern usually is similar during the other five days, with one day usually having the highest load.

Load varies from hour-to-hour each day. In most of the country the daily peak-load period is 13 to 15 hours, from about 7 a.m. to 8 p.m., 9 p.m., or 10 p.m. During other hours load is much less, with loads from 1 a.m. to 5 a.m. often being as little as 40% or 50% of the peak load for the same week. The annual minimum load often is 1/3 or less of the annual peak load.

Since the hydroelectric resources of the nation are insufficient to supply the nation's electric load, thermal plants are utilized. Thermal plants come in large variety. Fuels used are coal, oil, natural gas, nuclear, and in a few specialized situations, wood waste and refuse. The fuels generate either steam

Mr. Allen is Vice President and Principal Power Development Engineer, Harza Engineering Company, Chicago, Illinois.

or a heated air-gas mixture. In general, thermal units can be characterized as follows:

(1) High-temperature, high-pressure, high-efficiency, steam fuelled by coal or oil. Heat rates in range 8,500 Btu to 10,000 Btu per kWh.
(2) Moderate temperature, pressure, and efficiency steam fuelled by nuclear, coal, or oil. Heat rates, 10,000 Btu to 14,000 or 15,000 Btu per kWh.
(3) Combined cycle, utilizing steam and heated air, at high efficiency, burning oil or oil and natural gas. Heat rates, 9,000 Btu to 12,000 Btu per kWh.
(4) Combustion turbines, utilizing heated air, fuelled by oil or gas. Heat rates 10,000 to 16,000 Btu per kWh.
(5) Diesels, fuelled by oil or gas, heat rates 10,000 Btu per kWh.

The highest efficiency is obtained in high-temperature, high-pressure steam units. It is natural that they be used continuously for economy. Such units are unsuitable for rapidly-changing load and for loads less than 50% of unit rating, with coal-fired units being less suitable than oil-fired units. Nuclear units are less efficient but have low-fuel cost per kWh; it likewise is natural to keep nuclear plants in operation continuously for economy.

The variation in loads hour-to-hour and seasonally, related to characteristics of thermal units, gives utilities a problem in obtaining the most desirable mix of generation. The ideal situation is highly efficient thermal units operating continuously with hydroelectric units, which can start quickly, shut down readily, and readily accommodate varying loads, taking all loads above the base. In most of the United States, there are not sufficient hydroelectric resources available. The result, in most of the United States, is a mix of high-temperature, high-pressure steam units for base; lower-temperature, low pressure steam units for intermediate loads; and combustion turbines for the peak loads. The division between the three classes depends upon the relative magnitudes of hourly-load variations during seasons and during individual weeks.

Each week and season provides its own problems in scheduling preplanned maintenance outages, which usually require several weeks, and in scheduling short-term outages, which may require hours or days. There are three basic load seasons, winter, summer, and spring-autumn. Spring-autumn period is not long enough to accommodate all units and outages are scheduled all year. Short-term outages are usually emergency in nature and are handled between Friday night and Monday morning as much as possible.

General Application of Hydro

With the foregoing background, it is obvious that hydro-plants should provide the following functions:

(1) Replace less-efficient thermal generation whenever possible.
(2) Replace oil-fired or gas-fired generation whenever possible.
(3) Provide as much capacity as possible at time of peak loads.

(4) Replace thermal units during outages, whether long-term or short-term outages.
(5) Provide energy each week in amounts that can be predicted and used by the system load dispatcher to maximum advantage.

There are constraints on providing the foregoing five functions. The type and magnitude of constraints depend upon a large number of factors, among which are the following:

(1) The amount of storage available for seasonal flow regulation, and prior commitments for use of the storage.
(2) The amount of storage available for daily or weekly flow regulation, and prior commitments for use of the storage.
(3) The extent to which turbine discharge can be varied hourly or daily.
(4) The existence and characteristics of older hydroelectric plants, which, as a matter of economics, have first priority in providing the normal hydroelectric functions.

Among the prior commitments for storage use can be flood control, seasonal low-flow augmentation, and recreation. Flood control operation can shorten the time in which large inflows can be retained for gradual release, which limits hydro energy production and predictability. Seasonal low-flow augmentation can aid hydro in providing energy during periods that otherwise would be low in energy production. Flow augmentation may be required in the autumn and, even though system loads may be low, a dependable minimum energy production from hydro can facilitate scheduling outages of thermal units.

Hourly fluctuation of turbine discharge affects recreation on reservoirs, along reservoir shores, and in the river downstream from the reservoir. The amount of acceptable daily water level fluctuation has to be investigated. Fluctuation may affect boat docks or have aesthetic effects along shorelines. If shorelines are in flat topography, daily fluctuations may affect wildlife adversely. There may be limits to rate of increasing turbine discharge to minimize hazard to boaters, fishermen, and commercial activities along the river. Discharge and water level rates under hydro operation would be compared to natural conditions and other operation, however, so that hydro is not restricted unnecessarily.

Example of a Power System and Hydroelectric Plant

Application of the foregoing principles can be illustrated by a hydroelectric plant currently under study at Summersville Dam, Corps of Engineers. The hydroplant presently is proposed to be connected to customers through Allegheny Power System. At time of writing, studies are continuing and all data are tentative. However, the course of analysis of the plant can be presented.

Allegheny Power System had the load characteristics shown in Table B-3.1 in two recent years. Note that peak loads occur in winter, with there being a secondary peak in summer. Load is less in autumn than in summer, and is less

TABLE B-3.1
Load Characteristics

Month	1977 Peak Load MW	1977 Mean Load MW	1977 Load Factor	1978 Peak Load MW	1978 Mean Load MW	1978 Load Factor
January	5,031	4,019	0.799	5,174	4,020	0.777
February	4,634	3,714	0.802	4,937	3,857	0.781
March	4,434	3,472	0.783	4,182	3,245	0.776
April	4,301	3,271	0.760	4,056	3,228	0.796
May	4,119	3,232	0.785	4,103	3,267	0.796
June	4,139	3,515	0.849	4,362	3,347	0.767
July	4,524	3,317	0.733	4,575	3,324	0.726
August	4,539	3,349	0.738	4,632	3,587	0.774
September	4,478	3,246	0.725	4,544	3,442	0.757
October	4,296	3,313	0.771	4,436	3,500	0.789
November	4,549	3,524	0.750	4,631	3,638	0.785
December	4,883	3,778	0.774	4,921	3,872	0.787

TABLE B-3.2
Generation Owned In 1978

Plant	Type	Fuel	Capability - MW Summer	Capability - MW Winter	Average BTU per kW	Service
A	Steam	Coal	831	831	9,259	Base
B	Steam	Coal	1,920	1,920	9,648	Base
C	Steam	Coal	1,500	1,660	9,980	Base
D	Steam	Coal	282	291	10,267	Base
E	Steam	Coal	349	360	10,326	Base
F	Steam	Coal	238	246	11,128	Int.
G	Steam	Coal	283	292	11,303	Int.
H	Steam	Coal	127	129	11,455	Int.
I	Steam	Oil #6	219	223	12,290	Peak
J	Steam	Oil #2	38	39	12,769	Peak
K	Steam	Oil #2	44	46	13,184	Peak
L	Steam	Oil #6	169	178	13,280	Peak
M	Steam	Coal	137	142	13,308	Peak
N	Hydro		52	52		Peak
O	Hydro		7	10		Base

TABLE B-3.3
Summer Day/System Hourly Loads and Generation

Hour Ending	System Load-MW	Coal Gen.-MW	Existing Hydro MW	Oil-Fired Generation - MW With No New Hydro	With New Hydro Peaking	With New Hydro - No Peaking
1 AM	3,068	3,066	2	0	*	* *
2	3,022	3,020	2	0	*	* *
3	2,931	2,929	2	0	*	* *
4	2,880	2,878	2	0	*	* *
5	2,850	2,848	2	0	*	* *
6	2,934	2,932	2	0	*	* *
7	3,078	3,076	2	0	*	* *
8	3,348	3,346	2	0	*	* *
9	3,606	3,604	2	0	*	* *
10	3,875	3,821	2	52	50	33
11 AM	4,089	3,821	2	266	264	247
12 Noon	4,120	3,821	2	297	275	278
1 PM	4,135	3,821	2	312	275	293
2	4,246	3,821	59	366	275	347
3	4,231	3,821	59	351	275	332
4	4,231	3,821	59	351	275	332
5	4,212	3,821	59	332	275	313
6	4,211	3,821	59	331	275	312
7	4,071	3,821	2	248	246	229
8	3,967	3,821	2	144	142	125
9	3,964	3,821	2	141	139	122
10	4,030	3,821	2	207	205	188
11 PM	3,780	3,778	2	0	*	* *
12 NIGHT	3,366	3,364	2	0	*	* *
				3,398	2,971	3,151
	Reduction in oil use - MWh				427	247

* Coal-fired generation reduced by 2 MW for 11 hours, or 22 MWH total reduction.

* * Coal-fired gerneration reduced by 19 MW for 4 hours, plus 18 MW for 7 hours, total reduction 202 MWh.

in spring than in any other season. Spring and autumn are the obvious times for scheduled long outages, although summer outages are possible.

Generation owned in 1978 by Allegheny is shown in Table B-3.2. The five plants with lowest heat rates are the obvious base-load plants. The next three coal-fired plants are for intermediate operation. The four oil-fired units and one coal unit are listed as peaking. However, the oil has flexibility to be used for either intermediate or peaking. The large hydroplant is listed as peaking, the small hydro is run-of-river and usually will produce base energy, although in dry seasons generation is very small.

System load factors are high. Hourly loads for one weekday in a summer month, picked at random for illustration, and several corresponding patterns of generation to meet the loads are shown. The patterns are to illustrate principles and do not necessarily represent the final results of the study.

In Table B-3.3 the first column assumes several coal-fired units out of service for maintenance, with operating units providing ready reserve for loads larger than expected. The existing hydro is divided into base and peaking considering the most favorable use of energy for peaking. Oil-fired generation is used during a 13-hour peak period from 9 a.m. to 10 p.m.

Oil-fired generation is shown in three columns. The first column shows oil generation totalling 3,397 MWh on the day in question, with maximum generation of 366 MW. The second and third columns show how a new hydroelectric plant could reduce the oil-fired generation.

The hydroplant will have installed capacity of approximately 100 MW. One unit is planned to release the minimum flow of 100 cfs around the clock, generating 2 MW. The remainder of the plant will have three units, each approximately 33 MW. Minimum load for each 33 MW unit is about 16MW; at lower load, operation is expected to be impracticably rough. Thus, the plant can generate at 2 MW or at any load from 18 MW to 101 MW. In August, the month being studied, average daily hydro generation could be about 449 MWh based on head and on utilizing water made available after considering the prior needs of flood control, low-flow augmentation, and recreation.

The second column under oil-fired generation shows the oil use and reduction in oil use if the hydroplant could be used for peaking strictly for power needs. Under such operation, 427 MWh could be used to reduce oil-fired generation and 22 MWH unavoidably would replace coal off-peak. With such operation, the reservoir level would rise and fall over a range of approximately one foot during the day.

The third column under oil-fired generation shows the other extreme, assuming that turbine discharge throughout the day would have to be uniform. In such instance, only 247 MWh of the total hydro generation could be used to save oil; the remaining 202 MWh would displace coal. The reservoir level would not fluctuate during the day. Actual operation will be between the two extremes. Studies are currently underway of the amount of discharge changes and the rate of discharge changes that will fit with the various uses.

Conclusion

Hydroplants, whether large or small, can produce valuable generating capacity and energy, which should be maximized while protecting environmental features of the reservoir and stream.

HYDROPOWER DEVELOPMENT AT WATER SUPPLY DAMS

Lewis E. Linzell

The purpose of this paper is to discuss developing hydropower at dams used primarily for municipal water supply. About one-fourth of the dams in Ohio are such dams. The Corps of Engineers lists 45 candidate hydropower sites in Ohio; five of which are water supply dams.

The factors which affect adaptability of hydropower to municipal water supply dams will be discussed in general and with regard to three dams owned by the City of Columbus, Ohio. Two of these dams are on the Scioto River and have a watershed of about 1,000 square miles. Located northwest of Columbus is O'Shaughnessy Dam which has a gross head of 67 feet (20M). The hydropower feasibility study for this dam determined that a turbine of 5 megawatt (MW) capacity at a design discharge of 1,150 cubic feet per second (cfs) (33M3/s) was appropriate. Nine miles downstream, Griggs Dam has a gross head of 34 feet (10M). A 2 MW turbine with a design discharge of 1,000 cfs (28 m3/s) is proposed for this dam. These two dams supply water to the Dublin Road Water Plant 4.5 miles downstream from Griggs Dam. The third water supply dam is Hoover Dam located northeast of Columbus on Big Walnut Creek, a tributary of the Scioto River. It is about 3 1/2 miles upstream from the Morse Road Water Plant. This dam has a watershed of 190 square miles, a gross head of 65 feet (20M) and a hydroelectric potential of about 1/2 MW.

Generally all dams built primarily for water supply are or will be used to their full water supply reliable yield. Consequently, during dry periods, the maximum possible amount of inflow is stored in the reservoir and the total outflow which is drawn from storage is the raw water supply plus the minimum flow required downstream for environmental reasons or for riparian rights. The City of Columbus passes no water by the low head dam at the Dublin Water Plant when the water from the upstream dams is being drawn from storage. The minimum release from the low head dam at the Morse Road Water Plant is 1/2 cfs. When water is being drawn from storage, the City of Columbus would not permit more than these amounts of water to pass the low head dams for the purpose of increasing the power produced at the hydroplants. Similar restrictions on releases will exist at most water supply dams and will be assumed below.

The means by which the raw water supply is conveyed from the dam to the water plant has significant bearing on the feasibility of hydropower development at water supply dams. Raw water may be conveyed by releasing the water from the dam into the streambed where it flows by gravity to an intake pool (usually formed by a low-head dam) near the water plant. The raw water is then pumped into the water plant. Raw water may also be conveyed to the water plant through a pipeline extending from the dam to the water plant.

Mr. Linzell is a project engineer in the Bridge and Structural Section, Burgess and Niple Limited, Columbus, Ohio.

Griggs and O'Shaughnessy Dams use the streambed to convey the water to the water plant.

A system of three dams on the Cuyahoga River and its tributaries provide water supply for the City of Akron, Ohio. This system used both means of conveying the water to the water plant. The two upstream dams discharge the raw water supply into the streambed. The raw water supply flows into the downstream reservoir from which it is conveyed to the water plant by a pipeline.

Figure B-4.1 illustrates two extremes in outflow-duration curves that might exist at equal-height dams with identical inflow-duration curves. The curve on the left is for a dam providing little storage relative to the streamflow. This dam affects the outflow-duration curve significantly only during periods of extreme low flow where water is drawn for storage to meet the raw water demands. The curve on the right is for a dam of large storage relative to the streamflow which highly regulates the outflow.

The raw water flow-duration curves for these dams are also shown in Figure B-4.1 assuming the full water supply potential is used. The reliable yields for each dam is shown as well. The reliable yield for the dam with large storage is greater and the raw water flow-duration curve is higher than for the dam with small storage. The annual energy potential at these two hypothetical dams would be the same if the raw water is conveyed to the water plant down the streambed, but greater dependable power could be produced at the dam with the greater storage.

Now consider the annual energy potential at these dams assuming the raw water supply is conveyed by a pipeline to the water plant. If a power plant were to use only the flow discharged into the stream below the dam (flow in excess of the raw water needs), the dam with small storage would have the greater hydroelectric potential.

It may be possible to place a hydroplant at the water plant using the raw water pipeline as a penstock. The gross head would be the difference in elevation between the pool above the dam and the hydraulic gradient at the water plant. If the hydropower development was not considered in the design of the raw water pipeline, it is likely that the maximum discharge would be limited to about the maximum anticipated raw water demand due to function losses in the system. In such a case, the dam with the large storage has the greater hydropower potential. The water supply outlet works at Griggs and O'Shaughnessy Dams were not designed for hydraulic efficiency. At the proposed maximum turbine discharge, the head loss through water supply outlet work is 34 feet (10M) at O'Shaughnessy Dam and 50 feet (15M) at Griggs Dam. If a penstock/raw water line and inlet structure were designed considering hydropower development, it would be possible to pass much more than the raw water supply through the penstock/raw water line for greater power production by dumping the flow in excess of raw water needs back into the river at the hydroplant.

Presently, at Hoover Dam, raw water is conveyed down the streambed to the water plant, but the City is considering installing a raw water pipeline from the dam to the water plant in order to eliminate pumping costs, and to reduce treatment costs caused by the loss of water quality resulting from the water flows in the streambed between the dam and the water plant. The outflow flow-duration curve for Hoover Dam is highly regulated, suggesting use

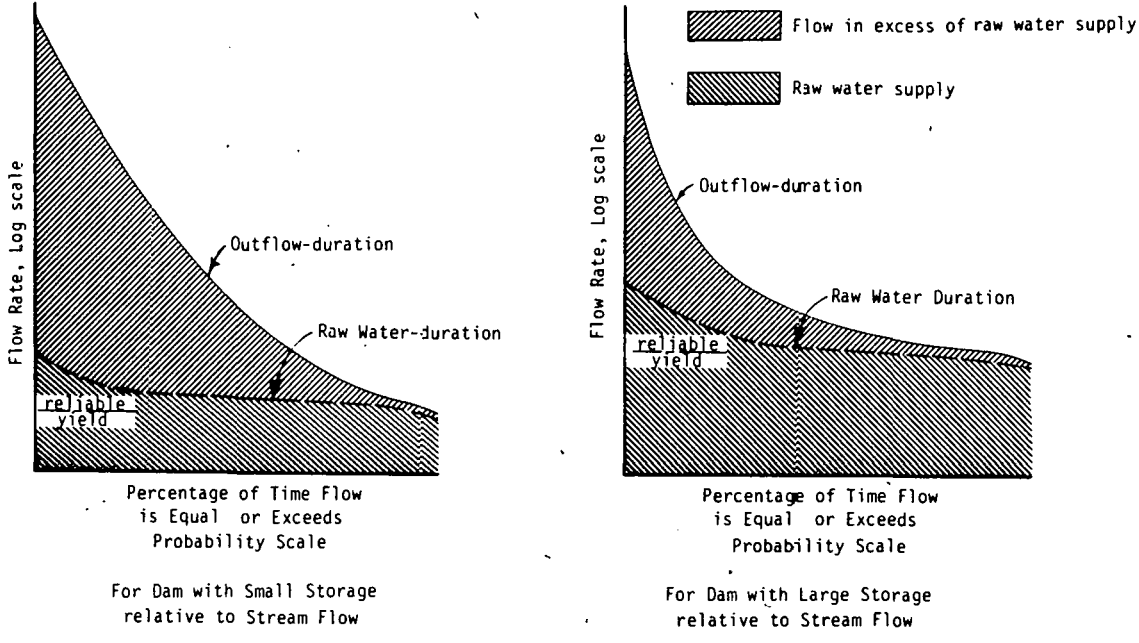


FIGURE B-4.1 Schematic Flow-Duration Curves

of the raw water supply for hydropower. A feasibility study for this dam would consider the economic return of hydropower development at the site with and without the raw water pipeline. The economic study would include such factors as the penstock/raw water-line costs, raw-water pumping costs, and changes in water-treatment costs.

Peaking herein will refer to a daily variation of the water release through the turbine resulting in a variation in the power produced. Permitting such peaking is economically beneficial to hydropower feasibility by increasing the annual energy produced and by reducing the owner's demand charge. The annual energy production can be increased by releasing, during dry periods, the daily raw water demand in a few hours at a rate equal to, or greater than, the turbines minimum required discharge. This permits using a turbine of greater capacity while still utilizing the low flow for power production. Peaking increased the estimated potential typical year energy production at O'Shaughnessy from 12.1 million kilowatt hours (kWh) to 14.4 million kWh, and at Griggs Dam from 5.6 million kWh to 6.4 million kWh.

Assuming that the owner of the hydropower facility uses the power produced to reduce the amount of purchased power, the demand charge can be reduced by coordinating powerplant operations with power use. The proposed hydropower development at Griggs and O'Shaughnessy Dams could reduce the City of Columbus - Division of Electricity demand during dry periods by about 3 MW and during wet periods by 7MW as shown on Figure B-4.2.

The possible sources of peaking at water supply dams are as follows:

1. Flow in excess of raw water demand.
2. Variations in finished water demand.
3. Clear well capacity at water plant.
4. Storage in stream.
5. Storage in intermediate reservoir.
6. Storage in water plant intake pool.

Flow in excess of raw water demands could be used for peaking in wetter periods, but in the dry period typically little water other than raw water demands would be released from the reservoir. From the standpoint of finished water quality, it is desirable to supply raw water to a water plant at nearly a constant rate. Daily variations in finished water demands are met by fluctuating the volume of finished water stored in the clear well. For dams connected to the water plant by a pipeline, peaking is possible while water is being drawn from storage only if daily variations in raw-water flow rates are permitted. This variation is limited by daily variations in finished water demands and clear well capacity. When more water than the raw-water requirements are available for power generation, peaking is possible by bypassing the flow in excess of the raw-water needs by the water plant.

Some peaking may be possible for dams located a substantial distance from the water plant which uses the streambed to convey the raw water to the water plant. The riffles and pools in the stream will dampen fluctuations in the rate that the water arrives at the water plant caused by the daily variations in discharge associated with peaking.

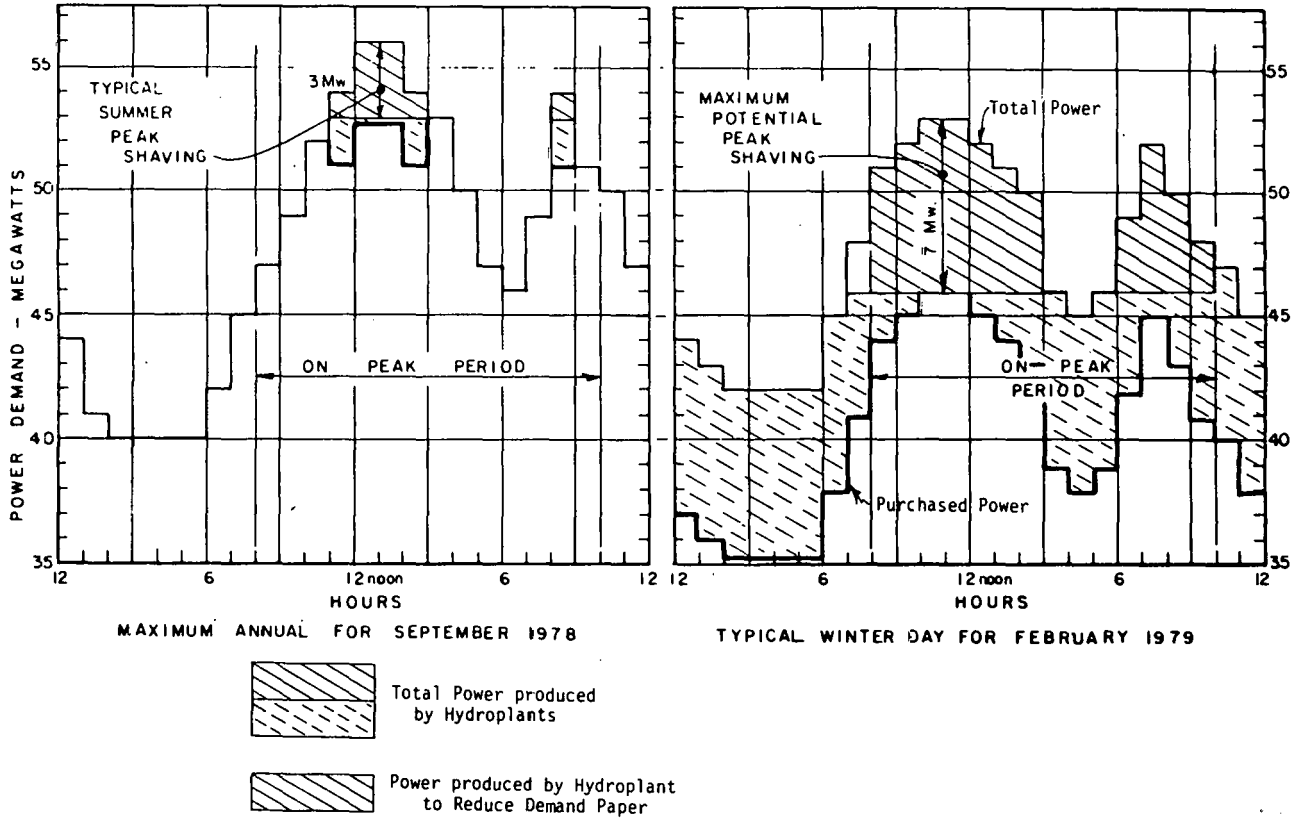


FIGURE B-4.2 Power Demands by Columbus Division of Electricity

An intermediate reservoir between the water plant and the dam being considered for hydropower development could permit full utilization of available flow for peaking. An intake pool at the water plant would permit some peaking, but these pools may have little usable storage. The intake pool at the Dublin Road Water Plant downstream from Griggs Dam has a storage capacity of about twice the daily water demand, permitting full utilization of the peaking potential at Griggs Dam. Downstream from Hoover Dam, the intake pool at the Morse Road Water Plant stores only about one-third of the daily water demand which may limit peaking.

The economic feasibility of hydropower development is enhanced if the owner of the hydropower facility uses the power produced because the worth of the power can be compared with a retail electric rate, and because an owner-user could better coordinate power production with power use to reduce the demand charge. Most water supply dams are municipally owned and most municipal governments use more energy than could be produced at their water supply dams. The City of Columbus could use all the power that could be produced at their three dams; they use over 300 million kWh per year. The Dublin Road Water Plant uses about 14 million kWh per year and the Morse Road Water Plant uses about 28 million kWh per year whereas the hydropower potential at Griggs and O'Shaughnessy Dams could produce about 21 million kWh in a typical year and Hoover Dam could produce about 5 million kWh.

Economic feasibility of city-owned water-supply dams is favorably affected by the low-interest rates that cities enjoy due to their tax free bonds. The City of Columbus has a six percent interest rate for general obligation bonds and seven to eight percent for revenue bonds. This is particularly an advantage at a time when the prime interest rate is about 13 percent.

Session Three

ENGINEERING

Topic: Generation Systems

Chairman: Mr. William E. Rumberger
Manager, Electric Systems Programs
Niagara Mohawk Power Corporation
300 Erie Boulevard West
Syracuse, New York 13202

ENERGY LOSSES AT HYDROELECTRIC POWERPLANTS

C.C. Purdy

Introduction

Increases in energy costs have spurred the need to develop more renewable sources for the production of electrical power. Approximately half of the oil consumed in the United States is imported. Such dependence on imported oil makes the nation vulnerable to an embargo or threats of an embargo. The increasing prices add to inflation, increase utility bills, hinder new investments by utilities and add to the balance of payments. If oil is replaced by coal or nuclear fuel, difficult and expensive solutions are required to overcome the environmental problems caused by the products of combustion, the escape of radioactive material, and the pile up of spent nuclear fuel. It had been anticipated that by the year 2000, nuclear power would provide a major portion of our electrical needs. However, because of what occurred at Three Mile Island and elsewhere, the nuclear timetable has been delayed and the future is unclear.

The objectives of the 1977 National Energy Plan are to reduce our dependence on imported oil and to provide renewable sources of energy for continued economic growth. Energy from solar and wind are being developed. However, other more immediate measures are required to assure a more stable supply. Hydroelectric power is one promising immediate measure.

At the turn of the century, hydraulic turbines provided a considerable portion of industrial power. Despite its early promise, the growth of hydroelectric was overshadowed by thermal plants. As fuels became more abundant investments declined in hydropower for new site development and existing site rehabilitation. Between 1930 and 1970 the contribution of hydroelectric to the total U.S. electric energy requirements decreased from 33 to 14%.

For hydro to continue to produce a viable share of the nation's electric demand, new hydroelectric facilities must be built and the existing facilities used more effectively. According to the Corps of Engineers report of July 1977 hydroelectric plants provided 288 billion kWh and the remaining potential is 159 billion kWh.

Hydroelectric facilities have long lives so increases in efficiency and reduction of losses which result in increased output can be relied upon indefinitely as replacements for nonrenewable energy sources. An in-depth analysis of existing hydroelectric facilities and the criteria for design and operation of future facilities should be made to identify and assess the areas where generation can be increased and costs reduced.

Mr. Purdy is Head, Hydraulic Machinery - Tippetts-Abbett-McCarthy-Stratton, New York, New York.

Efficiency and Losses

The overall efficiency of a hydroelectric plant is the ratio between the delivered energy and the available energy. The available energy is related to the area under the flow-duration curve and the gross head. The delivered energy is equal to the available energy minus the sum of the various equipment and hydraulic losses. The costs of operation, maintenance, outage and replacement are in addition to the cost of the losses.

An analysis of the methods for increasing efficiency and reducing costs of hydroelectric power is an important contribution to the generation of electric power. Each loss should be assessed as to magnitude and potential for reduction. Figure C-1.1 shows the losses sustained and the magnitude of these losses in a typical plant in the categories of flow, hydraulic head, turbine and electrical losses.

Identification of Losses

Loss of energy due to waiting:

- decision to proceed - this is the biggest loss of all. Equal to 318,000,-000 barrels of oil annually
- licensing time

Head loss

- due to drawdown
- between plants
- intake velocity
- conduit size
- inlet valve
- exit velocity
- tailwater elevation

Flow loss

- portion of flow duration curve-evaporation

Turbine loss

- runner
- remainder
- on peak operation
- off peak operation
- off head operation
- in favor of whole system
- the most efficient specific speed
- measurement error
- governing system
- bearing friction
- exit loss in relation draft tube
- exit area and runner specific speed

Auxiliaries' losses

Electrical losses

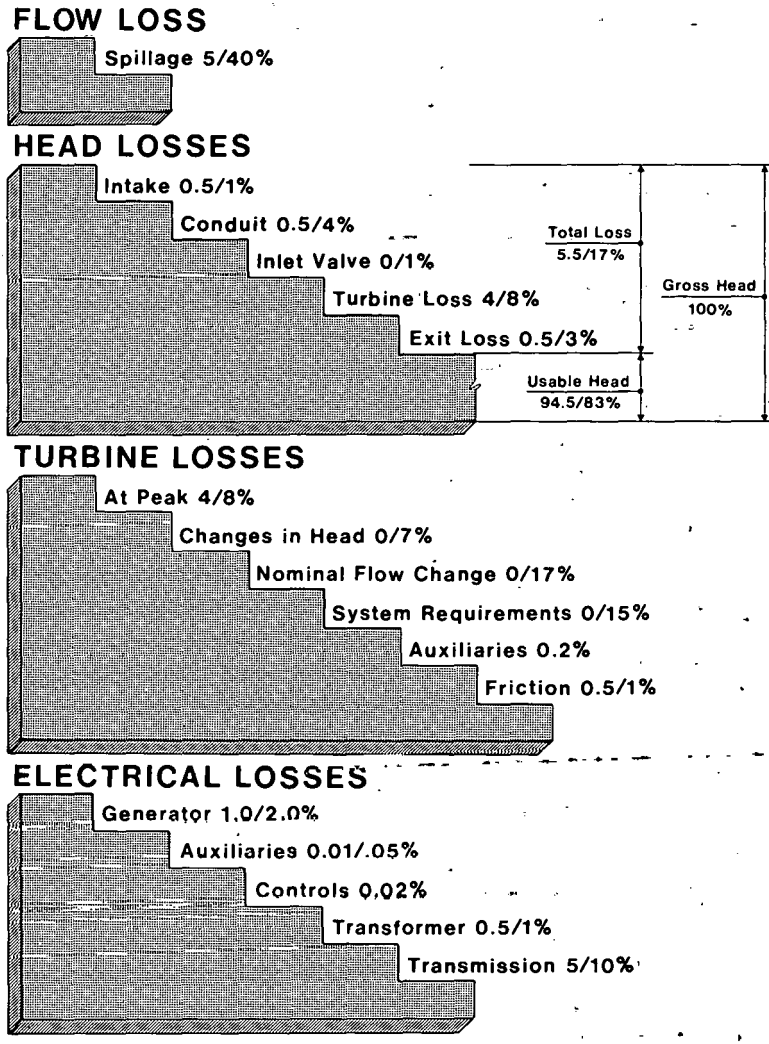


FIGURE C-1.1- Typical Generation Losses

The methodology of reviewing losses is first to identify each loss, determine the magniude of each, determine the magnitude of possible reduction of each loss, arrange and implement the reductions in order of magnitude, and later follow through to confirm the magnitude of the improvement. In industrial plants this is called energy management.

The value of money is changing so rapidly that losses and increased efficiency should be measured in equivalent fuel value. A barrel of fuel oil will generate about 500 to 600 kWh. The hydroelectric generation of 288 billion kWh is equivalent to 576 million barrels of oil annually. Each one percent improvement in generation or efficiency is equal to about six million barrels of oil annually. A few examples have been selected to show where hydroelectric generation can be increased or losses reduced to improve generation of efficiency:

Diversion — Water diversion or an increase in upstream storage such as occurred on the Columbia River is an example of what can be done to increase power generation.

Unequal size turbines — The best use of water occurs when the turbine is operated at peak efficiency. A plant with one turbine has one peak efficiency point. A multi-unit plant with equal size units has as many peak efficiency points as there are units. For small-hydro plants where the turbine size is within the range of predesigned turbines it may be feasible to use unequal size turbines. Figures C-1.2, C-1.3 and C-1.5 illustrate the advantage of unequal size turbines. A plant with two unequal size turbines has three peak efficiency points, a plant with three unequal size units has seven peak efficiency points. The ideal sizing is approximately 70-30 and 57-28-15, respectively. An important advantage of using unequal size turbines is the much improved operation during the low flow season. A large portion of the flow duration curve is utilized and the plant can be operated nearly at run-of-river with very little drawdown and high average head.

Draft tube exit loss — The function of the draft tube is to reduce the velocity of the discharge from the runner. The reduction in discharge velocity means less energy loss than if the turbine runner discharged directly to tailwater. If there were no draft tube and the water left the turbine runner at 35 ft/s (10.65 m/s) the energy remaining in the water would correspond to about 19 ft (5.8 m) of head. On the other hand, if there were a draft tube with exit area four times the inlet area then the water would leave the draft tube exit at about 8.75 ft/s (2.67 m/s). In this case the energy remaining in the water would correspond to 1.9 ft (.36 m) of head, a saving of 17.81 ft (5.44 m). All this is not new, but it bears repeating to establish the magnitude of the energy which the draft tube conserves or regains. More energy could be conserved if the draft tube exit velocity were reduced to 5.5 or 6 ft/s (1.68 or 1.83 m/s) as was normal when elbow draft tubes were first used.

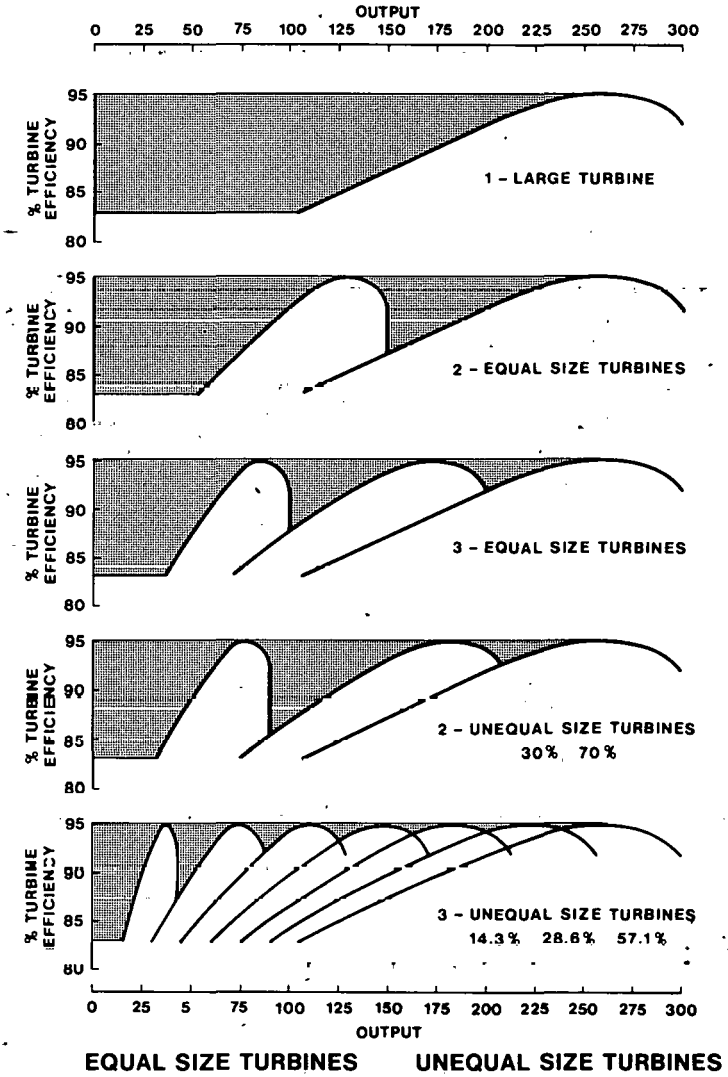


FIGURE C-1.2 Comparison of Efficiency

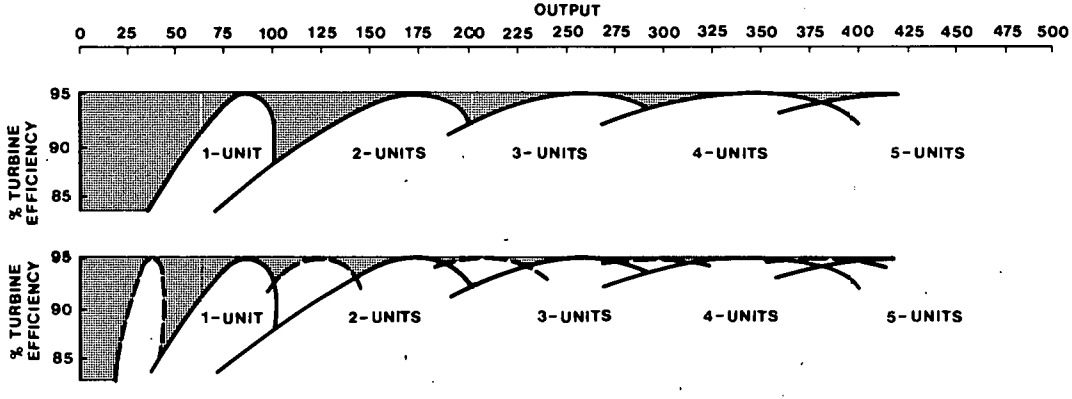


FIGURE C-1.3 Improvement in Efficiency due to Addition of Unequal Size Turbine

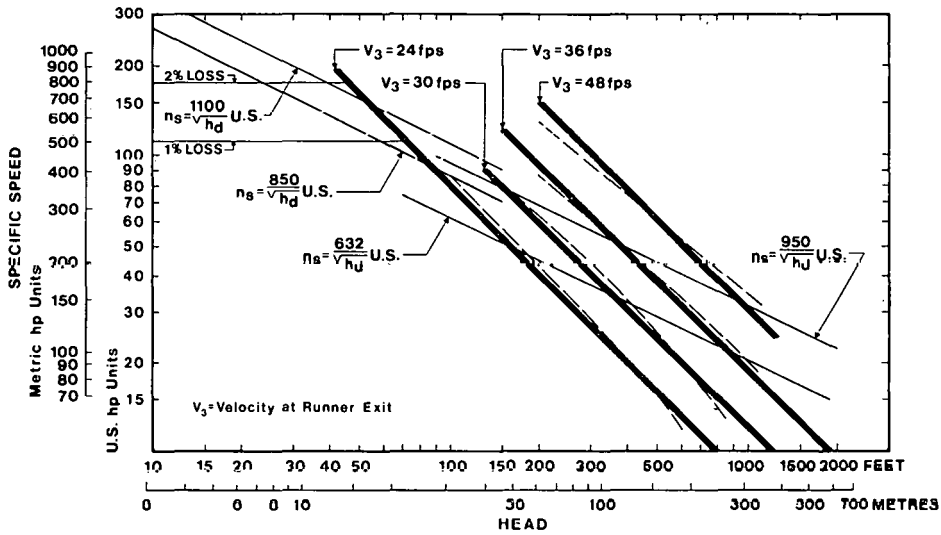


FIGURE C-1.4 Specific Speed Versus Velocity at Runner Exit

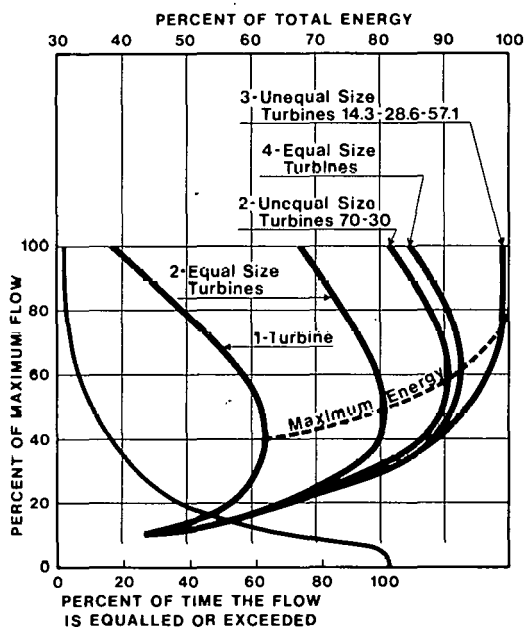


FIGURE C-1.5 The Case for Unequal Size Turbines

In order to reduce the size of turbines and powerhouses, specific speeds have been increased at all heads. An increase in specific speed means a higher rate of revolution, smaller turbine, and higher velocity at the runner discharge. Higher specific speeds are attractive because powerhouse costs are reduced. In Figure C-1.4 specific speed versus velocity at runner exit is shown by the four heavy lines of constant velocity. Lighter lines show the customary relation between specific speed and head.

Performance test codes give credit to the turbine for any increase of output made possible by the head regain in the draft tube but do not deduct from the turbine the output which is lost by draft tube exit velocity. This encourages the use of small-size, high-power runners and the only restraints are the setting relative to tailwater and cavitation. The incentive to use small-size, high-power runners comes from owners and consultants who specify higher speeds to reduce construction costs. The trend to increase specific speed and draft tube exit loss began when fuel oil was relatively inexpensive.

Expressing draft tube exit loss as a percentage of the available energy is deceptive, especially in the case of large plants. A draft tube exit loss of, say one percent, sounds small, even insignificant. But one percent of 4000 MW is 40 of the 1000 kW low-head hydroplants of the type now under scrutiny in the United States. A draft tube exit velocity of 12 feet per second from a 4000 MW plant will waste 474,000 barrels of oil annually.

Bulb turbines are often considered advantageous because of smaller unit spacing made possible by smaller draft tube exit areas. To conserve energy the draft tube exit velocity for a bulb turbine should be the same as for any other turbine of identical rating. An arbitrary draft tube exit velocity of 6 to 8 ft/s (2.44 to 1.83 m/s) may be too large for low-head turbines; for these, the exit losses should be a percentage of head loss. An exit velocity no greater than 0.8 head for heads up to 56 ft (17 m), is appropriate for low-head turbines.

Unfortunately, not much can be done to decrease the draft tube energy loss at existing plants because concrete and steel are "forever." Draft tubes in plants with only one or two units may perhaps be modified. The decision on the magnitude of the draft tube exit velocity should not be made lightly. Future plants should be designed to minimize losses by using large draft tube exit areas. This can be done by using either lower specific speed runners or longer draft tubes or a combination of the two. Reducing the exit velocity of a 4000 MW plant from 12 to 5 ft/s (3.66 to 1.83 m/s) could save as much as 355,000 barrels of oil annually. This saving consequent upon a lower exit loss would finance about nine 1000 kW low-head hydroplants, annually, assuming oil at $20 per barrel and low-head hydro at an existing dam to cost $800 per kW.

Turbine designers are straining to increase the efficiency of turbine runners by 0.1 percent while losses corresponding to twenty times that amount are escaping from the draft tube exit and, in some cases a hundred times that amount are lost in the penstock friction. The selection of velocity at the draft tube exit should be made on the basis of energy loss. Equivalent fuel values of losses over a long term should be the criteria for selecting specific speeds, draft tube exit areas and penstock diameters. Draft tube exit and penstock

velocities should err on the low side because the cost of energy can be expected to rise indefinitely and at a higher rate than equipment cost. Once a draft tube is formed in concrete and a penstock in steel, it is virtually impossible to make them larger.

The efficiency of a high specific speed runner may equal that of a low specific speed runner when efficiency is based on net head, but, because the high specific speed runner discharges at high velocity, less of the gross head is utilized. The use of high specific speed runners is a step backward rather than forward unless the draft tube is lengthened and enlarged to suit.

A REVIEW OF INDUCTION GENERATORS AND THEIR APPLICATION TO SMALL HYDROELECTRIC POWER PLANTS

John Slapp and Narain G. Hingorani

Introduction

Increasing stress has been placed on utilities to provide electrical energy from renewable resources which are environmentally clean. As a result, hydroelectric power sites which, up to a few years ago, were uneconomical to develop are being considered. Even so, these sites are scarce and there is considerable emphasis being given to the development of other sources of energy, such as solar power.

Perhaps it is time to revive one of mankind's oldest sources of power, the watermill. It is interesting to note that the Domesday Book of 1086 contains a well known statistic, that in the eleventh century England contained 5624 watermills; if these were developed today, they would probably yield in excess of 500 MW of power. The colonist in America developed his power for grist and sawmills from water with dams made from timber and, as a consequence, few, if any, remain today.

There are many old sites in New England which could be redeveloped and literally thousands of potential sites in the remainder of the United States waiting to be developed. To economically develop this form of generation demands that the machinery be simple and relatively maintenance free. To this end, the induction generator is ideally suited. This form of generation has been successfully used in many parts of the world, with machines ranging in size from 50 kW to 10,000 kW.

The Induction Machine

The induction motor was invented by Tesla and Ferraris in 1889 and since then it has become the workhorse of industry because of its versatility and robust and simple construction, which lends itself to modern production line techniques. Furthermore, it is able to operate in the most hostile climates and, with the advent of solid-state technology, has replaced the specialized commutation machines in most industrial applications. Electrically, the induction machine consists of two major parts, the stator and the rotor. The stationary windings are contained in the outer stator frame and connected to the a.c. system, while the rotor is mechanically coupled to the load or turbine. Steel

---

Mr. Slapp is Project Director - Engineering, for the Inga-Shaba 500 KV EHVDC Transmission System, Zaire, Africa, and Project Manager for the Electric Power Research Institute (EPRI) State of the Art Study on Grounding Electrodes, Palo Alto, California.

Dr. Hingorani is Program Manager for a.c. and d.c. transmission, EPRI. He is a co-author of a book on HVDC transmission and author of 70 papers.

laminations form the rotor, with the rotor windings of steel or copper bars embedded in the periphery; at each end of the rotor the bars are short-circuited by a metal ring.

Induction Machine Theory

The theory of induction machines can be found in most elementary texts on electrical engineering. The stator winding, when excited with an alternating voltage, produces a magnetic field in the air gap rotating at synchronous speed. This magnetic field induces a voltage in the rotor and the rotor current produces a magnetic field. It is the interaction between the stator and rotor magnetic fields which produces rotary motion. The rotor does not rotate at the same speed as the stator magnetic field, which is at synchronous speed, and the difference between these two speeds is known as the slip.

Thus, the analysis of the induction machine can follow the same principles as the transformer theory, treating the stator as primary winding and the rotor as the secondary winding. The phasor diagram for an induction machine when connected to an a.c. system can be developed, lending itself to an equivalent circuit as shown in Figure C-2.1. From the equivalent circuit can also be developed the circle diagram from which power and torque can readily be measured; this is shown in Figure C-2.2.

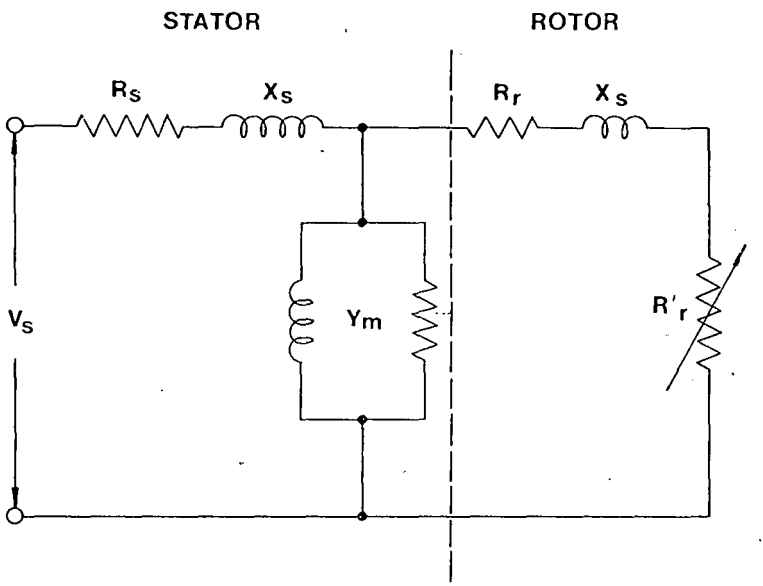
Salient Features of the Induction Generator

The theory of the induction machines shows that in general the induction generator requirements are identical to that of the induction motor. It is considerably simpler than the synchronous generator. The salient features of an induction generator are:

1. Like the motor, the generator requires reactive power from the supply system to which it is connected to provide it with its excitation.
2. The induction machine can only generate power when the rotor is driven faster than the rotating stator field, as shown in Figure C-2.3.

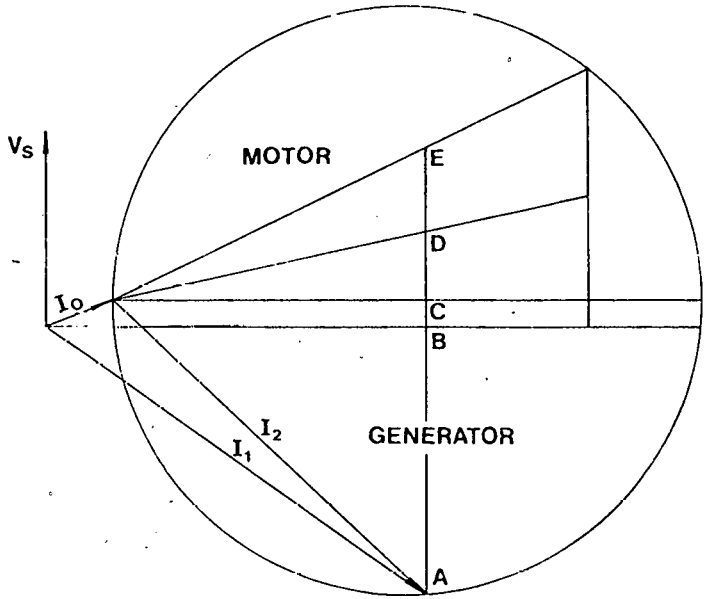
These characterisitcs have the following consequences on the design and cost of a generating plant when using an induction generator:

1. The induction generator has no excitation system.
2. The induction generator does not require a governor system. It operates asynchronously and is not responsible for maintaining the system frequency.
3. The induction generator is normally run up to speed by the turbine and when near synchronous speed, the circuit breaker closed; no synchronizing equipment is required. Small generators can be started as induction motors.



V_S = Supply voltage
R_S = Resistance of stator
X_S = Reactance of stator
R_r = Resistance of rotor (referred to stator)
Y_m = Magnetizing admittance
R_r = Power into rotor as generator

FIGURE C-2.1 Equivalent Circuit



V_S = Supply voltage
I_0 = No load stator current
I_1 = Current in stator
I_2 = Current in rotor (referred to stator)

Rotor copper loss = DE
Stator Copper loss = DC
Stray losses = BC
Output power = AB

FIGURE C-2.2 Circle Diagram

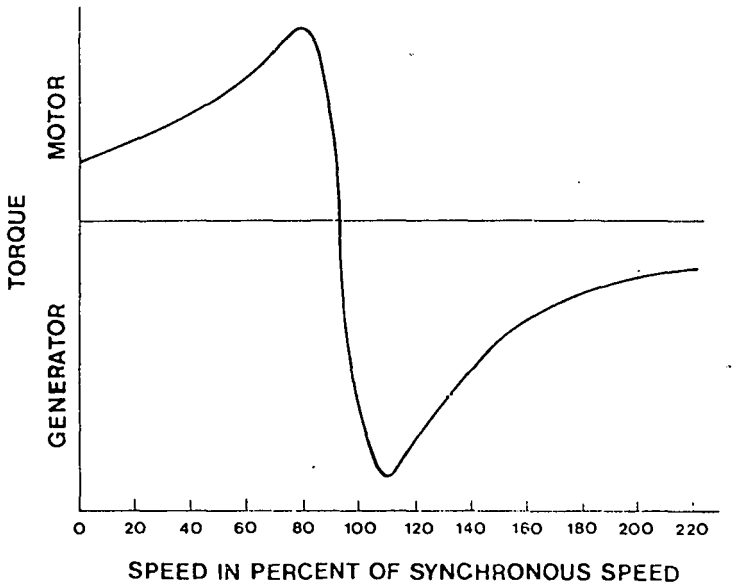


FIGURE C-2.3 Induction-Machine Torque-Slip Curve

4. The only production differences between an ordinary induction motor purchased off the shelf and an induction generator are:
   (a) It must be able to stand the overspeed or runaway speed of the turbine.
   (b) To provide the highest possible efficiency and power factor, the rotor resistance and reactance are usually lower than that of a corresponding motor.
   (c) An overspeed trip is required for protection of the generator. It is of interest to note that it is practically impossible to overload an induction generator, since it will only accept as much reactive power as it requires for excitation.
5. The auxiliary requirements are simple: A power plant using induction generators requires few parts and is simple to design and build. The generator, which is cheap compared to its synchronous generator counterpart, is well suited to small hydroelectric sites where a reliable power source is required with absolute minimum maintenance. Furthermore, because of the plant's simplicity, it lends itself easily to remote control.

Reactive Power Compensation

Obviously the ideal location for an induction generator is where reactive power is available from the power system. Current practice has been, for example, to connect induction generators to the a.c. system with an a.c. line, which also serves to control the voltage at light load. In a hydro power plant where compensation water is used to drive turbines for induction generators, the local synchronous generators would provide the reactive power.

It is also common practice and economical to provide reactive compensation by means of shunt capacitors connected in parallel with the system to provide reactive power. This is a viable alternative which, when necessary, should be used in conjunction with the power system to provide reactive power to induction generators. There has been reluctance in using this method because of the difficulty of regulating the voltage of the a.c. system and because of self-excitation which can occur during overspeed. These conditions can be overcome by switching the capacitors in banks.

With the advent of solid-state technology, more sophisticated means are available for providing reactive power by continuous control from static devices such as thyristor-controlled static capacitors or saturated reactors. While these devices are ideally suited to provide compensation, they are expensive and probably could only be justified when large induction generators over 10,000 kW are being considered. It is important to note that if the system to which an induction generator is to be connected is not large compared to the size of the machine, it could lead to instability.

Induction Generators Connected Through a D.C. Link

It is interesting to note that the operating range of an induction generator connected to an a.c. system via an a.c. line is limited by the fact that power

can only be transferred to the a.c. system when the induction generator is running at speeds greater than the synchronous speed of the system, as is shown in the power speed characteristics of an induction machine in Figure C-2.3. The induction generator works satisfactorily provided that:

1. The water flow through the turbine is not too erratic.
2. It is connected to an a.c. system of much larger short circuit capacity, which is therefore able to serve as an effective source of reference frequency, voltage level, and reactive power supply.
3. Line length is short.

If not, then the induction generator is subject to frequent stalls and overvoltages. Also, if the source of synchronous power to the a.c. system is somehow disconnected, the remaining load may be subjected to sustained overvoltages and overfrequency. It is therefore reasonable to assume that an asynchronous connection through the use of a.c./d.c. and d.c./a.c. converters may be a better alternative for many applications of induction generators.

Use of d.c. transmission or d.c. links for asynchronous connections is not new, and is well established for electric power systems as well as for industrial applications. Direct current transmission is being increasingly used for a variety of reasons, and the case for its application to power plants with induction generators may be even stronger. Converters of self—commutation and line commutation types are widely used for induction motors. The technology of d.c. links is a state-of-the-art technology; therefore, only the strategies of system configuration, operation, and control need to be established to obtain reliable and economical systems for power supply from small hydro plants with induction generators.

It is most important to maintain maximum simplicity at the generator end so that it can be rugged, reliable, and unattended. A proposed system for a single induction generator is shown in Figure C-2.4. It includes one three-phase full wave rectifier with diodes. For simplicity, the diode cooling can be achieved with heatpipes, which are in turn cooled externally with the stream water, so that no pumps or motors are required. With one generator, it is adequate to connect the generator to the diode rectifier without a transformer, provided of course the generator voltage is high enough for efficient transmission.

In this decoupled system, all the reactive power needed by the generator and the converter is provided locally by switched capacitors. These capacitors should be provided in a number of small banks which are switched automatically. The generator is allowed to find its own speed and frequency of supply. For up to 200 A d.c. current, the d.c. transmission could be monopolar ground-return requiring only a simple one-conductor line. Alternatively, a two-conductor line may be used with only one end grounded and the other end connected to the ground through a capacitor as shown in Figure C-2.5. The second conductor will have a very low insulation to ground, and could also serve as a shield wire.

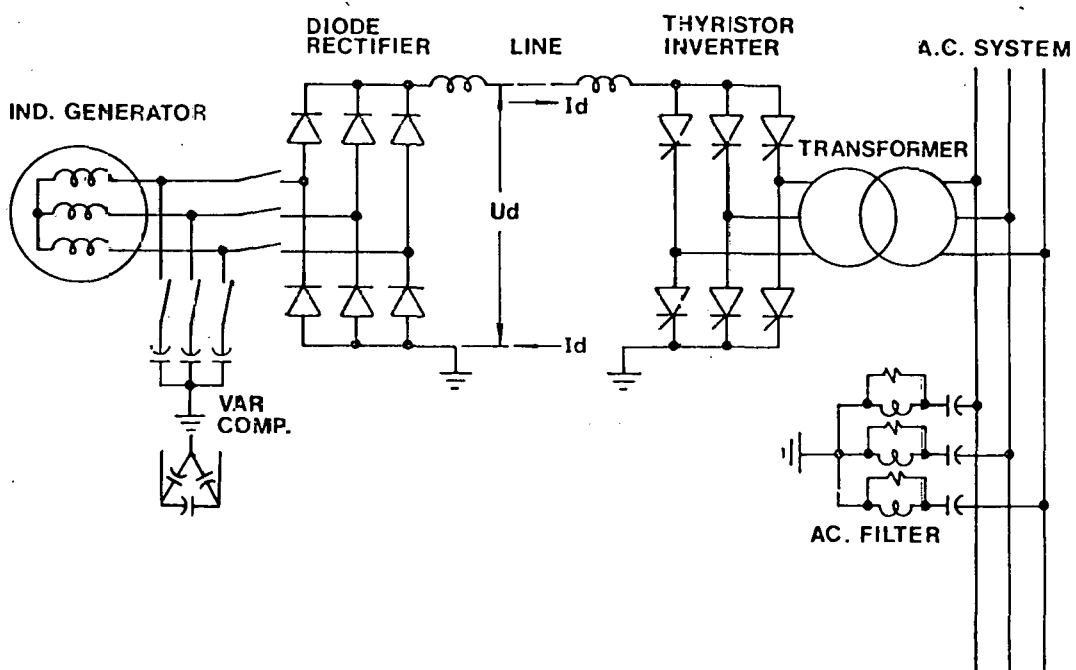


FIGURE C-2.4 Single Induction Generator

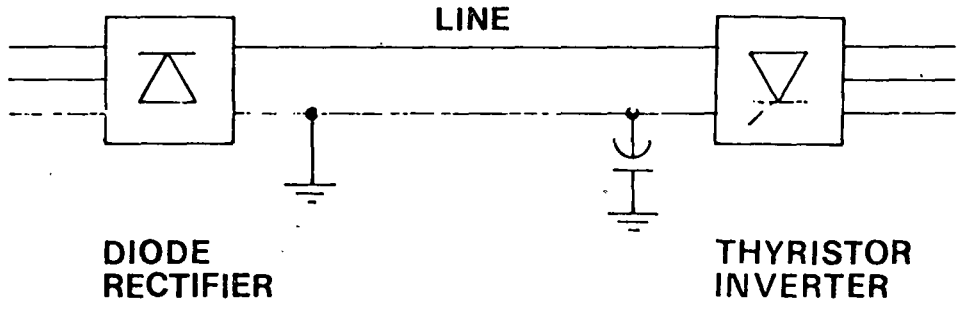


FIGURE C-2.5 Capacitor

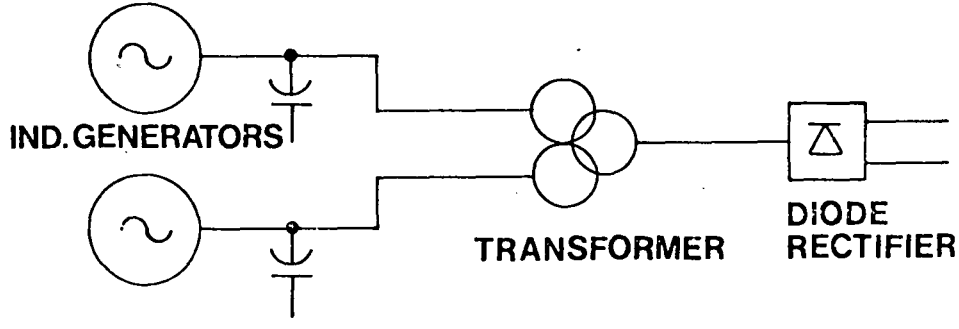


FIGURE C-2.6 Three-Winding Transformer

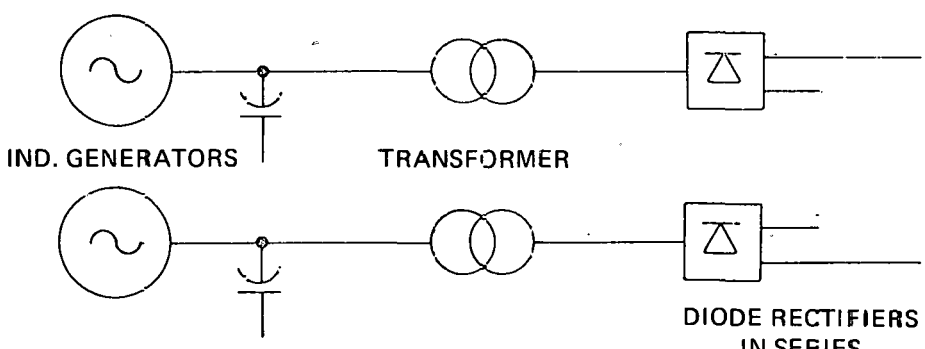


FIGURE C-2.7 Separate Transformer

The receiving end has to be a thyristor converter (working as an inverter) which, because of its controllability, can regulate the voltage and current flow in the d.c. line for stable generator operation. The inverter may be a self-commutating type, in which case the converter could be designed to operate as the sole source of power supply in the a.c. system. The inverter may also be a line-commutating type (a less costly approach), if the receiving a.c. system includes another source of reliable supply which establishes a short circuit capacity of at least 1.5 times the converter rating.

If there are two generators, these could be connected to a single diode rectifier through a three-winding transformer as shown in Figure C-2.6, or through separate transformers, as shown in Figure C-2.7, to separate diode rectifiers connected in series on the d.c. side. For more than two generators, a combination of the two arrangements could be used. While the d.c. line will be lower in cost and more efficient than the a.c. alternative, savings in line cost may or may not pay for the extra cost and losses in the converters. In any case, an improved and reliable delivery system offered by the proposed d.c. link may be worth a small extra cost in the overall generation-transmission project.

Conclusion:

The induction generator can make a substantial contribution to energy production in the United States and other countries in small hydroelectric stations with generators rated up to 10,000 kW. The induction generators when connected to an asynchronous intertie will allow hydraulic resources to be developed where the water flow is erratic. Such a system may also have advantages in allowing a wider range of operation in tidal power application. Furthermore, such a generator, which is simple and relatively maintenance-free, is well suited to bulb turbines.

CALCULATIONS OF CIRCUIT BREAKER CLOSING CRITERIA FOR SYNCHRONIZING A GENERATOR

Robert W. Beckwith

Introduction

It is well known that damage to a generator, and possibly to associated transformers, can be caused by the phase and frequency error which will always exist to some degree just as the circuit breaker is closed. This damage can range from the accumulated effects of many synchronizing and fault-induced force transients, incurred over a period of years, to a spectacular failure as a result of a single significant synchronizing error.

Considering the cost of replacement of a generator rotor or similar major component, present practice is at times remarkably imprecise. Synchronization is often done manually by the "seat of the pants" method of minimizing the amount of building vibration caused by the synchronizing transient. A skilled operator can consistently reduce the shock to an undetectable level. The potential for human error is generally reduced by use of a relatively crude phase-sensitive relay in series with the operator "close" contact.

Present technology can be depended on to eliminate the possibility for a catastrophic synchronizing error. It is less certain that incremental damage will always be eliminated. Extremely precise automatic synchronizers exist which are capable of reliably eliminating even incremental damage, but simple analytical criteria for their safe adjustment have not heretofore been available. Previous work has been directed toward the power/torque transient with precise mathematical modeling of a particular machine. There is a need for a simpler mathematical model which may not be as accurate but can easily be applied to any generator. To meet this need, it must be established that the resulting equations and method of application fail in accuracy in the direction safe to the machine. This paper is proposed as a solution to this problem, or at least a start in that direction.

Background

Previous work has explored in detail those aspects of synchronizing error that are equivalent to faults. The goal was mainly to establish accurate analytical models which could be used in the design of machines to withstand faults and synchronizing errors. With a few exceptions, this analysis is not generally used to calculate limit settings for automatic synchronizers.

The previous work develops a detailed analysis of forces produced by current buildup, in turn caused by a phase difference across the synchronizing breaker at the instant it closed. Frequency difference is assumed to be zero

---

Mr. Beckwith is President of Beckwith Electric Co., Inc. of Largo, Florida.

and the effects of a frequency error with no phase error at the instant of closing appear not to have been analyzed.

Previous analyses consider the torques set up by faults or synchronizing errors but do not directly consider the energy involved. This analysis will consider the energy balance of the rotating machine and the system to which it is being connected.

The Synchronizing Energy Transient

Consider a system consisting of an ideal generator connected by an impedance to a generator whose size approaches infinity. The ideal generator will have a single impedance and neither the generator nor the interconnecting impedance will have losses. It is clear that an energy transient can be defined for such a system and that the energy transient for a real system with losses can be no greater.

Figure C-3.1 is the simplified electrical model to be used. Figure C-3.2 describes the energy transient which will oscillate between the machine rotor and the interconnected system.

The transient oscillation can be explained in detail by following the sequence of four conditions 90° apart, as in Figure C-3.2. Starting at 0°, a positive phase angle, as defined here, delivers power to the infinite bus.

At 90°, this power flow from the machine has reduced the electrical phase angle to zero and has produced an underspeed in the rotor equivalent to $\Delta\omega$ radians per second electrically or $\Delta\omega/N$ radians per second of shaft rotation.

At 180°, the underspeed reduces again to zero and results in a negative phase angle of maximum power flow back to the finite machine.

At 270°, the power flow into the machine has again reduced the phase angle to zero resulting in an overspeed of $\Delta\omega$ electrically or $\Delta\omega/N$ mechanically. The process then repeats.

A standard fault is proposed which can be used as a base for the energy transient produced by any machine disturbance, whether it be a fault, a switching operation or synchronizing. The proposed definition follows:

A one per unit fault is a three phase fault on a fully loaded generator which produces no change in generator rotor position with respect to the expected no fault position.

The fault energy for a standard fault is then:

$$\epsilon_f = P_g \, \Delta t_f \text{ joules}$$

The stored energy in the rotor is: $\epsilon_r = P_g H'$ joules where: $H' = \frac{H}{PF}$

The fault energy in per unit with the stored energy in the rotor as a base is:

$$D_f = \frac{\Delta t_f}{H'} \qquad \text{(A)}$$

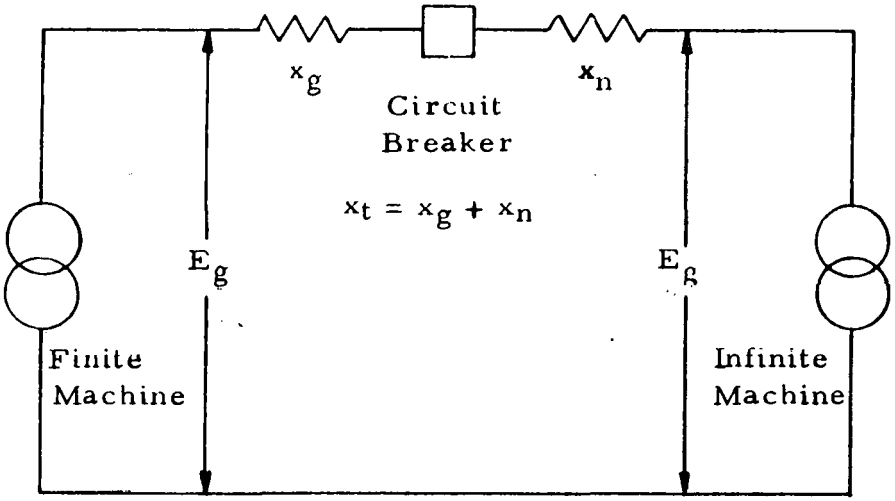


FIGURE C-3.1 Simplified Network

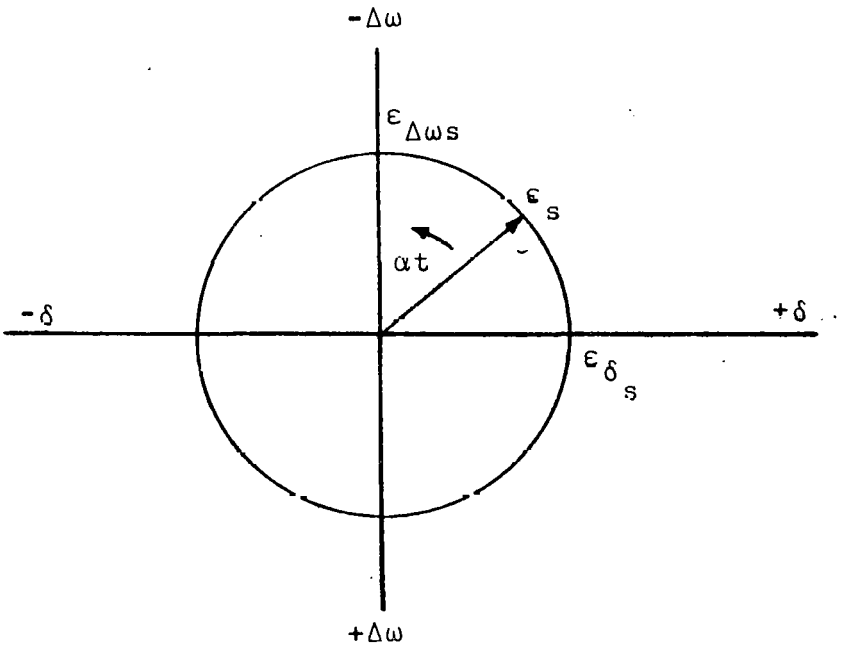


FIGURE C-3.2 Transient Diagram

While machines are designed to withstand faults, one does not fault machines on purpose. Synchronizing, on the other hand, is planned and necessary. It seems wise, therefore, to choose a value of D_s small in comparison with D_f, such as 10%.

Comments must be made about the use of H, above. The inertial constant H is normally defined as stored rotational energy divided by machine rating in kVA. This results in H having the dimensions of wattseconds per voltamphere. For the purpose of this paper, it is assumed that the machine rating in watts is used so that H' has the dimension of seconds. It is then easy to interpret H' as the number of seconds of rated prime mover input which equals the stored energy in the rotor.

Calculation of Automatic Synchronizer Settings

Data Required

H'	the machine inertial constant in seconds.
$\underline{x_t}$	the sum of the machine transient impedance, transformer impedance and line impedance in per unit.
Δt_f	the expected fault clearing time at the generator in seconds.

Procedure

Calculate: $D_f = \Delta t_f / H'$ from equation (A) a dimensionless per unit number.
Using additional equations derived in the appendix[1]:
Choose a safe D_s less than D_f.
Calculate: $\Delta f_s = 30 D_s$ (11)
maximum allowable slip rate in hertz.
Calculate: $\delta_s{}^\circ = 787 D_s (H' \underline{x_t})^{1/2}$ (12)

Maximum allowable closing angle error in degrees. Out of general interest, the fundamental resonant frequency of the generator and interconnected system is:

$$\alpha' = 2.185 \left(\frac{1}{H' \underline{x_t}} \right)^{1/2} \qquad (13)$$

resonant frequency in hertz.

Total error is: $\epsilon_s = \left(\epsilon_{\delta_s}{}^2 + \epsilon_{\Delta\omega_s}{}^2 \right)^{1/2}$ (2)

Typical Calculation

Assume the following:

H' = 3 seconds
x'' = 0.2
x' = 0.3
x = 1.5
x_n = 0.2 (transformer plus network)
Δt_f = 0.05 seconds

We obtain for a 60 Hz system; assuming $D_s = 0.1\ D_f$:
Δf_s = 0.05 Hz from equation (11)
$\delta_s°$ = 1.61° from equation (12)
α' = 1.99 Hz from equation (13)

Comments on Procedures

Note the following in the application of these procedures:

1. It is assumed no difference in rms voltage magnitude exists across the open breaker. If small differences did exist, the principal result would be the flow of reactive current which, in turn, would not contribute to the energy transient.
2. A problem will arise in deciding what machine impedance to use in the above procedure. In many instances, the machine impedance will be swamped out by the transformer and network impedance so that the choice will make little difference as compared to other judgement decisions, such as the ratio of D_s to D_f.
   The equations derived here have been used with the data from Dunlop and Parikh and compared to the first cycle of each curve of Figure 5 from that paper. The result was sufficiently accurate to support use of the simple equations derived here for the intended purpose of setting limits for generator synchronizing. Best results were obtained using the subsynchronous reactance. It is, therefore, suggested that the subsynchronous reactance be used in applying the equations derived in this paper.
3. It is assumed that the electrical angle θ measured across an open synchronizing breaker is equal to the rotor angle δ with respect to the infinite machine as a reference. The symbol δ is, therefore, used in the analysis to represent θ just before the breaker is closed or δ just after the breaker is closed.

Sources of Error

In applying the results, several errors must be considered:

1. Maximum phase angle error of an automatic synchronizer, if used.
2. Tolerance in breaker closing time. Note that an automatic synchronizer will compensate for the expected breaker closing time. The actual closing time will vary with temperature, age and other factors by at least ± 0.2 of the expected closing time. This will cause a closing phase angle error of: $\delta_e = 360\ \Delta f B \Delta t_b$
3. Error in synchroscope and worst case human error, if manual synchronizing is used. Note that frictional error of a rotating synchroscope may be several degrees, even when rotating very slowly.

The sum of the phase angle errors must be no greater than the calculated safe limit, since the transient from Δf and the one from $_s$ add in accordance with equation (14), and since it must be assumed that synchronizing can occur with worst case values of both Δf and $_s$, then the resulting power transient will be greater by $(2)^{1/2}$ times either one alone.

Note, in any system containing two generators, that for synchronizing transients a virtual point exists at the symmetrical midpoint of the network.

Conclusion

By using energy equations, simple criteria for setting phase angle and frequency difference for synchronizing have been established. In addition to the simplicity, the equations generated here relate the frequency difference and phase error in more detail and probably with greater accuracy. The results were useful for machine design by did not immediately lead to a safe setting of synchronizing phase angle error. As far as has been determined, past work did not approach the problem of frequency error.

Author's Note: [1]Due to space restrictions, sections of this paper have been deleted. A complete copy of this paper can be obtained from the author.

REFERENCE

R. D. Dunlop and A. C. Parikh, *Verification of Synchronous Machine Modeling in Stability Studies: Comparative Tests of Digital and Physical Scale Model Power System Simulations IEEE Transactions on Power Apparatus and Systems,* Vol. PAS-98, No. 2 March/April 1979.

PACKAGED ELECTRICAL EQUIPMENT FOR MINI-HYDROPOWER STATIONS

Johan Bergseng, Hermann J. Besel, Friedrich Riezinger, and Horst Butz

Introduction

This paper deals with a modern electrical concept for mini-hydropower stations. A comparison between induction and synchronous generators will be given showing their operation on the grid and also giving recommendations for the optimum production of kWh. From the viewpoint of unmanned operation, the switchgear and control system as well as the precise regulation of the water level are described. An example of the upgrading of an existing mini-hydropower station is given with data. Curves, diagrams, and pictures will be shown at the completion of the session.

Generators

The selection of an appropriate generator for mini-hydropower plants is based on the operating conditions which are usually specified by the utilities. The hydraulic situation, which dictates the selection of the hydro turbine type, determines the runaway speed. Brown Boveri's standardized induction and synchronous genrators are mechanically designed to withstand a maximum runaway speed three times the nominal speed, and therefore, they can be coupled easily to all kinds of hydro turbines. A comparison of both generator types is worthwhile because the specific knowledge of both electrical machines helps in the design of a mini-hydropower station.

Synchronous Generator

- No maintenance except for the bearings.
- Almost all generators for mini hydros are brushless excited.

Asynchronous or So-called Induction Generator

- No maintenance except for the bearings.

Mr. Bergseng is Sales Manager, A/S Norsk Elektrisk Brown Boveri, Division Engineering, Oslo 1, Norway; Mr. Besel is Section Manager, BBC Brown Boveri Company Ltd., Sales and Contract Dept. for Hydropower Plants, Baden, Switzerland; Mr. Riezinger is Section Manager Deputy, BBC Brown Boveri Company Ltd., Engineering for Hydrogenerators, Birn, Switzerland; and Mr. Butz is Product Manager for Mini Hydropower Plants, Brown Boveri Corporation, North Brunswick, New Jersey.

• Production of reactive power is always possible.	• The excitation current must be supplied by the grid. Low speed generators yield low power factors. Compensation by means of capacitors may be desireable.
• Voltage regulation possible.	• Voltage regulation not possible.
• The operating point, within the limit of stability, reactive and active power, can be continuously controlled.	• The operating point is fixed to the power chart diagram.
• Synchronizing is necessary.	• No synchronizing, direct switching to the grid (at a speed of approx. 102% of nominal speed).

Since the induction generator does not produce its own excitation current, the necessary excitation power must be supplied by the grid: i.e., by synchronous generators working in parallel. The question of how many or the maximum allowable size of an induction generator therefore rests with the existence of surplus reactive power. This matter must therefore be discussed and settled with the utility.

On the owner's side, 80 - 90% of the required reactive power may be compensated. Should this prove insufficient, a synchronous generator must be applied. It is not advisable to exceed this value as oscillations between the generator and the capacitor may easily occur, resulting in large overcurrents.

As already stated, the operating point of an induction generator is fixed to its power-chart diagram. It may operate between the no-load point and the breakdown point but the power factor depends upon the output. For this reason, the induction generator is most suited for operation at rated output.

Since the induction generator does not produce its own excitation current, it cannot participate in the voltage regulation of the grid. The voltage regulation must thus be carried out by the synchronous generators working in

parallel and, since the operating point of these generators may be set at any desirable value, load regulation of the grid should also be carried out by same. This will secure an optimal operation of the induction generator.

Type of generator	Suitability	Parallel Operation				Isolated Operation			
		a	b	c	d	a	b	c	d
Induction generator	Most suitable	X							
	Very suitable		X						
	Not very suitable					X			
	Unsuitable			X	X		X	X	X
Synch. gen.	Suitable	X	X	X	X	X	X	X	X

a: Operation with constant output
b: Operation with varying output
c: Operation with varying load and constant voltage
d: Operation with varying load and production of reactive power

SWITCHGEAR AND CONTROL SYSTEM

Protection System

Many mini-hydro stations will be operated unmanned. Therefore, the protection system has to be:

- Preventive; i.e. abnormal conditions must be detected at the earliest possible stage.
- Able to act instantly when faults develop rapidly.
- Able to protect the generators against faults in the grid.

Any faults of the hydrogeneration unit or in the grid will result in automatic disconnection from the grid, and the unit will be brought to a standstill. However, depending upon the location of the plant and the nature of the fault, it may be reasonable to keep the plant running but disconnected from the grid. This is especially important in areas where temperatures below 0°C (32°F) are to be expected. Otherwise, the penstock may freeze. The majority of faults cause an inadmissable temperature rise. To detect it, the obvious solution is to use temperature sensors.

Frequently, a winding short circuit will originate as a stator ground fault. A winding short circuit between two phases always entails considerable damage to the generator and costly repair. The main objective must therefore be to prevent a stator ground fault from developing into a winding short circuit. Thus it may be more appropriate to use a stator ground fault relay rather than a differential relay.

Automation Controls

Start-up:
The presence of the operating crew is required to initiate and control the start-up. Once initiated, the start-up procedure runs automatically.

Stopping procedure:

The unit is disconnected from the grid and brought to a standstill by the built-in automatic control, the general procedure being:

- De-loading of the turbine
- Closing of the valve in front of the turbine
- Tripping the curcuit breaker with a time delay (Time delay is adjustable)
- In the case of a synchronous generator: de-excitation.

Excitation System

Brown Boveri synchronous generators on a small-scale hydropower station have brushless excitation. The rotating diodes as well as the a.c. exciter are mounted on the generator shaft inside the stator frame. Slip rings and brushes are not recommended in order to keep down the additional maintenance.

Voltage Regulation

The generator, the solid-state voltage regulator, and the current transformers form a compact unit. These devices are mounted on the top of the generator. The excitation and voltage regulation system is designed for:

- A high accuracy within $+0.5\%$.
- An automatic built-up voltage with the help of the residual magnetism of the generator.
- Maintenance of a short circuit duration of max. 10 seconds.

Water-Level Regulator

Because small powerplants are designed for unmanned operation, automation of the turbine admission is necessary, as illustrated by the following problems and solutions:

a. Water supply to the reservoir varies throughout the day or the week.
b. Inlet to the penstock at the intake chamber is blocked by foreign bodies.
c. Regulation of the water level of the intake chamber is desired.
d. Best exploitation of varying water supply is maintaining constant level in the reservoir.

A new electronic water-level regulator has been developed, simple in construction, and reliable in operation.

Instead of water level sensoring in a reservoir, which often entails costly transmission of the sensor signal, icing problems etc., pressure is sensored at the intake within the powerplant and distributor opening is measured. With these two criteria, measurement of the static water level or the water line in the intake reservoir is possible for adjustment of the wicket gates or the runner blades. The servomotor of the turbine control system may be used.

As a secondary function, the regulator also monitors the pressure in the turbine. In the event that the water supply is completely or partly blocked, the regulator will register this as loss of pressure and react in the same way as for a low-water level, by adjusting the turbine output until satisfactory pressure has been restored. Emptying of the penstock and the subsequent release of the under-pressure protection may thus be avoided: the generator remains connected to the grid, however, at reduced output. Upon removal of the disturbance, operation reverts again to normal.

Switchgear

The relays, instruments and control devices are mounted in modules, and these again are mounted in a modular switchboard. For a low-voltage generator, the main circuit breaker is mounted in this modular switchboard, and is of the plug-in type. It is advisable, and in most cases necessary, to install a transformer between the generator and the grid due to the following:

- The impedance of the transformer helps to limit the short circuit current, thus reducing the stresses on the equipment.
- The generators are designed for standardized voltages, reducing the cost of the generators as well as the switchgear.

MODERNIZATION OF EXISTING SMALL-SCALE POWER STATION

With the help of a standardized small-scale hydro package, it is possible to meet the needs of a number of both new and out-of-date small-hydro-powerplants. However, additional requirements will be met as dictated by the project.

Reasons for Upgrading

- The operation of the existing power station is no longer economical.
- The equipment is obsolete and spare parts are no longer available.
- Manual operation of the power station demands the permanent attendance of operating staff for monitoring, and the power production of the plant does not justify this in view of the rising cost of personnel.
- The available water quantity is not efficiently utilized.

Upgrading Concept

Besides the renewal of the steel structure of the water intake and necessary rebuilding of the machine house, all the electromechanical equipment will be replaced.

- The powerplant will be equipped for unattended operation; i.e. for automatic start and stop.
- The powerplant will be remotely controlled and supervised from a control center.
- During normal operation, the power station shall operate dependent on the water level and flow (water level regulation).
- During peak load operation, the power station shall operate by lowering the storage level in order to assist in covering the peak load demand (load regulation).

The following example is of an existing hydropower plant in Switzerland which will be upgraded in 1980 in accordance with this concept.

This power station was built in 1903 and originally consisted of four units, each of 200 hp. They were replaced in 1903 by two units, rated 450 hp and 650 hp respectively. Today only one unit is in operation, the data being:

- Pelton turbine
- Water flow 0.125^3/s (4.4 cubic feet/sec.)

After the modernization, the output of the powerplant will be: 1 unit - 1720 kVA, 3 kV, 50 Hz and the powerplant will utilize 0.45 m^3/s (15.9 cubic feet/sec.).

The annual output increase in kWhs, based on 3850H per year shows:

Year	Installed capacity MW	Production MWhs
1930	0.672	2587
1980	1.376	5298

Conclusion

The packaging of electrical equipment for mini-hydro offers an economical solution for the following reasons:

1. Units are made in standard configurations thereby reducing production costs.
2. Pre-engineered, "Shelf" units can be supplied to meet the power demands of a variety of hydraulic situations.
3. Since each unit is not a custom design, but a standard product, years of experience have helped eliminate problems which may crop up in a custom-built unit.

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

Session Four

ENGINEERING

Topic: Hydraulics and Hydrology

Chairman: Mr. Vernon Hagen
Engineering Division
U.S. Army Corps of Engineers
Washington, D.C. 20314

PRACTICAL HYDROLOGY FOR HYDROPLANT PLANNING AND DESIGN

John H. Dixon

Development, understanding and application of hydrologic data are essential elements in the planning and design of hydroelectric plants. Hydrology provides a basis for estimating the generating capacity a stream can economically support, the available energy and the requirements for flood protection of the powerhouse and other facilities.

In the last three years, there has been a lot of time and money devoted to the planning and design of small-hydroelectric plants. It is estimated[1] that the cost of engineering for a feasibility study for a typical small plant is about $20 per kilowatt. A large percent of this cost is spent on the hydrologic aspects of projects. If follows then, that one way to cut down on the cost of engineering is to reduce the effort devoted to hydrology. A word of caution, however: the technical and safety needs of a project should not be compromised in order to reduce the cost of engineering.

This paper will relate some recent experience gained at Tippetts-Abbett-McCarthy-Stratton (TAMS) in the planning and design for small-hydroelectric plants and will emphasize areas where costs have been reduced without affecting the quality of engineering. This experience is based on the preparation of six feasibility reports in the Northeast, and performing screening studies for potential sites in the New England area.

The most practical and successful way we at TAMS were able to affect economics in this phase of the studies was to investigate, collect and use, when applicable, all available hydrologic data including the results of previous studies. Most proposed plants are at sites where plants have previously existed or have been planned. Data developed in the previous engineering work for these sites is generally available. This includes stream flow records, flood studies, planning studies, etc. A review of this data by an experienced and practical hydrologist will indicate those parts which can be used as a basis for a new engineering study.

Hydrologic procedures used in powerplant engineering have evolved over the years. Recent trends have been to use the electronic computer to process the large amounts of stream flow and other data that is now available. It should be noted that most stream-flow records have been computerized and analyzed by the U.S. Geological Survey. The actual daily flows, flow duration curves and flood frequency analyses are generally available for each gaging station at a nominal cost.

Two procedures which were found practical and economical for hydrologic analysis that give reliable results are a generalized flow duration

---

Mr. Dixon is a project engineer at Tippetts-Abbett-McCarthy-Stratton (TAMS), New York, New York

[1]Eugene O'Brien, Short Form Feasibility Studies, TAMS

curve developed for streams in the New England area and programs for use with an electronic computer for processing and analyzing historic stream gaging records. A description of these procedures follows:

Generalized Flow Duration Curve

A generalized flow duration curve was developed for making energy potential estimates for sites in New England. This curve is shown as Figure D-1.1 and is based on a ratio of discharge and average annual flow. It was developed from the historic gaging records for eight streams in the study area, whose upstream drainage areas contain no reservoir storage. The actual duration curves are shown on Figure D-1.2. These curves, reduced to the dimensional less discharge parameters are shown as Figure D-1.3. The curves in Figure D-1.3 were averaged to obtain the generalized curve Figure D-1.2. Another parameter which gave consistent results was a ratio of the discharge and median flow Figure D-1.4. In our work we used the parameter based on average annual flow because this flow is usually available from U.S. Geological Survey and state publications.

The curve was used to make energy estimates for about 11,000 identified possible sites. A comparison of energy estimates made for feasibility studies using this curve and using actual gaging records indicated maximum differences of about five percent. From this it was concluded that for studies where only average annual energy values are needed, the generalized curve will give reliable results.

Computer Analysis

For studies where more than average annual energy estimates were needed, a more detailed analysis was developed. This consisted of a computer program to process and analyze historic flow records from nearby U.S. Geological Survey gaging stations. Usually the power site and the gaging stations were not at the same location, and a correction based on some ration of the drainage areas was required. Also it was found desirable to check the computer cards for the gaging records. Invariably, there were some cards missing or out of order.

The program computed daily energy production based on the available head, turbine efficiencies and the flow. It could also rank the energy production estimates from maximum to minimum by days, months or years. Subroutines which can be added to the computation included reservior routings, head determination based in headwater and/or tailwater-rating curves, and reductions resulting from flows being diverted for other uses.

Flood Protection

Designing the powerhouse to prevent flood damage must also be considered. Setting the generator floor at or above the level of the maximum flood

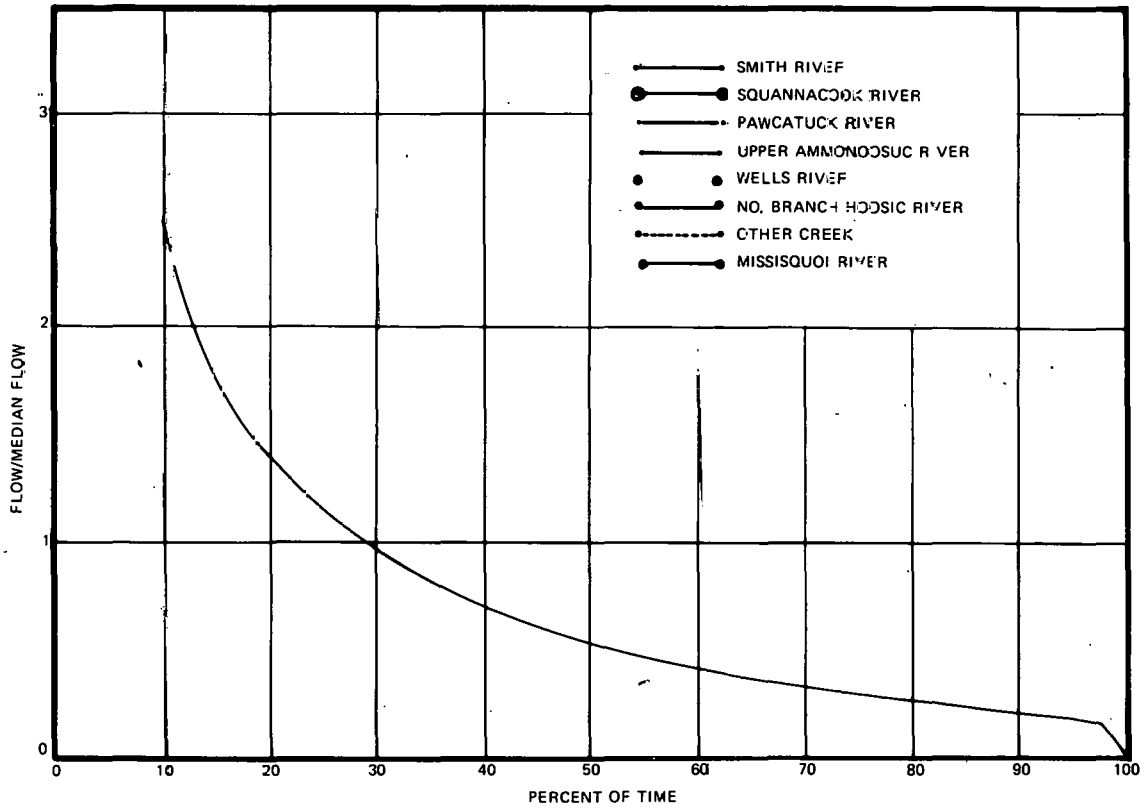


FIGURE D-1.1 Generalized Flow Duration Curve - New England Area

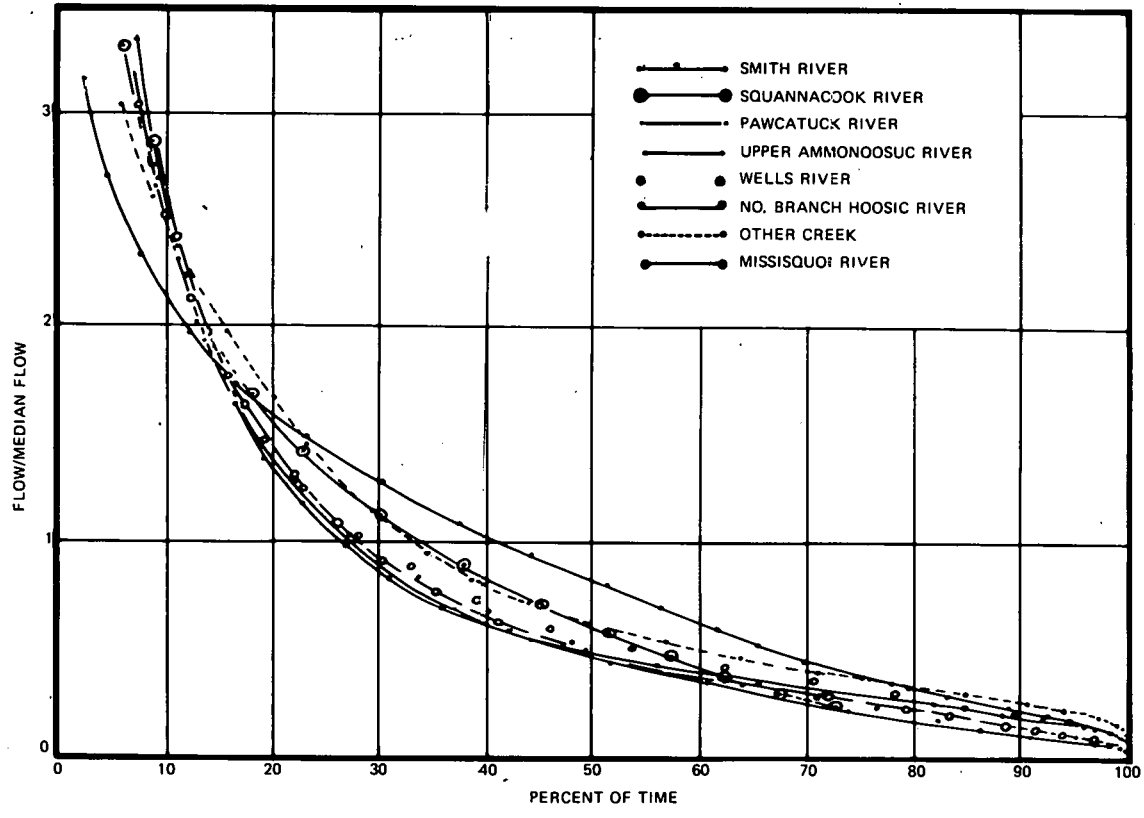


FIGURE D-1.2 Dimensionless Flow-Duration Curves for Selected Streams in the New England Area

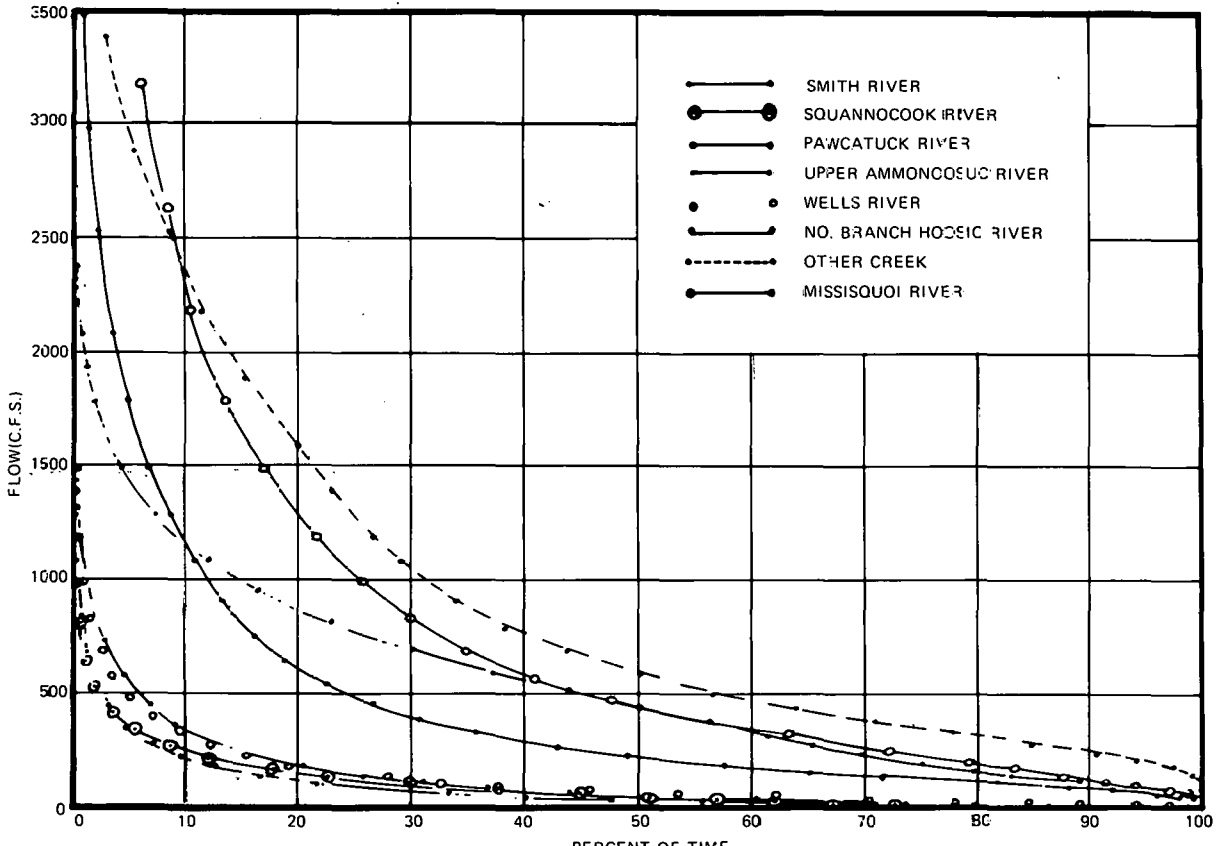


FIGURE D-1.3 Flow Duration Curves for Selected Streams in the New England Area

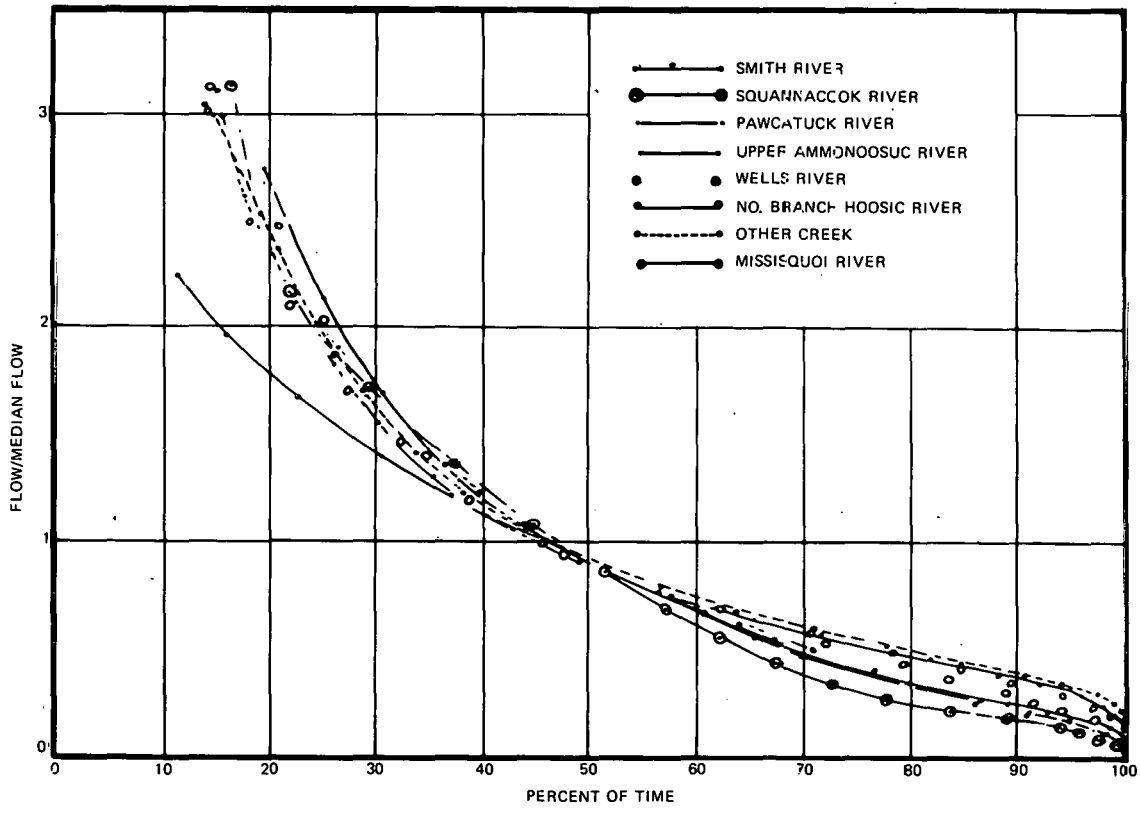


FIGURE D-1.4 Dimensionless Flow Duration Curves for Selected Streams in the New England Area

of record generally results in a conservative design. Also the 100 year flood level has often been used.

Another aspect is protecting the site from flooding during the construction period. The flood used in designing this protection should be a function of the damage that would occur if the construction area were flooded. The difference in cost for protecting against a 10-year flood and a 25-year flood in most cases is small. Except in those cases where the powerhouse will be located where differential flood levels are large, such as in a constricted high bank channel, the degree of protection should be based on a flood of reasonable frequency. In most cases, a 25-year flood is suggested.

Past flood levels are usually available at potential powerplant sites. The U.S. Geological Survey analyzed most of the large floods in the United States and developed flooded area and storm frequency data. Also Flood Insurance Studies from the Department of Housing and Urban Development can be used. These HUD studies have been prepared for most populated areas and are generally available from local governmental agencies in the vicinity.

Other Factors

The hydrologic analysis of most small hydroplants are similar in many respects. Yet there are some features or design considerations which are unique to each project. Some situations which have been encountered that were out of the ordinary and which might be of interest follows:

In the feasibility studies for two powerplants, one developing the head of an existing waterfall and the other, adding a generating unit to an existing powerplant adjacent to an overflow weir, it was required that a portion of the flow pass over the falls and weir for aesthetic purposes during low flow periods. The computer program for estimating the energy potential of each site was modified to account for the reduced flow. The weir crest which was constructed in 1937, is level and has no distinguished irregularities. It was fairly easy to estimate a minimum flow which would still result in a pleasant appearance. The waterfall was more difficult because of its irregular crest. It was finally decided that a reasonable value would be used for the feasibility study and a final value would be determined based on observations and recorded flows.

Another difficulty encountered was assigning power benefits when a new generating unit is to be installed at an existing plant. It was concluded that the energy production which could be assigned to the new unit would be the difference between that produced by the existing unit only and that produced by the combined existing and new unit operated to obtain maximum energy output. The computer program was modified to compute this difference based on the historic streamflow records.

An appraisal study for adding a low-head powerplant at the Mississippi-Old River Diversion in Louisiana presented some very complicated and unique hydrologic problems. The Red River-Atchafalay River Channel parallels the Mississippi River several miles to the west. A diversion channel (Old

River Channel) was constructed between the two rivers for navigation in the 1800's. In the 1950's, a second channel was constructed for diversion of flows from the Mississippi River for flood control and other purposes. By law, on an annual basis, 30 percent of the total flow in both rivers must be allowed to flow down the Atchafalay Channel. This requires diverting considerable flow from the Mississippi River. There is a 6-to 14-foot drop in water at the structure built to control the diverted flows.

An appraisal study was made of the desirability of adding a low head hydroelectric project at this drop. An investigation indicated the Corps of Engineers had made detailed studies of the hydrology in this area in connection with a study for doing some remedial work at the site. The Corps had computed the diversion flows which would have been diverted on a daily basis using historical records and legal requirements. They provided this data to TAMS on computer cards, as well as duration and frequency curves.

The study also provides headwater information which indicated a shifting rating. An investigation indicated a shift of about three feet downward had occurred during a flood in 1976. The channel downstream of the structure is also undergoing some changes, but to a lesser degree. The Corps as a part of its work is considering various patterns of diversion to encourage sediment flow from the Mississippi to the Atchafalay.

The appraisal study lead to the conclusion that the site was probably not viable, mainly because of the variable power head. It should be noted that without the input from the Corps of Engineers, the study would have been too complicated to complete. There were many other unique conditions encountered in the completed studies, but because of the lack of time they cannot be covered.

Conclusion

In concluding, it should be emphasized again that a data search, and review and use of existing information can lead to a reduction in the time required to prepare the hydrologic studies, analysis and design for many small hydroelectric sites.

DETERMINATION OF FLOW-DURATION CURVES AT UNGAGED POINTS IN REGULATED STREAMS

Rickey Emmert and Leroy Heitz

Introduction

In making feasibility analyses of hydroelectric power sites, it is essential to be able to define the time variability of flows at the sites. In many feasibility studies a flow-duration curve is used to define this variability of flow. The flow-duration curve is a plot of discharge versus the percent of time that the discharge can be expected to be equaled or exceeded. Figure D-2.1 shows a typical flow-duration curve. In general, duration curves are developed from stream gage records at the site of interest. In many cases though, there is no stream-flow gage at the site of interest so the problem is to estimate a duration curve for the ungaged point.

The authors along with researchers from Washington State University, Oregon State University, and Montana State University have developed methods for predicting duration curves at ungaged points in natural streams. The methodologies for making these predictions are contained in references 1 and 2 for this paper. While these methods worked well for estimating duration curves in natural streams, their direct application to streams where the natural flows have been substantially modified or regulated by man may result in erroneous duration curves.

It is the purpose of this paper to describe a method of estimating duration curves at ungaged points on regulated streams. This method was developed to predict duration curves on some highly regulated streams in the State of Idaho. The method was used in the Pacific Northwest Hydropower Resource Inventory, sponsored by the U.S. Department of Energy. The completion reports for this study are shown as references 2 and 4 of this paper.

Description of Method

The best way to describe the method is to work through a simple example of its use. The problem we have is to estimate the flow duration curve at a proposed hydro site which is downstream from an existing reservoir storage site. A diagram of the basin of interest is shown in Figure D-2.2.

We have a monthly record of outflows from the storage reservoir, but the large tributary area between the existing storage site and the proposed site contributes a substantial flow to the river. Because of these tributary inflows, it is felt that the flow-duration curve generated from the record of outflows from

---

Mr. Emmert is a hydraulic engineer, Walla Walla District, U.S. Army Corps of Engineers, Walla Walla, Washington.

Mr. Heitz, is a research associate, Idaho Water Resources Research Institute, University of Idaho, Moscow, Idaho.

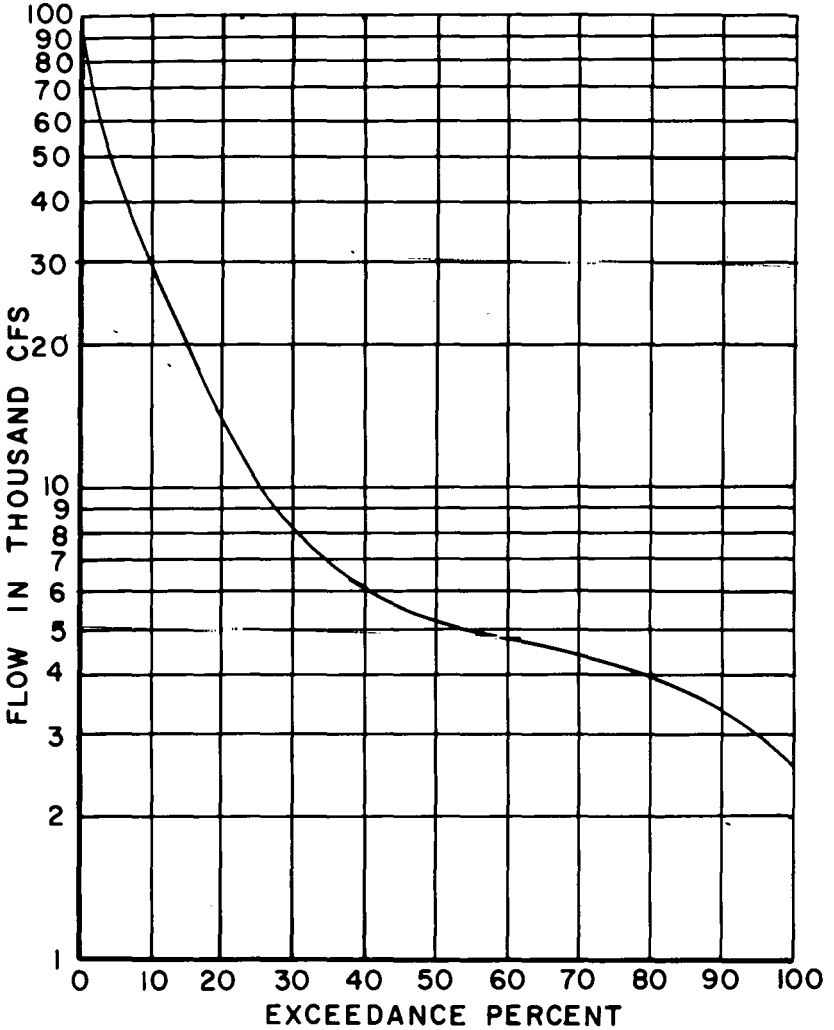


FIGURE D-2.1 Typical Duration Curve

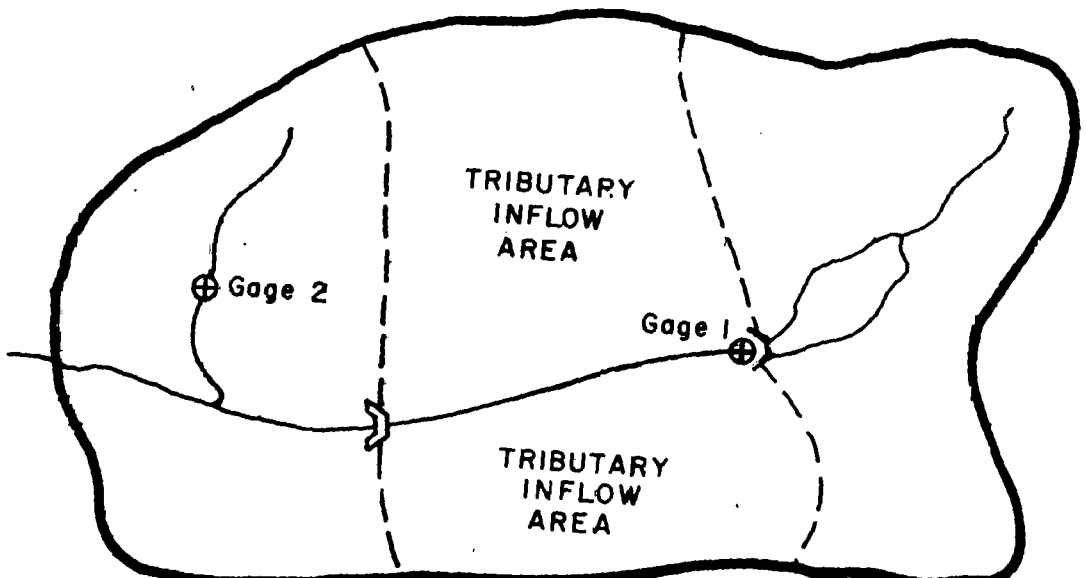


FIGURE D-2.2 Example Application of Regulated Flow Technique

the existing storage sites does not adequately reflect the flow distribution at the proposed site, so we will apply the regulated flow duration curve techniques.

In applying the method we will be generating a series of flows which will represent the natural inflows to the stream between the existing reservoir site and the proposed site. The sum of these generated flows and known outflows from the existing project will be used as the flows at the proposed site. A normal duration analysis can then be made on these summed flows at the proposed site.

The first step in applying the procedure will be to determine the average annual inflow to the stream from the tributary area between the known gage (Gage 1) and the proposed site. This is done by determining the average precipitation input to the area by using Normal Annual Precipitation (NAP) Maps. The isohyetal lines from the NAP maps are projected onto the basin map and the sub-section areas between the isohyetal lines are measured. The area of each sub-section is then multiplied by the average precipitation amount for the sub-sections to get the volume of water input to the area. The water volume inputs from each of the sub-sections are summed to get the total volume input for the entire tributary area. A more detailed description of the method for determining this precipitation volume input is contained in reference 1 and 2.

Next, a runoff coefficient (k) value is estimated for the tributary area. This k value is simply an estimate of the ratio of actual runoff volume to total water input to the basin from precipitation. The k value for the tributary area is estimated by comparison with k values for gaging stations in the area with similar runoff characteristics. The gage station k values are estimated by dividing the average annual runoff at the gage sites by the precipitation input volume measured as described above. The product of precipitation input volume and the estimated k value for the tributary area gives us the average annual runoff.

The next step in the method is to determine the monthly inflows from the tributary area for the period of record of interest. This is done by using what will be called a representative gage. This gage is felt to have a flow distribution that would be representative of the inflow distribution from the tributary area. Gage 2 shown on Figure D-2.2 has been chosen as the representative gage for the tributary area we are studying. The flow volume record for this representative flow is normalized for the period of record corresponding to that of the reservoir outflow, by dividing each monthly flow volume by the total flow volume for the period of record. The result of this division is called the monthly flow fraction.

The monthly inflow volumes from the tributary area are then computed as the product of the monthly flow fraction for the representative gage, the average annual runoff from the tributary area and the number of years in the period being analyzed. This product gives a synthetic flow record for the tributary area with a flow distribution proportional to the representative gage and an average annual runoff equal to that computed from the NAP maps. The tributary inflows are added to the monthly outflows from the upstream reservoir to determine a record of average monthly flows at the point of interest. The resulting flows are then analyzed to determine the synthetic duration

curve at the ungaged location. The resulting duration curve would be considered as a duration curve based on monthly flow data.

Application of Procedure

The regulated flow method has been applied to several different regulated streams in Idaho. An example of a fairly complex system on which the technique was applied is the Payette River System. A schematic diagram of the system is shown in Figure D-2.3. In the system there are two major storage reservoirs that modify the natural stream flows. Between these reservoirs are large areas of tributary inflow that substantially alter the regulated flow patterns released from the reservoirs.

Because of the complicated nature of the basin and the large number of computations to be performed, a generalized computer program was developed with which to apply the technique. Flow records from representative gages, tributary area precip volume and runoff factors, and regulated average monthly flows from upstream reservoirs were used as input to the program. The output from the program included estimated average monthly flows and duration curves at the desired locations in the basin.

Application of the technique to the Payette Basin was quite similar to the sample presented earlier. The starting points were gaged outflows. Tributary inflows were computed and added to the gaged flows in a downstream direction to determine the flows at the desired downstream points. Duration curves were computed for each point of interest. Flows downstream from major junctions were handled by summing the flows coming into the junction.

Synthetic flow duration curves were constructed for two locations in the stream where gage stations are located. Table D-2.1 and Figures D-2.4 and D-2.5 compare these synthetic duration curves with the duration curves computed for the actual flow record at the gage site.

The regulated flow method was applied to and tested on several other basins in Idaho, all with good results. The duration values that were predicted were used in the Pacific Northwest Hydro Survey (Reference 1, 2) being conducted for the DOE by the Water Institutes at Oregon, Washington, and Montana.

TABLE D-2.1

Predicted Versus Actual Discharge Values (cfs) for Gages on the Payette River.

Gage	Q_0	Q_{10}	Q_{30}	Q_{50}	Q_{80}	Q_{95}	Q_{100}
Actual[1]	10,000	4,800	2,000	1,200	640	520	400
Predicted	9,000	4,500	1,800	900	560	500	400
% Diff.	10	6.3	10.0	25.0	12.5	3.8	0
Actual[2]	20,000	8,800	3,600	2,300	1,200	780	500
Predicted	15,000	7,500	3,900	2,800	1,300	980	800
% Diff.	25.0	14.0	8.3	21.7	8.3	25.6	60

[1] Gage 13.2380.00, 1942 to 1974 [2] Gage 13.2475.00, 1942 to 1960

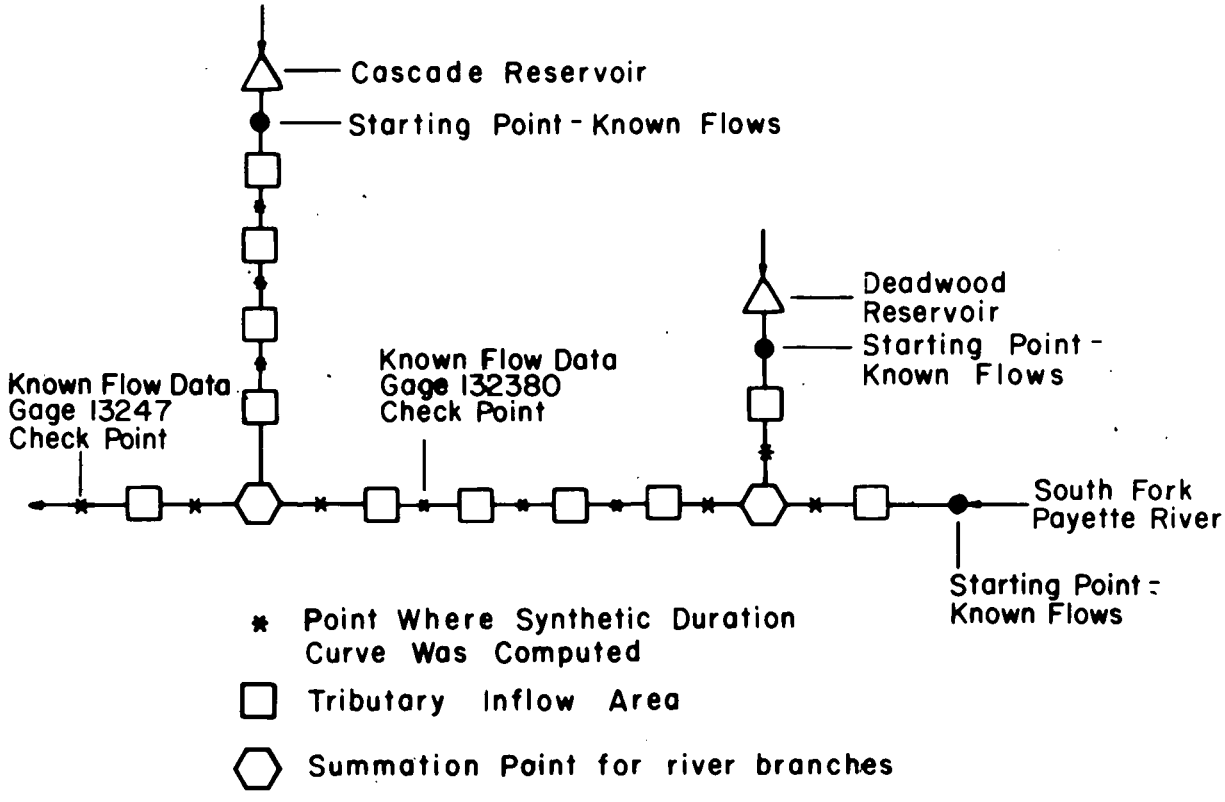


FIGURE D-2.3 Schematic Diagram of Payette River Basin

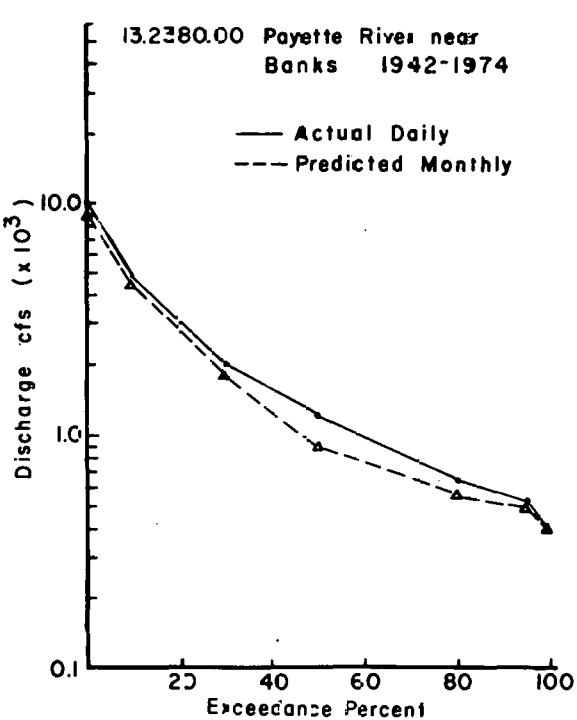


FIGURE D-2.4 Duration Curves for Stream Gage 13,2380.00

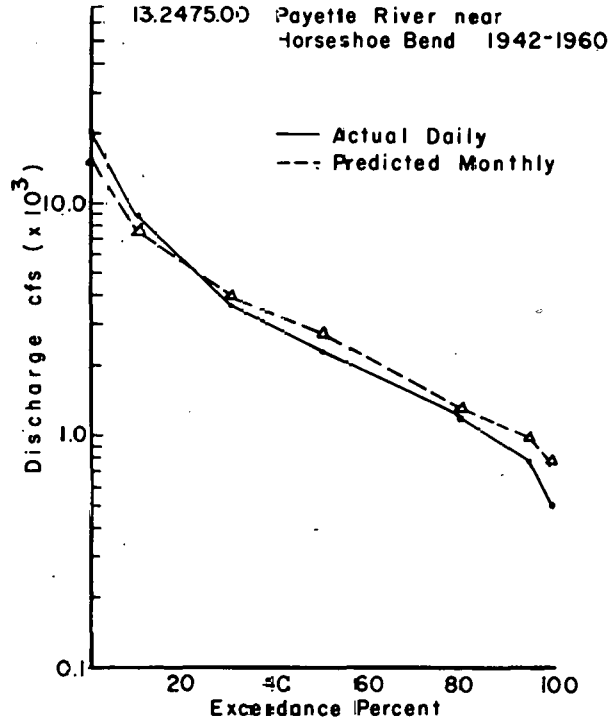


FIGURE D-2.5 Duration Curves for Stream Gage 13, 2475.00

Conclusion

This method is most useful in areas where precipitation variation due to orographic or other effects are high — causing a simpler method of computing tributary inflow to be unsatisfactory. The method does require a set of regulated flows from reservoirs or other regulating structures and a good Normal Annual Precipitation Map is essential to the accuracy of the method.

Because the method is simple, it is very easily computerized. Once the analysis technique is on computer a large number of sites in very complex basins can be easily analyzed. Information on computer application of the technique is available from the authors. If the proper data is available, this method can provide an easily applied and reliable method of computing duration curves at ungaged points in regulated streams.

REFERENCES

1. Heitz, L.E., *Some Hydrologic Analysis Techniques,* Paper in *Low-Head Hydro, An Examination of an Alternative Energy Source,* by J.S. Gladwell, and C.C. Warnick, Idaho Water Resources Research Institute, University of Idaho, Moscow, Idaho, 1978.

2. Gladwell, J.S., et.al., *A Resource Survey of Low-Head Hydroelectric Potential Pacific Northwest Region, Phase I Completion Report Volume A,* Idaho Water Resources Research Institute, University of Idaho, Moscow, Idaho, March, 1979.

3. Emmert R.L., "Methodologies for the Determination of Flow Duration Curves at Specific Sites in Ungaged Reaches of Streams," Master of Science Thesis, Department of Civil Engineering, University of Idaho, Moscow, Idaho, May, 1979.

4. Gladwell, J.S., et.al., *A Resource Survey of Low-Head Hydroelectric Potential at Existing Dams and Proposed Sites in the Pacific Northwest Region, Phase II Completion Report,* Idaho Water Resources Research Institute, University of Idaho, Moscow, Idaho, September, 1979.

COMPLEXITY OF HYDRAULIC PROBLEMS IN LOW-HEAD HYDROELECTRIC DEVELOPMENTS

Alexander B. Rudavsky and Sun-Quan Yuan

Introduction

Although one would assume hydraulic design problems and solutions for high dams would be more complex and difficult than the low dam developments, just the opposite is true. Due to the buffering effect of the reservoir behind a high dam and the independence between the headwater (HW) and tailwater (TW) levels in such structures, the range of flow conditions in high dams is much more predictable by analytical means and less complex than the hydraulics of low dams. This difference is easily apparent in Figure D-3.1.

The importance of modeling low-head hydroelectric developments before installation of the actual facilities cannot be over emphasized. Design parameters chosen for sediment transport, flood fluctuation, bed load movement, and ice blockage will be drastically changed after construction.

The natural equilibrium of the river is destroyed and all the river dynamics are imposed upon the new facilities. Unforeseen parameters then arise which were not considered during the investigative studies, often forcing extensive and costly modifications to be made on the completed structure. One of the main objectives of the designer is to take into account the impact of the new dynamics on the low-head structure and maintain the natural river equilibrium as much as possible. This difficult task is much easier with the use of physical models. New equilibrium parameters can be evaluated and the designs modified for maximum efficiency prior to the construction stage.

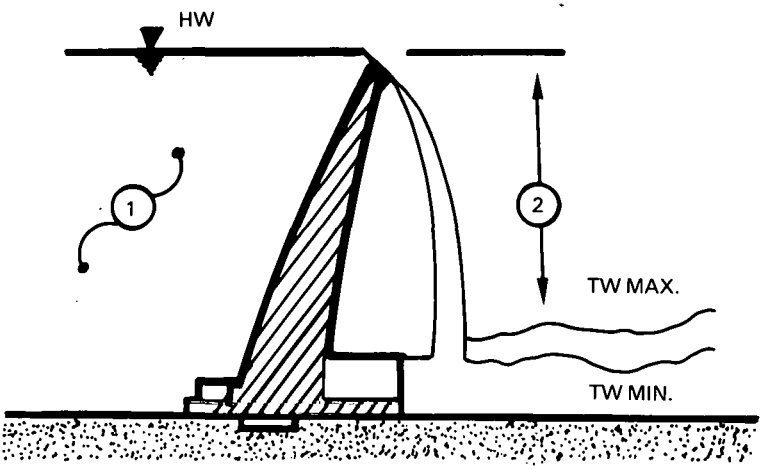
Low-Head Development

The low-head development can be classified in multiple fashion according to layout, type of powerhouse, type of turbines, and many other subdivisions. For the purposes of this paper, while dealing with complexities of hydraulic design and its solution employing the advance methodology of model study, the most logical subdivisions of low-head hydraulic developments are as follows:

- General layout hydraulics
- Weir hydraulics
- Powerhouse hydraulics

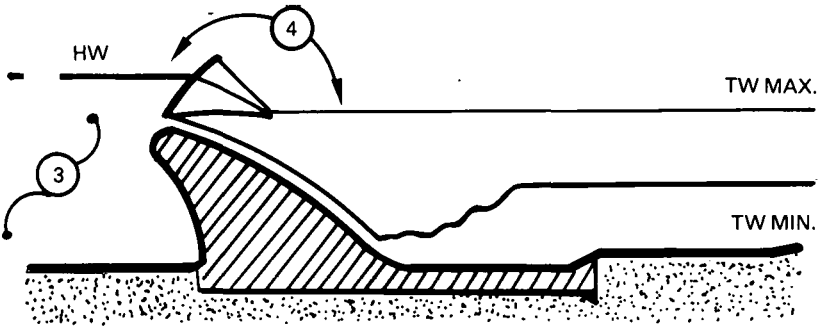
Dr. Rudavsky is the Founder and President of Hydro Research Science in Santa Clara, California.

Mr. Yuan is a research engineer, Hydro Research Science, Santa Clara, California



Typical High Head Dam

1 Buffering effect of a reservoir
2 Complete independence of HW and TW levels



Typical Low Head Dam

3 River dynamics transmitted to flow conditions
4 Interdependence of HW and TW levels influences Quad flow conditions

FIGURE D-3.1 High Head Dam vs Low Head Dam

General Layout Subdivision

The layout subdivisions can be considered to have three basic types as shown in Figure D-3.2.

- Diversion Canal Development
- River Development
- Tidal Development

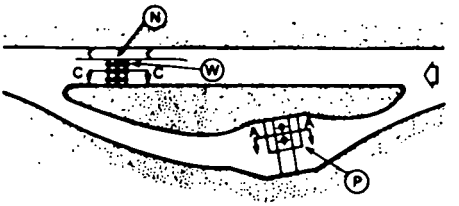
Because the canal differs from the river only in its guided and protected bed, the hydraulic problems associated with layout are combined and described concurrently.

1. *Diversion Canal Development.* The key components of the diversion canal development are the weir to regulate the flow, the canal to convey the flow, the powerhouse to produce the energy, and the locks to convey river traffic.
2. *River Power Development.* The key components of the river power development differ slightly from the canal development. They consist of the weir to regulate flow, the powerhouse to produce the energy and the locks to convey river traffic. Various alternates might be to have the powerhouse in the middle of the river, or to have a powerhouse on each side with the weir in the middle.
3. *Weir and Spillway.* The weir and spillway are the key control components in diversion canal and river development; consequently, their full understanding is imperative for proper design. Spillway hydraulics are more complex than most engineers admit, and therefore must be handled with extra care and expertise concerning flow conditions.
4. *Powerhouse.* The powerhouse is another key component that must be fully comprehended by the engineer for proper design. The complexity of it can be multiple; for example, the powerhouse can be used as a spillway. A general subdivision for the purposes of this paper would be:

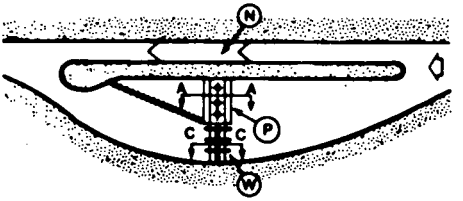
    - Block or multiple block design
    - Submersible design
    - Pier design

Figure D-3.3 shows three designs of powerhouse layouts in a river.

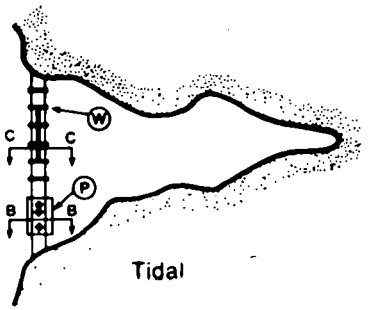
5. *Tidal Power Development.* Tidal power development differs from the other two subdivisions in that the production of energy depends on the ebb and tide cycles of the sea. The key components of a tidal development are the sluice gates to retain the tide, the basin to temporarily store the tide, and the powerhouse to produce energy. There are two basic classifications for tidal power stations:



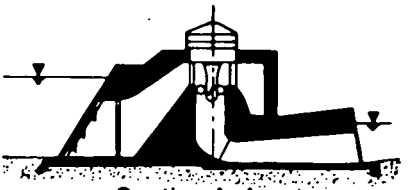
Diversion Canal



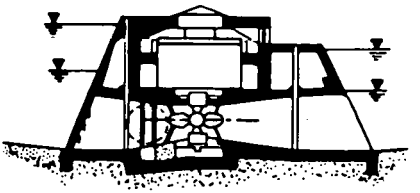
River



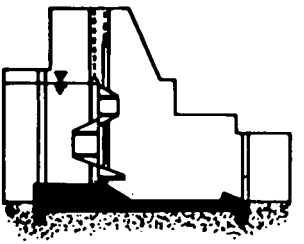
Tidal



Section A–A



Section B–B



Section C–C

Ⓝ Navigation
Ⓦ Weir
Ⓟ Powerhouse

FIGURE D-3.2 General Development Layouts

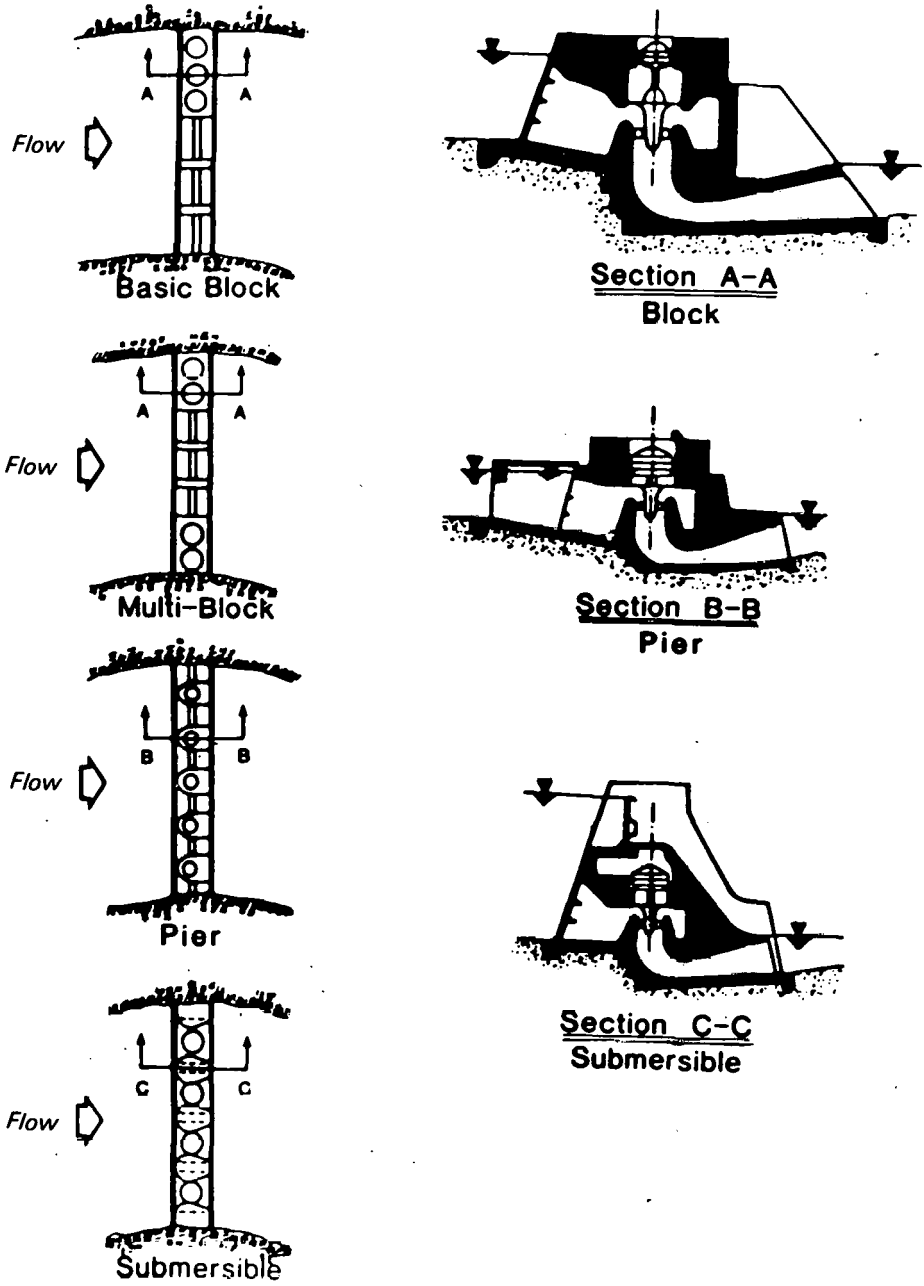


FIGURE D-3.3 Powerhouse Layouts in a River

a) *Tidal-Power Station with One Basin.* The two basic systems that use only one basin are:

- *Single-cycle System,* utilizing the ebb during the emptying of the basin or the tide during filling the basin.
- *Double-cycle System,* utilizing both the ebb and tide cycles.

b) *Tidal Power Stations with Two Basins.* A system of alternatively operating basins or co-operating basins can be devised. The advantage of using two basins is that it assures a more continuous energy production.

Model studies are especially useful to designers of tidal-power developments since dynamic forces and characteristics of the sea are wide ranging and of great complexity.

Hydraulics of Low-Head Development Layout

When an imaginative and trouble-free design is to be developed, canal river hydrology and hydraulics in the low-head development layout have to be closely interwoven and made to compliment the specific characteristics of the river hydrology and hydraulics in the low-head development layout must be sedimentation, detritus, and any other problems be taken into account so that the layout of bypassing sluices, gate arrangements, and operations can be tailored to alleviate and prevent any adverse conditions that may be encountered and cause sediment deposition, ice clogging, and debris deposition. In other words, when equilibrium is destroyed by placement of the development, the designer must ensure that all processes can be implemented as before.

Hydroelectric Development

In laying out a low-head hydro development, the designer must first realize that by introduction of structures, the equilibrium of the water course is destroyed. The dynamics of the river will be considerably influenced and the characteristics drastically changed, generally with disastrous results, unless the designer can readjust and control the water course for minimum changes in dynamics.

Need for Modeling

In an overall view, the designer must consider the geometric layout of the water course, the suspended and bed load sediment conditions, the icing problems, the construction methodology, and incorporation of the development into the environment. Advanced methods of physical modeling are imperative since many of these problems cannot be solved by computational methods.

Additional Training Required

Problems on designing low-head development can be avoided if the design engineer possesses or seeks the needed expertise in river hydrology, flood analysis, sediment transport, icing and other specialized disciplines requiring additional training and study beyond traditional engineering education. Information obtained from sophisticated models can be quite valuable to the hydraulic designer.

River Dynamic Equilibrium

1. *Sediment Problems.* Similarly effective and imaginative solutions for coping with sedimentation problems in river engineering can be developed for sediment entrapment or bypassing. Sediment transport deposition and erosion processes are not fully defined scientifically and superposition of presently used equations can differ in results as much as 1000 percent. The handling of sedimentation problems requires expertise in the field of modeling. HRS has used modeling for excellent solutions to sedimentation problems throughout its existence, using various simulation materials that have been perfected in our shop.
2. *Icing Problems.* Icing problems encountered in winter operations of low-head hydroelectric plants involve frazil ice, anchor ice, and sheet ice. Generally, plants which are subject to intermittent freezing and thawing are more susceptible to serious icing problems than plants in severe winter regions. Icing problems can include blockage of the intake, changes of the water velocity, or damage to the structures. Frazil ice, which sticks in great quantities to the surfaces of intake trashracks, can result in a complete clogging of the inlet area. Clogging of trash racks is very objectionable; not only because of operational problems, but also because a loss in energy production is involved. An unbalanced load on the trash rack will sometimes cause partial damage or total collapse.
   a) *Icing Solutions.* Possible solutions to icing span a large number of arrangements, including building heated structures, heating the trash racks, and discharging hot water to melt the ice. Use of diversion flows, compressed air, heated water, and the combination of compressed air and heated water have been described in a series of engineering references. Another solution involves the use of floating booms which are frequently used for ice protection. Such booms generally consist of a floating timber structure to deflect floating sheet ice. Depending on the circumstances, booms are made of timbers attached to one another or in sections. Booms are sometimes used in front of skimmer walls.
   b) *Use of Models to Solve Icing Problems.* Very often, icing problems can be solved using model studies and solutions can be effectively combined with sediment problems and debris removal. HRS has conducted model studies on using hot water to melt ice.

Hydraulics of Spillway

The spillway hydraulics for small dams is complex because the low height of the dam forces a variety of flow conditions depending upon the headwater level and the tailwater conditions, with both levels becoming interrelated at times. (See Figure D-3.1.) Although some studies have been done on classification of these flows, the presently used classification diagram is possibly one of the most confusing and least understood design diagrams used by engineers. A treatise by the author presents a more vigorous and scientifically based flow condition subdivision. Such rational analysis must be presented in terms of dimensionless parameters developed through dimensional analysis.

Vibration in Gates

In gates that use under and overflow, the vibration problem can be very acute. HRS has conducted special vibration studies on complex gates with outstanding results. It is recommended that vibration model studies should only be made by experienced persons familiar with state-of-the-art, flow-induced vibration, and model to prototype interpretation.

Hydraulics of a Powerhouse

The civil engineering design of powerhouses and the acquisition of proper turbines are too expensive for merely estimating final results. Turbine manufacturers show possible orientations of a turbine only. The approach configurations to such structures have not been standardized or properly designed and will produce destructive vortices without careful engineering. The design of a draft tube and its effectiveness in various tailwater conditions is also subject to a thorough analysis. If model studies are conducted, an imaginative design in the tailwater depression system can be generated that can be effectively introduced into the prototype. Although each turbine manufacturer outlines the recommended housing arrangement, the assurance of proper approaches and draft tube design is the final responsibility of the civil engineering designer. It is his responsibility to assure uniform approach flows to the turbines and streamline outflow through the draft tube. Through the use of models, draft tube design can be improved for better guidance and shaping to such a degree that flow conveyances are enhanced and does not take place. Improvements can be achieved by experimenting with various shapes and guide vanes for boundary layer suctions during the studies.

HYDROLOGIC INVESTIGATIONS FOR HYDROELECTRIC POWER

James G. Dalton and Gary M. Franc

Hydrologic investigations for the determination of hydroelectric power potential vary with the particular investigator and with the purpose of the investigation. The degree of sophistication and allowable expenditures depend upon the stage of the investigation as it proceeds from first thought, to reconnaissance level survey, to feasibility study, to advanced engineering and design, and to daily operational schemes for large systems of hydrologically and electrically associated water-management projects. This paper is not intended to present some exciting new breakthrough on hydrologic investigation techniques, but rather to provide information on the techniques utilized in the U.S. Army Corps of Engineers' National Hydroelectric Power Resources Study. A number of talks and presentations are being made at this conference which will discuss the history, purposes, and preliminary results of this National Study. This presentation is intended to summarize the hydrologic investigation techniques and the computer modeling techniques used in the study in order that you might assess the value of this study in meeting your particular needs whether they be: specific interest in an individual site, assessment of regional or national potential, marketing surveys for equipment or services, planning of similar studies for other regions or nations, or for academic interest.

The National Hydroelectric Power Resources Study, as directed by the United States Congress, will provide national and regional assessments of the need for hydropower, the physical potential for developing hydropower, and of the existing related institutional arrangements and policies. The study will determine the feasibility for developing various hydroelectric power projects and assess the environmental and socio-economic impacts for these developments. And finally, the study will provide the necessary justification for recommendations to the Congress.

In order to meet many of the needs and objectives of the National Study, an extensive, comprehensive, computer-oriented data base was conceived, designed and implemented. The objectives considered in designing the data base were that it be comprehensive, flexible, easy to use, and relatively inexpensive. The data base is comprehensive in that approximately 50,000 existing water resource projects and approximately 20,000 undeveloped potential projects have been investigated. The data base is flexible in terms of size, alternative computational procedures, user-supplied criteria, and in its ability to provide user-designed displays of results and summaries for various regions and purposes. The data base is intended to be used with a minimal amount of

---

Mr. Dalton is a hydraulic engineer, U.S. Army Corps of Engineers, Southwestern Division, Dallas Texas.

Mr. Franc is a hydraulic engineer, U.S. Army Corps of Engineers, Hydrologic Engineering Center, Davis, California.

user training, since personnel in approximately 50 Corps field offices are required to access the data base and since the data base will eventually be made available for use by a number of other Federal agencies and to other investigators. Particular attention has been given to the selection of computer facilities and to the efficiencies of data handling and of computational requirements due to the limited funds available to the National Study.

A series of computational techniques and a five-step screening plan were established. These procedures were intended to accomplish the study objectives associated with data collection and analysis and project selection within approximately two years. General guidelines for these procedures were to evolve during the two-year period as follows. Field personnel efforts would be initially oriented entirely to the collection of basic data and would evolve toward more detailed field computations and finally field level judgments on project selections for regional plans. Computer computational techniques would begin with very simple operations on minimal data available for the original 70,000 projects and would evolve toward sophisticated sequential project and hydrologic system analysis as more and more data become available on fewer and fewer projects. A centralized management team, assisted by representatives from each Corps Division office, would initially provide all direction of field efforts and make all decisions on criteria and procedural activities. This role would evolve toward less centralized management and increasing management responsibilities in the field. Assumptions made in each step of the screening process would tend to overestimate the potential of each site such that no potentially viable project would be dropped too soon. Any machine result could be superseded by field judgment for any reason. Investigations would be limited to existing projects and to undeveloped sites on which some type of investigation had been previously made and for which some basic data existed. In other words, field personnel were not expected to look for potential sites by topographic map surveys or by any other means.

The initial, rather superficial, analysis of approximately 70,000 sites was designed to take advantage of an existing computerized data base which was developed by the Corps to catalog and rank all existing dams in the United States for priority of study in a National Program of Inspection of Dams. For purposes of the National Hydropower Program, the earlier data base provided name, location, maximum storage capacity, and maximum hydraulic height of dam for some 49,500 existing dams. Since drainage area and flow data were not given, some assumptions had to be made which would allow a relative assessment of the potential at each site. The assumptions used were based on the rationale that height of dam and storage capacity provided in the construction of the dam would give some indication of the flow at the dam. The assumptions used were: that continuous flow would be available sufficient to refill the maximum storage capacity of the reservoir in each 24-hour period; that this flow could be converted to power with a net head equal to the maximum hydraulic height of the dam; and that the combined efficiency of this conversion would be 85 percent.

$$kW = \frac{QHE}{11.8} = 0.072\ QH$$

where kW = power in kilowatts
Q = flow in cubic feet per second
H = net power head in feet
E = efficiency

Since one acre-foot yields approximately 0.5 cubic feet per second for a 24-hour period,

$$kW = 0.072 \times 0.5\ SH = 0.036\ SH$$

where S = storage in acre-feet.

This computation, with its associated assumptions, gives an extremely optimistic estimate on power potential for most dams. Therefore, the screening level based on these results was 1,000 kW. Data on all existing dams which met these screening criteria were transferred by machine to the National Hydropower data base. Data on undeveloped sites which met these screening criteria were coded by field personnel, keypunched, and added to the National Hydropower data base. This initial screening activity reduced the number of projects under active consideration from approximately 70,000 to approximately 17,000.

The next step in the screening process required a preliminary analysis of physical potential at these 17,000 sites. The required results were: power potential in kilowatts; average annual energy in kilowatt-hours; annual costs for construction, operation and maintenance of the power features of the projects; and annual benefits from the power potential. Annual benefits were computed in each case based on the power potential, the average annual energy, the average annual plant factor and regionalized unit benefit values provided by the Federal Energy Regulatory Commission. Annual costs were computed in each case based on parametric cost-estimating curves developed for this purpose which related construction costs of the power features to power potential in kilowatt and design head for the project. Allowances for contingencies, engineering, design, supervision, and administration were added to the construction cost to determine a total investment cost. The total investment was annualized assuming a 50-year life and an interest rate of 6-5/8 percent. Estimated annual costs of operation, maintenance, and major replacement were then added to the annual investment cost to determine the total annual project cost.

In order for the computer program to compute the costs, benefits, power potential, and the average annual energy, the average net power head (assumed to be the design head) and the FERC benefit region must be determined. The field personnel were given three options for providing this information. First, information from a previous study could be entered into the data base. Second, a field estimate, performed specifically for this study could be entered. Third, sufficient basic data to allow machine computation of this

required information could be entered into the data base along with a coded request for machine computation. Basic data required for the third option included drainage area above the dam site, the average net power head, and a selected representative U.S. Geological Survey streamflow gage. Field determination of the drainage area was mandatory. However, options were given on the other two items. In the event the average net power head was not estimated by the field, a machine determination was made based on either the maximum hydraulic height of dam (mandatory) or on the height to normal retention (optional). Assumptions made in the machine selection resulted in an average net head equal to 85 percent of the height to normal retention, when given, or to 72.25 percent of the maximum hydraulic height of dam when the height to normal retention was not given. In the event that field personnel opted not to select a representative USGS flow gage, the latitude and longitude of the dam site were required as input data. Given drainage area, latitude, and longitude, the computation routines automatically selected a gage representative of the dam site.

Given an average net power head and a representative streamflow gage, the machine computations proceeded as follows:

1. Historical daily flows at the representative gage site were converted to a flow-duration curve.
2. The gage flow-duration curve was transferred to the dam site by a simple drainage area ratio.
3. The resulting dam-site flow-duration curve was converted to a power duration by multiplying each flow ordinate by the average net power head and a conversion factor of 1/11.8 or 0.08475.

For each of 10 points on the power-duration curve ranging from the value exceeded 95 percent of time to 5 percent of time, the following computations were performed:

1. Average annual energy was assumed to be equal to the area of the power-duration curve below the selected power ordinate.
2. Average annual plant factor was computed using the selected power value and the average annual energy.
3. Unit capacity and energy values were selected from the FERC power benefit curves and multiplied by the selected power value and average annual energy to obtain annual benefit.
4. Total annual power costs were computed, as stated above, based on the selected power and the average net head.
5. Benefit-to-cost ratio and annual net benefits were calculated from the results in 3 and 4.

A curve was fit to the 10 values of annual net benefits obtained in 5 above and the point of maximum net benefits within the range of investigation (5 percent to 95 percent exceedance) was determined.

The power potential and average annual energy computed at this point of maximum net benefits were selected for subsequent screening and were

printed in our report "National Hydroelectric Power Resources Study Preliminary Inventory of Hydropower Resources" for those projects with power potential greater than 50 kilowatts and a benefit-to-cost ratio greater than one. Some 11,207 sites of the approximately 17,000 sites investigated at this stage were summarized.

The criteria used in selecting power potential for the preliminary inventory (that is, optimization of net benefits) again present an optimistic estimate. These results indicate relative viability of the projects and, therefore, serve their intended purpose for the next screening step. However, these results should not be considered as indicative of the developable power at projects where the machine computation techniques were used. As mentioned, however, the National Hydroelectric Study data base was designed to be flexible and other analyses of the basic data have already been made to answer specific requests.

One such analysis was performed to provide preliminary screening of projects nominated for funding under the Department of Energy's Loan Program for Small Hydroelectric Feasibility Studies. Criteria for this analysis assumed 85 percent efficiency, power potential computed at the rate-of-flow exceeded 25 percent of time, and average annual energy determined by integrating the area under the power-duration curve at the power level. For most projects, these results are considered a more reasonable estimate of the developable power potential.

Results of the various analyses to date have already been used for briefing state and regional interests and for scoping of additional legislative actions. However, three more screening steps are considered necessary for completion of the National Hydropower Study. The original National Hydropower Study data base provided for 67 data items which could be input from the field and for approximately 180 data items resulting from machine computations. The data base has been expanded to accept approximately 225 additional data items from the field and approximately 100 additional data items from machine computations. Of the 17,000 projects analyzed during the preliminary stage, approximately 5,800 projects have been selected for advanced study. These are projects whose potential was shown to be greater than 1000 kilowatts under the preliminary analysis criteria.

The advanced analysis stage for physical potential provides for three optional computation procedures. The first option is a much refined flow-duration curve analysis technique designed primarily for run-of-river type power projects. The major improvements in this technique include: allowance for variable head with variable flow, allowance for upstream water diversions, and allowance for evaporation losses from the reservoir. Additional data items required from the field include: normal forebay elevation, tailwater elevation versus discharge relationships, average annual upstream diversions, and average annual evaporation rates.

Development of a dam-site flow-duration curve will be accomplished as in the preliminary investigations. From that point, computations will proceed as follows:

1. Dam-site flow ordinates will be reduced uniformly by the combined amount of upstream losses to diversions and evaporation.

2. The reduced flow-duration curve will be converted to a head-duration curve using the normal forebay elevation and the tailwater elevation versus discharge relationships assuming that discharge equals the reduced inflow.
3. Combination of the reduced flow-duration curve, the head-duration curve, and appropriate conversion factors will produce a power duration curve similar to that produced in the preliminary study but with a generally different shape.

Given the power-duration curve, a number of power installation sizes will be analyzed in a manner similar to the preliminary analysis and the most economically attractive size will be selected for reporting and screening purposes. More refined regional benefit curves and cost estimating curves are being added to the computation package.

Another refinement in benefit determinations is the selection of a dependable capacity value. For the purposes of this analysis, it will be assumed that the power represented on the power-duration curve, corresponding to the percent of time for which the reasonable alternative power source is considered dependable, will be considered as dependable capacity for the project. This dependable capacity will be credited with the full FERC unit capacity value. Any additional power potential considered during the analysis will be credited with some reduced unit capacity value (probably one-half of the dependable capacity value).

The second optional computation procedure is a single project multiple-purpose sequential analysis designed primarily for storage type reservoirs serving one or more project purposes including hydropower. This sequential analysis is provided by accessing an existing computer program developed by the Corps' Hydrologic Engineering Center in Davis, California. This computer program is commonly referred to as HEC-5C. Sequential analyses provide a much better estimate of potential energy and dependable capacity and provide additional information on the seasonal distribution of the available power potential. Additional data items required for the sequential analysis include: sequential monthly flows, operational reservoir elevations and storage capacities, average monthly upstream diversions, average monthly net evaporation rates, and a monthly distribution of the firm energy demands from the project. Results of the sequential analysis are utilized to determine design head and power potential and for economic computations.

The third optional computation procedure is a multi-project, multiple-purpose system analysis utilizing sequential computation techniques in the HEC-5C computer program. This option provides for analyzing the increased power potential provided by all of the reservoir storage capacities within a basin operating as a system to control the basin's water resources.

After screening of results from the advanced analyses of physical potential, additional information on the remaining projects will be gathered which reflect the environmental, political, and socio-economic effects which development of that potential might have. This will essentially complete the National Hydropower Data Base. At that time, field level judgment will be required in selecting and ranking of projects for development within each Corps

of Engineers district boundary. The district selections will then be coordinated and ranked by division and regional task forces to select and rank projects for development within each electrical reliability council area of the nation. This information, along with other pertinent information being developed for the National Hydropower Study, will be utilized in developing regional reports and final development plans to the Congress.

Special tribute must be given to Mr. Bill Eichert and his staff at the Hydrologic Engineering Center and particularly to Mr. Gary Franc for their efforts in support of the National Hydropower Study. Mr. Franc has done most of the programming for the computational techniques discussed in this presentation and has designed and developed the sophisticated data base management system which provides the flexibility required for this effort. Mr. Art Pabst of HEC is also to be commended for his accomplishments in analyzing the USGS streamflow data and providing, in an easily, computer-accessible form, the flow-duration curves and monthly sequential flow data for each USGS streamflow gage.

In conclusion, the National Hydroelectric Power Resources Study provides for a systematic analysis of each of the existing and previously studied potential water resource development projects in the Nation with regard to the projects' physical potential for hydropower development. We feel fortunate indeed, to be associated with this activity and the many engineers and employees of the US Army Corps of Engineers and of the other Federal agencies who are contributing to its success.

1. FIRST THOUGHT

2. RECONNAISSANCE STUDY

3. FEASIBILITY STUDY

4. ADVANCED ENGINEERING AND DESIGN

5. SYSTEM OPERATION STUDIES

FIGURE D-4.1 Levels of Study

1. SPECIFIC INTEREST IN AN INDIVIDUAL SITE

2. ASSESSMENT ON REGIONAL OR NATIONAL POTENTIAL

3. MARKETING SURVEY FOR EQUIPMENT OR SERVICES

4. SIMILAR STUDY OF OTHER REGION OR NATION

5. ACADEMIC INTEREST

FIGURE D-4.2 Uses of Study Results

1. NEED FOR HYDROPOWER

2. PHYSICAL POTENTIAL FOR HYDROPOWER

3. INSTITUTIONS AND POLICIES

4. FEASIBILITY OF HYDROPOWER DEVELOPMENTS

5. ENVIRONMENTAL AND SOCIO-ECONOMIC IMPACTS

6. RECOMMENDATIONS TO CONGRESS

FIGURE D-4.3 Study Provisions

1. COMPREHENSIVE

2. FLEXIBLE
   - SIZE
   - COMPUTATIONS
   - CRITERIA
   - DISPLAY

3. EASY TO USE

4. INEXPENSIVE

FIGURE D-4.4 Objectives of Data Base

1. SUPERFICIAL ANALYSIS ON EVERY PROJECT

SCREENING

2. PRELIMINARY ANALYSIS OF PHYSICAL POTENTIAL

SCREENING

3. ADVANCED ANALYSIS OF PHYSICAL POTENTIAL

SCREENING

4. PRELIMINARY ASSESSMENT OF IMPACTS

SCREENING

5. DISTRICT LEVEL SELECTION AND RANKING OF PROJECTS

DIVISION AND REGIONAL COORDINATION

6. FINAL SELECTION FOR REGIONAL AND NATIONAL PLANS

FIGURE D-4.5 Screening Plan

FIELD PERSONNEL

BASIC DATA

↘

Judgement on Project Selection

COMPUTATION TECHNIQUES

Simple with Limited Data

↘

Sophisticated with Substantial Data

MANAGEMENT

Centralized Management Team

↘

Increased Field Responsibilities

ASSUMPTIONS

For Optimistic Results

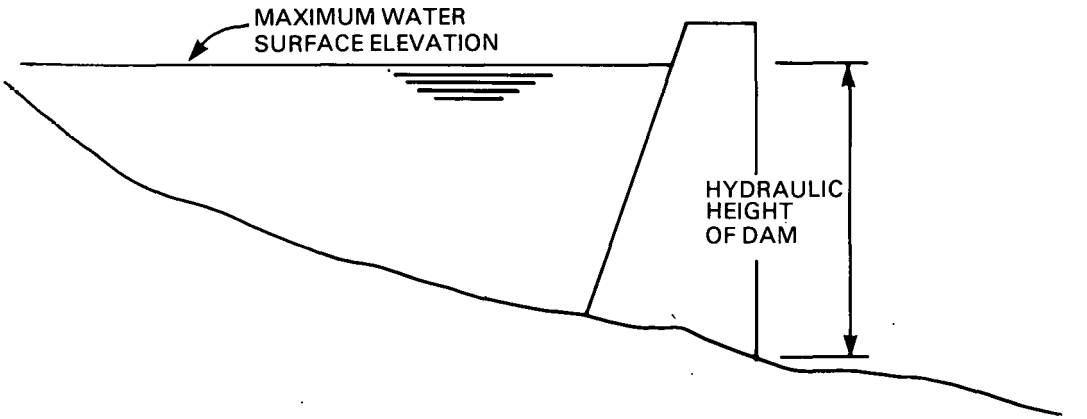
JUDGEMENT

Field Judgement Supercedes Machines Results

SCOPE

Limit to Existing Projects and
Previously Studied Potential Sites

FIGURE D-4.6 General Guidelines for Study Progress



$$kW = \frac{QHE}{11.8} = 0.072 \times Q \times H$$

1 AC-FT = 0.5 CFS FOR 24 HOURS

$kW = 0.072 \times 0.5 \times S \times H$

OR $kW = 0.036 \times S \times H$

WHERE S = STORAGE CAPACITY IN ACRE-FEET

H = HEAD IN FEET

FIGURE D-4.7 Assumptions - Superficial Analysis

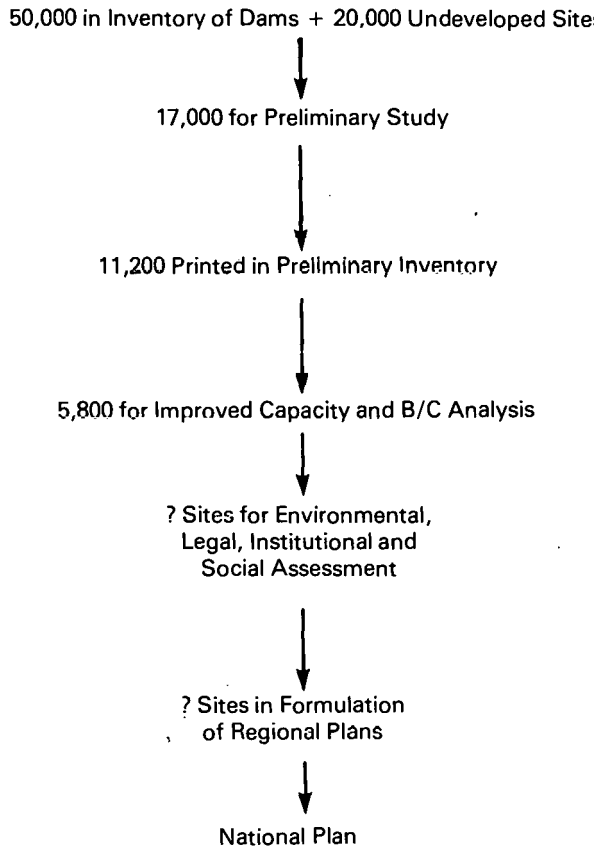


FIGURE D-4.8 National Plan

POWER POTENTIAL -
KILOWATTS

ENERGY POTENTIAL -
KILOWATT-HOURS PER YEAR

AVERAGE ANNUAL
PLANT FACTOR

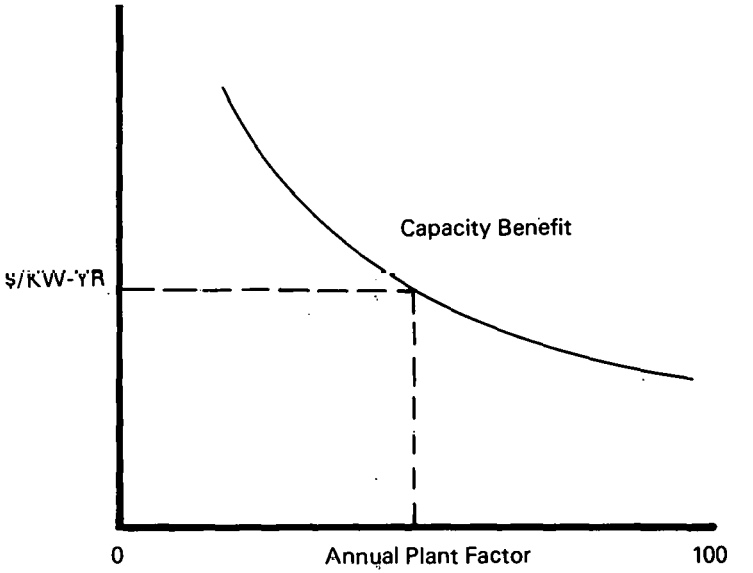
TOTAL ANNUAL COSTS
(POWER FEATURES ONLY)

TOTAL ANNUAL BENEFITS

BENEFIT - TO - COST RATIO

ANNUAL NET BENEFITS

FIGURE D-4.9 Annual Net Benefits



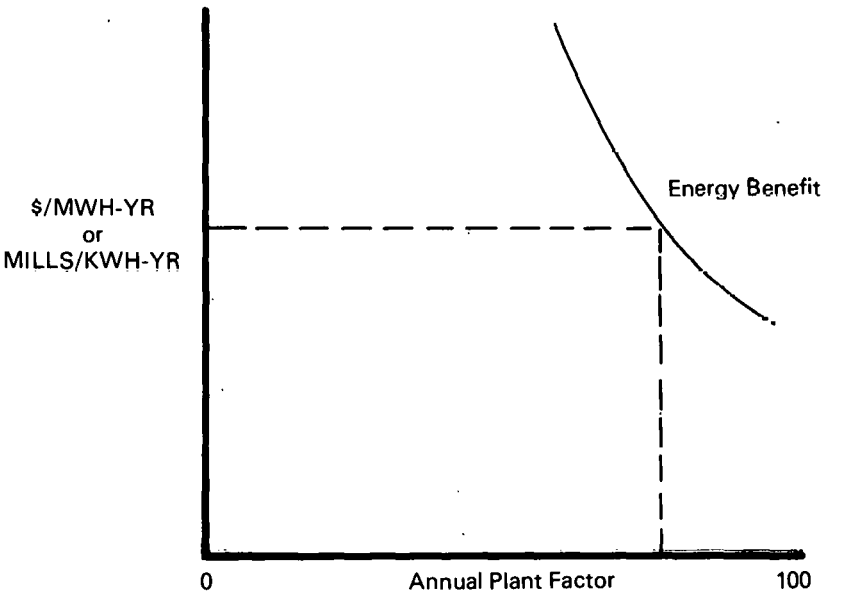


FIGURE D-4.10 Benefit Curves

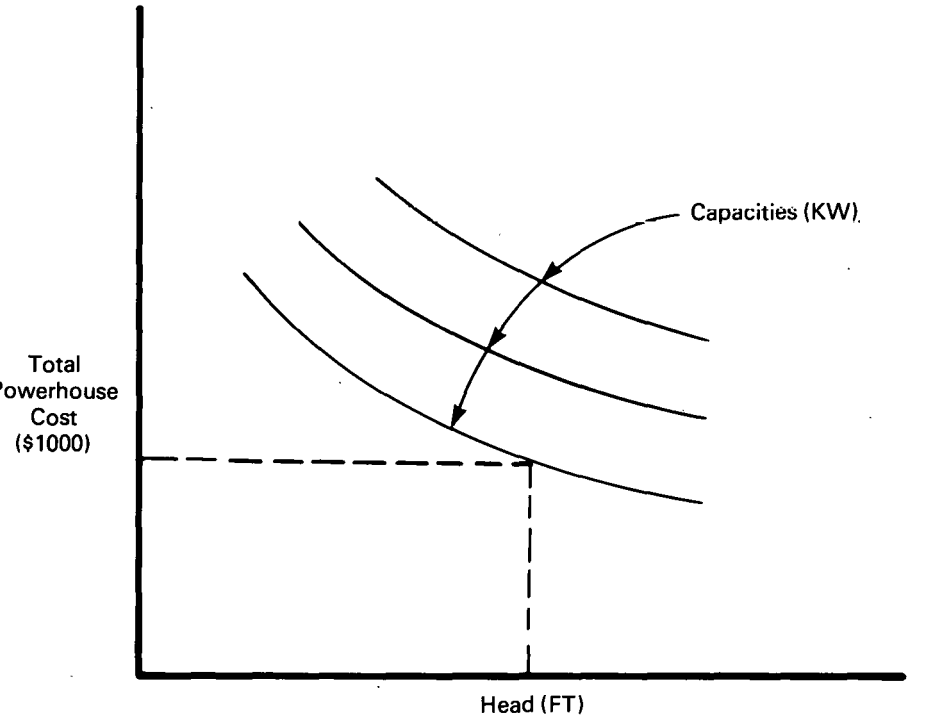


FIGURE D-4.11 Cost Curves

CONSTRUCTION COST

+

CONTINGENCIES

+

ENGINEERING AND DESIGN

+

SUPERVISION AND ADMINISTRATION

= TOTAL INVESTMENT COST

ASSUME: 50 Year Life and 6 5/8 Percent Interest

ANNUAL INVESTMENT COST

+

ANNUAL OPERATION AND MAINTENANCE

+

MAJOR REPLACEMENTS

= TOTAL ANNUAL PROJECT COST

FIGURE D-4.12 Development of Total Annual Project Costs - Preliminary Analysis

PRELIMINARY ANALYSIS RESULTS

1. PREVIOUS FIELD ESTIMATE

2. CURRENT FIELD ESTIMATE (FOR THIS STUDY)

3. SUFFICIENT BASIC DATA FOR MACHINE COMPUTATIONS

FIGURE D-4.13 Field of Options

PRELIMINARY ANALYSIS

1. DRAINAGE AREA *(MANDATORY)*

2. AVERAGE NET POWER HEAD
   A. FIELD ESTIMATE
   B. MACHINE ESTIMATE

3. REPRESENTATIVE U.S.G.S. STREAMFLOW GAGE
   A. FIELD SELECTION
   B. MACHINE SELECTION

(REQUIRES LATITUDE AND LONGITUDE)

FIGURE D-4.14 Basic Data for Machine Computations

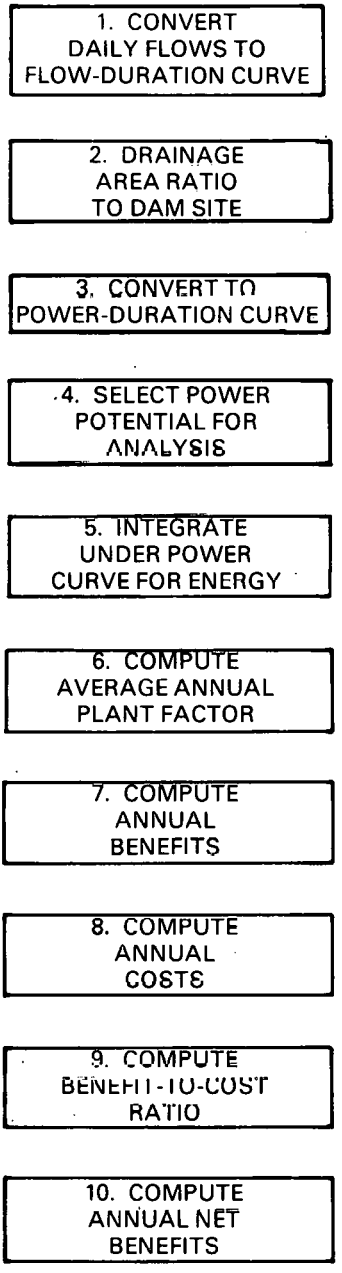


FIGURE D-4.15 Machine Computation Procedures

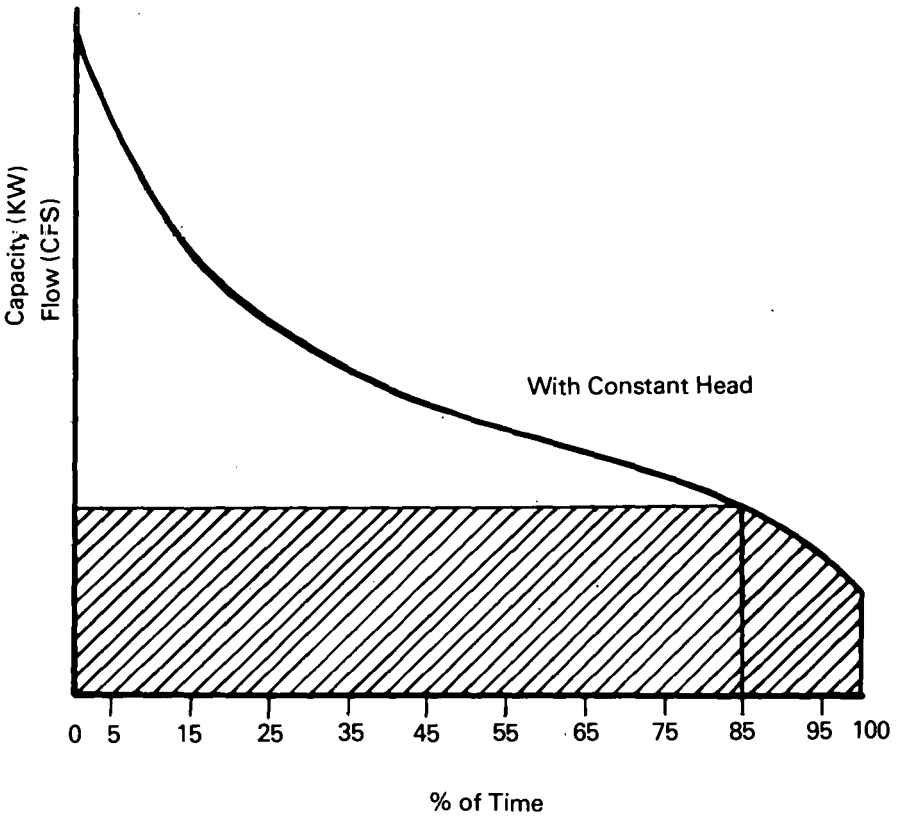


FIGURE D-4.16 Preliminary Analysis— Flow-Duration Curve, Power-Duration Curve

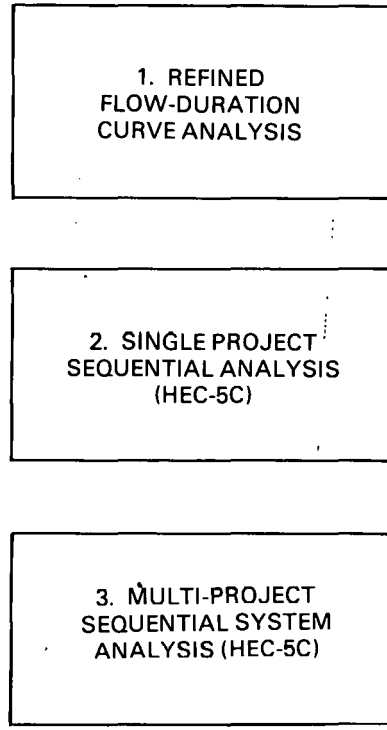


FIGURE D-4.17 Optional Computation Procedures - Advanced Analysis

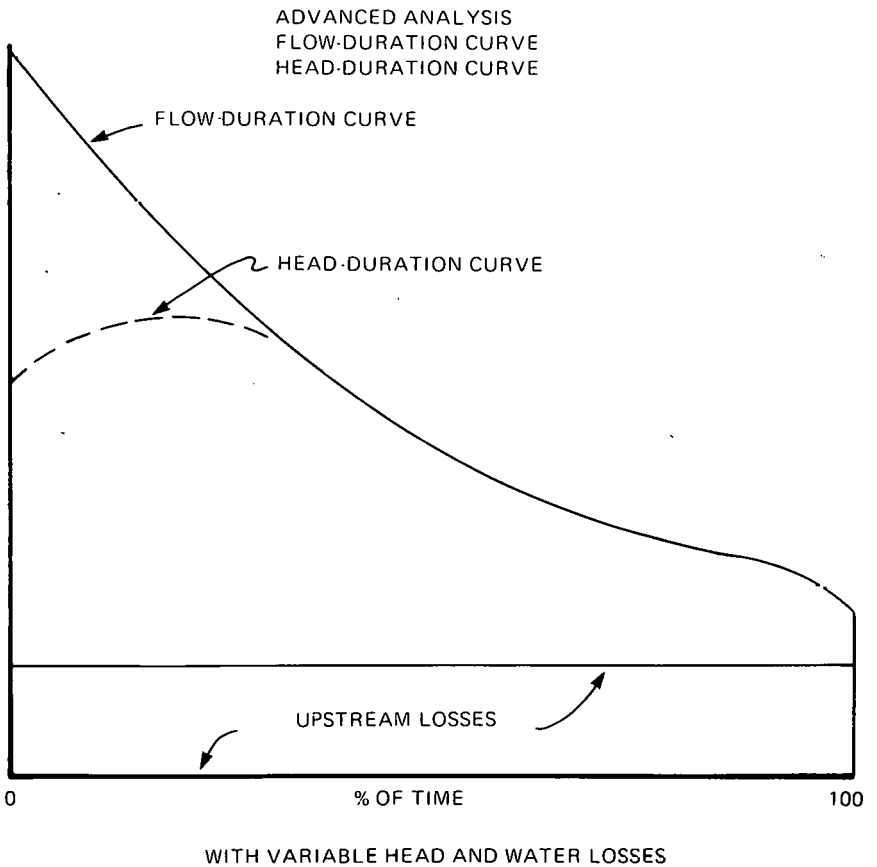


FIGURE D-4.18 Optional Computation Procedures - Advanced Analysis

ADVANCED ANALYSIS POWER DURATION CURVE

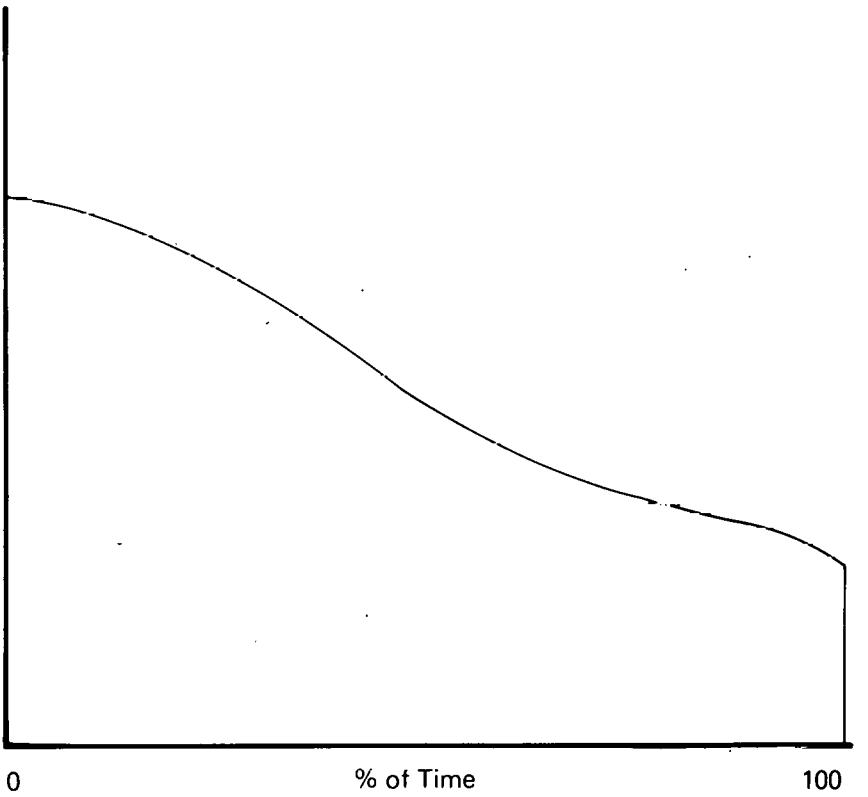


FIGURE D-4.19 Advanced Analysis Power-Duration Curve

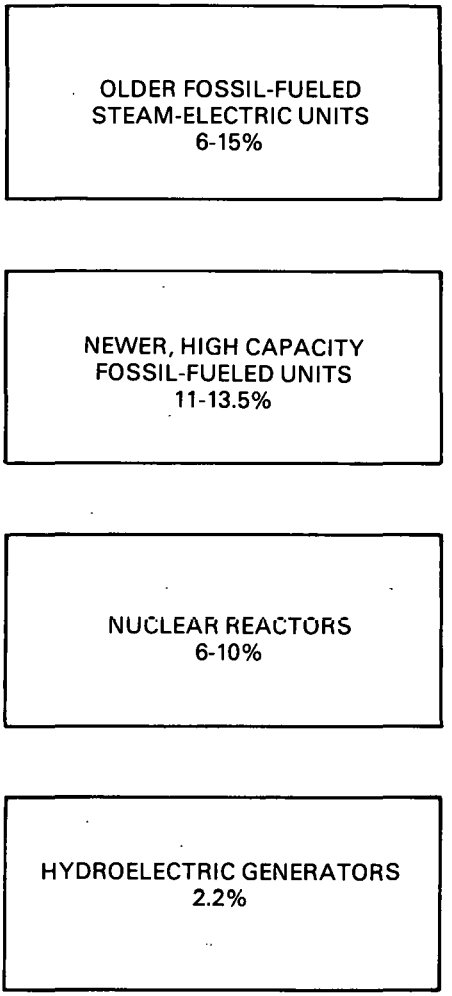


FIGURE D-4.20 Forced and Scheduled Outages

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

Session Twelve

ENGINEERING

Topic: New Ideas, Concepts and Technology I

Chairman: Mr. Richard McDonald
Institute for Water Resources
U.S. Army Corps of Engineers
Kingman Complex
Ft. Belvoir, Virginia 22060

RESEARCH AND DEVELOPMENT NEEDS FOR ALTERNATIVE APPROACHES TO SMALL HYDROPOWER

Edward J. Fritz

The author recently completed a hydropower feasibility study for the owner of an abandoned hydroelectric site near Cleveland, Ohio. The 200-square mile watershed and 50-foot head of the combined dam and waterfall appear more than adequate to support a hydroelectric project. Unfortunately, a very large proportion of total yearly runoff occurs at very high-flow rates because of an impermeable clay watershed and lack of forests and natural or man-made water storage impoundments.

The study indicated that there was no captive use or market for a seasonal and sporadic supply of electric power. Possible uses for the power included sale to the local utility, captive use in a small electrochemical processing plant that would be induced to locate at the site, and use for heating buildings adjacent to the site.

All indications were that the utility might buy power at the cost of displaced fuel, around one or two cents per kilowatt-hour. The anticipated revenue was considerably less than that required for a reasonable return on investment after operation and maintenance costs and debt service were paid. No candidates were found for an industrial use for the electric power.

The third alternative was to use the electric power to heat and light existing and proposed office buildings and apartments located near the damsite. Utility power would be required for backup during periods of low flow or when the generator was out of service. An intertie would involve the complications of purchase and sale of electricity to the utility. Isolated operation of the hydroelectric plant, with provision for switching all or part of the load to utility power, would have been prohibitively complicated and expensive.

These negative factors led to consideration of alternative or non-conventional forms of hydropower recovery in order to make the project economically feasible. Specifically it was proposed to produce hot water directly or to produce unregulated electricity that would be expended to heat water. The hot water would be used to provide space heat and potable hot water for buildings adjacent to the damsite. Summer flows were so low that absorption air conditioning was out of the question. A search was made to find equipment and systems for conversion of turbine energy into hot water or into unregulated electric power. Further consideration led to the idea that turbine controls could be simplified because the turbines would not be required to operate at fixed speed.

This paper will relate the state-of-the-art for application of these alternative forms of hydropower recovery and for simplified methods of turbine control. This will be followed by a digression into the economics of hydropower recovery in light of the need to reduce the consumption of imported oil.

Mr. Fritz is a consulting engineer with Polytech, Inc., Cleveland, Ohio.

Direct Conversion to Thermal Energy

The direct conversion of mechanical energy to hot water is currently being developed for recovery and storage of energy from wind turbines. This application is particularly attractive because the energy developed by a wind turbine is proportional to the cube of the wind speed, while power absorbed by an agitator in a tank of water is proportional to the cube of the agitator speed.

Therefore the speed of a properly selected wind turbine automatically adjusts to match the power input from the wind to the power absorbed by the agitator spinning in the tank of water. The controls for the energy conversion unit (ECU), as the agitated tank of water is called, are minimal and simple, consisting of thermostatic water valves to regulate the temperature of the hot water. It is my speculative opinion, as someone who is not a turbine engineer, that similar systems can be developed for water turbines that do not have to operate at constant speed. The systems should be as self-regulating as possible. Energy conversion units may have the added virtue of being relatively safe from damage at flood-prone dam sites.

The hardware to convert mechanical energy into hot water already exists. The principle has been applied by All American Engineering Company (AAE) to the arrestment of aircraft which cannot stop at the end of the runway. To quote from the manufacturer's literature:

> ... this arresting gear is installed at the edge of the runway with a cable or net stretched across the runway to engage the hook-equipped or hookless aircraft. As an overrunning aircraft engages the cable or net, the nylon tape is pulled off the tape storage drum, turning the paddle wheel. When an aircraft weighing 50,000 lbs. engages at 150 knots the 50,000,000 ft-lbs. of energy raises the 90 gallons of water in the Water Twisters^{R} on each side of the runway about 50°F in fifteen seconds. When the Water Twister^{R} reaches 1,000 RPM during the arrest the equivalent horsepower for a short time exceeds 34,000. AAE envisions a natural coupling of the Water Twister^{R} energy absorber to wind turbines and water wheels where hot water is the desired end product.

An important consideration in the design of any water turbine powered energy conversion unit (ECU) is to match the energy dissipation versus speed curve for the ECU to the energy absorption versus speed curve for the turbine. As mentioned earlier, similar work is underway for wind turbines but it does not appear that AAE is yet in a position to match their Water Twister^{R} to specific turbines. In other words, turbine and ECU hardware is available but matched systems for specific applications cannot yet be specified and purchased. Here is where R&D and demonstration projects are required to develop the system.

Unregulated Electric Power

A second form of energy recovery which is being applied in the wind turbine field is the generation of unregulated electric power. This power is expended in banks of resistors located in hot water tanks or in steam generators. Unregulated electric power has two advantages over direct conversion to hot water. It can be transmitted longer distances and it can be used to generate steam or for heating high temperature heat transfer fluids. Therefore this approach may be preferred where power will be used for industrial process loads.

Unregulated electric power generators are available for coupling to wind turbines. One example is a low-speed alternator that is offered for direct connection to a Darrieus wind turbine. This alternator develops 15 kilowatts at 300 RPM and 30 kilowatts at 600 RPM. Output voltage is a function of both the load and the speed and is approximately 280 volts at 300 RPM and 15 kilowatts. Frequency varies directly with speed, being 60 Hertz at 66 RPM and 180 Hertz at 200 RPM. By an electronic process called "series resonant load matching," the external load is matched to the power available from the wind turbine, while allowing the turbine to operate at the RPM which produces maximum power output for a given wind speed. Again, as in the case of the "hydrothermal" process, R&D is required to apply wind turbine technology to the water turbine.

Variable Speed Turbines

The development of water turbines has quite literally been locked into the need to operate at constant speed. This has led to the development of systems for regulating control gates, blade pitch, or both, in order to maintain high efficiency over a range of load and flow conditions, all the while maintaining constant speed. Constant speed operation requires sophisticated governors which cost almost as much for small as for large-hydro units. All the economies of scale favor the larger units. In addition, the maintenance of these devices requires skilled personnel who are often not available at small-hydro installations. It appears that R&D is in order to take a fresh look at the design and control of small turbines that are not required to operate at constant speed. These turbines should be suitable for driving "hydrothermal" energy conversion units or unregulated electric power generators.

District Heating

A hot water reservoir, heated by either the "hydrothermal" process or by unregulated electric power, has several potential advantages. It can be used to accumulate and store energy over a period of a day or two, and it is readily compatible with use of other energy sources, such as solar, wind, waste heat, and fossil fuel for backup energy.

The potential exists for using hot water from a hydro site for local district heating. District heating of sections of cities was originally developed in the United States a century ago, but as with other conservation-oriented energy processes, it has been largely updated and improved by Europeans. In modern district heating systems, hot water, and not steam, is the preferred medium for energy transfer.

In New England many small-hydro sites are located in towns and cities, or more correctly, towns and cities are located near hydro sites. The potential exists to use hot water generated at these sites for local district heating, perhaps as part of economic redevelopment projects in older sections of town. In most cases such projects would directly displace use of imported oil for space heating and potable hot water.

Economic Incentives for Small Hydro

A recent article in *Newsweek* expressed the popular notion that small hydro will become economically attractive when crude oil reaches $30 or $40 a barrel, a prospect which many people view as more or less inevitable. However, it appears that imported oil now costs considerably more than its world market price if the externalized or social costs or importing additional quantities of oil are added to the market costs.

A Harvard Business School study argues that the number one priority for the United States should be to halt the ever-increasing rate at which the U.S. imports OPEC oil. In making this case, the Harvard study computes the price escalation of all world supplies that will be caused by increased U.S. importation over and above the present level of nine million barrels a day. The Harvard study came up with a minimum social cost (direct plus externalized costs) of $35 a barrel. The study goes on to make the point that even this cost does not include other possible consequences of increased oil imports, such as collapse of the Western monetary system and a world-wide depression.

Will successful research, development, and demonstration of water powered hot water generators permit development of marginal small-hydro sites? Can some small-hydro developers afford to produce hot water? The objection will be raised that, since electricity is so much more valuable than heat, marginal-hydro sites will only be viable if they are used to generate electricity. The answer to this depends on how energy is priced and on what priority we, as citizens, acting through our government, give to all methods that serve to reduce consumption of imported oil.

Therefore the challenge must be met on all fronts. The technology for alternative small hydro must be developed and made commercially available and the price paid for small hydro energy must reflect a national goal of displacing imported oil.

REFERENCES

Hackett, Robert S. 1974. U.S. Patent 3,822,740, July 9, 1974.

Neyeloff, S. & Gunkel, W., 1978, "Design of a Direct Wind Energy Converter to Heat Water by Agitation in a Closed Tank." *Wind Technology Journal*, Vol. 2, No. 1 & 2, 1978.

Gunkel, W. et al., "Development of a Wind-Powered Water Heating System for Dairy Applications." USDA-DOE Workshop: Wind Energy Applications in Agriculture, Iowa State University, May 15-16, 1979.

Nissley, W., "The Wind Turbine/Water Twister^{R} Combination." All American Engineering Company, Wilmington, Delaware. Bulletin M-1394, 1978.

Dynergy Corporation. General Information on Dynergy Wind Turbines System Components and Design Features, Laconia, New Hampshire, 1979.

Zephyr Wind Dynamo Company. *Owners Manual for Series 647 VLS-PM Alternators,* Brunswick, Maine.

Strauss, S., "District Heating Links With Cogeneration." *Power*, August, 1979.

"Praise for Faint Dams," *Newsweek*, September 17, 1979, page 79.

Stobaugh, Robert and Yergin, Daniel, eds., *Energy Future: Report of the Energy Project at the Harvard Business School* Random House, N.Y., 1979.

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

CONCEPTS FOR SMALL-SCALE HYBRID SOLAR-HYDROELECTRIC POWERPLANTS

R. Lewis French and K. Thomas Miller

During the past several years, interest in small-scale hydropower has been rekindled by the same factors that have led to accelerating programs for the utilization of solar energy in more direct forms, and to increased interest in other renewable energy resources. Specifically, exploitation of conventional but relatively dormant domestic resources such as small-scale hydropower, and development of alternate energy resources such as direct solar, wind, biomass, ocean thermal, geothermal, etc. are needed to help fulfill the national goals for energy self-sufficiency. At the same time, the trends of energy economics are steadily improving the cost effectiveness of these alternate energy resources.

However, there are barriers to taking full advantage of all of these resources. There are numerous sites that would be attractive for small-scale hydropower but for their marginal or intermittent water resources. The solar electric technologies (both photovoltaic and thermal conversion) also suffer limitations because of the intermittence of solar radiation caused by the diurnal cycle and by meteorological effects. At present, the long-term storage of either thermal or electrical energy required to completely compensate for the intermittence of solar radiation appears to be beyond the realm of economic feasibility.

This paper discusses concepts for using solar-powered pumping to recycle a portion of the discharge water from small-scale hydroelectric plants. Such hybrid solar-hydroelectric plants have potential for enabling effective utilization of existing dam sites which otherwise may be unattractive for hydroelectric generation. At the same time, the hybrid approach provides an effective solution to the difficult energy storage problems encountered in producing and utilizing electricity from solar energy. Detailed analytical studies, leading to demonstration installations, are recommended to determine the potential of hybrids and to delineate their future role.

Systems Integration

The hydro subsystem of a hybrid solar-hydroelectric powerplant as defined here is essentially conventional whereas the solar subsystem may take any of several forms as indicated in Figure E-2.1 and discussed in the following sections. The linking element between the solar and hydro subsystems is the pump. Whether driven directly by a solar-thermal heat engine or driven by an electric motor running on solar-generated electricity, the pump, in effect further converts solar energy to potential energy by elevating water to an up-

---

Mr. French is Chief Scientist, Fort Hood Solar Total Energy Project at American Technological University, Kileen, Texas.

Mr. Miller is President, Fluid Energy Systems, Inc., Santa Monica, California.

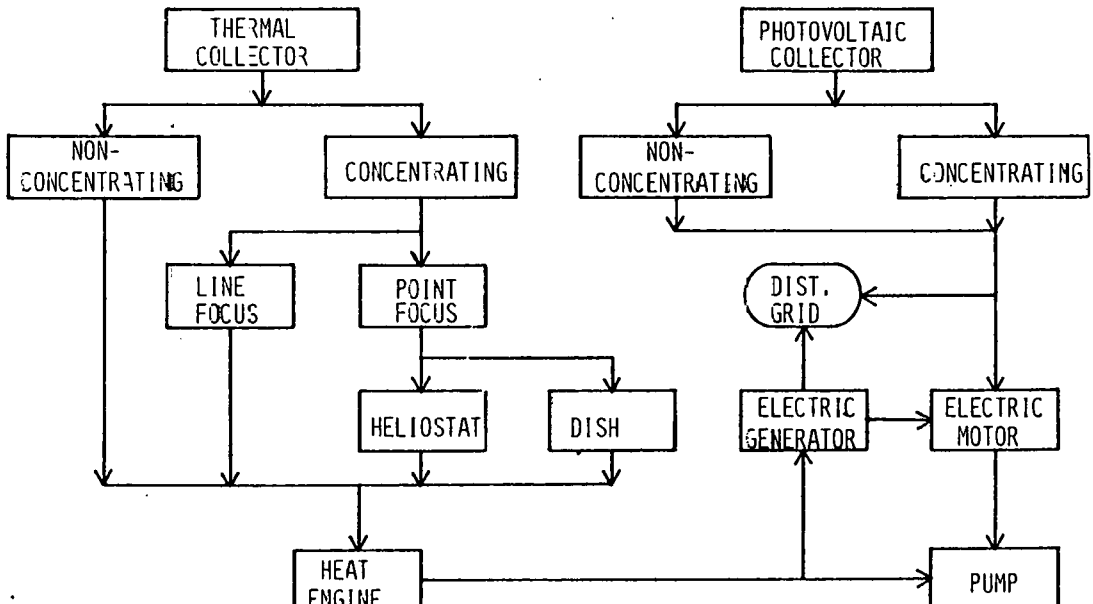


FIGURE E-2.1 Solar Subsystem Alternatives for Hybrid Solar-Hydroelectric Plants

per pool. This potential energy may be stored for long periods of time and then be converted to electricity with losses which are minor compared to the initial solar energy collection and conversion losses.

The upper pool is ordinarily an existing reservoir with considerable capacity and near sufficient water resources for effective stand-alone hydroelectric generation. The topography must be able to accommodate a smaller dam and reservoir, or afterbay, below the main dam. The capacity of the afterbay should be ample to store a few days accumulation of water when solar pumping is not available because of weather.

Water pumped back to the main reservoir differs from run-off water or other water resources supplying the reservoir only in availability as a function of time. Water may be recycled only at those times when usable amounts of solar radiation are available, and thus follows the diurnal and seasonal cycles with variations imposed by local meteorology. Provided there is ample water in the afterbay for recycling, the availability of recycled water is at most only feebly coupled to the availability of the reservoir's other water resources by climatic factors.

From the above, it follows that the physical installation and functioning of the solar subsystem may be essentially independent of the hydroelectric installation. However, the sizes of the solar and hydro subsystems of an effective hybrid system must be coordinated. For example, the output of a hydroelectric plant sized to 25 percent annual flow duration based upon its natural water resources would gain nothing from solar recycling during the 25 percent of the time the plant is already operating at full capacity. However, during this time the output of a solar-photovoltaic or solar-thermal-electric subsystem could be conditioned and fed into the distribution grid along with the hydroelectric output.

The independence of the solar and hydro subsystems suggests that, at one extreme, they could be physically separated and even owned and operated by different entities. However, there are potential benefits from closer integration. For example, multiple turbine-generator sets designed to operate in reverse as efficient motor and pump sets could be used in a hybrid plant with a solor-photovoltaic or solar-thermal-electric sybsystem. Depending upon the temporal characteristics of the load and other generating plants supplying the grid, certain (or even all) of these sets could be pumping water during periods of high insolation, and all sets would be available at other times for hydroelectric generation. Such common use of equipment, including commonality of control, operating and maintenance functions, should result in lower overall costs.

It is noted that a hybrid solar-hydroelectric plant with electrically driven pumps could also serve as a conventional pumped-storage facility for excess nighttime output available from other types of powerplants serving the same electrical grid.

Solar Thermal Subsystems

As may be seen in Figure E-2.1, the major choices for the solar subsystem of a hybrid are the use of photovoltaic cells, which convert solar radiation to electricity, and thermal collectors which collect solar radiation in the form of heat. There are a variety of types of concentrating collectors which could be

used in a solar thermal approach. Non-concentrating, or "flat-plate" collectors, are included in Figure E-2.1 for completeness although their relatively low operating temperatures (~200°F) are not well-suited for driving efficient heat engines.

Concentrating collectors may assume a number of different geometries and have in common the use of reflecting surfaces (or, in some cases, Fresnel lenses) to focus direct sunlight upon a receiver where the absorbed radiation heats a working fluid to temperatures better suited for operating heat engines. Line-focus collectors typically have operating temperatures as high as 400 to 600°F whereas point-focus collectors may produce temperatures of 1000°F or more. Collection efficiencies vary with both collector design and operating temperature, but 50 percent efficiency is a useful rule of thumb.

In 1975, a study was made of a solar-thermal electric generating system at Fort Hood, Texas which utilized pumped storage at nearby Belton Reservoir and Dam to maintain a constant output of 5 MW.[1] Although the size of this conceptual solar system is too large compared to the natural hydroelectric potential at Belton Dam (~2 MW, based on 25 percent flow duration) to view the combination as a realistically balanced hybrid system, some insight may be gained by scaling the solar system downward in size.

The above solar system assumed a field of linear concentrating collectors with 50 percent efficiency which, when scaled down to provide the heat equivalent of 500 kW electrical under average isolation conditions, has a total aperture (active area) of approximately 100,000 ft^2. The heat output of this collector field would be used to drive one or more steam turbines and pumps as shown in Figure E-2.2 for recycling water from the lower pool (an afterbay formed by adding a small dam below the existing dam) to the main reservoir. Enough water would be recycled to continuously generate 77 kW originating from the solar input.

Based upon 2-MW size for the hydro subsystem, the unaugmented annual output at Belton Dam would be 7,715,000 kWh. The solar subsystem would add 675,000 kWh (8.75 percent) annually, and would more than double the total output during the 25 percent of the time that the natural water resources produce less than the 77 kW average attributed to the solar subsystem.

The cost of the solar thermal subsystem described above is dominated by the collector field which, based upon a current representative cost of $25/$ft^2$ for linear concentrating collectors would be $2,500,000. The steam generator, turbine, condenser, pumps, tanks, controls, etc., for the solar subsystem would cost perhaps another $1,000,000. Estimates are not available for installation of the solar equipment and construction of the afterbay.

Photovoltaic Subsystems

Photovoltaic cells convert solar radiation into low-voltage direct-current by the direct interaction of photons in silicon and certain other materials. State-

---

[1] R.L. French, LTC A.J. Cates, D. Rapp and A.A.J. Hoffman, *Solar Energy Program for U.S. Army Installations, Volume III, Solar Thermal Conversion System Concepts for Fort Hood,* American Technological University Phase I Report (March 1975).

(Insert Figure E-2.2 Concept for Hybrid Plant with Solar-Thermal Subsystem at Belton Dam)

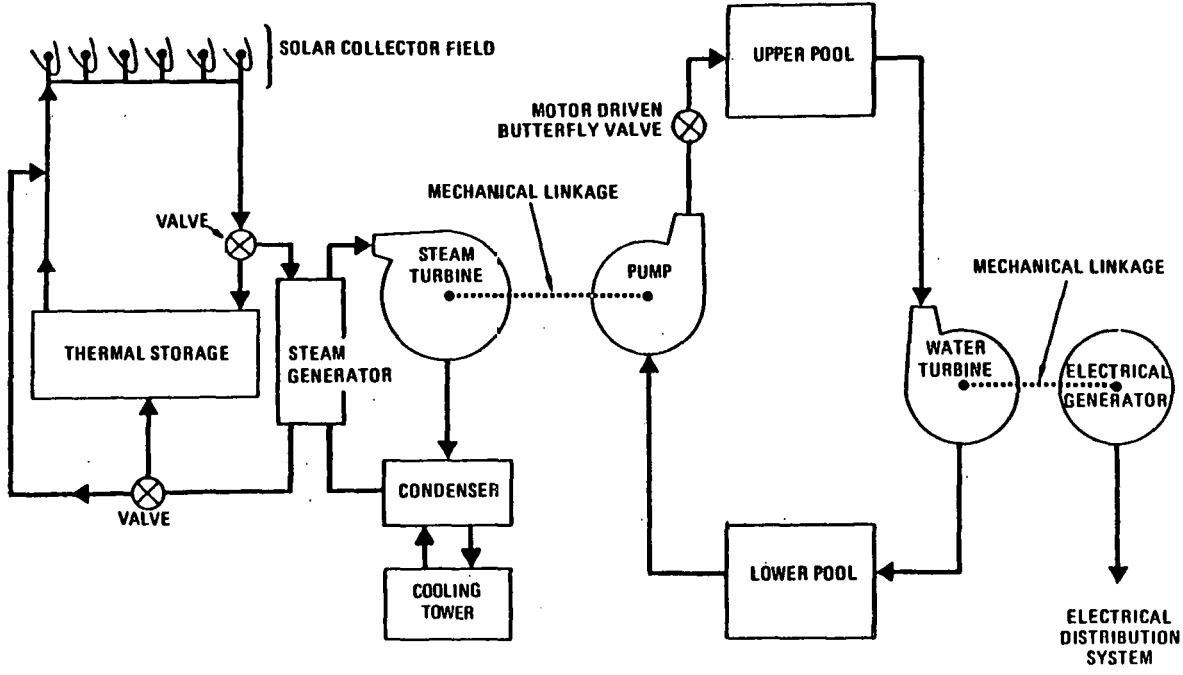


FIGURE E-2.2 Concept for Hybrid Plant with Solar-Thermal Subsystem at Belton Dam

of-the-art cells have a typical efficiency of 10 to 12 percent while advanced cells may reach 15 to 20 percent. Concentrators may be used to increase the amount of radiant energy incident upon individual cells, thus increasing their output. A portion of the solar radiation incident upon photovoltaic cells which is not converted to electricity appears in the form of heat and must be dissipated for effective operation. This is often accomplished by natural air convection, but concentrating arrays may require forced cooling.

An example of a solar photovoltaic subsystem in a hybrid solar-hydroelectric plant is the 500-kW solar test installation proposed for the Santa Felicia Dam at Lake Piru in California.[2] This installation uses 14,286 photovoltaic panels, each measuring approximately 1 by 4 feet. Each panel has 80 silicon wafer cells connected to provide 2 amps at 17.5 volts under maximum power conditions with a peak insolation level of 1000 watts/m^2. This represents an overall collection/conversion efficiency of 9.4 percent based on the actual panel area.

The panels are mounted in sections of 30 each on welded pipe stands on the south face of the dam at an angle of 34° 30' (equal to the latitude) for favorable exposure to the sun year around. The panels in each section are connected in series and the 478 sections are connected in parallel to provide a peak output of 500 kW at 525 volts. The output operates an array of fixed- and variable-capacity pumps. By operating different combinations of pumps, the available photovoltaic output can be utilized effectively under various insolation conditions.

The proposed hybrid system at Lake Piru, shown in Figure E-2.3, has a 2-MW hydroelectric generator planned for installation regardless of whether the solar photovoltaic subsystem is included. Preliminary analysis indicates that the solar subsystem would increase the annual output by 18 percent (from 4,559,000 to 5,392,000 kWh). During winter the solar subsystem increases the monthly output by as much as 60 percent, thus illustrating how seasonal variations may be compensated in a hybrid system.

The photovoltaic cells were originally estimated at $6.00/watt, or $3,000,000 for the 500-kW array, and the motors, pumps and controls for the solar subsystem were estimated at approximately $700,000. More recent estimates based upon $4.00/watt for photovoltaic cells delivered in 1982 would reduce the total equipment cost to about $2,700,000, and achievement of the DOE goal of $1.40/watt would reduce the cost to about $1,400,000. In each case, installation costs and afterbay enlargement would add approximately $1,000,000.

Since the solar subsystems of the hybrids examined for Belton Dam and Santa Felicia Dam are comparable in size, cost comparisons may be made. Based upon recent prices for solar equipment, the two approaches differ little in initial equipment costs, but cost reductions projected for photovoltaic cells are greater than reductions likely to be achieved for linear concentrating collectors, thus making the long-range outlook better for the photovoltaic approach. However, these comparisons are based on only one type of con-

---

[2]Proposed to the U.S. Department of Energy by Fluid Energy Systems, Inc. in response to Program Research and Development Announcement EM-78-D-04-0038 (Solar Photovoltaic Flat Panel Applications Experiments).

(Insert Figure E02.3 Proposed Hybrid Plant with Photovoltaic Subsystem at Santa Felicia Dam)

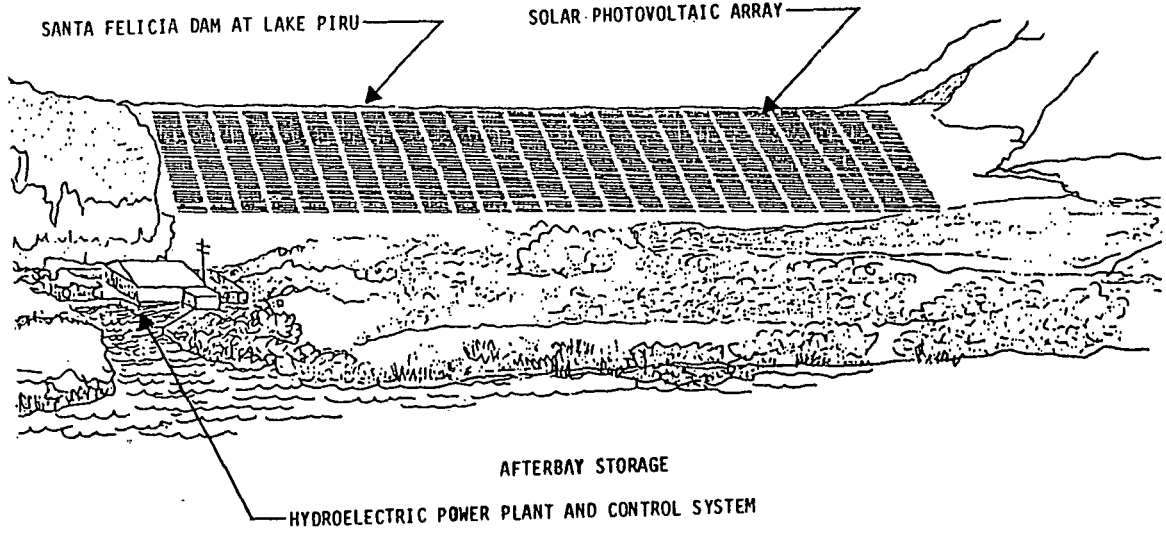


FIGURE E-2.3 Proposed Hybrid Plant with Photovoltaic Subsystem at Santa Felicia Dam

centrating collector; the economics as well as performance could be different with other types.

Conclusions and Recommendations

Preliminary studies of hybrid solar-hydroelectric powerplants indicate that the hybrid system concept has considerable potential, and that the solar and hydro subsystems of a hybrid would be highly complementary. In particular, solar subsystems for recycling discharge water and thus storing solar energy would enable more effective utilization of hydroelectric generating capacity. The output would be increased during periods of low flow, and the intermittent availability of solar radiation for electric power generation would be ameliorated by the pumped storage inherent to hybrid systems.

Questions that need answering regarding hybrid solar-hydroelectric plants include:

- Under what conditions (flow release duration, solar availability, load and operational requirements, etc.) are hybrids attractive?
- Where are the locations and what are the potential capacities of small-scale hydro sites suitable for hybridization?
- What is the total potential installed capacity (kW) and generation (kWh) available in the U.S. for hybrid solar-hydroelectric systems?

Further studies are also required to define the methodology and the best technical approach for the solar subsystem design under different conditions. Detailed lifecycle cost studies considering realistic future cost scenarios should be included.

Studies to resolve the above questions are recommended, and these should be followed by one or more demonstration installations provided the study results confirm a viable role for hybrid solar-hydroelectric plants. These recommendations are consistent with the recommendations made by a panel on hybrid systems at a recent DOE-sponsored workshop on small-scale hydropower.[3] This panel considered hybrids as described herein as part of a broader definition including the use of other alternate energy sources (wind, biomass, geothermal, etc.) in combination with hydropower to produce and/or store energy in a single system.

[3]Proceedings of the Western Regional Workshop on Small Scale Hydroelectric Resource Development, July 30-August 1, 1979, University of California at Los Angeles (to be published).

THE SCHNEIDER ENGINE: PERFORMANCE AND APPLICATIONS FOR HYDROPOWER

Daniel J. Schneider and Emory K. Damstrom

In 1738, Daniel Bernoulli, a Swiss physician, published his derivation of the dynamics and mathematics for describing the independent relationship between pressure, density, velocity and area variables in fluid-flow physics. His famous theorem is a classic of physics and remains the basis for designing working systems that react to the kinetic energy of fluids in motion.

In most flowing fresh-water settings, representing approximately 80% of the slope of our nation's rivers, only minimal pressure (and thereby velocity) differences can be established by means of dams without flooding of large acreages of valuable land. Applying physics defined by Bernoulli in conversion of the collectively emense quantities of kinetic energy into power (P_{KE}) from our numerous low-head settings, where $P_{KE} = \rho x \frac{V^3}{2} x A$, requires that technology be used that can treat stream-tube cross-section area (A) (necessarily large area) with absolute mathematical independence from density (ρ) and velocity (V). The "lift translator" is the only dynamic mechanical device which can fulfill this mathematical requirement; "lift rotors" such as turbines are mathematically excluded because both fluid-flow transection area and foil velocity (and thereby the velocity ratio) are functions of radius. This challenge to make extensive use of the extremely large quantity of kinetic energy in low-head hydropower settings (10^{16} MW at any instant worldwide) together with the 240 year-old physics set out by Bernoulli has inspired the invention of the "Schneider Engine", patented worldwide, which introduces the effective use of lift translators as prime movers at fixed locations (See Figure E-3.1). Historically, lift translators have been used for transport objectives— sails on sailboats, airplane wings, hydroplane foils; where we clearly understand the physics of their application.

Figures E-3.2 and E-3.3 depict the adaptation of the Schneider Engine applied to low-head hydropower settings. Water flow at entry is stabilized by the entryway to establish a uniform x-vector velocity distribution. The first cascade guidevanes use the pressure head to produce a downward z-vector component which is absorbed by the downward translating hydrofoils. The pressure head is hydrostatically shared by the second cascade guidevanes to produce an upward z-vector component which is absorbed by the upward translating hydrofoils. The water flow leaves the hydrofoils with only the original x-vector remaining, the kinetic energy of this vector quantity being recovered by means of a draft tube. The linear translation of the hydrofoils is converted to rotational motion of the axles at each end of travel. One of the axles is coupled to a transmission and generator.

The Schneider Engine is a breakthrough with many technological and cost advantages over conventional rotors; these are represented in Figures E-3.4, E-3.5 and E-3.6, and Tables E-3.1, E-3.2 and E-3.3. The *first major technological*

Dr. Schneider is owner of the Schneider Lift Translator Corporation and the Schneider Engine Co., Justin, Texas.

Mr. Damstrom is an aeroengineer with Schneider Lift Translator Co.

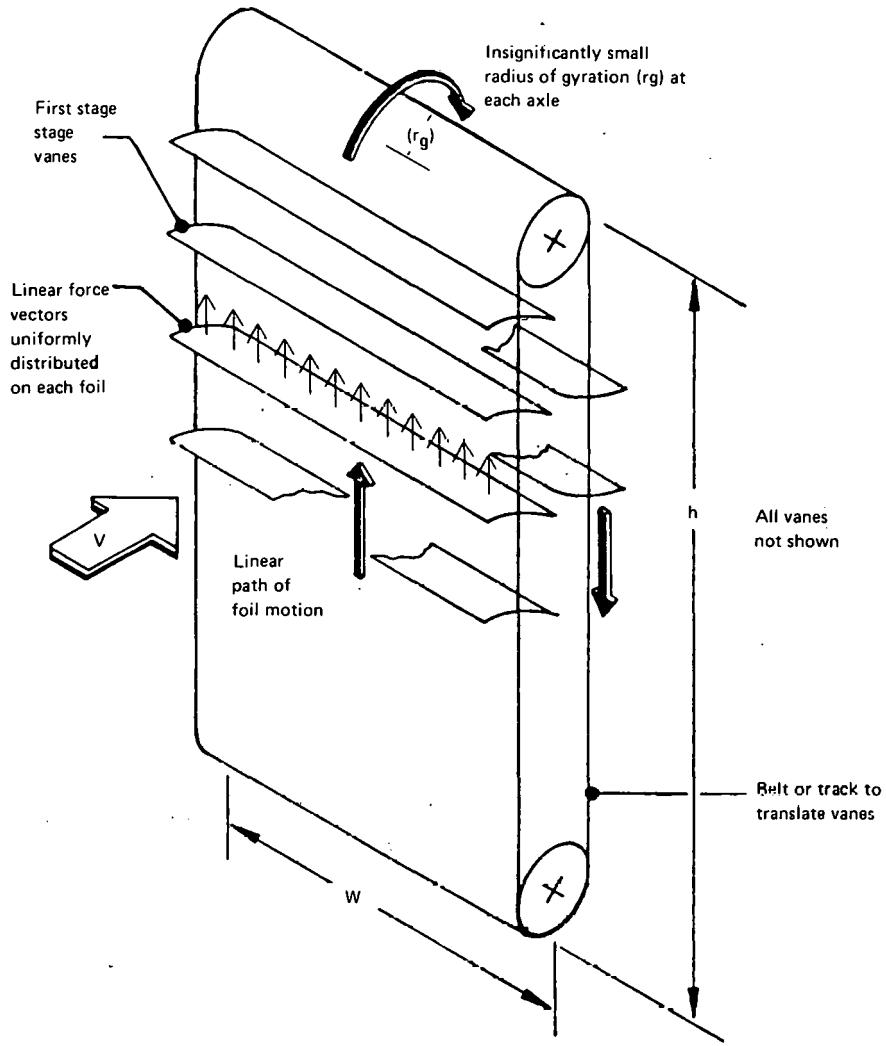


FIGURE E-3.1 Basic layout of the Schneider engine

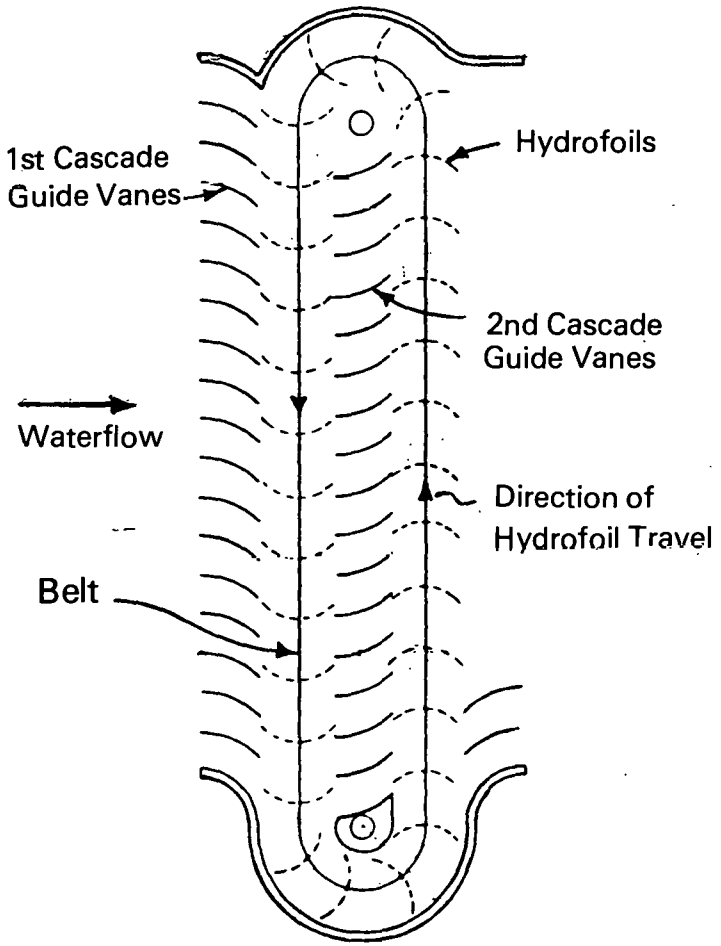


FIGURE E-3.2 Design and Operating Features of the Schneider Engine

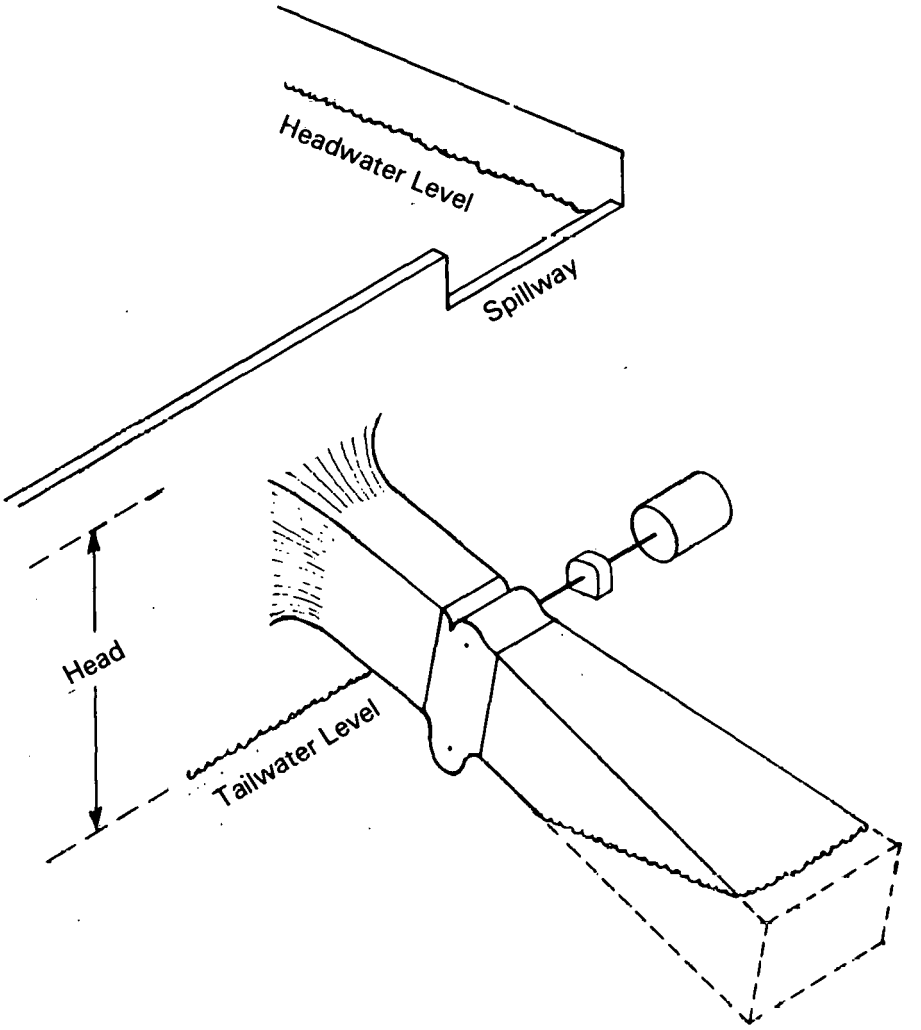


FIGURE E-3.3 Stylized Rendition of low-head Schneider Engine installation.

1) Achieves Large Area Independent of Vel. in Applying $P_{KE} = \frac{\rho \times V^3 \times A}{2}$

2) Conversion of Linear Reaction Force into Linear Motion; No C_F Strains.

3) Avoidance of Cavitation; Easy Manipulation of $p_1 + {}^1/_2\rho\, v_1^2 = p_2 + {}^1/_2\rho\, v_2^2$

4) Mechanically Simple; No Controls Needed For Pitch Control or Runaway.

5) Low Cost of Manufacture, Installation, Operation Because of Ease of Manufacture and Long Life of Foil Components.

6) Low Liability.

FIGURE E-3.4

MAJOR TECHNOLOGICAL ADVANTAGES OF THE SCHNEIDER ENGINE

TABLE E-3.1

SCHNEIDER ENGINE ADVANTAGES

Operating Characteristics	SE	TURBINE
1. Foil and Fluid Velocities		
Foil/Fluid Ratio	uniform	variable[1]
Magnitude	low	high
2. Wake Kinetic Energy Losses	absent	present
3. Centrifugal Acceleration		
Duration of Operating Time	25%	100%
Magnitude	low	high[1]
Head of 7 ft : Operation	3 g's	30 g's
(200 kW) Runaway	9 g's	100 to 270 g's
4. Foil Imbalance	insensitive	sensitive
5. Cavitation	absent	present
6. Flow Area		
Magnitude	arbitrary[3]	limited[1]
7. Shaft Speed	arbitrary[3]	limited[1]
8. Runaway Consequences		
Speed Above Normal	80%	80 to 200%
Centrifugal Force/Imbalance Hazards	avoided	possible
Flow Rate Decrease	30%	> 30%
Intolerable Surges	avoided	possible
Design Features		
1. Foil Design	simple	complex[1]
2. Throat Shape	rectangular	curved
Economic Factors		
1. Foil Design and Manufacturing Cost	low	high
2. Foil Maintenance Cost	none	uncertain
3. Delivered Cost[2]	low	high
Head of 13 ft	$230/kW	$350 to $1150/kW

[1] This undesirable turbine characteristic arises because of its dependence on the rotor radius.
[2] Prime mover, speed increaser, generator, and normal equipment and accessories.
[3] Flow area and shaft speed are completely independent.

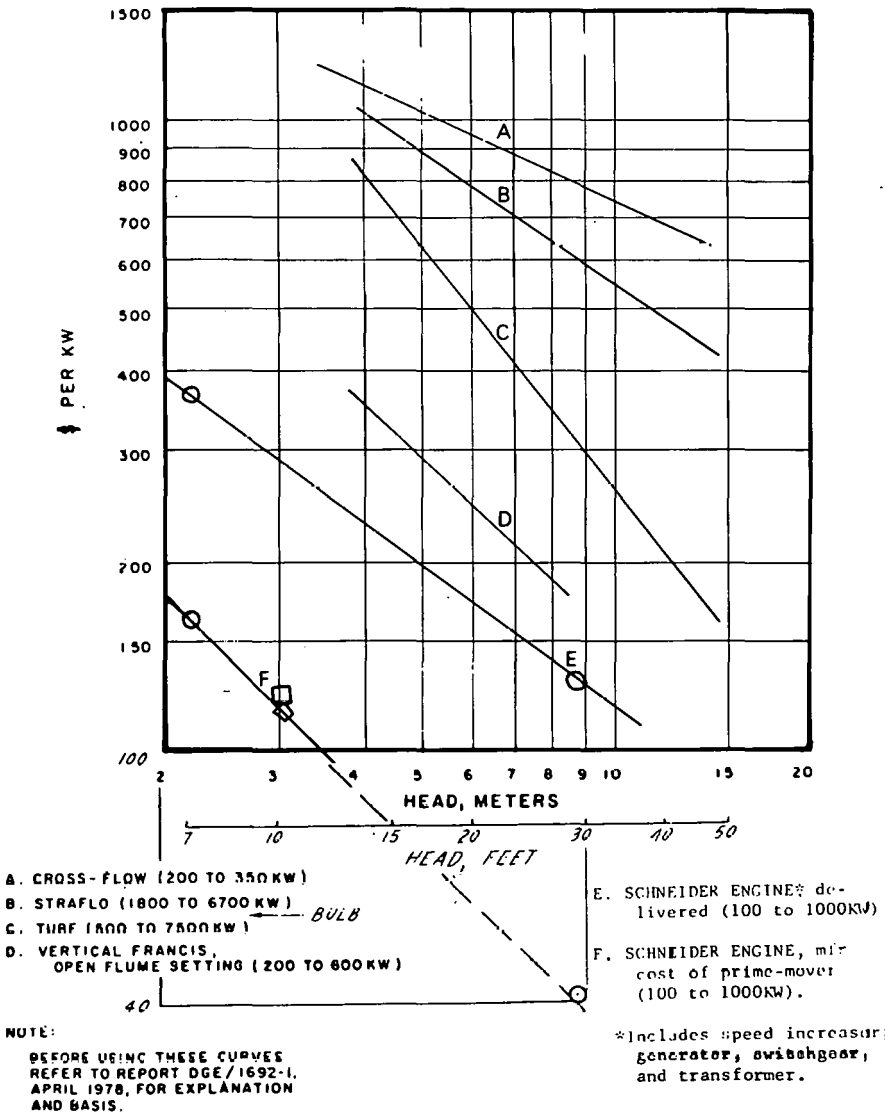


FIGURE E-3.5 Delivered Cost of Small Lowhead Turbo- Generator Equipment

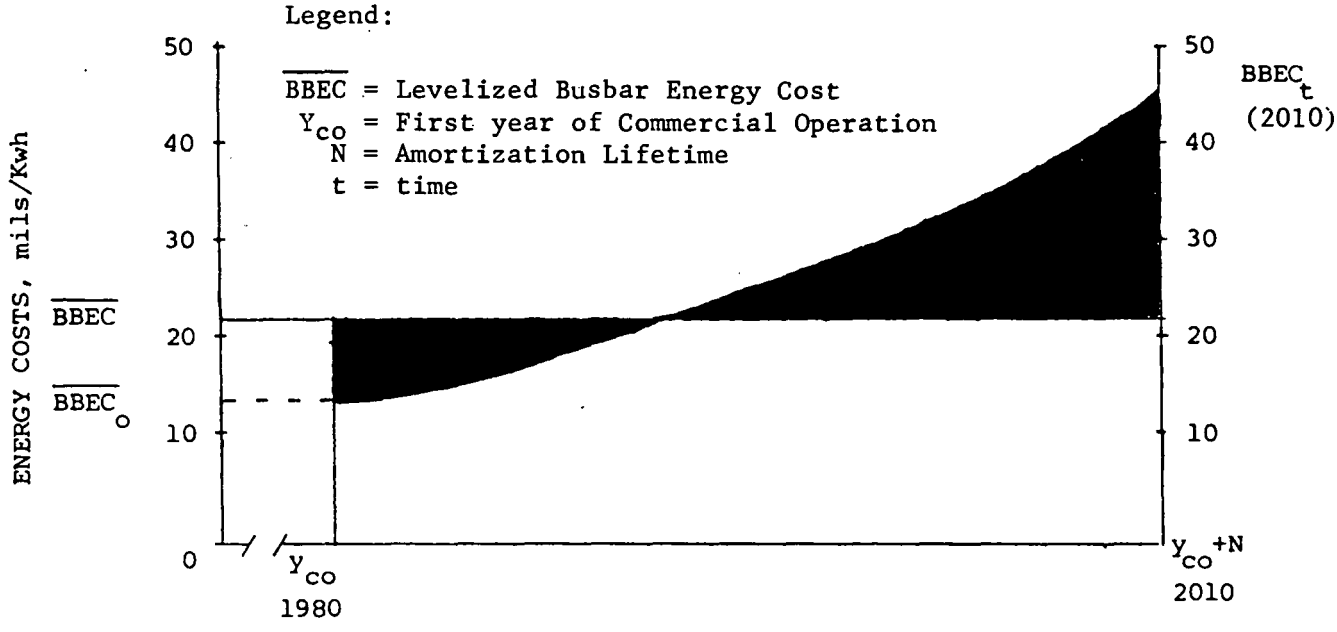


FIGURE E-3.6 Comparison of Levelized Energy Cost with Growing Energy Costs; Low-head Installation of Schneider Engine

TABLE E-3.2

SE WATER PASSAGEWAY ADVANTAGES

Operating Characteristics	SE	TURBINE
1. Main Flow Path	straight	curved
2. Energy Loss	negligible to small	small to significant
Design Features		
1. Entryway Size Relative to Throat Size	same	larger
2. Entryway and Draft Tube Design	simple	complex
Economic Factor		
1. Passageway Design and Construction Cost	low	high

advantage has already been discussed: ACHIEVEMENT OF AREA DIMENSIONED ARITHMATICALLY INDEPENDENT OF VELOCITY; thereby establishing a uniform velocity ratio over the entire stream cross-section. Regardless of span (foil length) the velocity of the foil is uniform; high-tip speeds are not encountered; and area can be easily manipulated to whatever extent the flow continuity equation might dictate for any given head and flow rate. Dimensions h and/or W of Figure E-3.1 can be varied with no effect on the independent relationship of foil velocity and V.

The *second major technological advantage* is: CONVERSION OF LINEAR REACTION FORCE EXERTED ON THE FOILS BY THE FLUID FLOW INTO LINEAR MOTION; as illustrated in Figure E-3.1. This technological advantage is a breakthrough of monumental significance because it eliminates serious induced g-loads on the foils. Lift rotors, by physical definition, convert the linear lift force exerted by the fluid flow into rotational blade motion resulting in high g-load stresses on the foil hubs as well as extreme sensitivity to balance severe technical disadvantages for rotors.

TABLE E-3.3

DELIVERED COST OF SCHNEIDER ENGINE
1:5.55 State-of-the-Art Scale Up

	Delivered Cost,	$/kW
Major Item	860 kW	6880 kW
	7.25 ft head[1]	29 ft head
SE Mfg (Parts 1-28)	160.05	41.74
Speed Increaser to 1800 rpm	60.00	30.70
Electrical: Induction generator, switchgear and transformer.	69.07	31.32
Profit, OH, Comm., and Royalty	69.76	23.26
Total Delivered Cost	358.88	127.02

[1] TID Drop 6

The *third major technological advantage* is: AVOIDANCE OF CAVITATION. Lift translators of the Schneider Engine can be mathematically manipulated with ease in application of Bernoulli's theorem, $p_1 + {}^1/_2\rho v^2 = p_2 + {}^1/_2\rho v_2^2$, such that p_2 never falls below the ambient vapor pressure of water. This is accomplished by geometric control of camber, chord, solidity and velocity ratio. Lift rotors must endure high tip speeds together with small-foil wetted surface area causing low-head turbines to suffer the significant disadvantage of cavitation; for low-head rotors, p_2 invariably falls below the ambient vapor pressure of water.

The *fourth major technological advantage* is: MECHANICAL SIMPLICITY AND HIGH SPECIFIC SPEED. The Schneider Engine hydrofoils typically do not require pitch control. The small axle sprocket diameter as contrasted to the large fluid stream cross-section provides a high output shaft rpm and a small radius of gyration as the foils migrate over each axle. Thus the Schneider Engine has a high specific speed which reduces output shaft size requirements and reduces speed increaser ratioing. The small radius of gyration results in centrifugal force stresses being low even under runaway conditions; thus runaway controls to safeguard the system are not needed. Rotors require complex controls both for pitch control and for runaway protection, and have low specific speeds that require heavier shafts and higher gear-up ratios.

The *most significant consequence* of these obviously major technological advantages of the Schneider Engine *is very low cost* of manufacture, installation, operation, and maintenance, reflected in Figures E-3.5 and E-3.6, and Table E-3.3. The basis of calculation of the Schneider Engine cost curves shown in Figure E-3.5 are as set forth in Stone & Webster/DOE IDO-1692-1, and the levelized busbar energy costs of Figure E-3.6 are computed using ERDA/EPRI methodology.

The net effect of these major technological and cost advantages are:

1. Facility to operate cost-effectively at heads as low as even ambient flow (i.e. ocean and tidal currents) where rotors are absolutely not cost-effective
2. Facility to operate at low heads where discharges are very large, i.e. the Mississippi river;
3. Facility to markedly reduce costs of power produced at settings of sufficient head for rotors to operate albeit at high cost of manufacture, installation, operation and maintenance, i.e. head below 50 feet; and
4. Facility to integrate the slope of rivers in small increments to produce collectively large quantities of power comparable to high head installations, but without inundating valuable land, i.e. St. John River valley in Maine.

Theoretical Analysis of the Schneider Engine and Test Results

Commencing in 1960, theoretical analyses of the Schneider Engine for hydropower operation have been performed to provide design guidance and to investigate operating characteristics of the lift translator concept. Theory assumes that the guidevane and hydrofoil forces are defined by the rate of

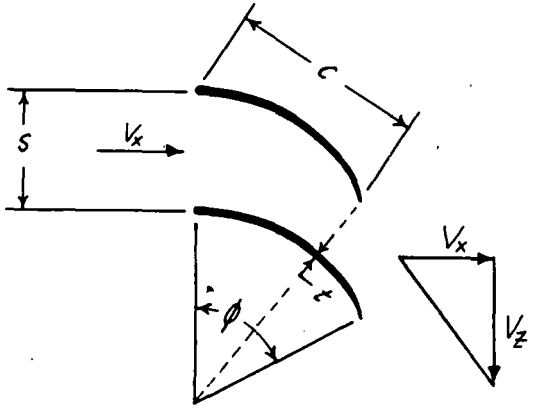
change in momentum of an incompressible, inviscid fluid. Convenient geometric parameters are used in solutions that define the fluid velocity provided by the stationary guidevanes and the fluid velocity required for the moving hydrofoils.

The cascade geometry and fluid velocities associated with the guidevanes are illustrated in Figure E-3.7. The magnitude of the fluid velocity leaving the guidevane cascade is established by applying flow continuity from leading edge to trailing edge of adjacent guidevanes. The fluid enters the cascade at a given velocity V_X which is perpendicular to the cascade and tangent to the vane mean camber line at the leading edge. The fluid leaves the cascade at a velocity defined by the mutually perpendicular components V_X and V_Z. The velocity ratio V_Z/V_X is a function of the cascade solidity σ, the guidevane camber angle ϕ, and vane thickness ratio t/c. An increase in one or more of these three geometric parameters causes an increase in flow convergence within the cascade and hence an increase in the velocity ratio provided to the hydrofoils, as illustrated in Figure E-3.7.

The cascade geometry and fluid velocities associated with the hydrofoils are illustrated in Figure E-3.8. The velocity of the fluid entering the hydrofoil cascade is established by the deviation of the exiting fluid velocity vector from the tangent to the hydrofoil mean camber line at the trailing edge. The fluid leaves the hydrofoil cascade at the same velocity V_X that the fluid entered the guidevane cascade. Relative to the moving hydrofoil, the given exiting velocity is defined by the mutually perpendicular components V_X and V_H, where V_H is the hydrofoil velocity. The angle formed by this relative velocity and the tangent to the hydrofoil mean line at the trailing edge is the flow deviation angle δ. As shown in Figure E-3.8, this angle is defined by Carter's rule as a function of hydrofoil camber angle ϕ and solidity σ. The fluid enters the cascade at a velocity tangent to the hydrofoil mean line at the leading edge. This velocity relative to the moving hydrofoil is defined by the mutually perpendicular components V_X and $V_Z - V_H$. The relation between the given exiting velocity and the unknown entering velocity was developed to show that the velocity ratio V_Z/V_X is a function of solidity and camber angle. An increase in one or both of these geometric parameters will increase the velocity ratio V_Z/V_X required from the guidevanes; see Figure E-3.8.

The hydrofoil and guidevane cascades are said to be matched, theoretically, when the ratio V_Z/V_X required by the hydrofoils is the same as the ratio provided by the guidevanes. Hense, theoretical matching based on V_Z/V_X, provided a means of selecting the hydrofoil and guidevane cascade geometry to be tested, as indicated by the test points in Figures E-3.7 and E-3.8. This velocity ratio not only provided a technique of matching hydrofoils with guidevanes in terms of camber angle and solidity, but also formed the basis for theoretical solution of flow conditions and operating characteristics.

The flow conditions and operating characteristics of the Schneider Engine are defined by non-dimensional coefficients which provide a means of applying theoretical predictions to an arbitrary size and in projecting model test data to a geometrically similar prototype. The scaling criteria—velocity (kinematic) similarity and force (dynamic) similarity—were satisfied in the development of unique definitions of coefficients for head, flow-rate, torque, and power. The uniqueness is in the use of two independent geometric



$\frac{c}{s} \equiv$ SOLIDITY σ

$\frac{t}{c} \equiv$ THICKNESS RATIO

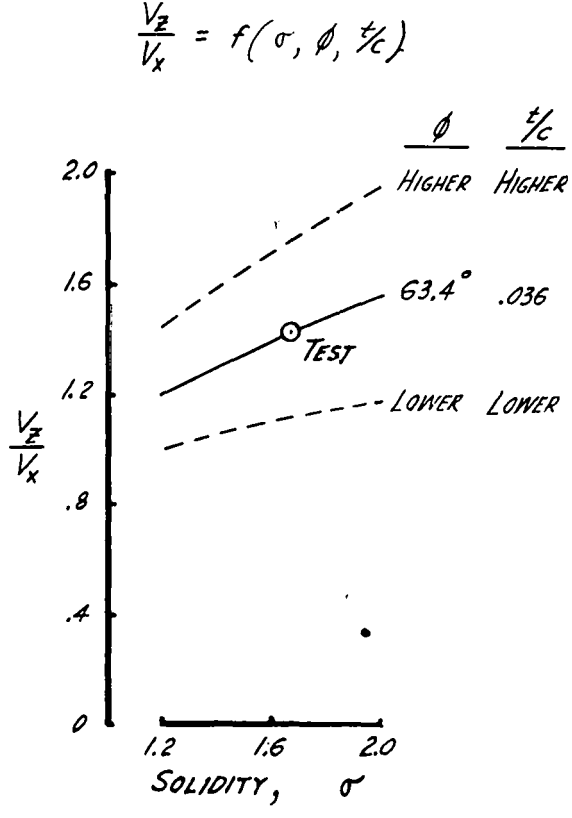
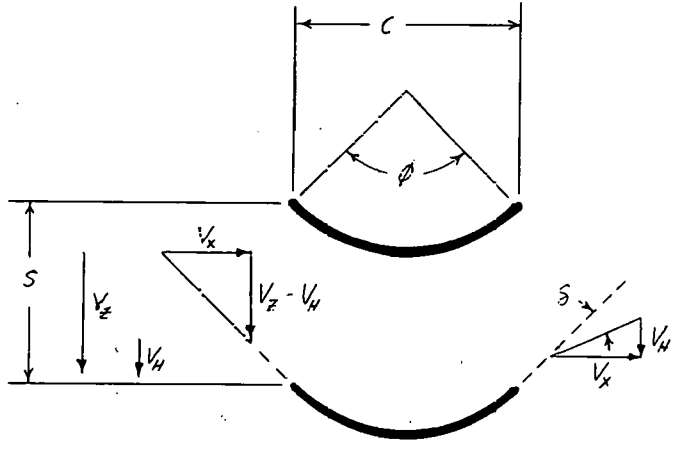


FIGURE E-3.7 Cascade Geometry and Velocity Ratio Provided by Guide Vanes



$\frac{c}{S} \equiv$ SOLIDITY σ

$\delta \equiv$ FLOW DEVIATION ANGLE $\propto \frac{\phi}{\sqrt{\sigma}}$

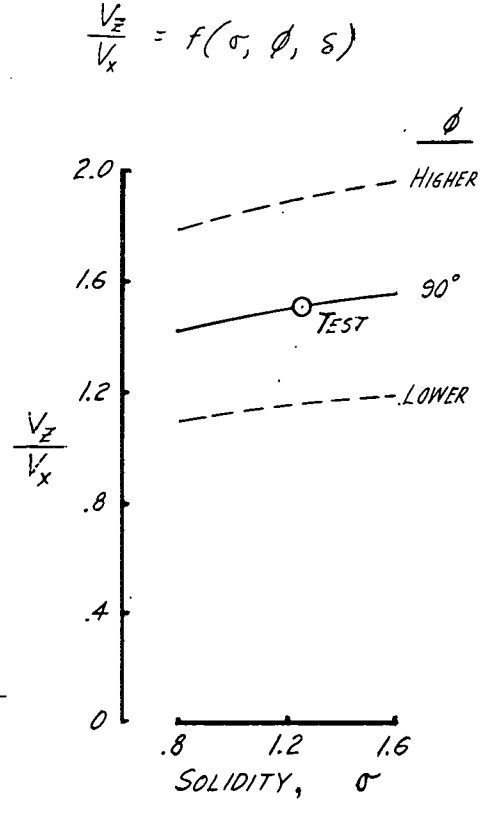


FIGURE E-3.8 Cascade Geometry and Velocity Ratio required of Hydrofoils

parameters, sheave pitch diameter D and throat flow area A, as opposed to a single parameter, e.g. rotor diameter, for conventional turbomachines. The uniqueness arises because of the translating, rather than rotating, feature of operation that allows the throat flow area to be independent of — not limited by — the hydrofoil velocity. The theoretical curves in Figure E-3.9 show a common value for the flow, torque, and power coefficients.

The performance coefficients for hydraulic efficiency and power specific speed in Figure E-3.10 are definitions common for all hydrodynamic machines. The theoretical curves show an efficiency of 80 percent and a peak value of power specific speed coefficient when the velocity ratio is $\sqrt{2}$. At higher velocity ratios, an increase in efficiency is predicted with only a slight decrease in power specific speed coefficient, thereby providing favorably high efficiencies for low-head applications. The dashed curve for the ratio C_H/C_Q^2 predicts the relationship between head, flow rate, and throat flow area for a given velocity ratio (i.e., given geometry for matched guidevane and hydrofoil cascades), thereby providing a means of sizing the Schneider Engine for a given head and flow rate.

In 1975 and 1976 the first models of the Schneider Engine for confined flow operation were built in Korea, and in 1977 and 1978 refined models were tested at the University of California, Davis Hydraulic Laboratory, the later model testing project receiving some support from the DOE. The guidevane and hydrofoil cascade geometries were matched for peak power specific speed coefficient, theoretically, i.e., $V_z/V_x = \sqrt{2}$. One model was tested at seven flow rates and at various shaft speeds to determine peak efficiency. The test data in Figures E-3.11 and E-3.12 show good correlation of the non-dimensional coefficients. The flow coefficient was chosen as the independent variable, since by definition this coefficient is a measure of the flow rate for operation at constant shaft speed. Theory at peak efficiency is shown to be in good agreement with test results. This indicates that the present theory is not only useful to match the guidevane and hydrofoil cascades: the theory is valid to predict flow conditions and operating characteristics of the Schneider Engine. Although the test peak efficiency of approximately 80% is a respectable value for low-head units, an efficiency of 90% is believed to be achievable by further geometric manipulation while still maintaining a high-power specific speed coefficient.

Application of the Schneider Engine to Low-Head Hydropower Production

The unique performance of the Schneider Engine both in terms of dynamic and cost parameters leads to definition of major market potentials. Four prominent application markets are obvious:

(1) In water distribution projects; i.e. irrigation canals, viaducts, etc. to enhance the cost-benefit of these projects.
(2) River basin power development.
(3) Tidal basin projects, which, with the Schneider Engine project 200% increase in power output over bulb turbines *and preserve the basin's ecology.*

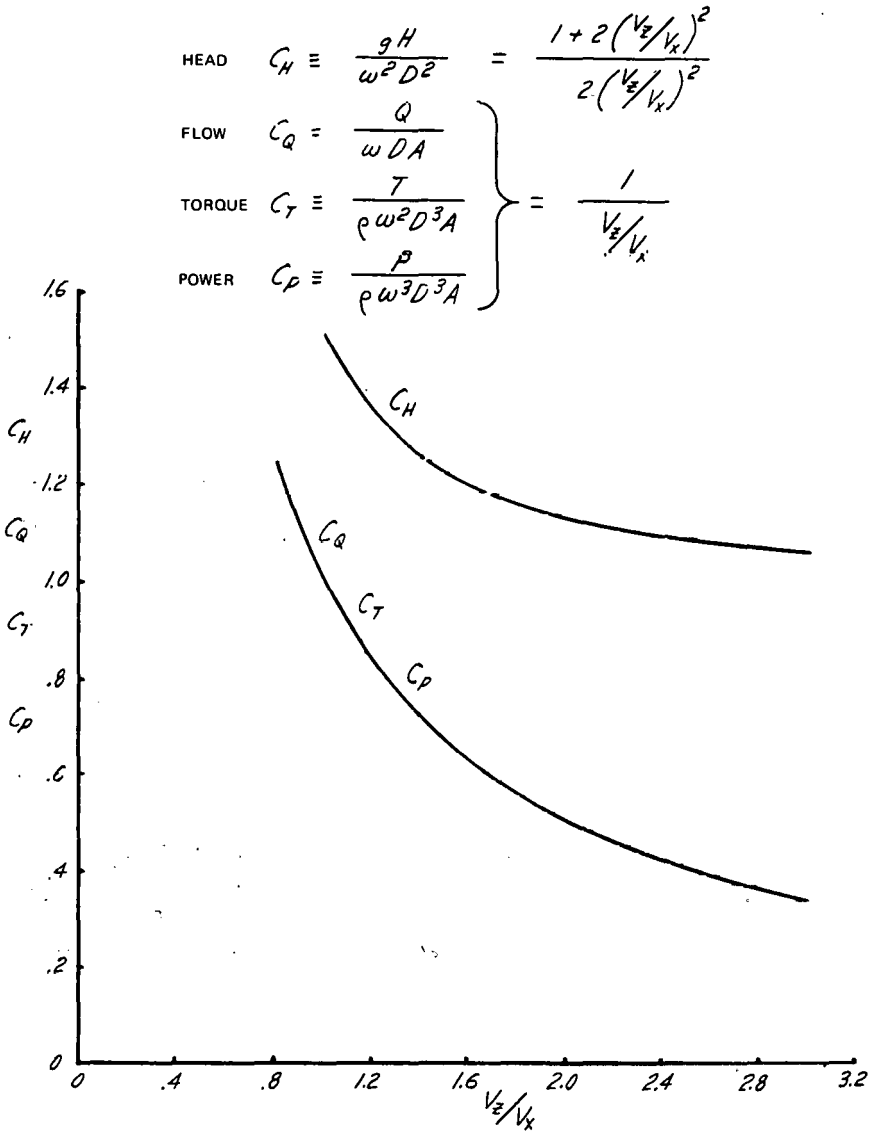


FIGURE E-3.9 Unique Hydrodynamic Coefficients

HYDRAULIC EFFICIENCY $\eta \equiv \dfrac{P}{g\rho QH} = \dfrac{2\left(V_z/V_x\right)^2}{1+2\left(V_z/V_x\right)^2}$

POWER SPECIFIC SPEED $C_{pss} \equiv \dfrac{\omega\sqrt{P}}{\sqrt{\rho}\,(gH)^{5/4}} = \dfrac{\sqrt{A}}{D}\,\dfrac{\left(V_z/V_x\right)^2}{\left[0.5+\left(V_z/V_x\right)^2\right]^{5/4}}$

$\dfrac{C_H}{C_Q^2} \equiv \dfrac{gHA^2}{Q^2} = 0.5+\left(V_z/V_x\right)^2$

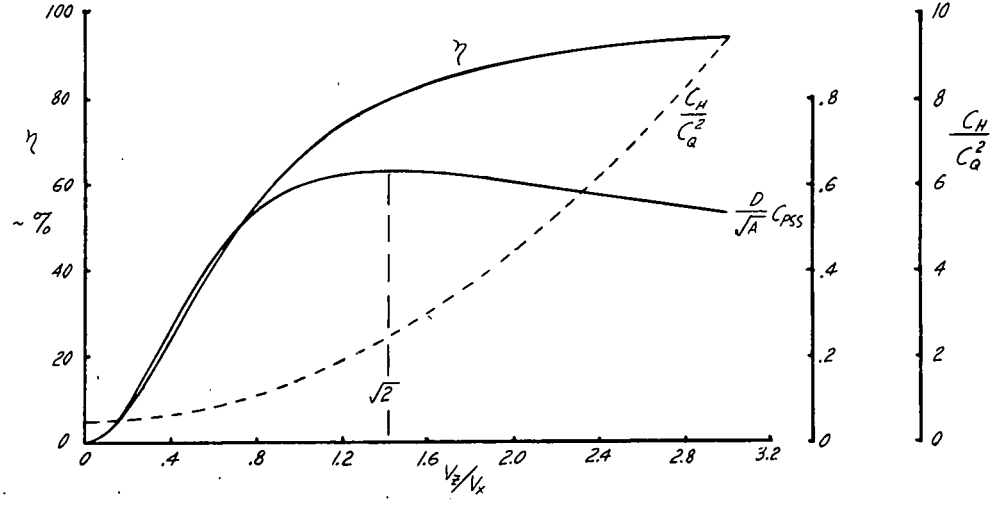


FIGURE E-3.10 Performance Coefficients

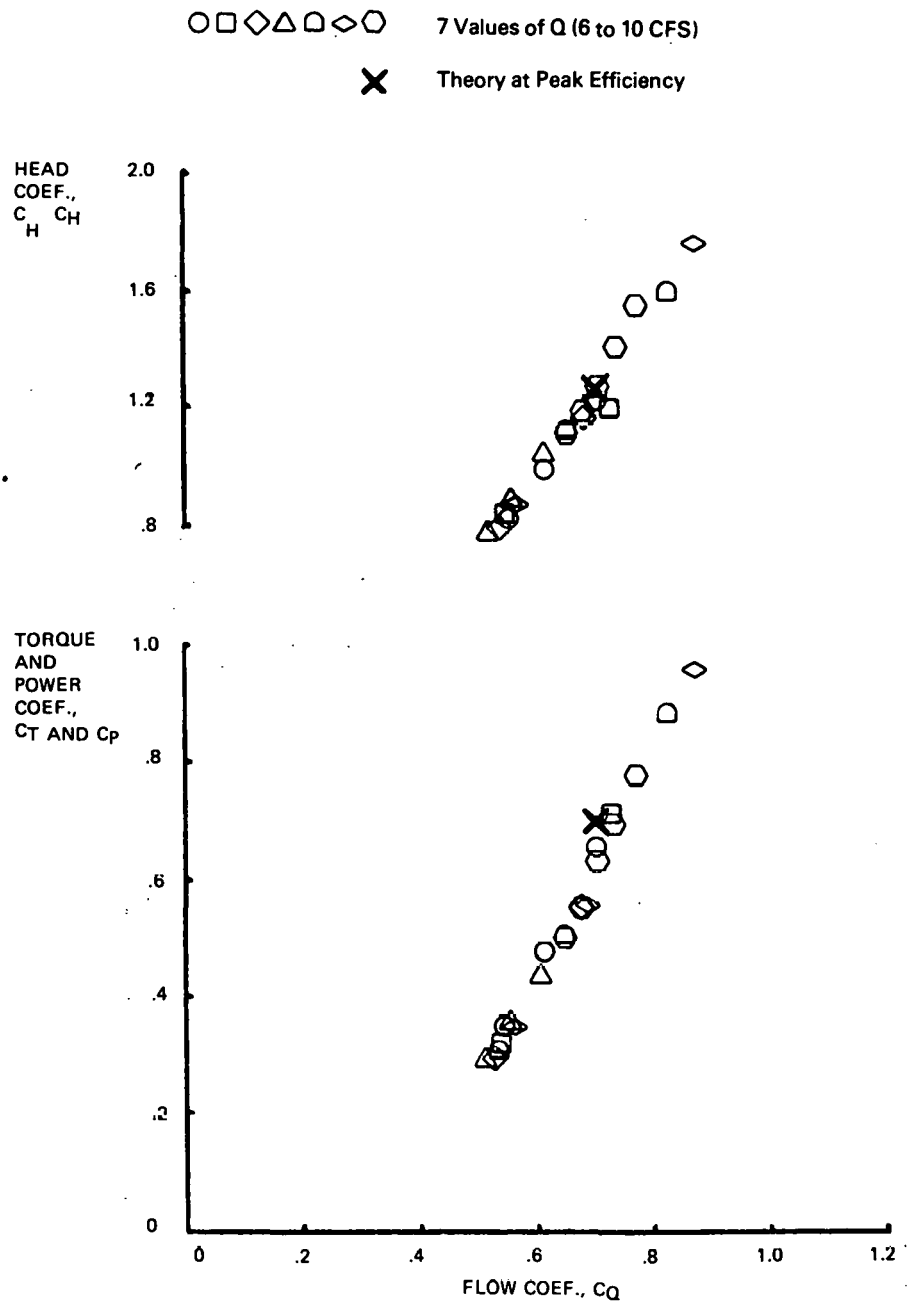


FIGURE E-3.11 Hydrodynamic Test Data

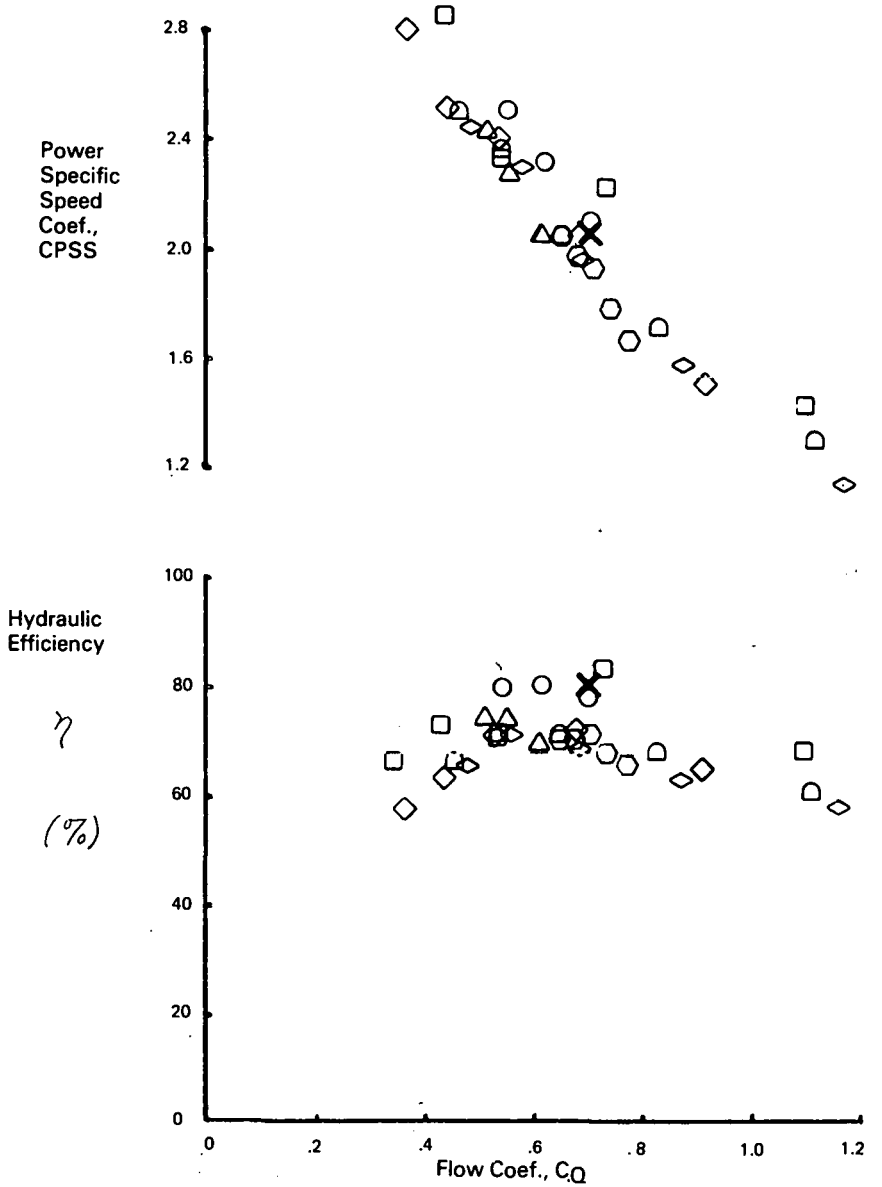


FIGURE E-3.12 Hydrodynamic Test Data

(4) Open ocean currents and coastal currents, i.e. Gulf Stream, the Race, etc.

The scope of this paper will allow only limited discussion of one of these application areas. The most important of these applications is development of the maximum power potential of our river basins. The greatest part of the slope, 80%, of our nation's rivers occurs in plains and broad or shallow valleys where head useful to rotors causes vast inundation of valuable land. Yet, just 5 feet of accumulated slope given the average flow rate of the Mississippi below St. Louis could yield about 500 MW of power. Needless to say, throat area would have to be very large, but the technological and cost advantages of the Schneider Engine make even such a large plant realistic.

Many river settings that are geophysically suited to high dam construction are also good candidates for Schneider Engine application. Competitive land use characterizes all river valleys, even in remote, mountainous wilderness areas. Priorities for river valley usage such as wilderness preservation, environment and life systems habitat protection, foresting, mining, agriculture, rural hamlets, communities, and historic artifacts all compete against flooding valley land behind high dams. One such controversial river valley is the St. John River Basin in Maine.

The St. John River scheme as presently contemplated would build two high dams; Dickey Dam of about 280' head and Lincoln School Dam of about 90' head. Figures E-3.13 and E-3.15 show the flooding pattern behind Dickey Dam for the reservoir portion formed by the Little Black River tributary when the water is impounded to the 900' elevation level. Figure E-3.17 shows the flooding behind the proposed Lincoln School Dam, with water flooding to 620' elevation. These two dams would impound 7,700,000 acre-feet of water, but only the top layer of 0.2% would be used in producing power each day; 88,240 acres of wilderness, agricultural and habitated land would be permanently flooded. The one remaining major wilderness valley of the Northeast U.S. would be inundated to produce 1,400,000 MWh per year from 830 MW of installed capacity.

Figure E-3.14, E-3.16 and E-3.18 help to illustrate the compromise approach to the St. John River valley using Schneider Engine units in a series of dams each having a head of 15-25 feet. This alternative, together with a few carefully located "pulsing" high head reservoirs for flood control and regulation of "run-of-river" flow rate during peaking power production periods, would both preserve the valley and give us the power we need. Focusing on the Little Black River to illustrate the scheme, Schneider Engine units would be installed in a series of low-cost, low-head barriers with high water levels at the 610, 625, 640, 660, 680, 700, 725, and 750 foot elevations. Figure E-3.16 shows how three pulsing reservoirs would possibly be encorporated at higher levels to catch flood waters and to moderate flow through the lower run of the river sites by establishing high flow rates for peaking power production periods. Figure E-3.18 shows how a pump storage subsystem with over 350 feet of head could be encorporated to store off-peaking run of the river power surplus and utility net base power surplus. Figure E-3.19 shows the head distribution at the sites along the Little Black River.

Such a low-head scheme for the St. John River basin using low-cost Schneider Engines would flood only about 4,500 acres and would impound

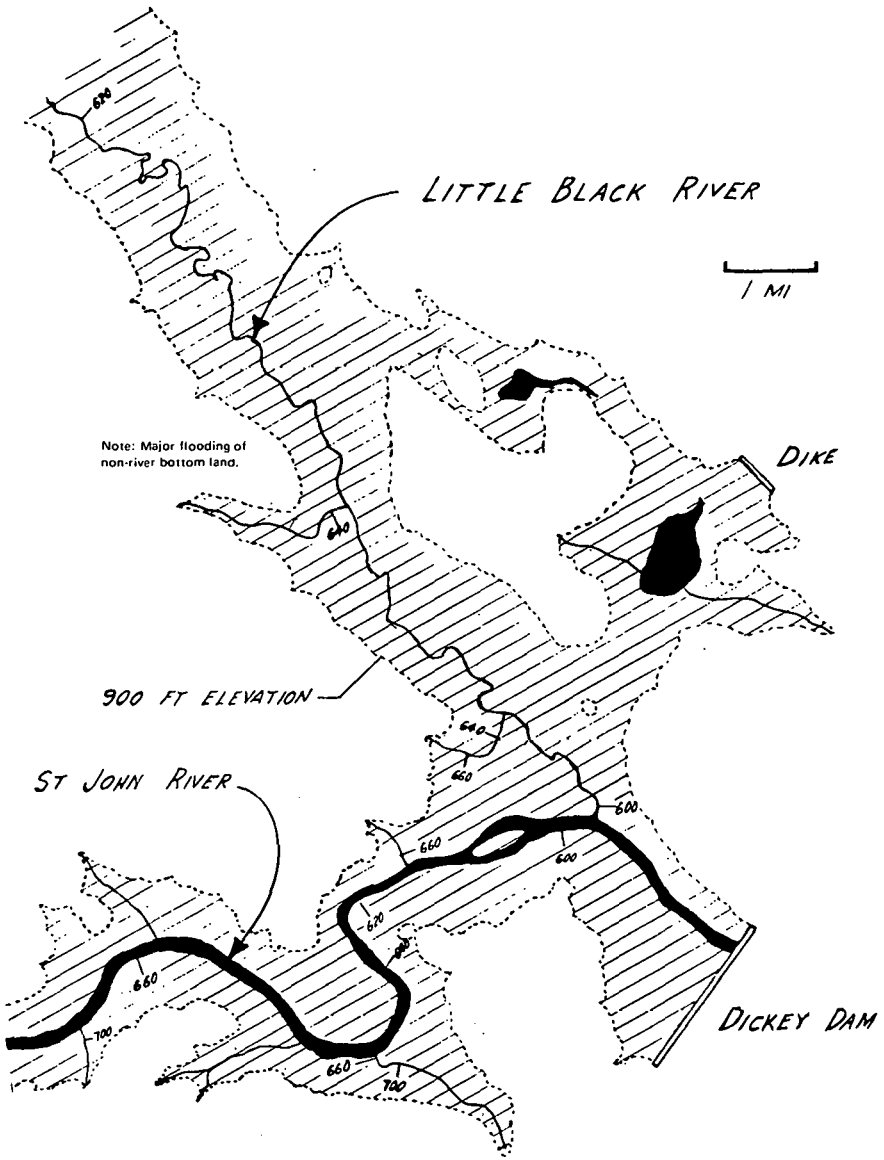


FIGURE E-3.13 Dickey Dam Flooding Pattern - low tributaries -proposed high dam.

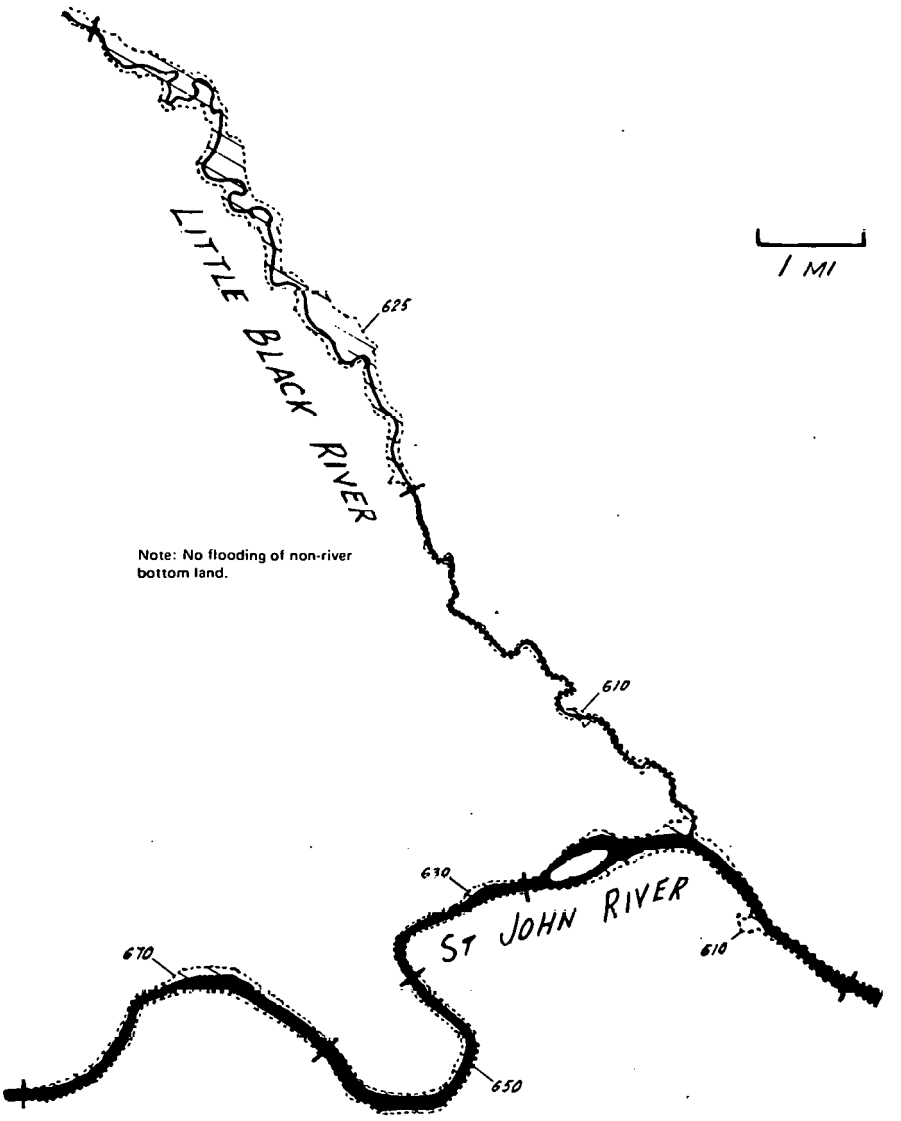


FIGURE E-3.14 Low-Head Reservoirs using Schneider engines, heads of 15-20 feet accumulated in series.

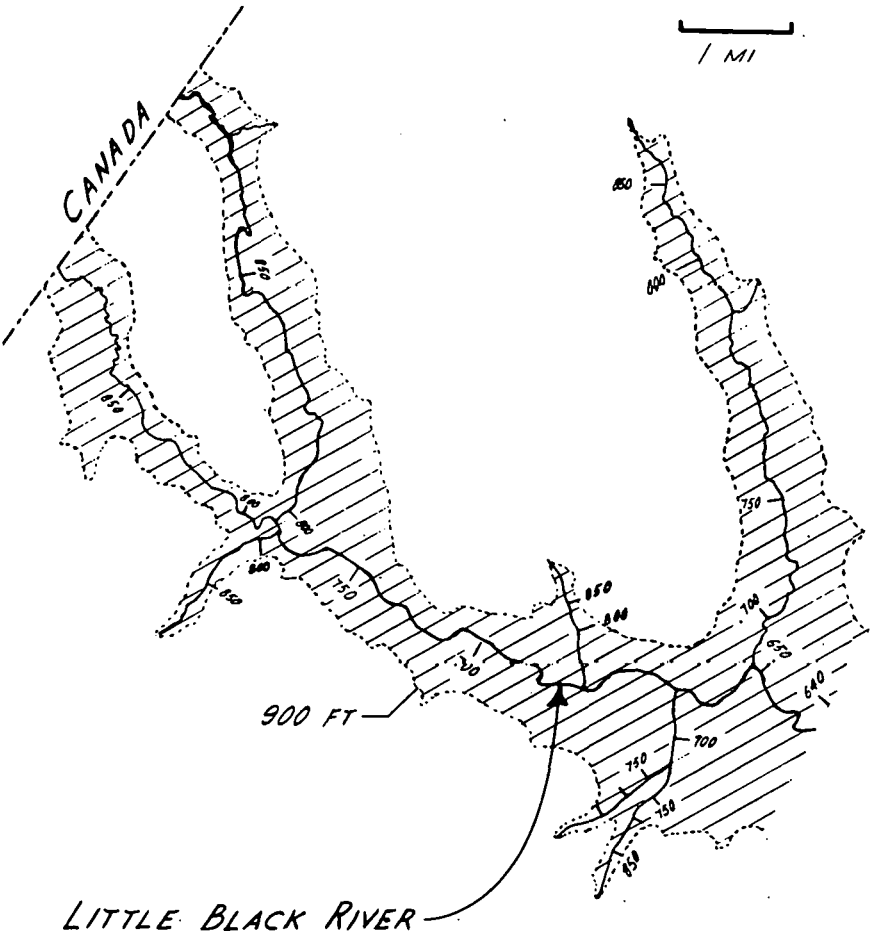
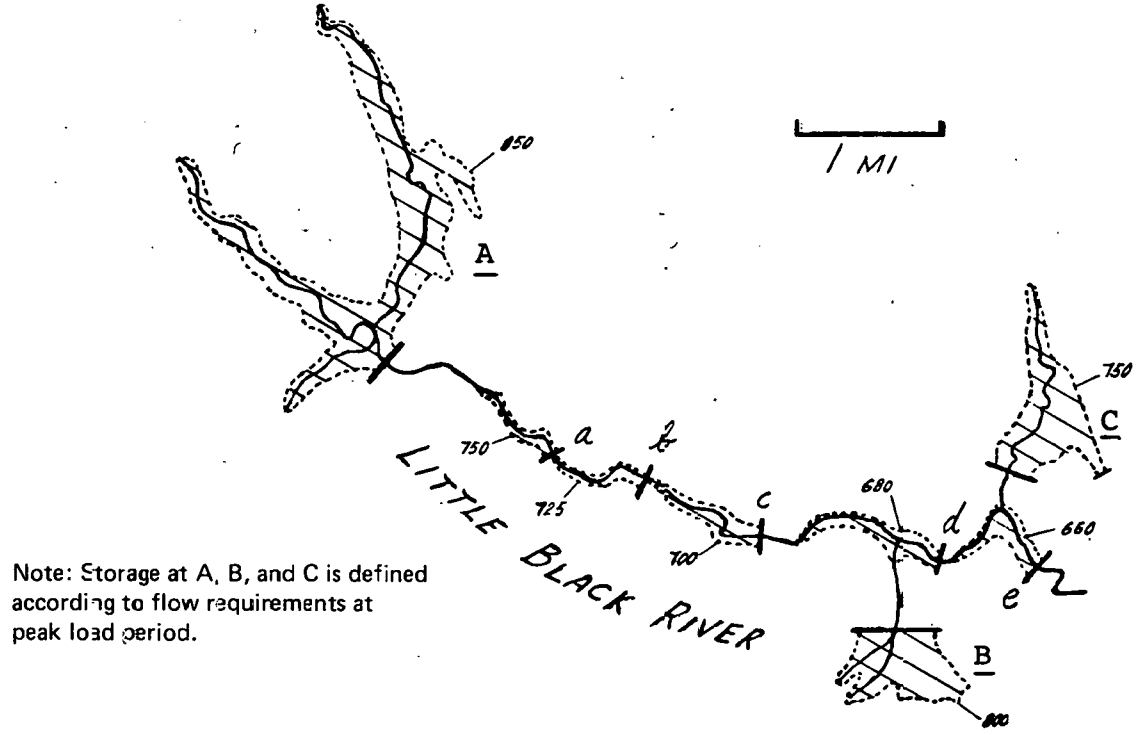


FIGURE E-3.15 Little Black River (Upper tributary of the St. John River) Flood Pattern of proposed high dam at Dickey Site on St. John River



Note: Storage at A, B, and C is defined according to flow requirements at peak load period.

FIGURE E-3.16 Little Black River (Upper tributary of the St. John River) Flood Pattern of Proposed Low-Head Dams (Sites a, b,c, d, and e) and Pulsing Reservoirs (Sites A,B, and C· Schneider Engines-Compare with Figure E-3.15

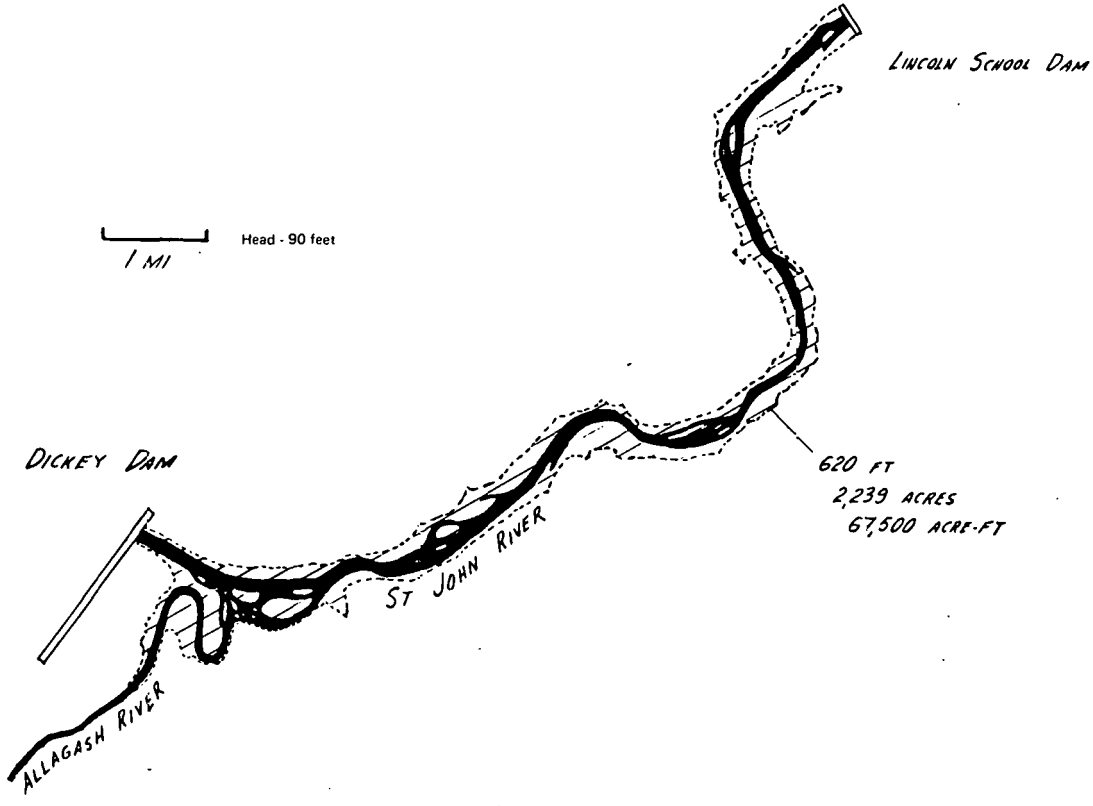


FIGURE E-3.17 Lincoln School Dam Flooding Pattern -proposed high dam.

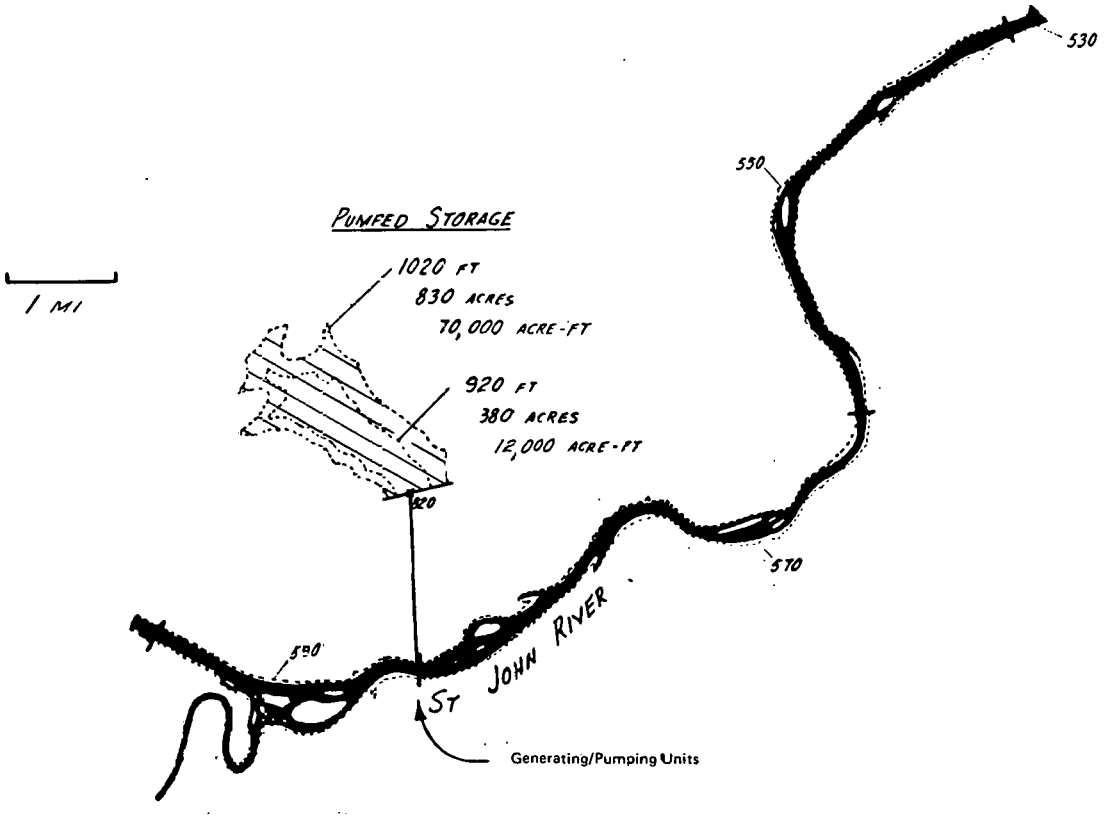
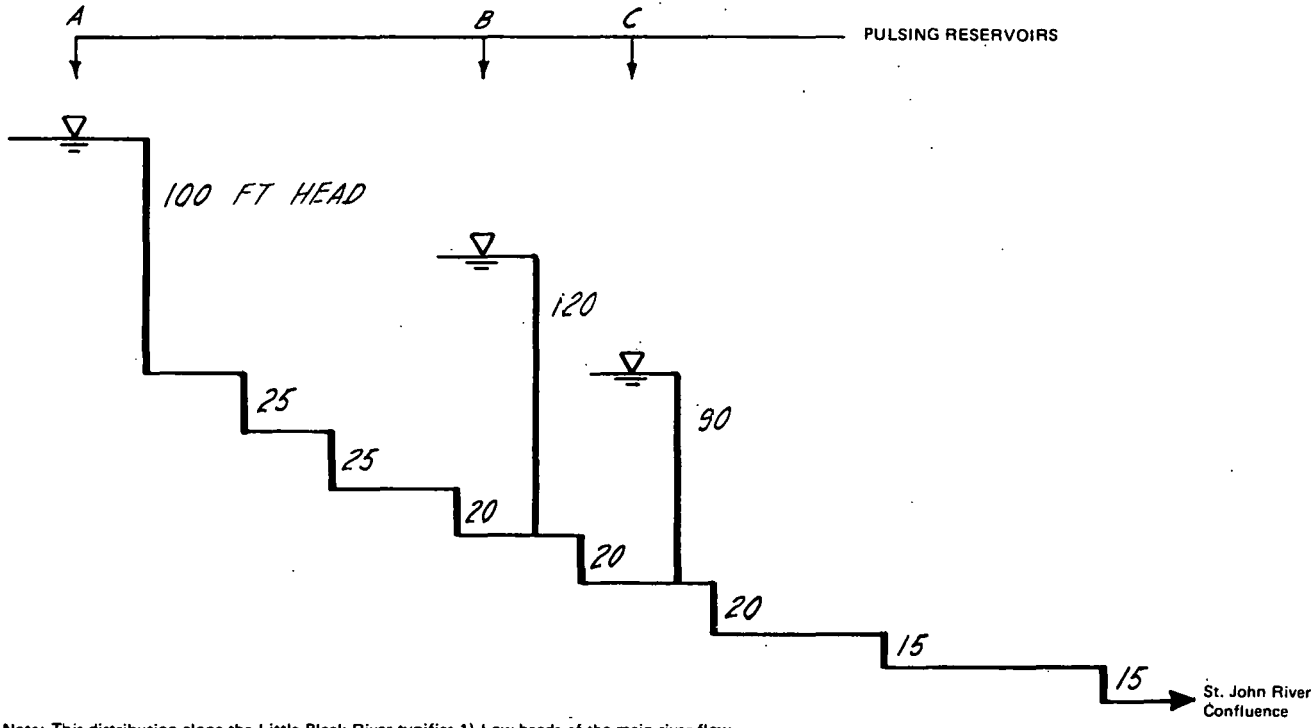


FIGURE E-3.1 Low Head and Pumped Storage Reservoir using Schneider Engines



Note: This distribution along the Little Black River typifies 1) Low heads of the main river flow, and 2) Higher heads of pulsing reservoirs, that are unique for application of Scheider Engines to any river management plan.

FIGURE E-3.19 Head Distribution along river for Schneider Engine Applications

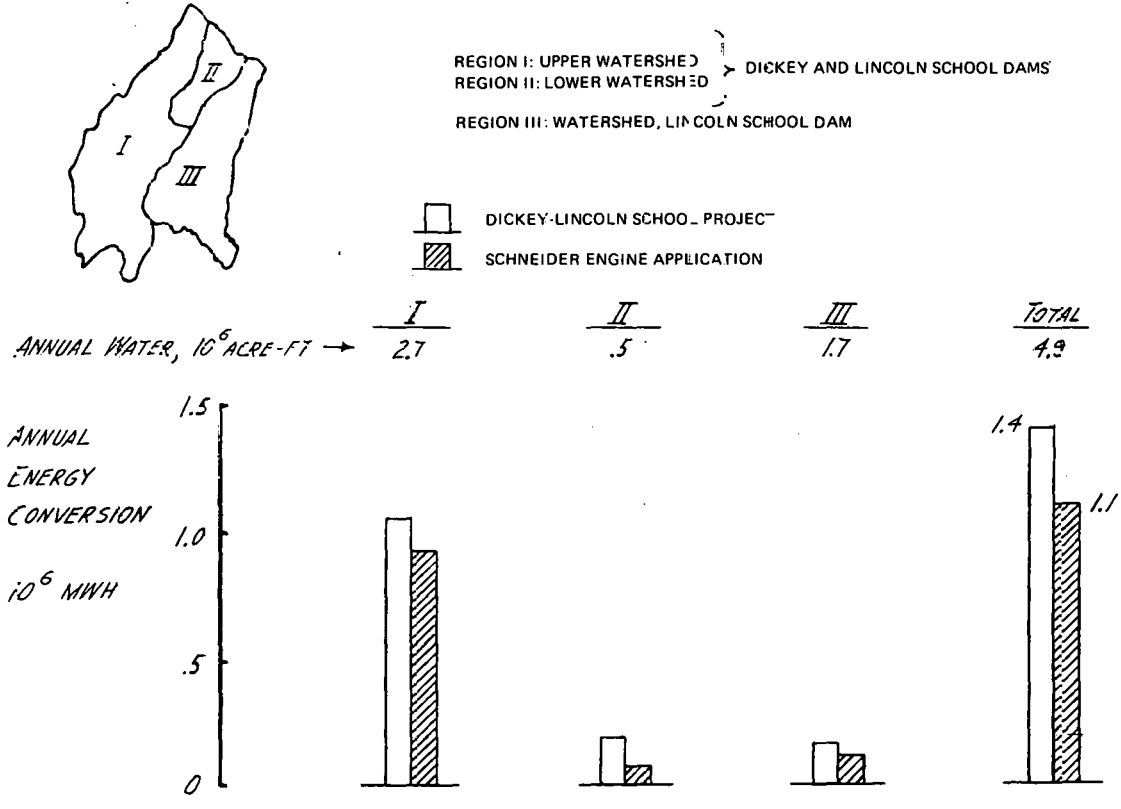


FIGURE E-3.20 Annual Energy Conversion

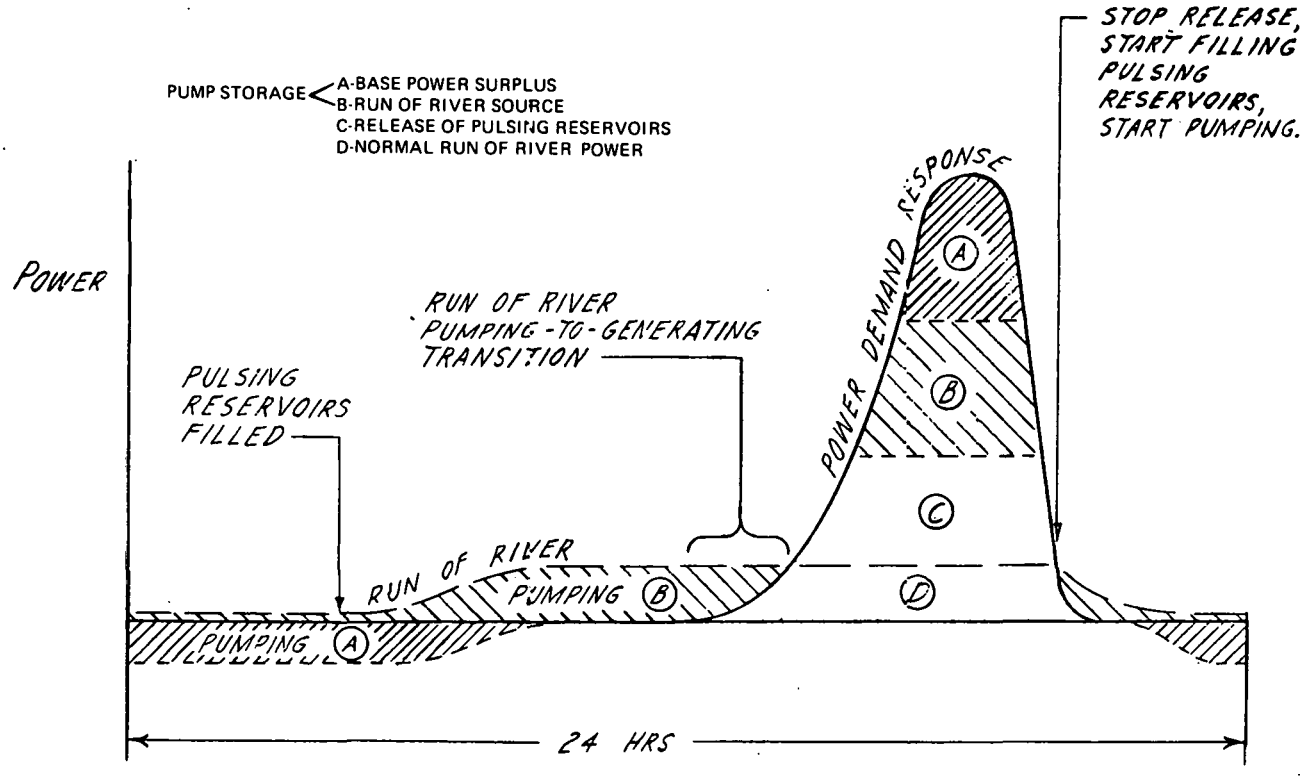


FIGURE E-3.21 Pumping/Generating Management Low-Head Schneider Engines for Peaking Power Demand

TABLE E-3.4

Dickey - Lincoln School Project:

High Head Approach vs. Low-Head Schneider Engines Concept

	Dickey-Lincoln School	Low Head Schneider Engines
Inundated Land (acres)	88,240	4,500 (5%)
Impounded Water (acre feet)	7.7×10^6	4×10^5 (5%)
Daily Discharge[1] (acre feet)	15,900	15,900
Utilized Head (feet)	370 (280 + 90)	320 (260 + 60)
Installed Capacity (MW)	830 (760 + 70)	similar (600 + 50 + pump storage)
Annual Energy Conversion (MWH)	1.4×10^6	1.1×10^6 (80%)
Civil Works Cost	high	low
Environmental Impact	severe	minimal
Cost of Inundated Land	extreme	negligible
Loss of Habitation of Valley	total	none

[1] Peaking usage of 6 hours per day.

only about 400,000 acre-feet of water, a significant part of which would be actively used in producing power each day. Only about 5% as much flooding would occur as compared to the high dam approach; yet the Schneider Engine system would generate almost as much power (over 80% as much) per year as the high dam system would generate. Table E-3.4 attempts to summarize the comparison of the two approaches, and Figure E-3.20 compares the annual energy conversion by the two methods. Reducing flooding by 95% while reducing power by only 10-20% allows us to keep both our assets— the river valley and the power. The saving in land cost alone would more than pay for the whole project. Additional benefits are lower liability from rupture of any one dam, and any one generating unit being down would have little effect on power production.

Figure E-3.21 illustrates a possible power demand response curve showing pump storage derived from base power surplus and off peaking run-of-river power surplus adding significantly to the power derived from pulsing reservoir release and real-time run-of-river power production. These four compartments of the output peak produce an output which is useful in meeting grid peaking power demand.

It would seem that very serious study of this low-cost, technologically advantaged, low-head alternative to massive river basin flooding ought to be given extensive, serious study, and major trial prior to condemning our few remaining river valleys to murder by drowning.

THE NEED FOR AND APPLICATION OF MICRO-HYDROELECTRIC TECHNOLOGY

Timothy J. Maloney

My contribution to hydroelectric technology will be small. The six-year energy study of the Energy Project at the Harvard Business School points out that the potential for low-head hydropower or small installations is considerable.[1] My six years of experience in passive solar energy have taught me that a word like small can mean very different things to different ears.

We have had a long and a very hard uphill climb with a solar technology whose principal fault was that it was so simple that it dissappointed the expectations of the engineering community, government, and even the general public. Farm boys could immediately grasp our no-moving-parts solar technology, but scientists found it somehow beneath their dignity. Now, finally, the Harvard study comes to our rescue and states unequivocally that passive solar is to be taken seriously by anyone who is serious about realistic solutions.

I have somewhat of a chip on my shoulder, or at least a fear. It seems inevitable that farm-scale hydro will be held up for years before it's given proper attention. It's so plain. It won't sound like a breakthrough to anyone. It just works. Even for this audience, the small hydro audience, I am required to modify small to "micro". It seems that even this audience has some difficulty taking less than 100 kW seriously. Is it impertinent to remind us that this country was largely built on micro hydropower?

I live in rural Virginia surrounded by old hydrosites and populated by farmers who can't make it on their farms. They take factory jobs and farm on the side. Almost all of them are forced to do this. A micro-mini hydroplant of 6 kW would yield almost $3,000.00 worth of energy if sold. If used on site, productively, that energy could be the backbone of a farm-scale enterprise that could replace the factory job and engender a sense of productivity that is sorely lacking in those rural communities. Their faces light up when I discuss these possibilities with them. They find it exciting but hard to believe. Each of them remembers when rural electrification put their little enterprises out of business. They have been convinced that bigger is the only way out. Our local utility tells me that they have no scenario for meeting the demands of next year. But everyone believes that the only solutions are too big and expensive (dangerous) to be feasible soon enough to be helpful. They tell me the economy of scale is against us.

When we sell solar space heating, we tell people they have to choose between spending money on oil that will last the time it takes to burn it or to spend on solar that puts them in the energy business for years to come. "Payback period" is a misnomer. It is a way of using numbers to support one's belief that alternative energy systems are frivolous. Our experience

---

Mr. Maloney is President, One Design Inc, Mountain Falls Route, Winchester, Virginia.

[1]Stobaugh, Robert, and Yergin, David (Eds.), *Energy Future: Report of the Energy Project at the Harvard Business School,* New York, Random House, 1979, p. 328.

shows that a hard-nosed economic analysis often yields positive cash flow in the first year. You haven't read that anywhere. The writers are speculating, we are building — first year payback. Once again the Harvard study is singular in its understanding that "solar energy is far more 'economic' than conventionally assumed."[2]

For that analysis to work, a system, whether hydro, solar or whatever, must be simple — simpler than most of us want to admit. Perhaps more importantly, it has to seem plausible so that a land owner can go ahead and do it. Things that haven't been done are felt to be impossible. Our early solar successes were not trusted, but now their collective impact has the bandwagon rolling. They now seem plausible because they are less unusual now than they were six years ago. It's the cumulative effect of all those little installations working here and now that is going to impact on the problem. Now, I'm not anti-large hydro, but large hydro is inadvertently, psychologically working against microhydro by supporting our big-is-better point-of-view.

The only thing better than big is big coupled to small. Consider the way nature works. What is more important, those few big rivers or all of those tiny streams? Since you can't have one without the other in nature, I think we should use both for different purposes. Our very bodies tell the story. The big arteries carry the heavy load over long distances, but all of that life blood moves through tiny veins in the process of sustaining our bodies. If you leave off one or the other you end up with the kind of imbalance that is capable of bringing this country to its knees. A question of too many eggs in one basket.

Many of our solar clients have streams on their properties. The question is always, "How do they harness that energy?" They tend to be opposed to dedicating much land to pondage. They are mystified by civil engineering and are afraid of costs. We are seeking designs that utilize farm skills rather than heavy capital. We are seeking solutions that can put the farmer to work on his own place, profitably.

I will show you how we are applying this philosophy to the construction of a head race. Our design starts with a small concrete diversion dam built to engineering specifications by farm labor. The big question is head race. Our sites are all on meandering streams requiring long runs. A short run can use steel pipe, but it's out of the economic question for long runs. Plastic pipe by Armco is beautiful and apparently reliable. It comes well recommended. It does not, however, meet our criteria of using farm labor rather than capital. Our criteria include:

1. Utilization of farm labor
2. Use skills common to the farmer
3. Design to avoid soil errosion resulting from ground cover removal
4. Freeze resistance
5. Understandability (non-intimidating)
6. Suitability to rough terrain

We are researching many solutions made of everything from advanced fabric hung between supports, to stabilized soil ditches, to ferro-cement trough sections. Our front-running design will be built by farm labor on a Virginia site. It is a polymer modified ferro-cement trough that is laid up by

[2] Ibid., p. 193.

hand on a male fiberglass mold at the site. The trough is 3/8 inch thick and structurally capable of carrying the loads required of it. Metal lath is stapled to the male mold before being covered with hand applied mortar. Number four rebar reinforces the lip at either side.

Each 125 lb. part is 8' long and has threaded stubs to receive 4 legs spaced four feet on center. Each successive part nests inside the next and is sealed at the joint with polysulphide or butyl. The footings are $1^1/_2$ inch stellpipe jack hammered into the ground regardless of terrain and without impact to ground cover. The legs are cut roughly to length and installed via 1 inch pipe dowels. The threaded stubs attached to the trough allow precise and simple leveling. The lid is translucent corrugated fiberglass.

Archeologists know that the Baths of Pompeii were filled with water brought in via aquaducts lined with black slate for solar heating of the water. It isn't yet clear how to best use that technology for freeze control, but in any case, the structure of our head race sections can tolerate repeated freezing by virtue of their shape. A vibrating trowel speeds the job of placing the concrete and will be rented to the builder along with the fiberglass molds. The other tools are either site available or locally rentable.

The price breakdown is for a 4.8 square foot cross section 8 feet long. The $9.50 per running foot includes self-leveling support system and yields a head race admirably easy to maintain, clean and repair. The scale of such a project virtually eliminates electrical distribution costs. The part shown with a cross section of 4.8 feet can be used on a 20' head to produce 33 kW.

I am here to solicit your attention to micro hydroelectric as a valuable energy source. If farm-scale hydro can receive the same incentives as now proposed for "small scale" (over 100 kW), we will be taking a significant step toward encouraging the entrepreneurial activity required by our impending energy shortage. If a license applicant got an incentive check rather than red tape, we would have a lot of people in the energy business. Include micro hydro in all aspects of program development. Further, I solicit your thoughts and help on our projects.

Session Nineteen

ENGINEERING

Topic: Redevelopment II

Chairman: Mr. George Fink
President
W. A. Wahler and Associates
1023 Corporation Way
Palo Alto, California 94303

SMALL-SCALE HYDROPOWER APPLICATION OF HYDROELECTRIC MINI-UNITS

H. Sattler

Synopsis

As a result of the continuous search and pressing need for alternative energy sources, the utilization of small-scale hydroelectric power is more widely considered and applied throughout the world. This trend has prompted the development of standard-type hydroelectric "mini-units." The different types and application of these "mini-units" is discussed in this paper.

Economic Importance of Small Hydroelectric Plants

As a result of the steady search for alternative energy sources, small powerplants are once again regaining worldwide importance. With the advancement of technology, the development of large powerplants predominated, and generally the generation of energy from small powerplants was ignored. However, it is now realized that small hydroelectric power installations are a more valuable asset in today's overall energy picture. The main advantages are the decentralized utilizations of waterpower and the possibility of saving irrecoverable fossil fuels. The simple rule that every kilowatt-hour generated from recoverable waterpower can save a quarter of a litre of fuel oil that would otherwise be burnt in thermal powerplants is not generally accepted worldwide. Small hydropower plants are now being widely used in the range from 10 kW to approximately 5000 kW at heads from 2 m to 500 m.

To cover the small-scale hydropower application, a range of standardized "mini-units" as shown in Figure F-1.1 has been developed.

Low Head Range

Because of the present market situation, design priority has been given to the low-head range with heads of up to 20 meters. In this range the application of tube turbines has proved most economical and a comprehensive program has been developed based upon the following considerations:

1. Generators and speed increasers arranged outside the water passage to facilitate maintenance.
2. Standard generators to be applied wherever possible.
3. Installation in any position between horizontal and vertical.
4. All wearing parts shall be easily accessible.

Mr. Sattler is Manager, Small Hydroelectric Powerplants, VOEST-ALPINE AG., Finished Products Division, Hydro Power Plants Engineering Department, Linz, Austria.

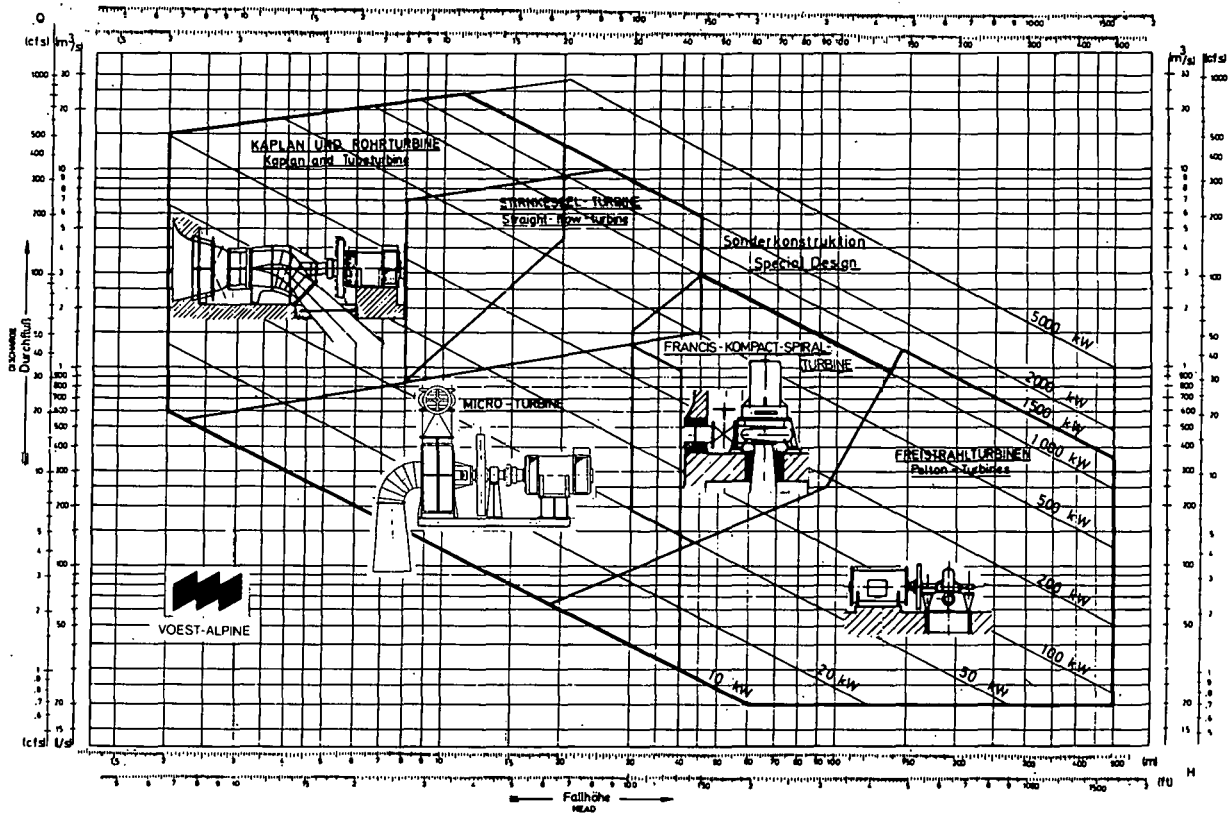


FIGURE F-1.1 Application Diagram of Small Scale Hydro-Turbines

5. All types of operation should be possible (parallel operation with an existing transmission system, as well as isolated operation in case of a power failure of the system).
6. Turbines to be delivered to site pre-assembled to facilitate erection and thus reduce erection costs.
7. Further, to meet the specific requirements of the site a module of twelve sizes with standardized dimensions are available with capacities up to 5000 kW.

Figures F-1.2, F-1.3, and F-1.4 give an indication of arrangement and installation of such standardized tube turbines.

Due to its excellent characteristics, the tube turbine will establish itself among small turbines. The favorable efficiencies which can be maintained at varying water flows and heads facilitate optimization of the annual generation and thus the annual earning. The design and flexibility of installation of tube turbines allows the powerhouse layout to blend into the landscape to the satisfaction and requirements of environmental authorities.

Medium Head Turbines

In the medium-head range compact Francis Turbine Units in the high specific speed range, n_s 100 to n_s 200, are applied and depending on the unit rating the following standard turbine types are available:

(a) Reiffenstein Turbines (micro-unit)
For very small units from 10 to 200 kW and a head range between 5 and 40 m this cheap micro-set finds wide applications. The simplified shape of the cast-iron spiral case and simplified control as well as the use of standard generators of any make contribute to low manufacturing costs. In the event of a considerable fluctuation of the water flow the installation of two or three units results in an increase in the operating safety and availability of the plant and better utilization of the water.

Typical horizontal and vertical arrangements of such micro-units are shown in Figures F-1.5 and F-1.6, respectively.

(b) Straight Flow Turbines
In the head range between 8 and 50 m the straight-flow turbine with horizontal shaft offers a favorable solution for many installations for an output of between 50 and 2000 kW. This turbine type bridges a gap between tube turbines and Francis spiral turbines and has the following advantages:

- Compact design, minimizing transport problems.
- Shop assembly.
- Use of standard generators, facilitated by the installation of speed increasers, when a direct coupling of the generator is not possible.
- High efficiencies down to approximately 40 percent rated flow.

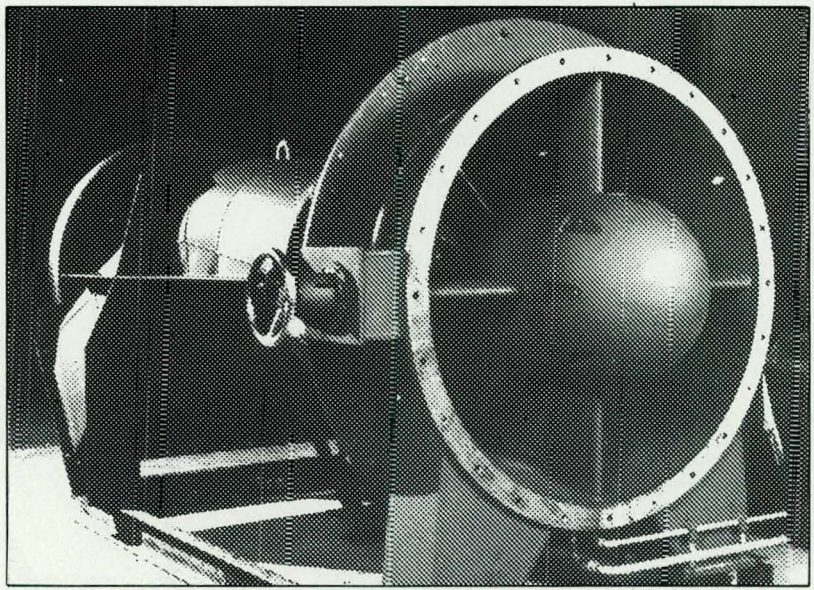


FIGURE F-1.2 Indication Arrangement - Standardized Turbine

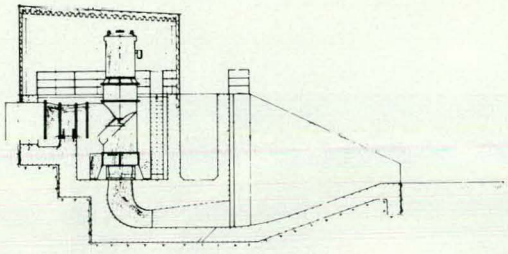


FIGURE F-1.3 Arrangement and Installation of Standardized Tube Turbine

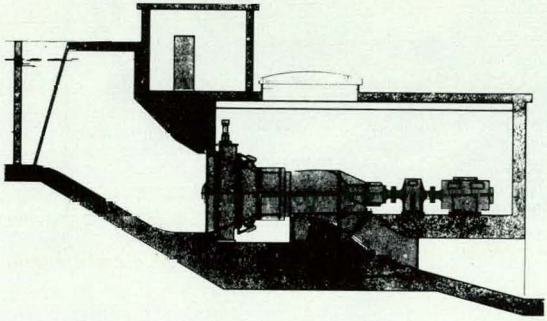


FIGURE F-1.4 Indication of Design and Flexibility

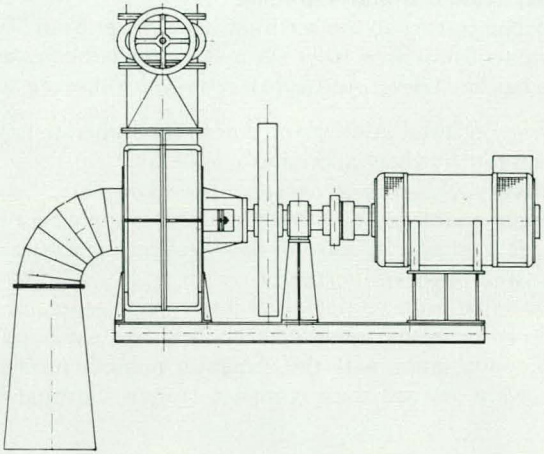


FIGURE F-1.5 Horizontal Arrangement of Micro-Unit

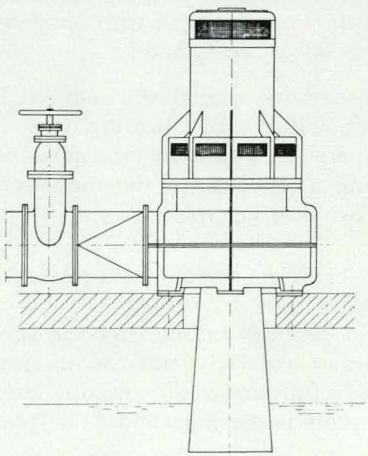


FIGURE F-1.6 Vertical Arrangement of Micro-Unit

Due to its characteristics, this type of turbine is particularly suitable for applications in developing countries. A typical arrangement is shown in Figure F-1.7.

(c) Compact Francis Spiral Turbines
As a special feature in the medium head range from 30 to 130 m and outputs from 50 to 1000 kW a vertical shaft compact Francis turbine has been developed which offers the following advantages:

- Saving on installation space due to the integration of turbine, generator, flywheel and control system.
- Delivery of turbo-generator unit completely assembled, thereby enabling quick installation on simple foundations.
- Lower total cost because of the two-bearing arrangement and omission of speed increasers.

For this type of installation, a vertical shaft low-voltage generator of special design with reinforced bearings, integrated flywheel and extended shaft has been developed in coordination with the generator manufacturer.

Figure F-1.8 shows a vertical shaft compact Francis Turbine after shop assembly.

High Pressure Turbines

The standard range comprises the "classical" impulse turbine with one or two jets, for heads from 40 to 500 m and an output range from 1 to 1500 kW. As a rule these standard turbines are designed with horizontal shaft.

Basically, there exist two possible arrangements:

1. Use of standard generators with elastic coupling between turbine shaft and generator shaft, i.e. four bearing type.
2. Use of special generators with shaft extensions on both sides for overhung arrangement of runner on the one side and the flywheel on the other, i.e. two bearing type.

The special range comprises all the less frequent requirements exceeding the output limit of 1500 kW.

This special program also includes turbines for the supply of drinking water, of which the design and material standards require more stringent specifications. An example of a fully automatic drinking-water turbine working satisfactorily for many years is the Balavaud Powerplant, Switzerland, Figure F-1.9.

Tendency

Considering the prospective increase in the price of energy, efficiency of "mini-units", which until recently was not given much attention, becomes more important and it may easily be calculated and subsequently substantiated, that a more expensive hydro-turbine installation with high hydraulic characteristics and mechanical qualities, the difference between the

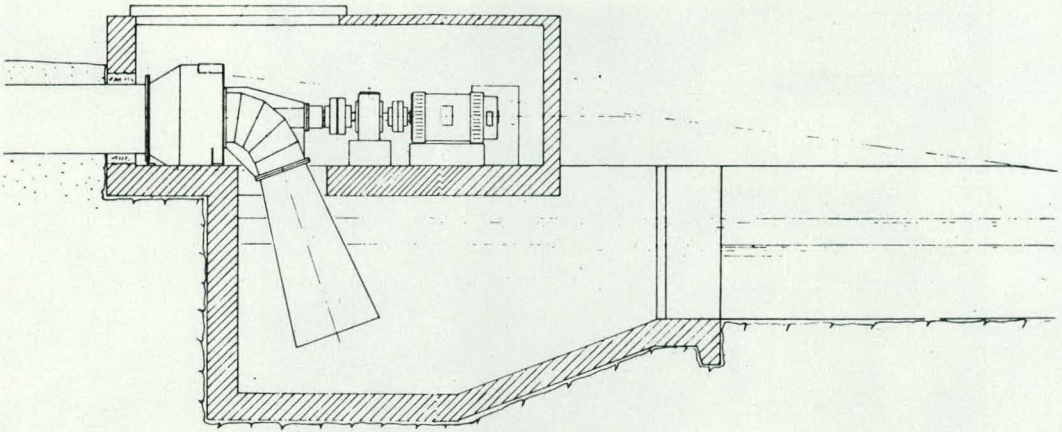


FIGURE F-1.7 Typical Arrangment

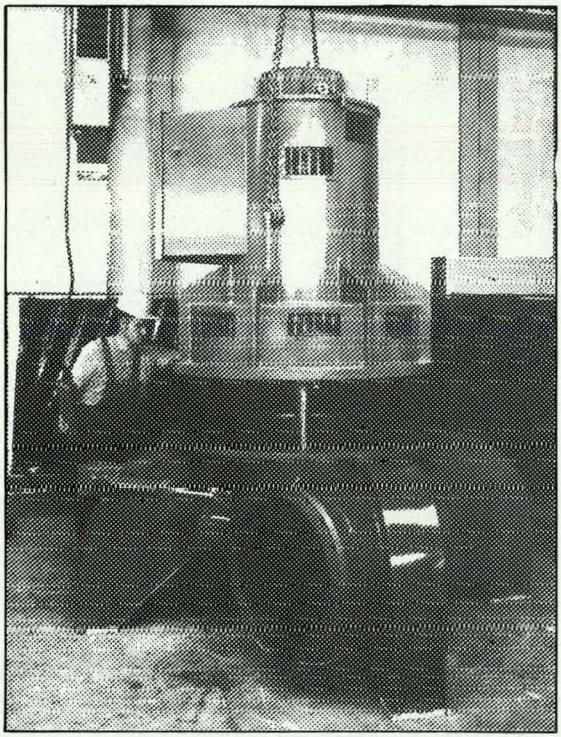


FIGURE F-1.8 Vertical Shaft

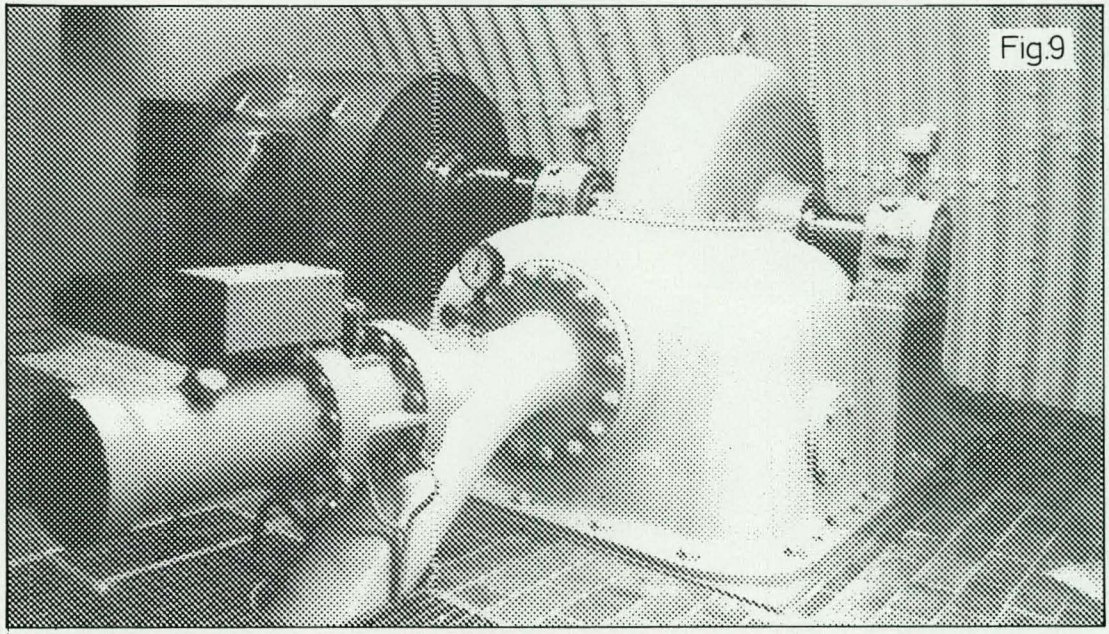


FIGURE F-1.9 Fully automatic drinking water turbine

capitalization of efficiences over a long period, will prove more economical in spite of the higher investment cost.

This need for high quality does not however, only result from the demand for high efficiency, but also from the tendency to automation, in an attempt to reduce uneconomical operating and personnel costs as far as possible. Therefore, the question of reliability in connection with the higher requirements for automation, maintenance-free operation and operational safety are continuously reviewed.

As a result of the development of the technology of "mini-units" and auxiliary equipment, fully automatic small-scale hydroelectric powerplants are now offered as a standard range and there is a substantial increase in inquiries for this type of equipment.

DAM SAFETY — AN IMPORTANT FACTOR IN CONSIDERING SMALL-SCALE HYDROPOWER AT EXISTING RESERVOIRS

Anthony R. Dolcimascolo

The often heard and frequently followed admonition, "Never look a gift horse in the mouth!" turns out to be poor advice in many engineering situations. This is particularly so when the "gift horse" is in the form of an existing dam and reservoir which are being considered for a small-scale hydropower installation.

The ultimate decision on whether or not such a project would be worthwhile is based on an accurate assessment of many factors: hydrology, power demand, marketability and overall cost. The safety of the existing dam may, in many instances, be as significant as the other factors in the technical feasibility and economic viability of a potential small-scale hydropower installation. The significance of safety is imposed, in part, by Federal regulations governing the licensing of hydropower projects.

Proposed Federal Energy Regulatory Commission (FERC) regulations governing license applications for "major" (capacity greater than 1.5 MW) projects would require each applicant to submit general design drawings of the principal project works—indicating both existing and proposed structures—accompanied by "sufficient information relating to composition and competency of foundations and other structures, gradation of filter and riprap material, design strength and ultimate strength of concrete and steel, stress and stability analysis, the project design flood (and Standard Project Flood or Probable Maximum Flood, if different from the design flood) used for stability analysis, spillway rating curves, water levels, and other controlling factors to demonstrate that the structures are safe and adequate to fulfill their stated functions." These requirements make it necessary that the applicant show that the proposed project, including existing structures, is safe.

From the applicant's point of view, the significance of dam safety — aside from satisfying FERC and possibly other regulatory license application requirements — stems from a need to protect a potentially substantial capital investment and to limit liability. An even more immediate need during the feasibility study phase of any potential project is that of determining the costs of remedies or improvements needed to mitigate unsafe conditions, if any are found in the existing structures and if any would be created by the proposed installation.

The concern for dam safety is not academic. On December 1, 1978, the Chief of Engineers submitted to the President a report on the first year's progress in the inspection of non-Federal dams. The inspection program, which was started the previous year after the failure of several dams had focused attention on dam safety, is directed primarily at performing safety in-

Mr. Dolcimascolo is Associate and Principal Geotechnical Engineer, Tippetts, Abbett, McCarthy, Stratton, New York.

spections and evaluations of non-Federal dams which pose a high degree of hazard to the public in case of failure.

About 2,000 dams were inspected during the first year. Of the 1,400 or so reported at the close of the first year, nearly one-quarter were assessed as unsafe. Nine out of ten unsafe assessments were attributed to hydrologic and hydraulic deficiencies (inadequate spillway capacity), either as the sole cause or in conjunction with other deficiencies, Other causes to which unsafe assessments were attributed were seepage problems (4.3 percent of the dams reported), structural distress (2.5 percent) and embankment instability (2.5 percent).

The Corps' progress report for the month ending May 1979 indicated that since the inception of the program, nearly 3,850 inspections had been initiated and 2,950 completed. Of those dams inspected at that time, about 27 percent were assessed as unsafe. The distribution of dams assessed as unsafe in each state, expressed as a percent of the total number of dam inspections completed in that state, is shown on Figure F-2.1. Although a breakdown of the causes for the unsafe assessments is not available for the May progress report, it is likely that it is similar to that reported to the President after 1978.

On the basis of the experience to date, it could be anticipated that one of every four existing dams being considered for a small-scale hydropower installation would be unsafe, if Corps' criteria were to be used.

Incidents of unsatisfactory and/or unsafe dam performance during the past are also evidence for concern about the safety of existing dams — particularly older dams. About 16 percent of the dams constructed during the period between 1850 and 1930 performed unsatisfactorily whereas only 4 percent of the dams constructed after 1930 experienced incidents of unsatisfactory performance.

An inspection and safety assessment of an existing dam should be carried out early during the feasibility studies for a small-scale hydropower project. The additional costs needed to mitigate unsafe conditions can be included in the feasibility studies for the project only if unsafe conditions have been identified early enough. The need for and costs of additional investigations which might arise because of identified or potentially unsafe conditions would also have to be considered during early stages of the project feasibility study. The inspection and assessment would be concerned primarily with:

- Hydrology and hydraulic adequacy of the existing dam
- Stability of the dam sections
- Structural adequacy of the existing component structures
- Effect on each of the above due to the proposed hydropower installation

After an initial review of available information about the dam and reservoir (i.e. design drawings, construction records, instrumentation data, hydrologic data, operation and maintenance records) an on-site inspection should be carried out. One purpose of such an inspection would be to determine whether or not the existing facilities are, in fact, as indicated in the drawings or records. Quite often, accurate records of modifications made either during construction or some time afterwards have not been kept. The primary purpose of the site inspection, however, is to examine the physical condition of all

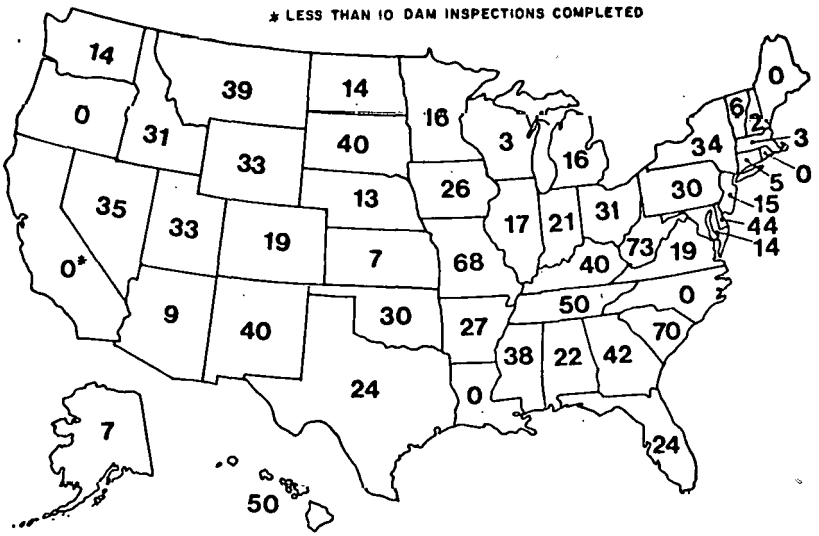


FIGURE F-2.1 Dams Assessed as Unsafe as Percentage of the Total Reported in Each State Under the National Dam Inspection Program as of May 1979

the project features and to look for symptoms representative of unsafe or potentially unsafe conditions.

Evidence of seepage emerging from either the dam or its foundation during the inspection of any dam — particularly for an earth embankment — should be carefully examined in an attempt to determine whether the leakage is excessive, and whether it is causing migration of fine particles. The area of the dam abutments should be the subject of close scrutiny. Seepage quantities should be either measured, where feasible, or estimated. Existing piezometers should be inspected and, if found to be operational, read. The great concern for excessive seepage is warranted, since excessive or unprotected seepage was the cause of 30 percent of incidents of unsatisfactory dam performance for dams constructed after 1930. The percentage of incidents attributed to other causes is given on Figure F-2.2.

Evidence of differential settlements along various portions of the dam could be a sign of a potentially unsafe condition. Local subsidence or depressions on an embankment could be symptomatic of an unsafe condition if associated with excessive seepage. Local subsidence could also be indicative of embankment slope instability resulting from other causes.

Relative displacement of structural components or monoliths, where easily observable, could be indicative of earlier or recent over-stressing of either the dam or its foundation. Cracks, spalls or other signs of structural distress are evidence of over-stress, possibly caused by differential movements often too small to be easily observable.

Unsafe conditions can arise from the failure of outlet and overflow facilities, especially when timely and successful gate operation is required to pass large floods. Such failures can be caused by damage to the gates themselves, inadequacies in gate hoists and stems and excessive damage to outlet conduits such that gates cannot be opened.

Where a small-scale hydro installation is being considered at an existing dam, the safety assessment should consider not only the existing conditions, but also possible changes which would be necessitated by construction and operation of the proposed plant.

Hydrologic and hydraulic studies would be needed to determine whether or not the existing discharge facilities could safely pass the Project Design Flood, Standard Project Flood or even the Probable Maximum Flood. In many instances where the reservoir is normally maintained at low levels or where the pool level can be lowered in anticipation of a storm, the inflow flood can be significantly attenuated by storage in the reservoir such that the outflow flood is passed without exceeding the spillway discharge capacity. If the feasibility of the proposed hydropower installation is based on changing reservoir operation to maintain a high-pool level for power generation, the same inflow flood could result in an outflow greater than the project discharge capacity, and, overtopping of the dam.

Changes in reservoir operation required for power generation could also affect seepage. If the normal reservoir level is raised — either by gate operation or by the addition of a semi-permanent barrier such as flash boards in an ungated spillway — seepage gradients could increase and patterns change to the degree that internal erosion and piping are potential problems. In these cases the installation and monitoring of piezometers (water-level measuring devices) would be prudent.

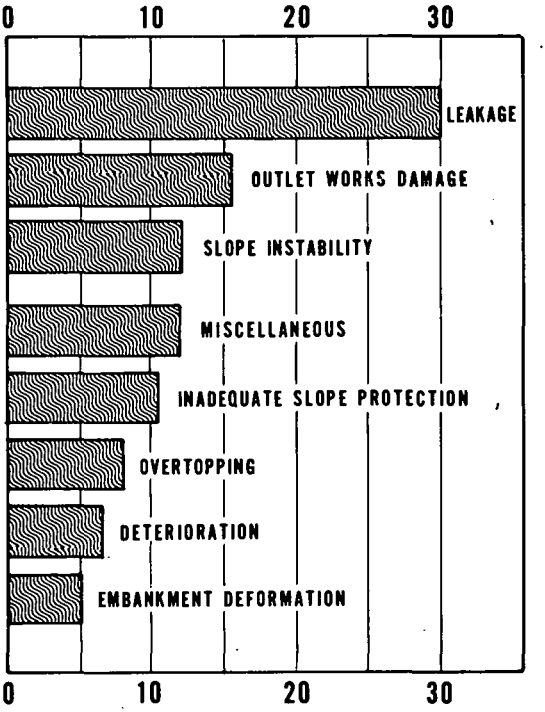


FIGURE F-2.2 Cause of Dam Incidents as a Percentage of the Total Occuring at Dams Constructed After 1930

Wherever existing water conduits and gates are considered for incorporation into the proposed hydropower installation, the ability of these equipment to perform satisfactorily and safely should be assessed with regard to compatibility of the proposed use and the original design, present condition and materials. The conversion of one or several existing old cast iron outlet conduits to a power waterway would require studies to show that the condition and materials are able to perform under the new imposed stresses.

The engineering studies for a thorough assessment could include hydrologic, hydraulic, seepage, stability and structural analyses. Additional information may be required for a satisfactory and accurate safety assessment of existing conditions and, of conditions during construction and operation of the hydropower facility. Such information could include soil, rock and concrete sampling in borings, laboratory testing of recovered samples, insitu testing and installation of instrumentation. Non-destructive testing of concrete and metal components may also be necessary.

Additional information would also be necessary for preliminary and final design of any measures to mitigate unsafe or potentially unsafe conditions. An accurate estimate of the costs of the mitigating measures would have to be considered in the economic feasibility studies for the proposed projects. The costs of the investigation program, which could be quite substantial depending on the necessary degree of certainty and accuracy desired, would most certainly have to be included in the cost of the feasibility study itself.

REFERENCES:

ASCE/USCOLD, Lessons from Dam Incidents, USA, 1975.

Department of the Army, Office of the Chief of Engineers, Report to the President, Inspection of Non-Federal Dams, First Years Progress, December 1, 1978.

Federal Energy Regulatory Commission Notice of Proposed Rulemaking, Regulations Governing Applications for Licenses for Major Projects — Existing Dams, Docket No. RM 79-36, Issued April 19, 1979.

RETIRED HYDROPOWER PLANT SITES IN THE UNITED STATES

Eugene A. Jarecki, Daniel R. McConnell, and Ernest E. Sligh

Introduction

In the mid-1930's hydroelectric power comprised about 30 percent of the Nation's total generating capacity. As most of the best sites for hydropower development were utilized, the relative contribution of hydropower to the Nation's electric generating capacity decreased to 20 percent in the early 1960's and to 12 or 13 percent in 1979. Fossil and nuclear fuels were being relied upon to produce a greater and greater percentage of the total electric load. Also, during this period of approximately 40 years, the unit cost of electricity was decreasing. The significant increase in efficiencies of steam-electric plants aided by the use of large units and the relatively stable fuel costs resulted in many small-hydropower developments not being able to justify even the operation and maintenance costs. Consequently, many small-hydroelectric plants were abandoned or dismantled.

A significant change in this situation began in 1973 with the oil embargo. Prices of oil and coal tripled, and prices of gas quadrupled. National average efficiencies of steam plants had already leveled off at around 33 percent (heat rate of about 10,400 Btu per kilowatt-hour) ten years earlier. The Nation became acutely aware of its dependency on foreign fuels and the prices being paid became a serious drain on the Nation's monetary resources. The Administration began serious consideration of crash programs and long-range programs that would help the Nation become more independent of foreign sources. Some price controls were lifted and domestic fuel prices soared. The Army Corps of Engineers, the Department of Energy, and other agencies were directed to make studies to identify actions that could help solve the energy problem.

Among other actions, renewed attention was given to the hydropower potential at existing dams, existing but standby powerplants, and small-hydro in general, i.e. previously uneconomically feasible hydropower became economically feasible at many sites. This change in the relative economic situation between the fossil and nuclear fueled steam-electric plants and the hydropower plants were primarily due to the rapidly increasing fuel costs.

FERC's Role

Since the early 1950's, the Federal Power Commission (now the Federal Energy Regulatory Commission — FERC) has maintained an inventory of existing and potential hydropower sites in the United States. These data are utilized by the Commission in its licensing and water resources planning activities and by the Corps of Engineers, Bureau of Reclamation, and other

Mr. Jarecki, Mr. McConnell, and Mr. Sligh are civil engineers with the Division of River Basins, Federal Energy Regulatory Commission, Washington, D.C.

water resource planning agencies, and by libraries and information services. This inventory has already been used and is expected to continue to constitute a base source of information for legislators, planners, consulting firms, utilities, equipment manufacturers and others in the development of hydroelectric power.

The Commission publishes much of this information on both the existing and potential capacity in its report titled, "Hydroelectric Power Resources of the United States, Developed and Undeveloped." This report, which is published every four years, was last published in 1976.

Data provided for in the Commission's inventory of hydropower resources includes such items as ownership, location, installed capacity, generation, dam and reservoir data, streamflow, head, license or Federal status information, and date of and reason for retirement (for retired plants).

As a preliminary step toward the development of small-hydropower potential (under 15,000 kW) to assist both Federal and private entities, the Commission began compiling readily available information on "retired plants."

The initial listing of retired plants, completed in the spring of 1978, consisted of about 750 plants which had been included in the hydropower inventory as operating plants sometime during the past 30 years but had since been retired. The listing has been continuously expanded using sources such as Senate Document No. 125, "Water-Power Plants in the United States," dated August 4, 1939; FERC annual electric utility reports; Corps of Engineers "308" Survey Reports; and USGS state Publications.

Based on the initial review, it was predicted that about 3,000 plants with capacities greater than 100 kilowatts would be identified. The present list totals 2,316 sites and is still growing. Although the search has been primarily for retired plants which originally had at least 100 kilowatts of capacity, the list now contains about 156 plants with capacities of less than that size.

An initial screening indicates that 97 sites do not have any redevelopment potential because they have been inundated, the stream has been designated as wild and scenic, or for similar reasons. The remaining 2,219 retired plant sites had combined capacities amounting to about 1,286 megawatts. The listing will continue to be expanded as plant sites are added and as data associated with existing plants are obtained.

Type of Data Available

The data contained in the retired plant listing include name of project, owner, river and state location, installed capacity, and date of retirement. The latest listing containing much of the above information is being prepared and will be available in the near future as a part of a staff paper. Additional data, such as streamflow, dam and reservoir, and generation information, are available in the inventory for some of the sites.

Redevelopment Potential

We have also made a cursory analysis of the plant sites' viabilities for redevelopment and have classified them based on remaining structures,

reasons for retirement, and other pertinent information. For example, if a previous plant site was inundated by a reservoir or was proposed for future inundation, it was classified as not viable for redevelopment. Conversely, if a dam and powerhouse still remained, the presently retired plant would be classified as reasonable for redevelopment.

Characteristics of Retired Hydropower Sites

Table F-3.1 indicates the previously installed capacities at retired hydropower plant sites which may have potential for redevelopment. Out of the total of 1,286 megawatts of retired capacity, the State of New York has 169 megawatts at 260 sites. Massachusetts follows closely with 102 megawatts at 170 sites. In fact, every state except Mississippi has one or more retired hydropower sites.

Although nearly half the total number of retired plants had installed capacities of less than 200 kilowatts, the bulk of the retired capacity is in the 200-5,000 kilowatt range.

As shown in Figure F-3.1, the major drainages of North Atlantic and Great Lakes-St. Lawrence contain more than half the total number and total capacity of retired plant sites in the United States.

Table F-3.2 shows that the Connecticut, Merrimack, and Hudson River Basins have the largest number of retired plant sites with 166, 119, and 113, respectively. A substantial number of plants in these river basins and in the remainder of the United States were built in the early 1900s.

Many retirements can be attributed to obsolete equipment and non-economical operation after the great industrial development. Most of the 2,316 sites were retired during the last three decades. Also, about 75 percent of the small-hydropower plants with a generating capacity under 15 megawatts were retired. A further review shows that out of the 2,300 retired plants, 45 percent were owned by utilities, 45 percent were industrially owned, and the remainder were either owned by a municipality, cooperative, or a private individual.

The FERC Hydropower Resources Inventory, which includes the Retired Plant Listing, is a dynamic record which is undergoing continuous revision.

Additional studies by Federal, state, and local governments, and other entities are used to expand the amount of information and the list of projects. Persons with additions or corrections to the inventory are encouraged to write to the Division of River Basins, Federal Energy Regulatory Commission, 400 First Street, N.W., Washington, D.C. 20426, or call (202) 376-9795.

Conclusions

Of 2,316 retired plant sites identified, approximately 2,200 plant sites which had an estimated capacity of about 1,300 megawatts have some potential for redevelopment. This redevelopment possibility exists at sites where the dam, reservoir, and most of the major structures still exist to sites where the dam and major structures have been removed. Information on many of these sites is inadequate to make a conclusive classification. However, studies and construction activities for redevelopment are underway at some sites.

TABLE F-3.1

Summary of Retired Hydropower Plants with Some Potential for Development by States and Geographic Divisions

State and Geographic Division	Number of Sites	Previously Installed Capacity kW	Number of Sites by Capacity Range			
			<201 kW	201-1,000 kW	1,001-5,000 kW	>5,000 kW
Maine	131	75,620	69	49	9	4
New Hampshire	139	69,087	68	55	16	-
Vermont	113	38,006	64	45	3	1
Massachusetts	170	102,678	83	73	13	1
Rhode Island	51	22,909	20	28	3	-
Connecticut	89	34,737	49	31	9	-
New England	693	343,037	353	281	53	6
New York	260	168,930	99	118	39	4
New Jersey	20	7,214	13	6	1	-
Pennsylvania	31	21,446	11	14	6	-
Middle Atlantic	311	197,590	123	138	46	4
Ohio	23	20,630	11	7	5	-
Indiana	36	19,715	14	16	6	-
Illinois	50	30,358	13	25	12	-
Michigan	176	80,485	100	56	20	-
Wisconsin	171	67,770	97	60	13	1
East North Central	456	218,958	235	164	56	1
Minnesota	72	84,718	29	24	14	5
Iowa	121	29,677	89	26	6	-
Missouri	25	19,905	11	10	3	1
North Dakota	1	67	1	-	-	-
South Dakota	7	5,791	1	4	2	-
Nebraska	38	36,301	21	15	1	1

Kansas	15	7,560	9	5	1	-
West North Central	279	184,019	161	84	27	7
Delaware	3	1,104	1	2	-	-
Maryland	5	1,325	3	2	-	-
District of Columbia	1	785	-	1	-	-
Virginia	35	39,787	10	15	9	1
West Virginia	2	1,120	-	2	-	-
North Carolina	75	33,925	28	42	5	-
South Carolina	35	24,581	8	18	9	-
Georgia	19	15,441	3	11	5	-
Florida	3	12,463	-	1	1	1
South Atlantic	178	130,531	53	94	29	2
Kentucky	6	5,612	5	-	1	-
Tennessee	25	19,094	12	11	1	1
Alabama	3	8,680	-	-	3	-
Mississippi	-	-	-	-	-	-
East South Central	34	33,386	17	11	5	1
Arkansas	2	1,040	-	2	-	-
Louisiana	1	2,000	-	-	1	-
Oklahoma	5	1,690	2	2	1	-
Texas	17	10,208	8	4	5	-
West South Central	25	14,938	10	8	7	-
Montana	14	5,113	8	5	1	-
Idaho	35	44,026	11	17	5	2
Wyoming	13	9,443	2	6	5	-
Colorado	39	16,303	20	17	2	-
New Mexico	6	1,192	2	4	-	-
Arizona	5	2,795	1	4	-	-
Utah	15	12,127	4	7	4	-

Table F-3.1 continued

State and Geographic Division	Number of Sites	Previously Installed Capacity kW	Number of Sites by Capacity Range			
			< 201kW	201-1,000 kW	1,001-5,000 kW	> 5,000 kW
Nevada	6	4,070	2	3	1	-
Mountain	133	95,069	50	63	18	2
Washington	34	34,758	14	10	9	1
Oregon	32	14,271	12	16	4	-
California	25	11,304	11	12	2	-
Pacific	91	60,333	37	38	15	1
Alaska	12	4,632	9	2	1	-
Hawaii	4	921	3	1	-	-
Puerto Rico	3	2,440	3	-	-	-
Total	2,219	1,285,854	1,054	384	257	24

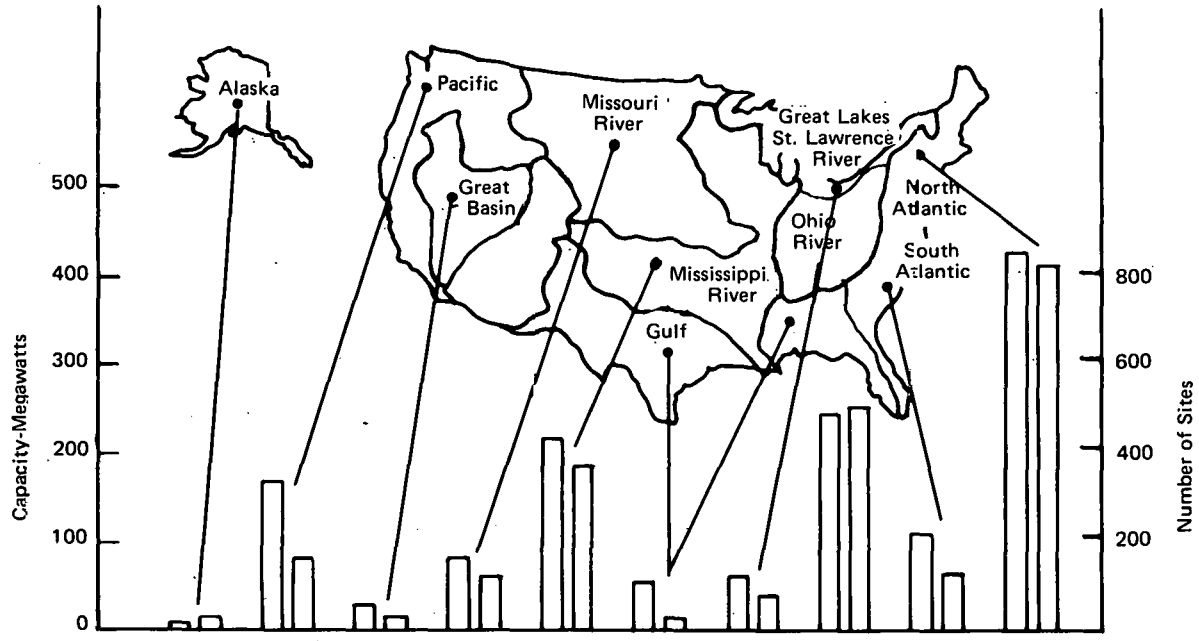


FIGURE F-3.1 Retired Hydropower by Major Drainages

TABLE F-3.2

Summary of Retired Hydropower Plants with Some Potential for Development By River Basins* and Major Drainages

River Basins and Major Drainage	Number of Sites	Previously Installed Capacity, kW	River Basins and Major Drainage	Number of Sites	Previously Installed Capacity, kW
Penobscot	21	8,815	Tennessee	30	22,683
Kennebec	32	11,206	Miami	12	5,205
Androscoggin	23	40,549	Other River Basins*	32	24,951
Presumpscot-Saco	24	10,061	Ohio	74	52,839
Piscataqua-Salmon Fall	18	16,417			
Merrimack	119	58,800	Richelieu	90	43,312
Providence	68	25,510	Oswegatchie	15	6,284
Thames	54	22,533	Black	16	20,453
Connecticut	166	99,465	Oswego	49	72,166
Housatonic	29	11,669	Huron	17	12,004
Hudson	113	64,096	Grand	35	12,823
Delaware	20	7,847	Kalamazoo	28	8,156
Susquehanna	32	19,166	St. Joseph	28	12,157
Potomac	11	4,385	Fox	63	19,760
Other River Basins*	85	26,457	Other River Basins*	153	38,921
North Atlantic	815	426,976	Great Lakes - St. Lawrence	494	246,036
James	13	26,989	Hudson Bay	9	2,512
Cape Fear	25	10,966	Kansas	47	16,098
Yadkin-Pee Dee	21	6,647	Platte	33	39,615
Santee	41	26,644	Other River Basins*	29	21,843
Savannah	13	9,727	Missouri	118	80,068
Other River Basins*	23	18,545			
South Atlantic	136	99,518	Great Basin	26	17,164

Table F-3.2 continued

River Basins and Major Drainage	Number of Sites	Previously Installed Capacity, kW
Guadalupe	11	4,388
Other River Basins*	22	8,562
Gulf (exclusive of Mississippi R.)	33	12,950
Mississippi main stream	24	69,725
Arkansas	13	9,950
Illinois	28	10,961
Des Moines	36	7,198
Iowa	45	9,014
Rock	43	25,348
Wisconsin	38	23,162
Chippewa	20	13,791
St. Croix	19	4,804
Other River Basins*	79	52,725
Mississippi (exclusive of Ohio and Missouri Rivers)	345	226,688
Columbia (excluding Snake River)	49	35,316
Snake	36	45,694
Colorado	31	11,986
Other River Basins*	43	22,626
Pacific	159	115,622
Hawaii	4	921
Alaska	12	4,632
Puerto Rico	3	2,440
Total	2,219	1,285,854

*River basins with 10 or less sites are aggregated in Other River Basins.

The capacities identified here should be used only as a relative measure of the generating potential of these sites — not as an absolute measure. With improved technologies and advanced engineering techniques, most of these plant sites can be redeveloped to yield a much greater generating capacity and energy output than was originally developed. The integration of a hydropower plant into a much larger power system with automatic operation from a larger station would allow it to operate at a lower-plant factor and thus facilitate larger capacities.

One should be aware that retired plant sites constitute a relatively small amount of power — equivalent to only one or two moderate size steam-electric units or a few large hydroelectric units. Nevertheless, serious considerations should be given to its redevelopment because of the inherent advantages of hydropower which are:

1. Use a renewable energy resource;
2. Do not consume water, contribute to air pollution, or add heat to rivers and streams;
3. Have the ability to start quickly and make changes in the power output which is particularly suitable for carrying peak loads and supplying increased power during emergency conditions;
4. Have less frequent unscheduled outages and downtime for overhaul is of short duration;
5. Make possible other water resource benefits such as flood control, recreation, fish and wildlife enhancement, and water supply; and
6. Could help reduce the international balance of payments deficit by the reduction of oil imports.

MINIMIZING CAPITAL COST IN SMALL-SCALE HYDRO DEVELOPMENT

Malcolm R. Vanderburgh and David C. Willett

Introduction

The current resurgence in interest in small-scale hydro stems both from the desire to use a renewable resource and from the recognition of the essentially "inflation-proof" nature of resulting power generated. It has to be recognized, however, that small hydro is a capital-intensive investment, and since capital is a renewable resource only in the hands of the Federal Reserve Board, these projects are particularly sensitive to the care and effort put into the basic facility design, from the standpoint of first cost as well as the ultimate life and operational/maintenance costs of the facility. There are, to be sure, a number of approaches and specific features which can be adopted in the development of a hydro facility to reduce capital costs. There are also a number of diseconomies, which, although appearing to save money, initially will inevitably result in additional expenditures, either during construction or during the operational life of the plant. This paper briefly reviews a range of cost-saving measures encountered by the authors and examines the impact of these measures on the ultimate cost of the facility.

Approach

Virtually all hydro projects, whether new facilities or redeveloped from existing or abandoned sites, follow a sequence of preliminary engineering leading to licensing, detailed design, procurement, construction and commissioning. Possible cost-saving measures will be examined under these headings.

Before proceeding, one important point should be noted — small-scale hydro, like golf, is a game of inches, and therefore, it is unlikely that any one item to be discussed here will result in a major cost saving. True economy, like a well-functioning hydro plant, will be obtained through careful attention to detail and by achieving small savings in a number of areas throughout the facility design.

Table F-4.1 presents cost breakdowns for four representative small-scale hydro projects, currently either in the planning or detailed design phase. The total costs of the various installations have been adjusted to September 1979 cost levels for comparative purposes.

Preliminary Engineering and Licensing

The first point at which cost-saving measures can be applied is perhaps in the initial decision as to whether to proceed with development of the facility,

Mr. Vanderburgh is Project Manager and Mr. Willett is Vice President, Acres American, Incorporated, Buffalo, New York.

TABLE F-4.1

Representative Small-Scale Hydro Projects
Breakdown of Project Costs

Project	A	B	C	D
Installed Capacity (MW)	10.0	10.0	10.0	6.0
Rated Head (ft)	20	18	23	53
Number of Units	5	5	2	2
Land and Land Development	11.9	2.6	2.6	0.4
Structures and Improvements	16.9	14.4	19.9	7.3
Reservoirs, Dams and Waterways	12.1	6.7	12.2	31.4
Turbines and Generators	32.3	38.7	35.0	24.2
Accessory Electrical Equipment	1.7	3.7	3.0	1.8
Misc. Power Plant Equipment	1.1	2.1	1.6	0.3
Roads and Access	—	0.5	0.6	1.0
Substation	2.0	1.2	1.7	1.0
Direct Capital Cost	77.3	69.9	76.5	67.4
Contingencies	5.5	5.3	4.2	11.0
Engineering and Administration	12.7	16.4	8.7	16.0
AFDC	4.5	8.4	10.6	5.6
Total Project	100.0	100.0	100.0	100.0
Cost Per Installed Kilowatt	$1700	$1630	$1390	$1490

to purchase power or to build an alternative facility. The feasibility study should follow a phased approach, with go/no-go decision points at key intervals along the way. A large and elaborate feasibility study which ends with an infeasible project is a luxury a small-scale hydrosite owner cannot afford. The problem is usually somewhat more straightforward in the case of a site redevelopment — a site which was once economic is probably economic for redevelopment today, or in the very near future.

One area not recommended for cost-cutting is the geotechnical investigation program. Three potential problems exist with bargain-basement exploration programs:

1. The licensing procedure will be delayed if either of the approving agencies questions the basic technical concept or deems the support data to be inadequate;
2. An unexpected foundation problem could delay the project, increase its cost and invite litigation; and
3. Annual maintenance and/or major remedial work could result in severe financial loss during operation.

This is not to say the investigation program needs to be excessive — a cost-effective program for a 10 to 20 MW facility can be completed for between $40,000 and $60,000, including site supervision and engineering.

The procedures to be followed for licensing a hydrofacility are well-documented, if not straightforward. Beyond insuring that the proper regulatory procedures are followed, maintaining close contact and a high degree of cooperation with the various licensing agencies, opportunities to minimize

capital cost during licensing are for the most part outside the control of the owner and the engineer. Although Federal and some state agencies are making attempts to streamline the process, any benefit from these efforts will probably be partially or completely offset by more active involvement of those environmental pressure groups whose basic objective, either stated or implied, is zero energy growth. Small-hydro projects usually involve a fair degree of local interest and can provide rather attractive targets for intervenors. As the importance of small-hydro as an energy source increases, proponents of zero energy growth will undoubtedly focus their attention more and more on these projects.

Selection of the Major Equipment

Two basic approaches have generally been followed with respect to selection of turbine/generator equipment:

1. The engineer selects the number, type and capacity of the generating units and specifies the performance characteristics of the equipment within relatively narrow limits; and
2. The equipment is part of a turnkey package which includes licensing, detailed engineering, equipment procurement, construction and installation.

The former method has been the traditional approach to hydroelectric development in the past, particularly larger projects. The turnkey method appears to be gaining favor as more redevelopment projects are being undertaken. The methods are examined below within the context of economic small-scale hydro development.

Traditional Approach: The traditional approach to major equipment selection, particularly for larger developments, has been to develop an optimized solution for the numbers, types and capacities of turbine/generator units at a given site. The selection of the type of unit in the medium-head range is usually somewhat limited and relatively straightforward. As mentioned above, the engineer usually establishes the type and operating characteristics of turbine and generating units early in the preliminary engineering phases and prepares procurement specifications based on fairly narrow and detailed requirements. For larger developments, the turbine/generator equipment usually comprises a relatively small component (10 to 20 percent) of the total project cost, and the arrangement of the civil works usually is the controlling factor in the final project design.

For small and low-head hydro projects, however, this situation is much different; the turbine/generator equipment costs represent approximately 25 to 60 percent of the total construction cost. A relatively large number of unit types and configurations are available, many as standardized or packaged units. These include:

- Horizontal tube units (variable pitch or fixed blade)
- Vertical fixed-blade propeller units
- Vertical Kaplan units
- Rim-type generator units (Straflo)
- Cross-flow units (Ossberger)

Selection of a unit type on the basis of "guestimates" or preliminary quotations from the suppliers can result in an installation which is ultimately less

efficient and more costly than necessary. Selection of a specific "optimized" unit ignores the opportunity for cost savings which are available with certain standard units offered by manufacturers.

Turnkey Approach: This approach, while not common in the past, presents some advantages for a small-hydro site owner without the in-house engineering and administrative resources and expertise to direct or undertake development of a site. There are a number of ways turnkey proposals can be structured, but they normally involve a sponsor, such as an entrepreneur, equipment supplier or contractor who assembles a complete package for licensing, design, equipment procurement construction and installation. The package often includes negotiation of a contract for power and energy from the facility. Since both the costs to the owner as well as the revenues are reasonably well-defined, this approach is often an attractive one to some site owners. The disadvantages of the arrangement are as follows:

1. The risks associated with licensing and construction delays, unexpected construction problems and inflation must be built into the turnkey price structure as additional cost, this is particularly the case with respect to licensing;
2. If the project is undertaken without competitive bidding, the owner may be paying significantly more than necessary for the development; and
3. Since major equipment components are often fixed as part of the original proposal, the opportunities for cost-saving during the planning and design process are limited.

Alternative Approach: A third approach is possible which takes into account the pecularities of small-hydro development and focuses effort on those items which involve significant percentages of the project cost. This procedure involves establishing certain general criteria with respect to overall plant output and efficiency based on the expected head and flow conditions, together with any specific site limitations. This information is then provided to potential suppliers of various types of turbine-generator equipment, who are then free to propose various combinations of numbers and types of units. This enables suppliers to offer the most suitable of their available equipment, taking advantage of any cost reductions which may be possible with standardized or "off-the-shelf" items. The bid evaluation for this equipment requires an estimate of the structural costs associated with each alternative, a comparative estimate of the energy available and consideration of probable future costs, such as reliability and operating and maintenance costs.

This approach takes maximum advantage of the technical capabilities of the various manufacturers, and is more likely to result in innovative approaches to overall plant design than either of the methods described above. The engineering costs are likely to be somewhat higher than for the other two approaches, but these costs should be more than offset by the savings available in equipment costs.

Designing the Power Station

In the engineering design of hydrostations, the most overlooked minority group in the utility industry is probably the Operating and Maintenance Divi-

sion. Invariably the O&M group inherits the completed station designed either by the utility's in-house engineering department or a consultant, although O&M participation in the design process is often either minimal or provided very late in the design program. The consequence of this benign neglect usually falls into two categories:

1. The plant is designed with undue emphasis on minimum first cost resulting in a facility which tends to have high operating and maintenance costs.
2. The plant incorporates a number of costly design features which are incorrectly assumed to minimize O&M costs.

Both extremes obviously result in unnecessary costs which remain with the project over its useful life. Examples of design economies which tend to increase annual O&M cost are shallow-turbine settings which lead to runner cavitation, and inadequate provisions for dewatering a unit for annual routine inspection. Examples of over-conservative design would include unnecessary duplication of access galleries, the provision of excessive space within the powerhouse for routine maintenance, over-elaborate station service systems and improper emphasis on maintenance-related facilities.

It should be noted that since many of the plants currently under redevelopment were designed in the first quarter of this century, the operating and maintenance staffs of the utilities owning these plants represent one of the most valuable existing sources of knowledge concerning small-scale hydro, particularly with regard to those aspects which are important to the long life of the facility. It is advisable, therefore, to involve O&M personnel at an early stage of the design and planning process; if the site owner does not have any hydroplants in his system, the designer should consult with knowledgeable personnel from a utility that does.

Our experience has been that there are few cost-saving measures that can be universally applied to the range of unit types and configuration likely to be encountered in small-scale hydro development. A few of the general rules that do apply include:

1. Attempts to reduce the structural dimensions of the powerhouse beyond a certain point may result in an increase in cost, due to increased costs of formwork and reinforcing steel as well as in the overall complexity of the structure;
2. The use of items such as precast concrete have somewhat limited application, in spite of their apparent attractiveness upon initial examination; and
3. Embedded pipe and electrical conduit should be kept to a minimum.

Measures to minimize construction costs are essentially site specific. Figure F-4.1 shows a section through a 10 MW station with two vertical fixed-blade propeller units operating under a head of 23.5 feet. The width available for the redeveloped station is limited by a concrete overflow dam on one side and commercial and residential property on the other. During development of the project arrangement for this station, several components were designed for dual-function operation. These included:

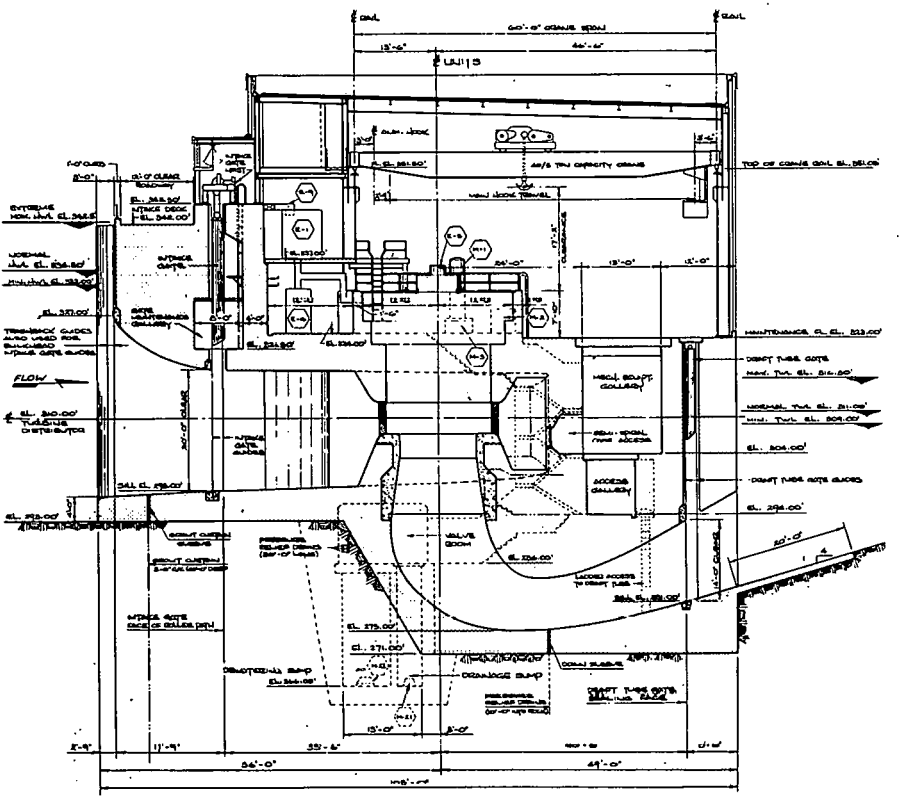


FIGURE F-4.1 Cross Section at Unit 2 Centerline

1. The trashrack guides on the upstream face of the structure were designed to accommodate the intake bulkhead gates or stoplogs during inspection or repair of the main intake gates;
2. The powerhouse crane was designed to permit assembly and dismantling of the turbines and generators plus handling of the draft-tube gates; this feature required a somewhat larger capacity crane than would normally be required and increased superstructure costs; however, these costs were more than offset by the decrease in the cost of the substructure since the requirement for a tailrace deck was eliminated.

Space within the powerhouse is, of course, at a premium, and the area upstream of the units has been subdivided into three levels. The upper level accommodates the battery room, locker room and a small office; below this the generator breakers, control metering and relaying panel and cable bus duct are located; the static excitation equipment and station service equipment are situated on the lower level. The area downstream of the units is reserved for maintenance activities. A gallery is provided just below the maintenance floor level for service water and fire protection systems and compressed air systems. The station arrangement was developed in close cooperation with the owner's O&M staff, as described above.

If small-scale hydro is to reach its full potential in the United States, careful planning and design of the individual projects is required. It is hoped that these few points will assist site developers to avoid some of the pitfalls which are associated with this recently rediscovered technology.

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

Session Twenty

ENGINEERING

Topic: Development and Operation Economics

Chairman: Mr. John Casazza
President
Ransom and Casazza
1000 Connecticut Avenue, N.W.
Washington, D.C. 20036

A BASIC ECONOMIC COMPARISON OF SMALL-SCALE HYDROELECTRIC BUSBAR COSTS

James P. Searls

This is a study of the competitive position of electrical generation by small-hydro technology. The first part of the study will be an analysis of historical cost trends of three component parts of the smaller sizes of hydroelectric generation plants. The second part, will continue with a comparison of the costs of small-hydro busbar costs to the busbar costs of alternative technologies by availability and capacity factor. This comparison will show that, depending on site-specific qualities, small-hydro is competitive with alternative technologies.

The paper will study the historic costs of three subdivisions of the total small-hydro site cost, and then the effects of various types of developers on the fixed annual charge rate that has to be levied to pay back development money, taxes, depreciation, and insurance. The summation of this charge rate and the yearly operations and maintenance charges, when divided by the total kWh of generation per year, sets the busbar costs in mills per kilowatt-hour (mills/kWh) where a mill is a tenth of a cent. With busbar costs and capacity and capacity factors one can compare the competitive position of small-hydro to those of competitive technologies.

For this study, sites in FERC's Region I (New England Region) were chosen with sizes from 11.3 MW to 140.4 MW and start-up dates between 1929 and 1974. All sites are utility owned. The cost data for each dam was put into three categories: "dam and dam site", "structures and improvements," and "turbines, generators, electrical and miscellaneous equipment." Since this study is primarily concerned with rejuvenated hydrosites the "turbines, generators and electrical equipment" category and the "structures and improvements" category are given the most attention.

A. Equipment Costs (Turbines, Generators, Electrical and Miscellaneous Equipment)

The "turbine and electrical equipment" historical costs were inflated to 1976 dollars using the GNP Implicit Price Deflator Series for electrical equipment in the National Income and Product Accounts of the United States, 1929-1974 and later data from the Surveys of Current Business. The costs of the "turbines, generators, and electrical and miscellaneous equipment" were then converted to cost per kW by dividing by the site electrical generating capacity. The year of start-up, the site's capacity, and the available head were regressed against the cost per kW.

Predictive equation for "Turbines, Generators, and Equipment"

$$1976\ \$\ \text{cost/kW} = -44.23 + 2.69\,(10^6) + 84.22\left(\frac{10}{MW^4\ \text{head}\ 1/4}\right)$$

where $-44.23 = 6600.4 + 3.3179^{*}$ (year)

R^2 corrected $= .861$

Mr. Searls is an economist, Department of Energy, Washington, D.C.

The implicit deflator for this category for 1976-77 was 4.88% . Assuming a conservative 5% for the two years after that, the 1979 cost can be found by solving for 1979 prices in 1976 $ (replacing year by 1979 in the equation), then multiplying by the inflation factor of 1.1563 (inflation for 3 years of 15.63%). Example: 12.5 MW site at 50ft in 1979 would cost $327.55/kW in 1976 $. Inflation up to 1979 $ brings the price up to $378.75/kW. This category includes the transformer, crane, and electrical safety equipment to the point where the transmission line is connected, plus the installation of all the above equipment. A regression on the historic percentages of total costs of turbines, generators, and equipment by the year of start-up shows interpolated percentage of 36.5% .

B. Costs of Structures and Improvements

The "structures and improvements" historic costs were inflated to 1976 $ using the GNP Implicit Price Deflator Series for "Structures, Nonresidential, New, Public Utilities, Electric Light and Power" (see table). These costs were then converted to cost per kW by dividing by the site's electrical generating capacity. The year of start-up, the site's capacity, and the construction cost of the dam in 1976 $ were regressed against the cost per kW of the structures and appurtenances.

Predictive equation for "Structures and Improvements"

$$\text{1976 \$ cost/kW} = 182.5 + 1.505\,(10^6)\,\frac{\text{MW}^4}{10^{10}} = .482\ \frac{\text{dam cost}^4}{\text{KW}}$$

where $182.5 = -9450.5 + 4.875^{*}$ (year)

R^2 corrected $= .855$

The implicit deflator for this category of prices for 1976-77 was 6.8% . Assuming 7% for the two years after that, the 1979 cost can be found by solving for 1979 prices in 1976 $ in the equation. That value must be inflated to 1979 $ using 1.2227 (inflation of 22.27% for three years). Example: 12.5 MW in a $500/kW dam (1976 cost of the building of the dam) would cost 261.78 $/kW in 1976 $. Multiplying that by 1.2227 to get a $320.07/kW for 1979 $.

This is a cost of new powerhouse, water conduits, flood gates, and transformer pad. For the small-hydro program the costs may be less if the site is an abandoned small station with many of these requirements already in place.

A regression on the historic percentages of total costs that is the "structure and improvement" cost onto the year of start-up shows an increasing percentage of 0.57% per year and a 1974 interpolated percentage of 26.5% of costs.

C. Costs of the Dam

The cost of the dam is considered the most-site-specific portion of a dam site, being related to the local geology and topology. It has not been studied closely here because the small-hydro program is concerned primarily with

retrofitting existing dams. Some dams are no longer owned and might be free because the original owner has erased his name from the county records, or the dam is owned but used for some other purpose (e.g. a municipal water supply dam), and the owner is now considering retrofitting power-generation capacity at the site.

A regression of the percentage of cost of the dam on year of start-up shows a declining percentage of 1.3% per year. By interpolation, the 1974 dam site accounted for 37.0% of the total costs.

D. Financial Costs

The fixed cost portion of the costs of a hydro-site are computed in such a way as to set them equal throughout the lifetime of the project. The fixed annual charge rate of a hydro-site is dependent upon the cost of money to the developer, the tax status of the developer, and the book lifetime of the site. That is, for the same site and the same capital cost, different owners would charge different values for their levelized annual fixed charge rate according to their cost of money, tax status, and allowed book life.

Using the formula for computing the Levelized Annual Fixed Charges Rate for an energy project from the EPRI "Technical Assessment Guide", the following "fixed annual charge rates" were computed according to type of developer. (Table G-1.1).

TABLE G-1.1

	Fixed Annual Charge Rate
Utility	14.72%
Private	14.04% - 19%
Nonprofit (Co-op & REAs)	10.84% [1]
Publics (Municipals and Districts)	6.52%

AFDC is added as .1% in simplifying assumption.

[1] REA loans require only interest payments for the first eight years.

With the fixed-charge rate established for the various potential developers under consideration, the next step is to establish two hypothetical capital cost examples. Table G-1.2 uses a cost from page 2 (example) and two other hypothetical costs to derive a low-cost example and a high-cost example.

At $500/kW for a 12.5 MW site the total capital cost would be $6,250,000. At $1500/kW for a 12.5 MW site the total capital cost would be $18,750,000. The fixed annual charge is the product of the fixed charge rate and capital cost of the site (see Table G-1.2).

TABLE G-1.2

Fixed Annual Charge by Owner and Capital Cost for a 12.5 MW site

($/year)

Type of Owner	Example 1 $500/kW	Example 2 $1500/kW
Utility	920,000	2,731,875
Private (Low)	877,500	2,632,500
Private (High)	1,187,500	3,562,500
Co-op	677,500	2,032,500
Public	390,625	1,222,500

E. Operations and Maintenance Costs

The variable cost, called the Operations and Maintenance (O&M) cost, for the sites studied had an average of $4,410.00 per MW capacity for 1976. Using a 12.5 MW site and a GNP inflation rate of 7.5% per year from 1976-1979, the O&M cost would be $68,482. The GNP inflation rate is probably more applicable here since this category includes labor, management and engineering, utilities, and maintenance consumables, such as lubricating oil. The owner of the 12.5 MW dam site then adds his fixed and variable yearly charges together to obtain his total annual charges.

F. Busbar Costs

Now the plant factor (FERC usage) or capacity factor (utility usage) must be introduced. A 12.5 MW electricity generating station that is generating at full power for a full year for 100% CF would generate (12,500/kW x 24 hrs/day x 365 days/yr) 190,500,000 kWh. In the New England area, the plant factor is typically less, in the 30% to 90% range. The plant factor is controlled by the flow-of-water down the stream all through the year, and to some extent how the utility chooses to use the dam, that is, whether for baseload or peaking or some mix. Some sites run baseload all of the year, some run baseload for part of the year, then one of the turbines as base and another turbine for peaking during the lower-flow part of the year. Some streams allow only peaking power during some parts of the year and are "dry" during some parts of the year. For our 12.5 MW site the busbar costs are set by the type of owner and the capacity factor because the busbar costs are the total annual costs divided by the millions of kWh generated. (Table G-1.3).

G. Comparison to Alternative Technologies

For comparisons of competitive technologies there is data available through FERC called the "Preliminary Generalized Power Values." This is data generated by FERC and transmitted to the COE for site specific C/B studies of hydro-installations. It provides the busbar costs in a slightly different form, using the categories of "power value" and "energy value" which sum to provide the busbar cost. Power value is defined as the sum of Levelized Fixed-Annual Charge Rate, as defined and used in this paper, and the Fixed Operations and Maintenance (O&M) cost/year, assumed to be 65% of the total O&M cost/year. The energy value is the fuel cost/year plus the remaining 35% of O&M/year which is assumed to be the variable portion of the total O&M cost/year.

One has to compare availability (the percentage of the year that the facility is ready to be turned on), capacity factor (the fraction of hours per year that the technology actually generates power), and busbar costs for that capacity factor. For the New England States, with full-year availability at full capacity and 30/ capacity factor, a small-hydro site might be brought on by all (Figure G-1.1), but the private (high cost) entrepeneur because it can match the busbar cost of combined cycle turbines (55.5 (power value) + 28.9 =84.4

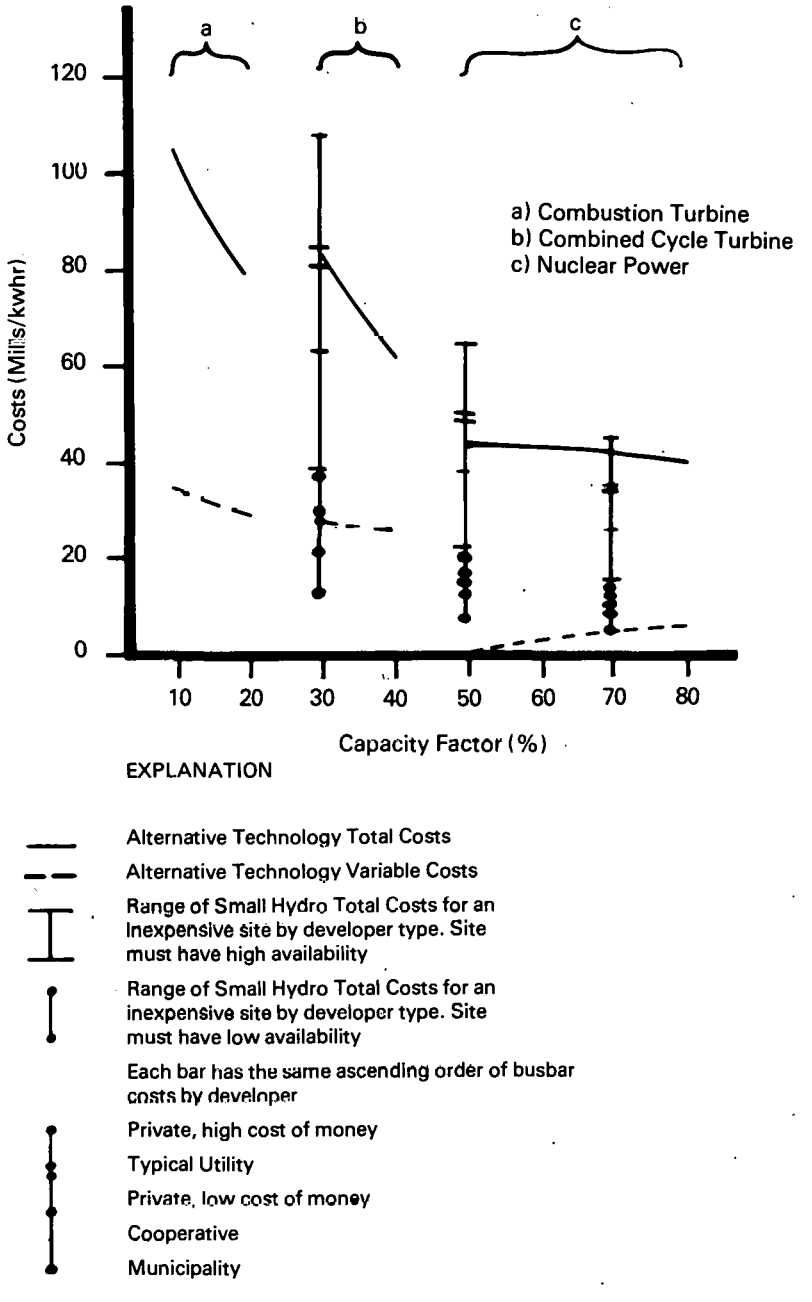


FIGURE G-1.1 Comparison of a 12.5 MW Small Hydro Site Busbar Costs and Alternative Technology Costs in New England

TABLE G-3.1

Computation of Busbar Costs
12.5 MW Site, $500/kW Capital Cost

Type of Owner	Annual Total Costs ($)	Generation at 30% CF (10^6 kWh)	Busbar Costs (mills/kWh)	Generation at 50% CF (10^6 kWh)	Busbar Costs (mills/kWh)
Utility	988,500	32.85	30.1	54.75	18.1
Private (Low)	946,000	32.85	28.8	54.75	17.3
(High)	1,256,000	32.85	38.2	54.75	22.9
Coop	746,000	32.85	22.7	54.75	13.6
Public	459,000	32.85	14.0	54.75	8.4

Type of Owner	Annual Total Costs ($)	Generation at 70% CF (10^6 kWh)	Busbar Costs (mills/kWh)	Generation at 90% CF (10^6 kWh)	Busbar Costs (mills/kWh)
Utility	988,500	76.65	12.9	98.55	10.0
Private (Low)	946,000	76.65	12.3	98.55	9.6
(High)	1,256,000	76.65	16.4	98.55	12.7
Coop	745,000	76.65	9.7	98.55	7.6
Public	459,000	76.65	6.0	98.55	4.7

12.5MW Site, $1500/kW Capital Cost

Type of Owner	Annual Total Costs ($)	Generation at 30% CF (10^6 kWh)	Busbar Costs (mills/kWh)	Generation at 50% CF (10^6 kWh)	Busbar Costs (mills/kWh)

Table G-3.1 continued

Utility	2,800,357	32.85	85.25	54.75	51.15
Private (Low)	2,700,982	32.85	82.22	54.75	49.33
(High)	3,600,982	32.85	109.62	54.75	65.77
Coop	2,100,982	32.85	63.96	54.75	38.73
Public	1,290,982	32.85	39.30	54.75	23.58

Type of Owner	Annual Total Costs ($)	Generation at 70% CF (10^6 kWh)	Busbar Costs (mills/kWh)	Generation at 90% CF (10^6 kWh)	Busbar Costs (mills/kWh)
Utility	2,800,357	76.65	36.53	98.55	28.42
Private (Low)	2,700,982	76.65	35.24	98.55	27.41
(High)	3,600,982	76.65	46.98[1]	98.55	36.54
Coop	2,100,982	76.65	27.41	98.55	21.32
Public	1,290,982	76.65	16.84	98.55	13.10

[1] The actual value for Lawrence Hydro Association with 70% CF at $1500/kW and 19% fixed charge rate is 43.2 mills/kWh for a 14.8 MW site.

mills/kWh) at capital costs (energy value) up to $1500/kW, especially since fuel costs have risen since the FERC paper was put together and oil costs will continue to rise. However, if the site were available only 50% of the year due to low-stream flow during the summer, the site, at 30% capacity factor, would only be developed if the capital cost were $500/kW or below because its cost has to be below the 28.9 mills/kWh of the variable cost (or energy value) the cost of fuel and variable operations and maintenance. At $1500/kW, not even a public entity could afford to bring in the site because its costs are 11 mills/kWh above the displaced variable cost of the alternative.

H. Increasing Costs with Decreasing Sizes

An example of the increases in cost from decreasing sizes can be drawn from an A-E study on small-hydro in New England that assumed 45% availability and studied the busbar according to size, head, and drainage basin (flow rate). A possible, but one of many, rate of increase in busbar costs as size goes below the 12.5 MW example developed above would be from the following table.

TABLE G-1.4

Schedule of Possible Cost Increases as Capacity Decreases

Size decrease (MWe)	Cost increase (mills/kwhr)	Accumulated cost increase (mills/kwhr)
12,500 - 10,000	1.2	1.2
10,000 - 7,500	1.4	2.6
7,000 - 5,000	2.5	5.1
5,000 - 2,500	3.9	9.0
2,500 - 1,000	7.5	16.5
1,000 - 500	15.0	31.5
500 - 300	19.2	50.7

By using only the increases in busbar costs according to size from the A-E's study and not absolute values it is hoped that use of this study is free of the questionable assumptions such as; the relationship of equipment cost to total cost (a factor of 2), 12.5% of capital cost to include both the fixed charge rate and the operations and maintenance costs, and the assumption that 2.0 cubic feet per second of water per square mile of drainage basin are available.

ECONOMIC EVALUATION OF SMALL-SCALE HYDROPOWER PLANTS

Alvin S. Goodman and Ruben S. Brown

Introduction

This paper discusses the experience of investigators at the Polytechnic Institute of New York in applying generalized techniques of economic analysis to an inventory of existing and potential hydropower-sites in the State of New York, in a project sponsored by the New York State Energy Research and Development Authority. The study has included preliminary technical assessments of the sites in the inventory and preliminary cost estimates for a large number of the projects. Criteria have been formulated for classifying hydropower sites in various time frames according to their prospects for development. The study has also included the preparation of a developer's manual with a suggested approach for a preliminary determination of whether a feasible project is likely, and whether to proceed to more detailed studies. The developer may be an entrepreneur, municipality, manufacturer, or electric utility.

The paper also discusses the experience of Tippetts-Abbett-McCarthy-Stratton in the application of economic criteria to screen all identified sites in New England in a project sponsored by the utilities of the New England Power Pool.

Cost Estimates of New York Hydropowersites

The hydropower inventory of the Polytechnic Institute of New York contains data on 1734 existing and proposed hydropower sites in the New York State including retired sites capable of redevelopment. This inventory emerged from an original list of about 7000 sites with additional sites added over the past two years. Preliminary cost estimates were made for 645 sites having adequate data for such evaluation. A generalized approach was adopted, depending upon the type of development involved. The assessment indicated that, overall, 255 sites can be developed at a cost not exceeding 10 cents per kWh and 84 sites at a cost not exceeding 5 cents per kWh. Table G-2.1 summarizes the capacity and energy that can be developed with these cost limitations.

For each category, projects were ranked in order of increasing cost and curves drawn for the cumulative installed capacity (in kW) versus maximum cost per kWh for that capacity and also for the cumulative average annual generation (in kWh) versus maximum cost per kWh for that energy. As an example, a set of curves for redevelopment of retired hydropower sites is shown

Dr. Goodman is Professor of Civil and Environmental Engineering, Polytechnic Institute, Brooklyn, New York, and Staff Consultant, Tippetts-Abbett-McCarthy-Stratton.

Mr. Brown is Director, Center for Regional Technology, Polytechnic Institute, Brooklyn, New York.

TABLE G-2.1

CUMULATIVE INSTALLED CAPACITY AND CUMULATIVE AVERAGE ANNUAL GENERATION AT A COST NOT EXCEEDING 10¢ PER kWh

Category and sub-category	5¢/kWh or less			10¢/kWh or less		
	No. of Sites	Installed Capacity (mW)	Annual Generation (GWH)	No. of Sites	Installed Capacity (mW)	Annual Generation (GWH)
I. NENYIAC Sites						
1. Redevelopment at existing dam sites	5	73	305	8	85	359
2. Redevelopment at existing dam sites requiring u/s storage	12	186	382	16	254	501
3. Development at sites without dams	5	104	463	17	359	1160
Total Category I	22	363	1150	41	698	2020
II. Retired Sites						
1. Restoration to previous existing capacity or	29	49	255	58	69	223
2. Development to potential capacity	15	53	289	42	145	738
Total Category II Option	15	53	289	42	145	738

Table G-2.1 continued

III. Existing Sites with Dams						
1. Existing hydropower sites with additional power potential.	12	387	849	46	784	1716
2. Existing Other Purpose sites.	19	326	716	55	546	1194
Total Category III	31	713	1565	101	1330	2910
IV. Potential Multipurpose Sites						
1. Sites including apportioned cost of dam and reservoir.	4	209	457	43	665	1430
2. Sites for which apportioned cost of dam/reservoir not included.	12	140	303	28	162	354
Total Category IV	16	349	765	71	827	1784
TOTAL ALL CATEGORIES	84	1478	3769	255	3000	7452

in Figure G-2.1. Such curves are useful in estimating the additional capacity and/or energy that could be developed for a cost not exceeding a specified value. An overall capacity of 1478 MW can be developed at a cost not exceeding 5 cents per kWh, which is considered a reasonable upper limit for near-term development. An overall capacity of 3000 MW can be developed at a cost not exceeding 10 cents per kWh which may be a reasonable upper limit for the foreseeable future. These estimates assume development by a public agency or a private entity with equivalent financing and tax abatements, and do not contain adjustments for environmental, social, and institutional constraints.

Classification of New York Hydropower-Sites

The classification scheme has been formulated with the principal objective of being able to classify the sites in the hydropower inventory in immediate, near-term, mid-term or long-term time frames. The time frames, representing the *potential* for development and *not* a *forecast* of development, assume that construction would be started or underway within two years in the case of the immediate class, within five years for near-term, within fifteen years for mid-term and in greater than 15 years for the long-term class. The classification was performed for most of the sites that could produce energy at 10 cents per kWh or less. The results of the classification are shown in Table G-2.2 which indicates, for each time frame, the number of sites, the megawatts of capacity, average capacity per site and average cost per kWh. Out of 239 sites classified, the largest number, 124 sites, are in the mid-term category having prospects of development within 15 years. The list of long-term sites would obviously be larger if all sites, including those costing more than 10 cents per kWh, are included.

The assignment of a site to a time frame was determined by a scoring system based on three criteria associated with development. Criterion 1 relates to the status of documents, Criterion 2 to project constraints, and Criterion 3 to engineering and economic feasibility. A score was determined for each criterion, based on factors, weights signifying the importance of these factors, and ratings by which these weights are multiplied.

The classification was based on the types of information available in the inventory. As expert knowledge about a particular site becomes available, the classification of that site may change to reflect more accurate and complete information.

Methodology For Economic Analysis Of Specific Sites

The *Site Owner's Manual for Small-Scale Hydropower Development* provides guidelines and a procedure that a developer of a site in New York State can follow to perform a reconnaissance level study of the site to determine whether a feasible project is likely at the proposed site. The manual considers project formulation, cost estimates of power, and the regulatory issues important for a feasibility determination. A recently completed manual is also available from the U.S. Army Corps of Engineers, for the determination of

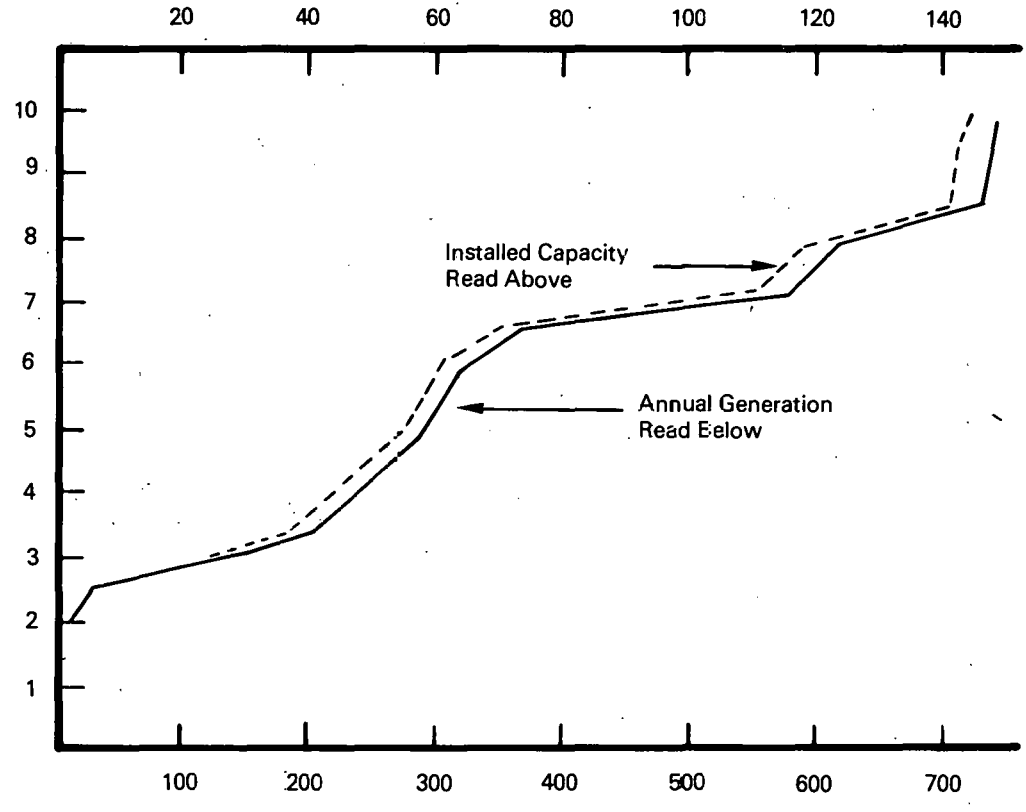


FIGURE G-2.1 Development of Retired Sites to Potential Capacity

TABLE G-2.2

Classification of Sites According
To Their Prospect for Development

Development Class	Site category	Number of Sites	Potential Capacity Thousand kW	Average Capacity per site Thousand kW	Average cost per KWH ¢
Immediate	NYSERDA ongoing study sites	5	27	5.4	5.8
Near-Term	NYSERDA Ongoing study sites	29	244	8.4	6.4
	NENYIAC	1	25	25.0	4.3
	TOTAL - Near Term	30	269	9.0	6.3
	NYSERDA ongoing study	13	214	16.5	4.8
	Retired	4	2	0,5	5.4
Mid-Term	Existing with additional potential and other purposes	103	1444	14.0	6.0
	Potential Multi-purpose	4	209	52.3	4.8
	TOTAL - Mid Term	124	1869	15.0	5.8

Table G-2.2 continued

	NENYIAC	6	71	11.8	5.3
	Retired	7	12	1.7	4.9
Long-Term	Potential Multi-purpose	67	618	9.2	6.9
	TOTAL - Long Term	80	701	8.7	6.6

the feasibility of adding small-hydropower to an existing facility. The Corps of Engineers' Manual is meant for performing full feasibility studies for a project. These feasibility studies should be undertaken only when there is a a reasonable expectation of a feasible project. The use of the *Site Owner's Manual* leads to the determination of this expectation. The corps of Engineers' Manual is prepared for sites with existing dams while the *Site Owner's Manual* covers sites without dams, as well as those with dams, and has specific reference to New York State, although most of its principles are also applicable elsewhere.

The *Site Owner's Manual* provides a standardized format to a potential sponsor for conducting preliminary economic analysis. The net economic feasibility of a project is evaluated through the use of screening criteria. Although a project's benefits can be broadly categorized as both monetary and non-monetary, for the purpose of project reconnaissance the analysis should be limited to the strictly quantifiable costs and benefits which are associated with the production of power. The cost benefit formulation is based on:

(a) The present and future values of cash outflows on the costs side, and
(b) The present and future values of cash inflows on the benefits side.

For a reconnaissance study, the project's fixed charges and variable costs of operation may be expressed as a percentage of the project's completed capital investment. For a public project, a typical annual cost may be 12.5 percent of the total capital investment. For a private project, without special financing or tax advantages, it can reach 23.5 percent or more. The 12.5 percent cost multiplier was adopted in the study of the projects in the inventory.

Annual project benefits are a function of the value of the electrical output which, in turn, is measured by a capacity component and an annual energy component. In New York State, the major determination of power value is its energy component because only a small part of the capacity is dependable due to the variability of streamflow and the lack of large reservoir storage. The energy values are derived from an examination of fuel costs at the most likely alternative source of thermal power.

A crucial element of analysis in an economic feasibility study is the values of hydroelectric output. The manual outlines the procedures for calculating the power values for three types of intended usage of power output. In the first case, the sponsor consumes all of the output of the facility. In the second case, the facility's output is sold to an existing electric utility and in the third case, the utility's sponsors the hydroelectric facilities. Other situations could be a combination of these cases. In these studies, an energy value has been projected at 5 cents per kWh along with a projected capacity value of $30 per year for each kW of dependable capacity.

The methodology of power output calculations is illustrated by a simple example utilizing the parameters listed in Table G-2.3 for a case where the sponsor sells the facility's output to an existing utility.

STEP I: Determine the gross value of power based on the sale of facility's output to an existing utility.
Gross value will be a function of both the value of energy and the value of capacity. Thus; the gross value

(i) for capacity 150x30/year = $4500/yr.

(ii) for energy 8146800x0.05 = $407340/yr.

Total $411840 per annum

STEP II: Determine the net value of hydroelectric power to the sponsor by deducting the cost of operating the facility from the gross revenues the facility is responsible for:

(i) Assuming that a 12.5 percent multiplier (for public project) is applicable.

Total annual cost of the facility = 0.125x1411110

= $176,389 per annum

(ii) The net value of power (411840 - 176389) is calculated at $235451 per year or 2.9¢ per kWh. The project in this example is economically feasible.

TABLE G-2.3

Parameters For Typical Hydroelectric Site

1.	Installed capacity	1.5 mW
2.	Dependable capacity	.15 mW
3.	Unit cost of construction	$800 per kW
4.	Construction cost	$1,200,000
5.	Completed capital cost	$1,411,110
6.	Plant factor	.62
7.	Annual Output	8,146,800 kWh

The effects of inflation on all key variables such as the cost of operating the facility, the value of energy and the present value of the facility's benefits can be examined by a Net Present Value (NPV) calculation. The NPV calculation, which channels all of a project's present and future economic data into a single evaluative statistic expressed as a dollar amount, allows a sponsor to screen a project to assess the venture's return on invested equity. The decision rule is to reject a proposal with a negative NPV. Table G-2.4 demonstrates the computation of NPV for a project used as an example for evaluation.

Justification of Economic Criteria

In economic analysis the value of energy has been projected at 5 cents per kWh and the value of capacity at $30 per year for each kW of dependable capacity. The "levelized" value of energy (5 cents per kWh) assumes that the price of fuel will rise at a higher rate than the consumer price index. It further assumes that unless energy markets are subject to severe disruptions even greater than those projected in mid-1979, the levelized value will be applicable for a 20 year period of analysis. The values for energy are consistent both

TABLE G-2.4

NET PRESENT VALUE FOR PROJECT DESCRIBED IN Table G-2.3

Year	Fixed[1] Costs	Variable[2] Costs	Total Costs	Value[3] per kWh	Benefits	Net Benefits	Present[4] Value Factor	Present Value
	$	$	$		$	$		$
1	148,167	28,222	176,389	.020	162,936	(13,453)	.935	(12,579)
2	148,167	32,312	180,479	.023	187,376	6,897	.873	6,021
3	148,167	34,573	182,740	.025	203,670	20,930	.816	17,079
4	148,167	36,994	185,161	.027	219,964	34,803	.762	26,520
5	148,167	39,583	187,750	.030	244,404	56,654	.712	40,338
6	148,167	42,354	190,521	.032	260,698	70,177	.666	46,738
7	148,167	45,317	193,484	.035	285,138	91,654	.623	57,100
8	148,167	48,491	196,658	.038	309,578	112,920	.582	65,719
9	148,167	51,885	200,052	.041	334,019	133,967	.544	72,878
10	148,167	55,517	203,684	.045	366,606	162,922	.508	82,764
11	148,167	59,404	207,571	.049	399,193	191,622	.475	91,020
12	148,167	63,562	211,729	.053	431,780	220,051	.444	97,707
13	148,167	68,011	216,178	.057	464,368	248,190	.414	102,751
14	148,167	71,772	220,939	.062	505,101	284,162	.388	110,255
15	148,167	77,865	226,033	.067	545,835	319,802	.362	115,768
16	148,167	83,317	231,484	.073	594,716	363,232	.338	122,772
17	148,167	89,149	237,316	.080	651,744	414,428	.316	130,959
18	148,167	95,389	243,556	.086	700,624	457,068	.295	134,835
19	148,167	102,066	250,233	.094	765,799	515,566	.276	142,296
20	148,167	109,211	257,378	.102	830,973	573,595	.258	147,988

NET PRESENT VALUE = $1,598,925

[1] Fixed costs equal .105 × 1,411,100

[2] Variable costs equal .02 × 1,411,100; these costs are escalated at 7 percent

[3] These values represent the basis of the levelized values used in Example Two. The value of energy is escalated at 8.5 percent.

[4] The present value factors are generated with a discount rate of 7 percent

with trends that are now emerging in hydroelectric power purchasing agreements and with prevailing economic conditions.

The capacity value of $30 per year per kW is on the low side compared with the marginal power values published by the Federal Energy Regulatory Commission for the New York area, but is believed suitable for projects with little dependable capacity. The capacity value component is not an important factor in most small-scale hydro development, as discussed earlier.

The annual cost multiplier of 12.5 percent is appropriate for a public agency or a private developer who qualifies for tax exemption and has access to low-cost financing. In studies evaluating potential, use of this percentage provides a means for estimating reasonable upper limits of potential development. A project sponsor not having these cost advantages would have to apply a suitably higher factor.

Economic Criteria In Screening New England Hydropower Sites

The TAMS study aimed to estimate commercial viable hydroelectric potential in New England. It commenced by screening more than 11,000 sites. After two screenings, 458 sites were retained on which further screenings were directed toward developing more information on power, energy and cost. In these screenings, it was presumed that no work other than powerplant would be required at the sites (except for sites that are undeveloped). The values of capacity and energy were capitalized and compared with the cost of the powerplant. Cost estimates were based on generalized values and cost indexes, and capacity and energy computations were made utilizing generalized flow-duration values, but the approach was slightly different than Polytechnic's study. Different criteria, as listed below, were applied in TAMS' analysis:

a. Annual costs of project are 20 percent of gross project investment.
b. Value of energy is 5 cents per kWh levelized over assumed 50 years plant life.
c. Value of capacity is $70 per kW per year for plants having adequate storage.

Other Considerations

There are additional important factors that weigh in favor of hydroelectric power. As world and domestic prices for oil increase, the significance of low-head hydroelectric developments becomes more pronounced since hydro uses natural renewable resources to reduce the nation's dependency on foreign oil. Another factor recognizes the fact that hydropower generation does not contribute to air, water or thermal pollution of the environment, unlike thermal power. Many of those responsible for decisions concerning powerplant construction may explicitly or implicitly include such considerations in determining the attractiveness of hydropower.

A CONCEPTUAL ECONOMIC MODEL OF SMALL-SCALE, RUN-OF-RIVER HYDROELECTRIC FACILITIES

Donald W. Lystra

Introduction

The sizing of hydroelectric equipment in relation to available streamflow is a matter which is often given too little attention in engineering feasibility studies. Often the influence of equipment ratings on project economics is severely underestimated and turbine and generator capacities become fixed at the very earliest stages of a study. Unsubstantiated rules-of-thumb, the unverified recommendations of manufacturers, or the desire of an owner to maximize output are all often used as the basis for determining these capacities. Given this situation, project cost-effectiveness then becomes a function solely of the remaining facility design alternatives: type of turbines, generators, the number of generating units employed, or powerhouse design. The actual productive capacity of a hydroelectric facility is often the first design parameter to be determined and the last to be altered.

In fact, however, the selection of turbine and generator capacities has a major impact on project cost-effectiveness, often far greater than the impact of other design parameters. This is particularly true today, during the resurgence of small-scale hydropower, when so many available dam sites are limited to a "run-of-the-river" operating mode, taking water only when and in the quantities made available by Mother Nature. In these instances, in particular, the selection of equipment capacities in relation to stream discharge can be absolutely critical, frequently making the difference between a project which is economically worthwhile to develop, and one which is economically not worthwhile to develop. And as many of us have noticed, no matter how well a project might score in terms of environmental and engineering feasibility, if it is not economically feasible, it is not a worthwhile investment, and it will not be built.

In the following pages, I will attempt to illustrate the important relationship between equipment capacity and project economics by developing a conceptual model of small-scale, run-of-the-river hydroelectric facility economics. I will begin by showing first how available waterpower can be visualized by use of what hydrologists call the flow-duration curve. Secondly, I will then describe the relationship between equipment rating and the projected-power output at a typical dam site. Thirdly, I will graphically illustrate project costs and revenues as functions of plant size, and show their relationship to benefit/cost ratios. Finally, I will present a brief case study example that will hopefully make clear how optimum equipment capacity can be determined in a real-world situation.

Mr. Lystra is Head, Electrical Department, Ayres, Lewis, Norris and May, Inc., Ann Arbor, Michigan.

Flow-Duration and Available Waterpower

Typically, an investor in a capital project is faced with a situation in which revenues and costs increase proportionately with production capacity. If an entrepreneur builds twice as large a manufacturing plant, for example, he can theoretically hope to both produce and sell twice as much of his product. Of course, the situation is sometimes confused by such things as production bottlenecks, economies of scale, and declining revenues due to saturated demand, but in general it is true that twice as much of an investment will lead to twice as much of a return.

Small-scale hydroelectric projects, on the other hand, have project-cost curves which increase at a rate significantly less than proportional, and revenue curves which are distinguished by a sharply declining rate of marginal increase, eventually, in fact, equalling zero.

Let me illustrate the second of these phenomenon first: declining marginal revenues with increasing facility size. Refer to Figure G-3.1 which shows a flow-duration curve for a typical dam site. Stream discharge rate on a vertical axis is plotted against the exceedence percentage along the horizontal axis (i.e., the percent of time a given discharge rate is equalled or exceeded). As common logic would indicate, the flow-duration curve approximates a hyperbole, with drought flows showing a very high exceedence percentage, and flood flows showing a very low exceedence percentage.

The importance of the flow-duration curve for hydropower studies lies in the fact that the area under the curve, or any portion thereof, is proportional to the theoretical waterpower available at different plant capacities. Figure G-3.1 shows this principal more clearly. It illustrates the operating characteristics of a hypothetical run-of-the-river hydropower facility containing a single turbine rated to pass a given discharge at full load. The area under the flow-duration curve which lies above discharge limit represents water which cannot be put through the turbine, and therefore must be discharged over the spillway. The area under the discharge limit represents water which can be passed through the turbine and converted into electric energy. If the turbine has adjustable gates or runner blades it can be throttled and continue to generate electricity as the stream discharge drops below its rated output. At some point, however, turbine efficiency usually falls to an unacceptably low level and it becomes better to operate the turbine intermittently, letting storage build up until it can be passed at an efficient rate, than to operate continuously at a very low flow. If the impoundment is too small to tolerate this intermittent storage and depletion, the low flows would have to be passed immediately and that potential power would be lost.

One other point is worth noting before leaving Figure G-3.1: On most waterways there is a necessity to maintain a minimum discharge downstream of a dam, and so a certain amount of water will usually have to be spilled whenever the turbine is shut down. In Figure G-3.1 this is shown as the shaded area below the minimum discharge line.

A short study of the flow-duration curve reveals that the marginal increase of usable water power decreases substantially as the installed generating capacity of the facility is increased. One can imagine a series of parallel lines representing various turbine discharge limits. As each line is drawn at a higher rating, it takes in a smaller and smaller area under the flow-duration curve.

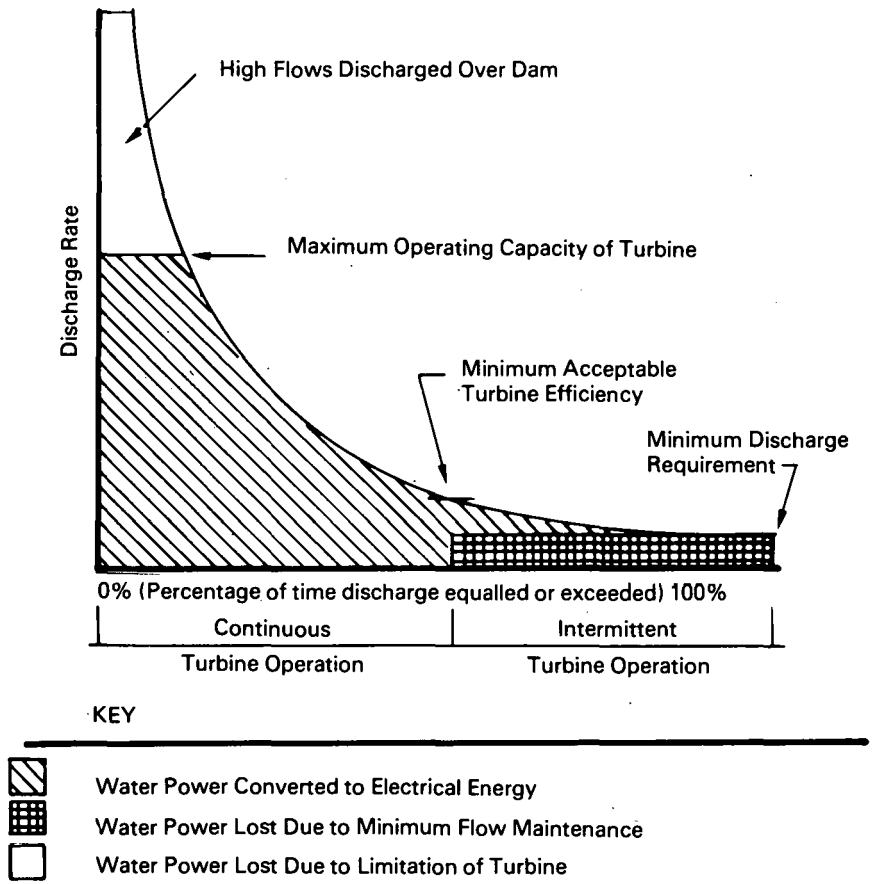


FIGURE G-3.1 Operating Characteristics of a small Run-of-River Hydroelectric Plant in relation to Flow Duration Curve

Each unit of production capacity which is added to the facility returns a smaller marginal amount of total energy. This is due to the fact that the higher magnitudes of streamflow which would utilize the additional generating capacity are available an ever-decreasing proportion of time.

Table G-3.1 below illustrates this situation quantitatively by showing the average utilized capacity of different sized plants at the French Landing Dam site on the Huron River in Van Buren Township, Michigan. This particular dam site has an average hydraulic head of about thirty-three feet and a mean streamflow of about 520 cubic feet per second (cfs). As the table shows, the incremental effective capacity decreases with each increment in plant size. The first 500 kW of production capacity will be utilized 90 percent of the time, whereas the last 500 kW of capacity will be utilized only 28 percent of the time.

TABLE G-3.1

Installed Capacity (kW)	500	750	1000	1500
Effective Capacity (kW)	448	596	703	844
Increment (kW)	448	148	107	141
Utilization	90%	59%	43%	28%

The consequence of this phenomenon on the economics of a small run-of-the-river hydroelectric plant cannot be overemphasized. As production capacity is added to a site, project costs increase but marginal project revenues (i.e., energy output) drop significantly. Of course, project costs do not increase linearly with capacity. If this were the case, the benefit/cost ratio would constantly decrease and the optimum plant would be sized for the 100 percent exceedence discharge. Hydropower facilities, even at existing dam sites, have large civil and structural costs which must be borne regardless of the size of the generating equipment. Consequently, the optimum plant capacity becomes that which generates sufficient revenue to optimally amortize the initial civil and structural costs, plus the more variable project costs associated with equipment capacity.

Project Costs and Revenues

Figure G-3.2 illustrates this principal more clearly by means of a conceptual-graphical model of hydroelectric facility economics. This graph represents what we have found to be the typical relationship of project costs, revenues, and benefit/cost ratios, as a function of plant size (i.e., installed capacity). For the purposes of this model, it does not matter whether the figures are expressed in average annual rates or life-cycle values; the relationships shown would be the same in either case. As indicated on the graph, the curve representing civil and structural works cost starts at a fairly high initial level (point A); however small the production capacity, there are certain necessary expenses related to dam refurbishment and powerhouse construction. As the size of the facility increases, however, the marginal cost of civil and structural expenses becomes smaller and the curve flattens out. The structural costs to install a 500 kW turbine, for example, are not greatly different than those to install a 300 kW unit.

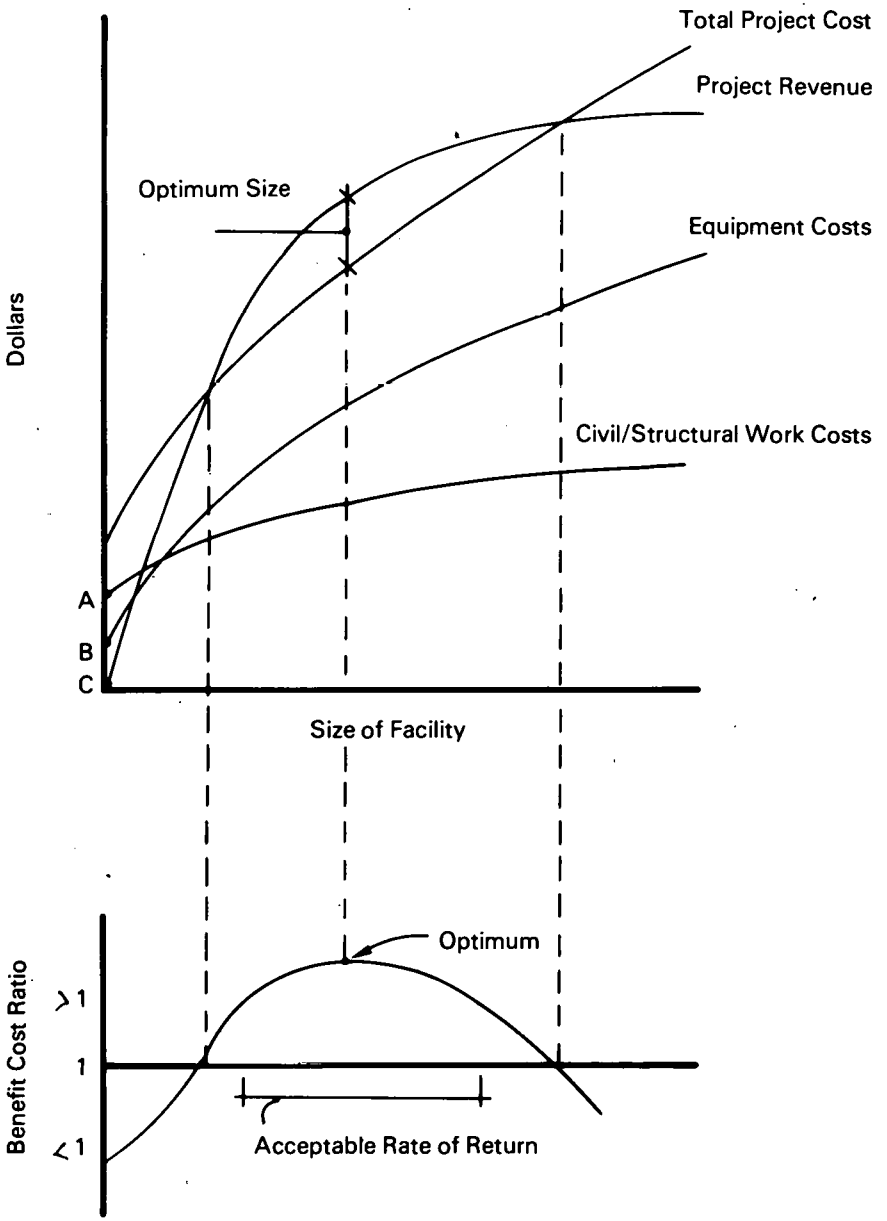


FIGURE G-3.2 Conceptual Model of Hydroelectric Facility Economics

The equipment-cost curve starts at a low initial level (point B) and rises as the size of the facility increases, but at a rate slightly less than proportional. The project revenue curve starts at zero, increases sharply as the lower stream flows are utilized, and then becomes quite flat as the water power potential at the site begins to be fully utilized. Eventually, in fact, it becomes perfectly parallel, representing the total utilization of all available water power.

For the project to be at all costfective, the revenue curve must at some point be higher than the project-cost curve. The point at which there is the greatest positive differential between the project revenue and cost curves represents the optimum facility size.

Case Study Example

Figure G-3.2 may be an interesting conceptual model but how, in fact, can the optimum plant capacity at a site actually be determined? Presumably, if project costs and the flow-duration curve could be defined in precise mathematical expressions, it would be possible to exactly determine the optimum plant capacity at any given site, or even to define a range of acceptable capacities based upon different investment criteria. The flow-duration curve, however, because it is based on a succession of natural events which do not fit a known statistical distribution, does not lend itself to a precise mathematical expression. As a consequence, an approximation technique is often used. The approximation technique which we have chosen involves the calculation of marginal rates of return for specific alternate plant capacities. By noting the effect of plant size on the marginal rate of return it is possible to identify the range of greatest cost-effectiveness and thereby be able to define a project which will have the best chance of being able to pay for itself.

Table G-3.2 summarizes the results of such an analysis based on four capacity alternatives at the French Landing Dam site introduced earlier.

TABLE G-3.2

Installed Capacity (kW)	500	750	1000	1500
Estimated Projcct Cost (x1000)	$835	$1063	$1294	$1749
Project Cost Increment (x1000)	$835	$ 228	$ 231	$ 455
Projected Annual Revenue (x1000)	$ 94	$ 125	$ 149	$ 174
Revenue Increment (x1000)	$ 94	$ 31	$ 24	$ 25
Incremental Rate of Return	0.11	0.14	0.10	0.05

The table shows project costs and project cost increments, project revenues and revenue increments, and the resultant marginal rate of return for each capacity alternative.

Just as the model would suggest, we can observe the marginal rate of return (which is directly related to the benefit/cost ratio) rise to a maximum value and then drop off again. Based upon this analysis, we can say with some confidence that the most cost-effective plant capacity at the French Landing Dam site is somewhere between 500 and 1000 kW, since this is the range in which the marginal rate of return goes through a peak value.

Conclusion

This paper has attempted to illustrate the importance of hydroelectric plant capacity on project cost-effectiveness. The application of this method of analysis to several actual sites has led us to the general conclusion that where small-scale hydro is concerned, less is often better. That is to say, it is often better to take a smaller quantity of the available water power from a given site, in a manner which will be cost-effective, than to try to extract every last bit of energy from the water, in a project that cannot pay for itself or attract the necessary capital to be developed.

COMPARATIVE PROJECT ECONOMICS OF SMALL-SCALE HYDROPOWER

Kemal Satir

Introduction

Small-hydro projects normally are the run-of-river type with little or no storage. During the past decade the price of electricity increased while many generating systems were falling behind demands. For the past several years the price of electricity has accelerated and the nationwide generation capacities have become critical. The solutions of the energy supply problems are very complex and will be extremely costly. These solutions would come through time consuming technological efforts which are all intertwined with our scientific, socio-economic and socio-political systems. The latest trends in price increases will continue at least at a minimum of 7% /year. The electricity generated by fossil or nuclear plants recently energized would be at least 40 mills/kWh. For smaller steam plants to be constructed during the years of 1990 to 2000, the costs of generation would be about 80 and 160 mills/kWh.

A comparison of energy generated by small-hydro project is done with respect to the generation by coal and nuclear-fired plants, as well as, the wholesale rate of electrical power in Figure G-4.1.

Description Of Comparative Projects

This paper considers examples of typical characteristics for project sites around the nation, and any of these illustrations does not represent a specific existing project. It is assumed that such project sites normally would have design flows between 1 and 40 cms because they would be on small streams. Small-hydro project site evaluations suggest that the design flows should be mostly well below 50 cms. Most of the existing low-head dams have a maximum design head of 20 meters. New sites are compared for the same design flows mentioned above but under two different design heads, namely:

1. Low-head projects with 20-meter design head, and
2. High-head project with 100-meter design head.

The payout period for all project is assumed at 40 years with a 10% interest rate. Time for planning, engineering and construction activities would be about five years. For project operation and maintenance one to three technicians are considered. Smaller plants may require one-half time attendance although the projects would be designed to operate automatically. Reserves and contingencies for 40-year payout is considered to be about 35% of the total construction cost.

Mr. Satir, is an electric utility consultant, Spokane, Washington

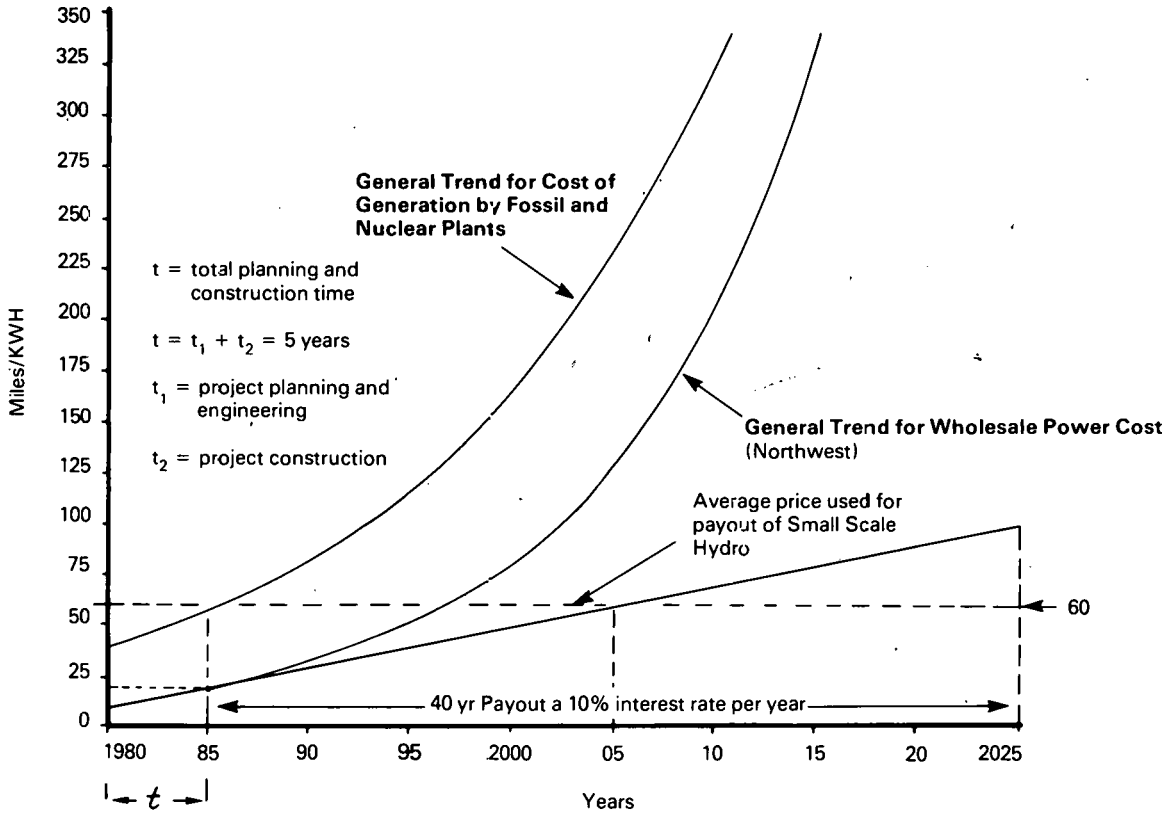


FIGURE G-4.1 Cost of Electricity vs Payout Criteria for Small Scale Hydro Projects

TABLE G-4.1

Nominal generating capabilities for illustrated projects.

Design Flow (Q_d in cms)	Low-Head Projects ($H_d = 20$ m.)		High-Head Projects ($H_d = 100$ m.)	
	kW	kWh (annually)*	kW	kWh (annually)*
40	6,400	25,800,000	32,000	129,000,000
20	3,200	12,900,000	16,000	64,500,000
15	2,400	9,700,000	12,000	48,500,000
10	1,600	6,450,000	8,000	32,250,000
5	800	3,225,000	4,000	16,125,000
4	640	2,580,000	3,200	12,900,000
3	480	1,930,000	2,400	9,650,000
2	320	1,290,000	1,600	6,450,000
1	160	645,000	800	3,225,000

(*) Capacity factor is 46%

Detailed Planning & Engineering Activities:

First-Phase

1. Basic field survey, application for preliminary permit.
2. Site mapping, basic planning & feasibility study.
3. Core drilling, flow instrumentation and EIS Report.

Second-Phase

1. Expansion of planning & engineering and financing activities.
2. Application for construction license.
3. Detailed designs & plans; construction contract.

Third-Phase

1. Call for bids.
2. Bid opening and construction follow-up.
3. Final tests and authorization for project operation

Cost And Economic Comparisons

a. *Cost Items of Each Project Case for Total Construction Requirements:*

1. Land purchase including resources (i.e. timber.), etc.
2. Access road
3. Road or railroad relocations
4. Pondage clearing*
5. Dam, gates, trash racks, fish ladders and recreational facilities: The head in high-head projects is accomplished by penstock run, and therefore, the dam for a high-head project would be much smaller both in height and width.*

6. Penstock: Low-head project at 20-meter design head would normally require less than several hundred feet penstock. But, it is assumed that high head project would require up to 8000 feet penstock runs in order to gain 100 feet of design head.
7. Powerhouse including the crain, etc.
8. All retaining walls and rock fills by head and tail water areas.
9. Turbines & governors, inlet valve, generators, switchgear & controls.
10. Power transmission or distribution lines (it is assumed that each project would require 10 miles of power line).
11. Detailed engineering & planning activities in three phases.
12. Administrative expenses.
13. Allowances for nominal indeterminates.
14. Nominal budget contingencies & escalations.
15. Cost of money during major planning & construction activities.
16. Working Capital

Total Cost . . . . . (Total Construction Requirements)

b. *Comparative Cost Trends for Installed Capacities (Figure G-4.2):*

The cost of generating electricity with today's fossil and nuclear plants, and directly from the sun's energy, when compared with small-hydropower generation, the attractiveness of small projects becomes obvious. The present cost of developing commercial electrical power from the sun's energy will vary between $6000 to $12,000 per installed *KW* capacity depending the type of design. Presently constructed nuclear and coal-fire plants would cost between $1200 and $1600 per installed *kW* capacity upon their completion.

c. *Benefit/Cost Ratio vs. Total Plant Output (Figure G-4.3):*

Benefit/Cost Ratios clearly indicate that the concentration efforts on the development of small-hydropower projects should be more and more in the coming years, particularly with the emphasis on high-head sites.

d. *Mills/*KWH *vs. Total Plant Output (Figure G-4.4) (when benefit cost ratio is 1.0 for all project cases):*

For the same output, the high-head projects are more economical, and furthermore the high-head project will contribute more effectively to the nation's energy problems. Another observation is that even though some of the small-hydro projects may not be economically feasible today, however, they would be feasible sometime in the future.

** **NOTES:** For the project with an existing dam it is assumed that there may be no cost for Items #1 through #4. For the low-head project with an existing dam, the cost of Item #5 is considered to be only 20% as compared to an identical low-head project with a new dam. It should be remembered that most of the existing dams are very old, and normally would not meet the present standard requirements, therefore they will require some upgrading, also additional construction needed to modernize them.

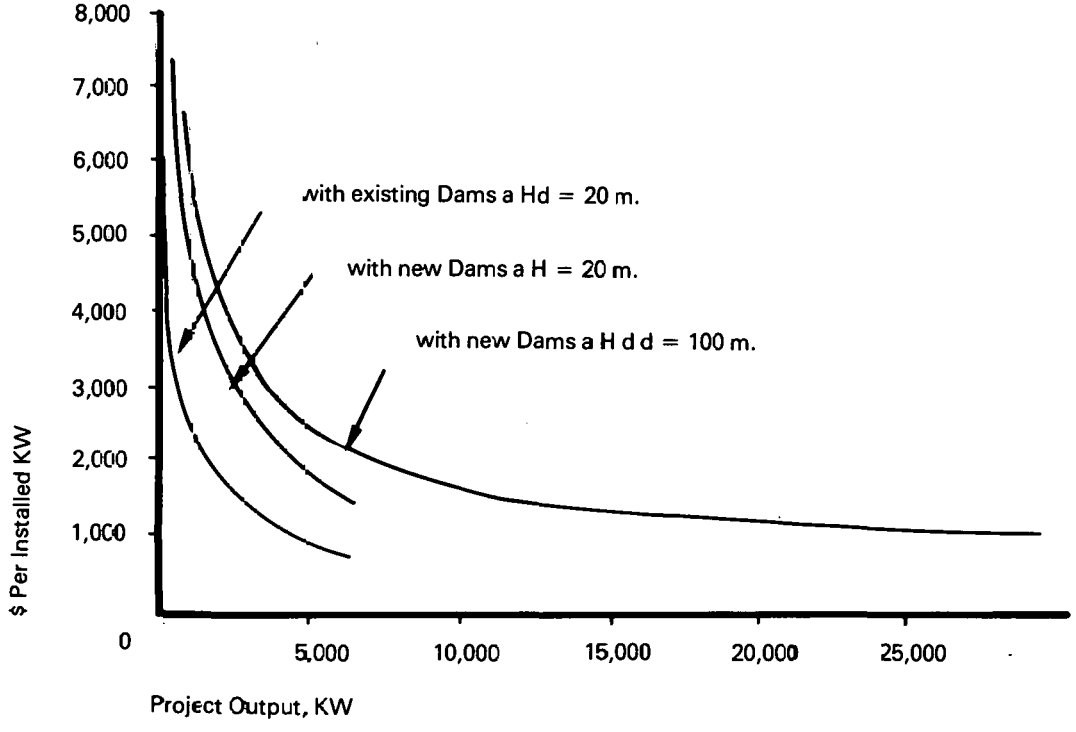


FIGURE G-4.2 Comparative Cost Trends for Installed Capacity (Small-Scale Hydro Projects)

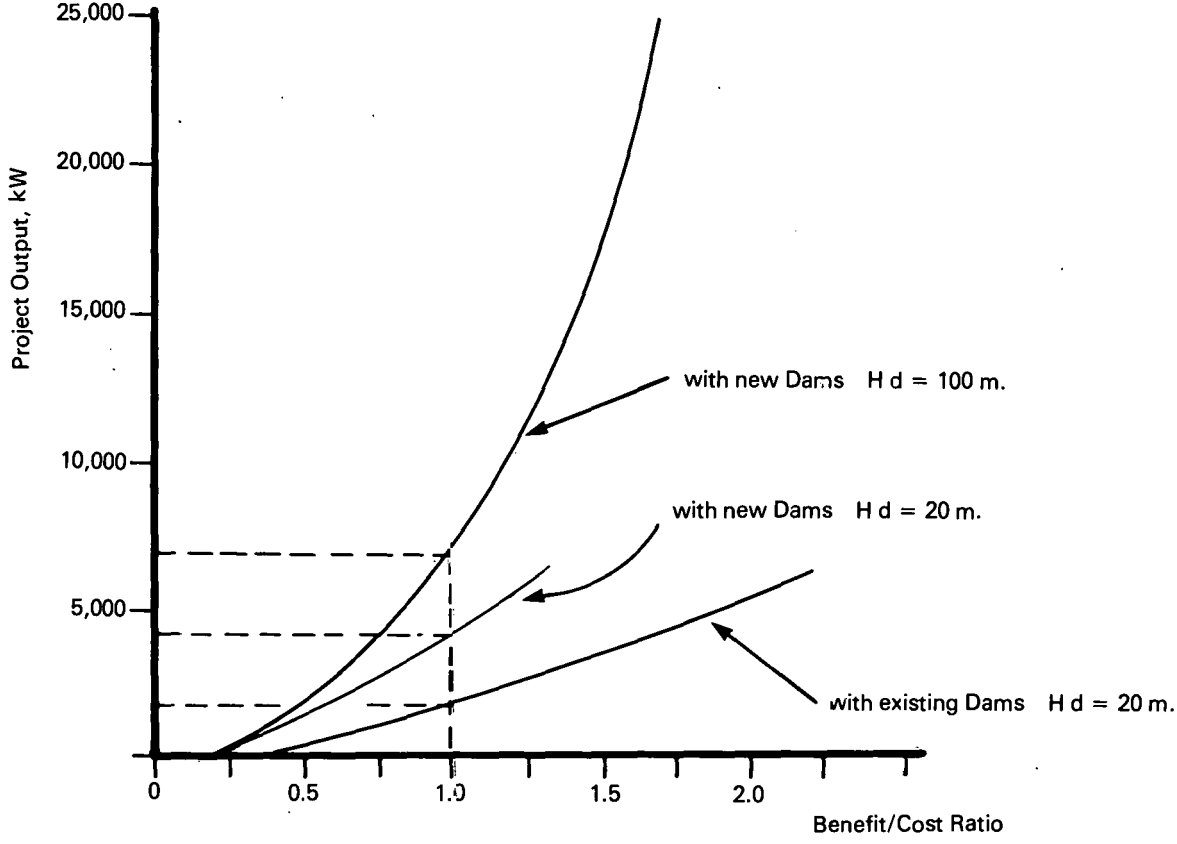


FIGURE G-4.3 Benefit/Cost Ratio vs. Installed Capacity (Small-Scale Hydro Projects)

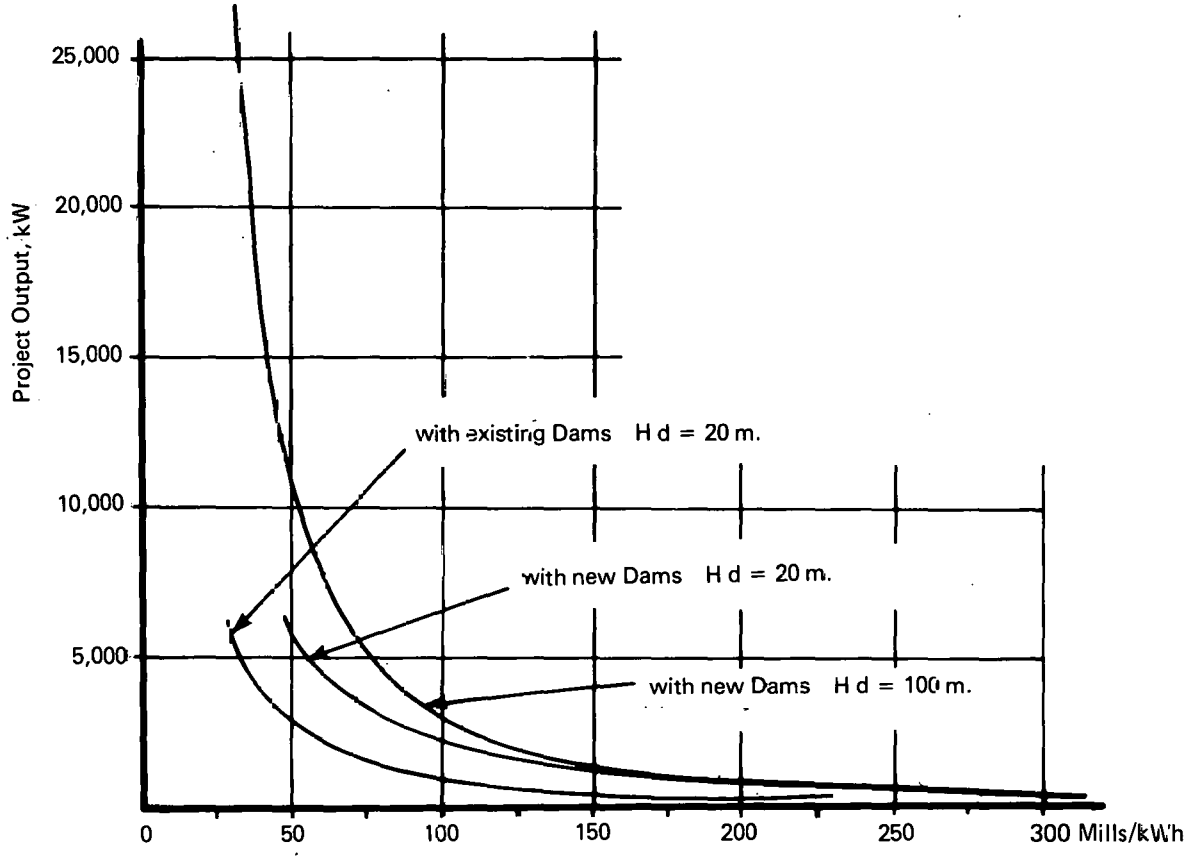


FIGURE G-4.4 Mills/kWh vs. Installed Capacity Wher Benefit/Cost ratio = 1.0 for all project cases (Small-Scale Hydro Projects)

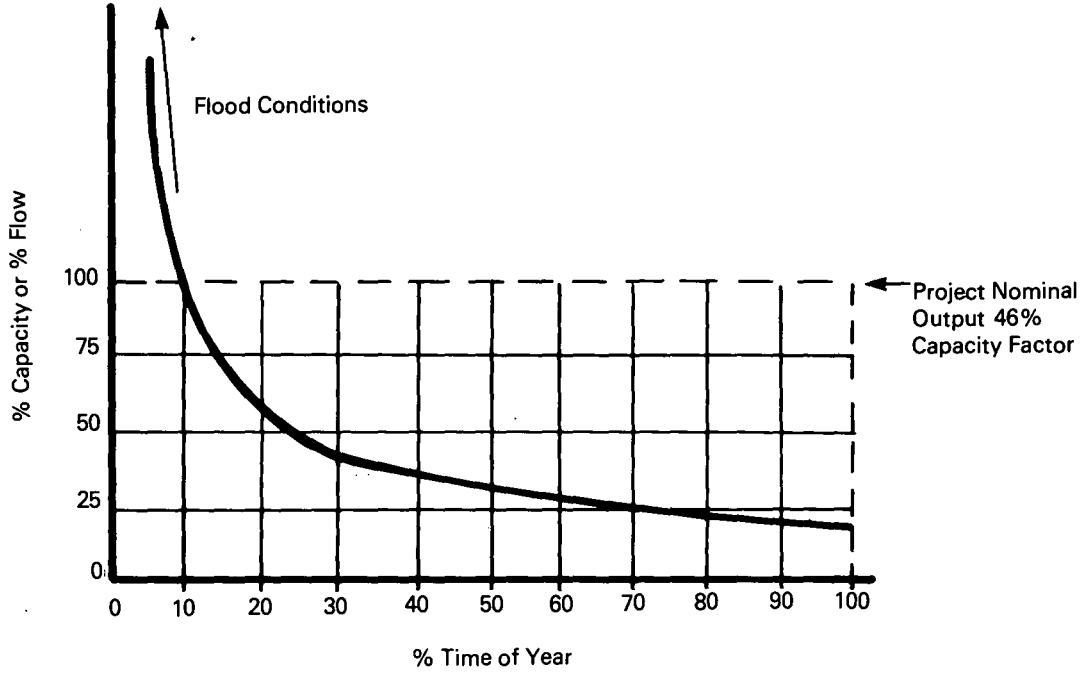


FIGURE G-4.5 Typical Flow Duration Curve for Run-of-River Type Projects (Small-Scale Hydro Projects)

Conclusion

Whether it is a low or high-head project, the development of small-hydropower is more costly than would be expected. However, recent trends indicate that many of the small-hydro projects are now becoming feasible. Rapid increases in the price of electricity and of other energy forms obviously is the main reason for the attractiveness of small-hydropower developments. When giving consideration to priorities in the solution of energy problems, our efforts regarding small-hydropower developments should be concentrated in the following areas:

1. Besides the present trends for low-head projects with existing dams, emphasis must be given to high-head projects with new dams;
2. Practical and less time consuming governmental rules with helpful and expedient guidelines should consider vital priority items in developing hydropower sites so that we can build the economically feasible and technically possible projects in a timely manner;
3. Special and expedient governmental incentives in technical, economical, legal and institutional activities associated with small-hydropower development should provide: (a) tax and financing incentives; (b) other developmental incentives for the use of standard machinery, equipment and tools, as well as for engineering specifications and planning activities; and (c) a general simplification in environmental and licensing activities.
4. In case some hydro-projects are not economically feasible at today's costs they may be feasible sometime in the future. Therefore, the pertinent factors governing how far in the future a project would be feasible must be assessed *now* and accordingly future planning steps should be taken for the timely initiation of these projects.

REFERENCES

Chen, Henry H., *Economics of Low-Head Hydro, U.S. Case Study,* Harza Engineering Co., Chicago, Illinois, 1978.

Gladwell, John S., Warnick, Calvin C., *Low-Head Hydro — An Examination of an Alternative Energy Source,* University of Idaho, 1978.

Reeves, Joseph N., *Solar One Project, A 10-Megawatt Solar Thermal Central Receiver Pilot Plant Project,* Research and Development Department, Southern California Edison Company, Rosemead, California, 1979.

Publications No. 54B4872-01, 54P10244, 54P4213, 54R3636, 54S4921-01 on Tube Turbines, Allis-Chalmers, Hydraulic Division, York, Pennsylvania.

Session Twenty-One

ENGINEERING

Topic: New Ideas, Concepts, and Technology II

Chairman: Mr. Howard A. Mayo, Jr.
Manager, Market Development
Allis-Chalmers Corp.
York, Pennsylvania 17405

IDENTIFICATION OF HYDROELECTRIC RESEARCH IN SUPPORT OF SMALL-SCALE AND LARGE-SCALE DEVELOPMENTS

Antonio Ferreira

The Electric Power Research Institute

The institute (EPRI) came into existence in 1972 under the voluntary sponsorship of the nation's public, private, and cooperative electric utilities. Its formation was responsive to the need for a broad program of research and development in technologies for electric power production, transmission, distribution, and utilization that is economically and environmentally acceptable. Its activities are coordinated with those of the Federal government, state agencies, individual utilities and research organizations in other countries.

Hydroelectric Reborn Through Economics

The hydroelectric industry appears to be undergoing a resurgence of life from one point of view. Generation of electricity by water power appears to have been reborn or rediscovered, viewed from other points. Certainly these are the public concepts as shown to us by the recent articles in the news journals. The calendars of technical meetings throughout the country are carrying increased notifications of hydro-meetings, seminars and conferences.

Those of us who have been in the hydroelectric industry for the past twenty-five years can recognize that the recent activity is not due to a "rediscovery" of a technology but, rather, the increased interest in this natural resource is due to the changing economic baseline. Projects that through years of continuing economic evaluation have been on the economic fence have now fallen off the fence on to the economic side not because the project data or technical know-how has changed, but simply because the fence line itself has moved — and is still moving — principally as a result of the continuing rise in the fossil fuel costs for the alternative forms of generation.

The fact is, however, that hydroelectric generation is much more visible today than it was ten, fifteen, perhaps even twenty years ago. This visibility has caused the Electric Power Research Institute to review its activities relative to the hydroelectric industry not only from an internal staff concept, but also in reaction to queries from member utilities and other research institutes and laboratories.

Need For Improving Economy of Hydro

The utility industry recognizes the need for improving the efficiencies and economy in the design and construction of hydroelectric plants if these

---

Mr. Ferreira is Project Manager, Energy Storage and Hydraulic Engineering Electric Power Research Institute, and Hydroelectric Consultant, Northeast Utilities Service Company, West Springfield, Massachusetts.

facilities are to maintain their attractive position in the choice of generating alternative not only to utility managers but also to investors. Fossil and nuclear plant technology have improved spectacularly in recent years, yet the plants dependent upon hydraulic energy seem to coast along with the same old designs, concepts, and efficiencies with which we have lived for many years. However, good dam sites are fast disappearing, operating and maintenance costs are soaring, and high reliability and availability of hydro generating units are becoming harder goals to achieve and maintain.

In the background, recognition must be taken that several large hydro-turbine manufacturers have recently gone out of business — there is only one major manufacturer today with major manufacturing and research laboratory facilities left in the United States. Also, EPRI and other academic and commercial research facilities have been heavily involved with supporting those generation technologies which have been, in current times, experiencing the economic limelight.

The renewed utility interest in the hydroelectric technology, created partially by the rapid escalation of alternative energy costs and the cognizance of the necessity to reduce capital costs and production costs, is surfacing many design, engineering, construction, operation and maintenance problems which are best resolved on a coordinated basis, so that the results may be made available to the utility industry as a whole.

Program of R&D Identification

The EPRI staff has initiated a program of identifying those areas of the hydroelectric technology that can best reap the advantages and benefits of a coordinated effort of generic research, development, and demonstration. The engineering issues to be addressed will encompass the entire field from the small to the large conventional hydro and the pumped storage hydro. Those utilities which have substantial hydroelectric facilities or have indicated the planning initiatives towards hydro facilities are cooperating in this program of prioritizing, as well as identifying the supporting research needs that will provide long-term, as well as, near-term dividends.

The generic research work is contemplated at this early stage of program identification towards satisfying the following basic objectives. Posted under each of the broad objectives are some design and study projects that have been identified to date by the EPRI staff and by a number of utilities; the list is not intended to be all-inclusive nor by any means restrictive.

Objective A — Advancing the state-of-the-art of hydroelectric technology.

Identified projects/subjects for consideration/prioritization:

- Pump-turbine model and operation correlation studies.
- Review/survey recent and current research in U.S. and Int'l.
- Fast response and regulation of pump-turbines.
- Use of drag reducing polymers in water conduits and turbine passages.

- Development of high head pump-turbine with regulating capability.

Objective B — Improve the performance, reliability, and availability of existing and new generating units; improve the safety and reliability of existing and new dams and other water impounding and transfer structures.

Identified projects/subjects for consideration/prioritization:

- Acoustic flow-measurement verification.
- Improve reliability of hydroplants.
- Development of improved earthquake-resistant design and analysis procedures for dams; simplified procedures for seismic analysis; improved procedures for simulating dam-reservoir interaction in dynamic analysis.
- Review of the effects of erosion, piping, and hydraulic fracturing of earth fill materials on dam failures.
- Assessment of the effects of multiple-cycle drawdown in pumped storage reservoirs (i.e., effect on slope stability, slope movement, slope protection).
- Development of improved procedures for dam performance observation and monitoring; establishment of criteria for amount of movement and acceptable performance.

Objective C — Reduce the capital, operating and maintenance costs of hydroelectric facilities.

Identified projects/subjects for consideration/prioritization:

- Identification and cost effectiveness of potential efficiency increases at existing hydroplants.
- Determination of potential and benefits of utilizing non-metals for cast/molded unit components.
- Optimize cavern sizes and configurations in underground plants.
- Review, evaluation, and determination of improved methods of reducing cavitation pitting damage on hydraulic turbines.
- Analytical prediction of circulation and vortices at intakes.
- Develop improved procedures for sealing of reservoirs, including thin membranes in upstream face of dams, and review methods of evaporation control.
- Investigate resistance of rock fill dams to overtopping.

Objective D — Assess, evaluate, and improve the utilization of hydroelectric resources and increase public and environmental acceptability of hydroelectric facilities.

Identified projects/subjects for consideration/prioritization:

- Develop improved analytical techniques and procedures for routing of floods downstream of a ruptured dam.
- Development of a simplified methodology for technical and economic screening of small-capacity/low-head hydroplants.
- Development of improved analysis techniques for determination of economic feasibility of hydro projects.
- Assessment and utilization of unused hydro potential at existing installations other than dams.
- Determination of heat dissipation at surface reservoirs for UPH plants.
- Investigation of air injection/aspiration methods and procedures for water quality improvements.
- Develop low-cost low-head/small-capacity plants of readily available components.

Operating within its budgetary constraints, EPRI must recognize and be responsive to the economic, environmental, and social factors that affect its utility constituents. The hydroelectric research and development activities will, therefore, be identified, prioritized, and developed primarily as guided by the utility industry itself. Additional important guidance is being furnished by the technical staff of government agencies, engineering consultants, manufacturers, the academic field, commercial laboratories, and private developers.

The economic growth that this nation will enjoy will continue to be satisfied to a substantial degree by the electrical energy generated from its water resources. The goals of ensuring acceptable and economic hydroelectric facilities provide the motivation for the formulation and the direction of the Electric Power Research Institute's hydroelectric research and development programs.

THE VERTICAL HYDRAULIC RAM — A LOW-HEAD, HIGH-FLOW DEVICE FOR POWER DEVELOPMENT. DESIGN OUTLINE FOR A 1000 kW PLANT FOR A SIX-FOOT HEAD

Hamilton Baird

Introduction

Very low-head hydro sites remain undeveloped largely because the cost would be too high in relation to the output.

Research efforts recently have been directed toward developing new turbine designs which would be more suitable for use at very low-head sites. Papers being presented at this conference will have considered in detail the turbine problems which are encountered at very low-heads, but at the risk of repetition it may be desirable here to refer to two basic points:

1. A turbine designed for a very low head will cost practically the same as a turbine of the same diameter, which has been designed for working under a higher head and for producing much more power.
2. A turbine operating under a higher head will rotate at higher R.P.M., which would be more suitable for direct connection to a generator.

For these reasons, then, a very low-head turbine, in terms of power output will tend to be a high-cost turbine.

As a device for utilizing low-head water, the hydraulic ram was in wide use 50 to 100 years ago on farms and along railway lines to force water up to water towers which served the steam locomotives.

Under laboratory conditions the ram will operate under a head of only one inch, and under favorable conditions it will operate at a hydraulic efficiency in the 90% range.

A description of its operation can be found in the older engineer's handbooks and in encyclopedias, in which it will be noted, unfortunately, that the volume of water handled is relatively small, far too small to be useful for hydropower development.

Redesigning The Hydraulic Ram

Many attempts have been made to design the hydraulic ram on a large scale, but without real success due to problems of valve inertia and unacceptable pressure build-ups; but through the application of modern techniques such as computer controls and fluidic valves it may be possible to redesign the

---

Mr. Baird is a consultant and resides at 191 Bonaccord Street, Moncton New Brunswick, Canada.

hydraulic ram in a manner which would permit scaling up to power-development dimensions.

Specifically, it may be possible to eliminate the large impulse valve and to eliminate the large air-cushion tank. Also, it may be possible to avoid the necessity for the long drive (supply) pipe which must be capable of withstanding high pressure throughout its entire length.

The Rotary Hydraulic Ram

In an effort to overcome at least some of the problems which are involved in a scaling up of the ram, a rotary version of the ram was devised and has been the subject of considerable study and experiment. It comprises a rotating sleeve valve which permits elimination of the impulse valve, the check valve and the air-cushion chamber. Like the spokes of a wheel, a number of drive (supply) pipes are arranged to feed in to the rotating valve, from which there is a continuous high-pressure output.

After some years in the doldrums this rotary version of the hydraulic ram is now back in a hydraulics laboratory and thus, the Rotary Hydraulic Ram may be the subject of a progress report at the next conference on low-head hydropower.

However, it should be recognized that the rotary version of the ram is heir to its own set of problems, especially in that the rotary valve might be too costly in relation to output. It would be constructed to close tolerances, probably equivalent to those of a high performance centrifugal pump.

Therefore, it would seem to be wise to vigorously pursue an examination of any other possible means of accomplishing the desired conversion.

The Vertical Hydraulic Ram

The vertical hydraulic ram is offered by this writer, as the best approach which he has been able to find to the problem of devising a mechanism which might meet the demand for cheap, robust equipment.

Figure H-2.1 is a schematic drawing of one unit of the vertical ram. The main elements of which are shown as follows:

1. A fluidic switching valve to provide input alternatively to two rams.
2. A vertical cylinder arranged to receive input through the switching valve.
3. A plunger which after receiving its load of water, falls due to gravity at an accelerating rate.
4. A free-floating piston which is impacted by the falling plunger in a manner similar to the action of a pile driver. The impact forces the bottom end of the piston into a water-filled housing.
5. An orifice connected with the housing, produces a rising jet.
6. A silo, at the top of which the jets from a number of rams are deflected into a high-level flume which leads to the intake of a conventional hydroelectric plant, or it may lead to a storage basin for peaking use.

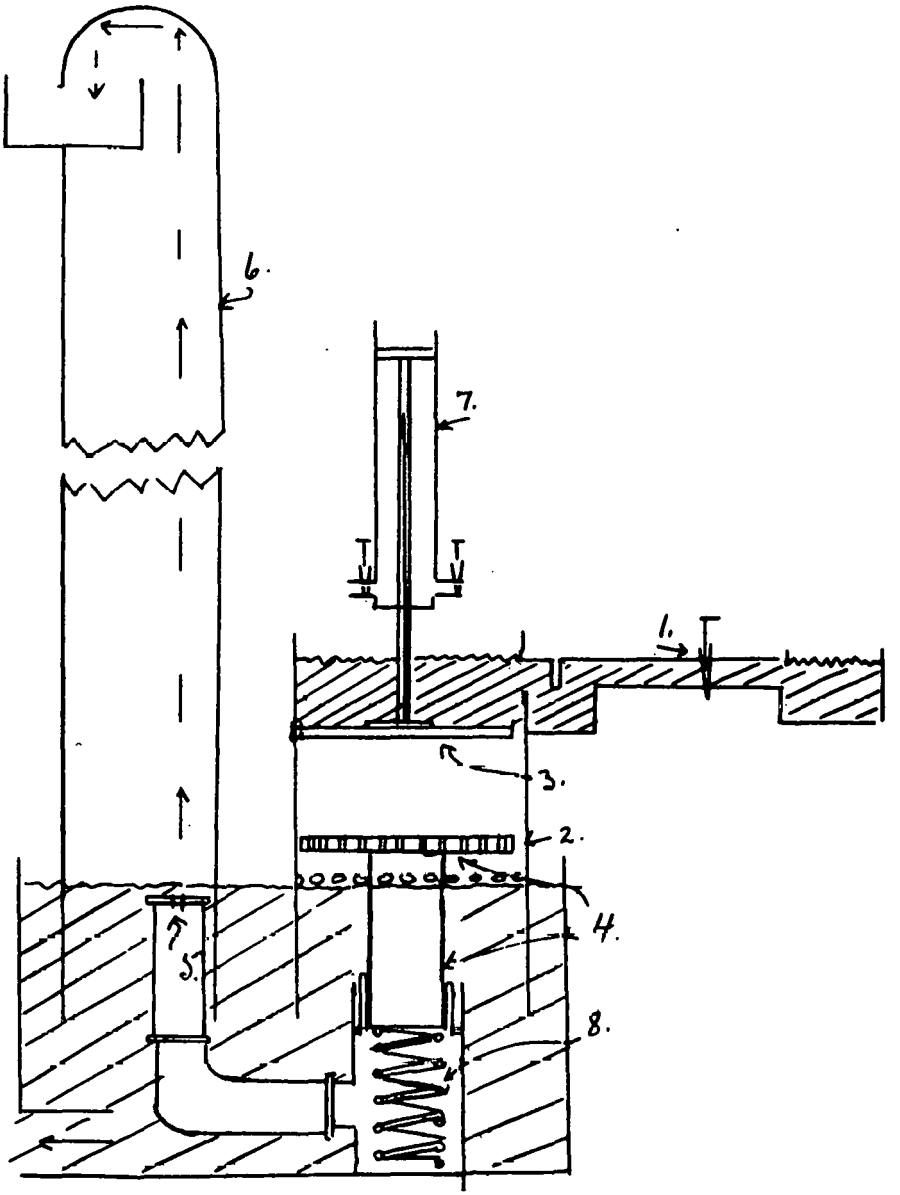


FIGURE H-2.1 Vertical Hydraulic Ram

The basic cycle of the vertical hydraulic ram will be fairly clear from the drawing. A hydraulic-servo cylinder will control the operation of the plunger, in combination with suitably controlled release cams. A compression coil spring will provide for the return of the piston to its top position.

The design of the vertical ram provides for the elimination of a number of the problem elements of the conventional ram, namely the long drive (supply) pipe, the impulse valve, the check valve and the air chamber. However, the important basic characteristics have been retained, namely an employment of the forces of gravitation, acceleration and deceleration and the dividing up of the supply water into batches.

A problem which exists in the case of a turbine when used at very low-heads is that, to quote Professor Herman Sheets of Rhode Island University, "In the energy conversion the fluid velocity cannot be reduced to zero, as this would stop the motion." The fluid velocity is reduced to zero, however, by the hydraulic ram which operates on a batch system, rather than on a continuous flow system. This intermittent or batch system has been retained in the vertical hydraulic ram through the device of arranging the rams in pairs, with a switching valve alternating the supply first to one and then to the other. A conventional type of switching valve might be used for experimental models of the vertical ram, but in production quantities it is anticipated that a fluidic bistable switching valve, based on the Coanda principle could be used effectively.

The idea of employing a jet for the output is due to Professor J. R. Tippetts. The jet permits elimination both of the check valve and the air cushion chamber. It may be noted from the drawing, the jet orifice is located slightly below the tail water level in order that water may be drawn back through the orifice to provide for the next cycle.

The batch of water which flows into the cylinder, from the point of view of efficiency, should be shallow, in order that the center of gravity of the batch would experience a fall of maximum distance. An example of a shallow batch as employed in a hydraulic mechanism is to be found in the old but very efficient overshot water wheel, in which the buckets were so shaped that as the water flowed into them it assumed a quite shallow shape at the commencement of its downward travel.

Estimates as to Appropriate Size, Output and Efficiency of the Vertical Hydraulic Ram

For the purpose of working out an example, an available head of 6 feet has been assumed, with the vertical drive pipe also being 6 feet in diameter. In this case, in order to obtain reasonably good efficiency, it would appear that the depth of the batch of water ought not to exceed 2 feet, which would mean that at the time of release for the drop, the center of gravity of the water would be 5 feet above the tail water level.

If a surplus volume of water were available, the depth of the batch could be increased, which might produce a greater output of energy per cycle, but with some loss of hydraulic efficiency, as is the case in normal turbine operation. The above dimensions suggest there would be some 56 cubic feet of water in the batch; falling a distance of 5 feet and performing an assumed 720 cycles

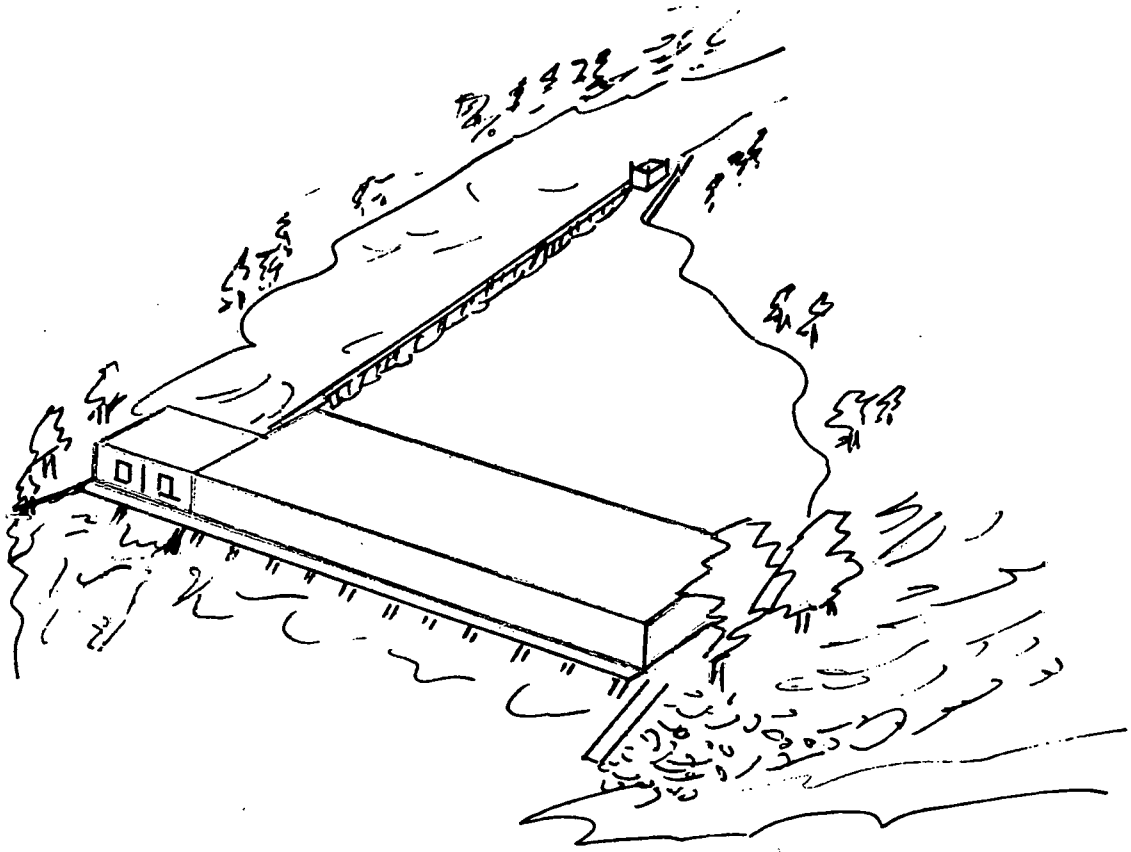


FIGURE H-2.2 Impression of a 1,000 KW power development showing a rapids section of a small river where the available head is only 6 feet. In the distance is an intake house through which water is supplied to the head-pond for the enclosed area containing a battery of 400 vertical hydraulic rams adjacent to which is a small powerhouse containing two turbine-generator units.

per hour, and assuming 50% overall efficiency, the ram should be capable of producing the equivalent of 2.5 kW. A battery of 400 such rams would represent an output of 1,000 kW. Such a battery of rams, together with a system of supply flumes, high level output flumes and spent water flumes could be constructed, it is estimated, within an area measuring 300 feet along the face of the river dam and 150 feet back from the face of the dam. Figure H-2.2 offers an impression of a complete very low-head hydroelectric power development of 1,000 kW capacity.

Conclusion

The concept of the vertical hydraulic ram is not yet fully proven; it will require the cooperation of a research group with laboratory facilities if progress is to be made in this area of development of very low-head river and tidal power sites.

REFERENCES

Iverson, H.W., *Analysis of Hydraulic Ram*, ASME paper M75-FE-F

Krol, J., *The Automatic Hydraulic Ram, Its Theory and Design*, ASME paper 76-DE-17 345 East 47th St., New York NY 10017

Mercer, A.G., *Study of Factors Affecting Feasibility of Low-Head Hydroelectric Generation*, Colorado State Univ., Denver, CO, March 1969

Tippetts, J R , *Fluidics Quarterly Vol 6 No 2*, April, 1974. Fluidic Hydraulic Ram.

HYDROELECTRIC DEVELOPMENT, WITHOUT DAMS, RESERVOIRS, AND PENSTOCKS

Phillip R. Hoffman

Introduction

The problem of pressure regulation on water supply systems is practically universal. Water impounding reservoirs are typically located in mountainous regions, perhaps thousands of feet above the city to be supplied. Generally, much of the head is utilized to generate at hydroelectric stations along the aqueduct. However, the terminal reservoirs near the city are generally much higher than required to furnish the desired maximum pressure to the ultimate consumers. Pressure regulating stations are, therefore, installed to maintain a satisfactory maximum pressure in the service areas. These stations are generally located in vaults beneath the streets.

As indicated in Figure H-3.1 the amount of head to be dissipated varies with the time of the day. At night, when water usage is minimal, friction head losses in the supply pipe lines from the reservoir are small and the excess head is much larger than in daytime hours when usage is very much greater, resulting in higher head losses due to friction. The energy dissipated at these stations may be rather large. The electrical equivalent is many kilowatts, more than 500 kW in one such station in a large city.

The purpose of this paper is to illustrate a simple, very economic scheme to recover the energy presently being wasted at these stations. Perhaps the most important benefit is the environmental effect. For each 100 kW (average) recovery station the fuel oil saving would be more than four barrels per day — approximately 1,500 barrels per year.

Since hydroelectric projects in the lower megawatt range are commonly referred to as "mini" hydro units, the author has chosen the word "micro" to designate the units involved in this type of energy recovery program. They would probably be in 50-500 kW range. A recent article in the literature discusses the extensive development of small-hydro units in Finland. Their definition of mini hydro units is 200 kW to 2 MW. Units less than 200 kW are called "micro-plants."

Environmental Considerations

Today it appears essential to solve the environmental problems of a proposed project *first*. And, if this is not properly executed, there may follow a great waste of time and money.

The type of energy recovery project proposed in this paper happens to be the *first* hydroelectric development ever to come to the attention of the author, in which there are no *adverse environmental* effects. On the basis of experience

---

Mr. Hoffman is a consulting engineer, Hydroelectric Mini-Micro Hydro, Los Angeles, California.

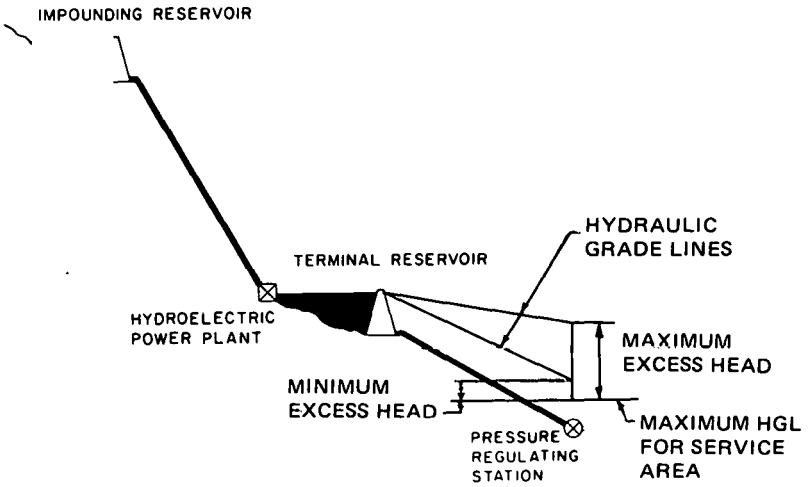


FIGURE H-3.1 Typical Schematic - Water System with Pressure Regulating Station

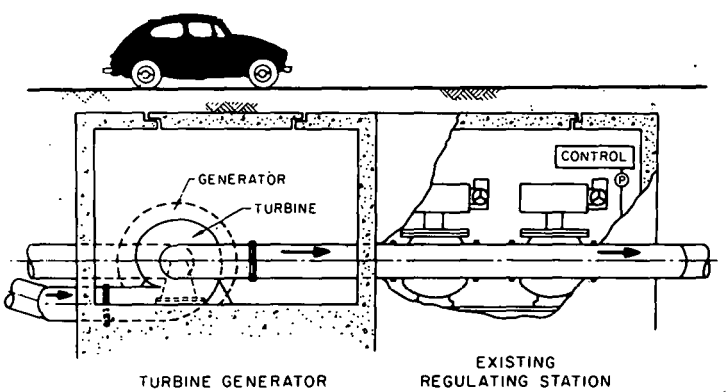


FIGURE H-3.2 Schematic for Energy Recovery Station Series Type Installation (Bypass Valving Not Shown)

with several Environmental Impact Statements involving hydroelectric development it appears difficult to overestimate the significance of this situation.

The only way to really appreciate the environmental benefit of such energy recovery is to consider the alternative, use of fossil fuels. Looking beyond the near future, one would have to assume a shortage of oil. Then the real, long-range alternative would become coal and/or oil shale.

The use of coal poses many large scale environmental problems. The mining operation is perhaps the smallest. Combustion poses several problems, i.e. emission of the particulates and other pollutants, even with a 99% reduction. Next comes ash disposal on a permanent basis — and for enormous volumes. Oil shale poses other problems. The most precise evaluation of the environmental benefits of this energy recovery process is, therefore, the reduction — to zero — of the above deteriorating effects on the environment, for as much energy as can be recovered by this simple and cost effective process.

Typical Installation

Traditionally, one associates certain essential facilities with hydroelectric development. Typically, these would include: a dam to provide impoundment, a power tunnel and/or penstocks, a surge chamber and, perhaps, a downstream flow reregulating reservoir — in addition to the actual power plant. Also, transformation is generally required to obtain transmission voltage. The transmission line itself almost inevitably involves extensive right-of-way problems and probably a separate E.I.S.

None of the above are required in developing an energy recovery facility at any existing pressure regulating station. There may be *one* permit required, an excavation permit for the vault to house the facility beneath the street. Transformation is avoided by generating at the local distribution voltage. Transmission would consist of an underground connection to the nearest power pole.

Figure H-3.2 is a vertical section schematic of such an energy recovery facility. There is a choice in the type of turbine. For the smaller installations it would not presently be economic to have a hydraulic turbine especially designed. A centrifugal pump can be utilized at a slightly lower efficiency. For larger facilities, such as the one discussed under "economic considerations," it may be worthwhile to actually use a turbine. However, no wickets would be required for an "in series" type installation as the basic flow control could be accomplished by the existing pressure regulating station.

Because the large flow variation (5 to 50 CFS) indicated in Figure H-3.3, it may develop that, at minimum flows, the generator may actually function as a motor, and draw power from the system. This is correct; however the amount of power involved is relatively trivial, and is *always* during an off peak period for the power system.

Controls are optional. Regardless of the circumstances, the existing regulating station would continue to perform its design function. For example: if the generator loses load due to an outage in the connected distribution system, the turbine would simply "float" on the line at a speed determined by the regulated flow, as controlled by the existing station. There is therefore, no problem of "runaway" overspeed.

Optimal Installation Size

The determination of optimal size is very simple. Refering to the graph of typical weekly flow (Figure H-3.3), it may appear that an installation large enough to utilize the maximum flow would not be economic. However, let us consider, for example, the increment of additional energy recovered by a plant expansion of 5 CFS (from 35 to 40 CFS), compared to the incremental cost of the plant expansion.

Since the cost data presently available is totally inadequate, a definite conclusion is not possible. However, the incremental cost of the plant expansion will certainly be extremely small. If appropriate consideration of escalation is given to the additional energy benefit it will greatly favor the enlarged plant.

Economics

An estimated cost of $1,000/kW has been used for the following example although most of the expensive facilities required for a hydroproject, - such as a dam, reservoir, power tunnel and/or penstocks, surge chamber, transformation, transmission and right of way are absent. This figure, obviously much too high, has been chosen because, even at such a high installed cost, an energy recovery project of this type is very cost effective, without any government subsidy.

Example:

Assume a micro-hydroelectric unit to be installed at a pressure regulating station where:

Maximum flow is 50 Cfs (1.4 m^3/s)
with, net effective head = 270 Ft (82 m)
Minimum flow is 5 Cfs (0.14 m^3/s)
with net effective head = 300 Ft (91 m)
Maximum capacity = 900 kW
Average output = 500 kW
Plant cost (900 kW @ $1,000/kW) = $900,000
Benefits: Assuming oil @ $15/bbl.
(Equivalent to 25 mils/kWh)
Energy production (8,600 hours/year)
4.3×10^6 kWh/year

Annual benefits: $4.3 \times 10^6 \times \$0.025/kWh = \$107,500$/year; with interest at 7%, the payout period would be approximately 13 years. Operating and maintainance have been neglected, however they are expected to be less than those for the existing valves.

History

The earliest example of energy recovery at a regulating station, which has come to the attention of the author, was an extremely small installation. In 1956 the Water System of the Department of Water and Power, Los Angeles, was about to do considerable work on maintenance of a regulating station. In

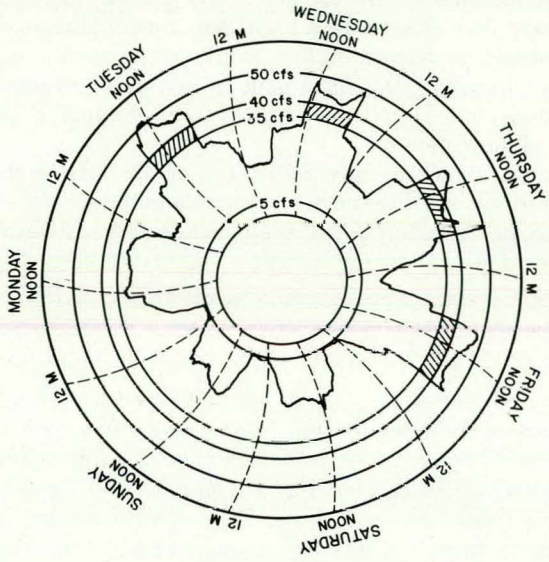


FIGURE H-3.3 Typical Weekly Flow Measurements for Regulating Station No. 154 Mean Flow 25.7 c.f.s. (0.728 M 3/s)

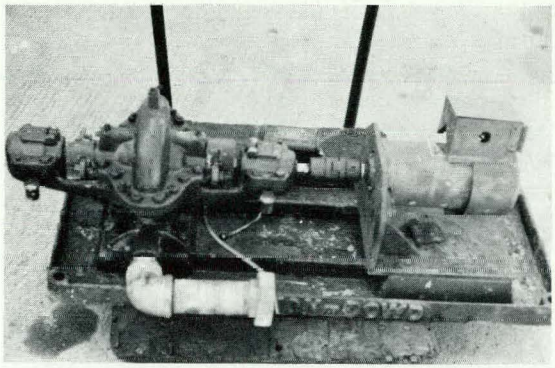


FIGURE H-3.4 Probably the first energy recovery unit ever to be installed in the vault of a pressure regulating station, circa 1956

the vault there was no power available. A special power service would have been very costly.

An ingenious electrician solved the problem by installing a tiny turbine generator unit in the vault to provide power. An interested pump company donated a small centrifugal pump which was driven backwards to serve as a turbine and connected to a large automotive type generator. Primitive but sufficient! The Department has preserved the entire unit and it was removed from its storage place for its picture. (Figure H-3.4).

Conclusions

This paper proposes the utilization of an energy source, available almost universally, but not obvious - perhaps because it is widely dispersed in many vaults beneath the public streets.

Economics are discussed only briefly because there is inadequate data to justify precise figures. The example given uses an assumed installation cost of $1,000/kW which, although extremely high, was chosen to illustrate the probable cost effectiveness.

The many environmental benefits of such an energy recovery development are discussed in relation to the numerous deteriorating effects (for the fossil fueled alternative), all of which are completely absent in this process.

APPROPRIATE TECHNOLOGY IN HYDROPOWER

Rene D. Tegtmeyer

Introduction

My subject relates to appropriate technology in patents for small-scale hydropower systems. I will be discussing patents generally as a source for appropriate technology in all fields, and I will be discussing patents as a source for appropriate technology in the hydropower area.

What is the nature of information contained within patents? How can you access patent information? To what extent is hydropower technology covered, and what are the trends in hydropower patenting activity?

Encouraging Technological and Economic Progress

In the year 1990, only a decade away, we will celebrate the bicentennial of the U.S. Patent System. The framers of the United States Constitution saw fit to include a patent provision "to promote the progress of science and the useful arts." The patent system promotes technological progress in two ways. First, it provides the inventor or the owner of a patent with seventeen years of patent protection, the right to exclude others from making, using or selling the subject matter protected by the patent. Second, the patent system provides for the disclosure of new patented technology to the public in return for the grant of a patent.

The value of patents has become well established in the American System; indeed, the patent system is a cornerstone of free enterprise economy. Patents are incentives for innovation—for R&D investment—for ventures in commercialization. The seventeen year protection encourages the investment of risk capital. No less important is the encouragement offered by the patent system for disclosing new inventions rather than keeping them secret. The resultant flow of technological information adds immeasurably to that universe of knowledge from which future inventors and innovators draw, and upon which corporate planners rely.

In 1790 the first U.S. patent was granted. Just yesterday, the Patent and Trademark Office (PTO) issued patent No. 4,170,041 among normally more than 1200 weekly grants—covering the gamut of applied technology. Each year, the PTO Examining Staff, numbering around 1000, considers more than 100,000 patent applications, around 2/3 of which eventually result in patent grants.

An Appropriate Technology Resource

Overall use of the system continues, as inventors throughout the world seek the advantage of protection offered by the U.S. patent grant. The legal re-

---

Mr. Tegtmeyer is Assistant Commissioner, Patents and Trademark Office, Washington, D.C.

quirement for a full disclosure of the details of each invention—which is then published at time of grant—has resulted in a vast collection of technical knowledge within the files of the PTO. This collection, probably the largest of its kind in the world, includes more than 23 million documents,[1] and is growing by more than one-half million annually. These 23 million documents are broken down by subject matter into 350 classes and over 100,000 subclasses or discrete subcategories of technology in the search files of the PTO. Literally volumes of information describe this extensive classification system including an alphabetic subject index, a complete schedule listing titles for all classes and subclasses, and definitions and search notes for each subclass. These materials, along with the entire search file, are available for use by the public. (Figure H-4.1 illustrates a typical patent disclosure.)

The patent file thus reflects nearly every significant advance in applied science and technology over a span of nearly 200 years. Further, studies have shown that as much as 70-80% or more of the technology contained in patents is not otherwise disclosed in the generally circulated technical literature.

The availability of this impressive and unique collection of detailed specifications of the latest developments as well as older, more basic (and frequently more "appropriate") technologies is considered especially valuable to small-scale industries, local governmental planners, and developing countries—frequently with insufficient capability or resources for problem-solving research and development.

Locating Patent Information

Recognizing the importance of disseminating patent information, the PTO maintains a Public Search Room within its Crystal City complex in Arlington, Va. This facility contains a complete collection of U.S. patents (classified by technology) for use by any member of the public, free of charge. Patent copies may be purchased at a charge of 50¢ each. (More than 20,000 orders for patent copies are processed each day.) A relatively large number of private sector patent search firms are available in the Washington area to assist in patentability and state-of-the-art searches.

U.S. patents may be viewed in a growing number of libraries across the country. Presently, 32 facilities designated as Patent Depository Libraries (PDL's) are supplied with patent documents (numerically arranged, rather than classified by technology), many on microfilm.

Additionally, special report services are available from our own Office of Technology Assessment and Forecast (OTAF). These services generally analyze computer-stored bibliographic information for patents issued in more recent years to provide the identification of corporate patent owners, national origin, activity trends over time, and patenting levels for specific technologies. Moreover, on an experimental basis (and as resources permit), OTAF will facilitate the identification and transfer of "appropriate technology" from the U.S. patent file. This paper includes results of a brief OTAF analysis of selected areas of the hydropower field.

---

[1]12 million U.S. patent documents (principle and cross-reference copies), more than 10 million foreign patent documents, and over a million other technical documents.

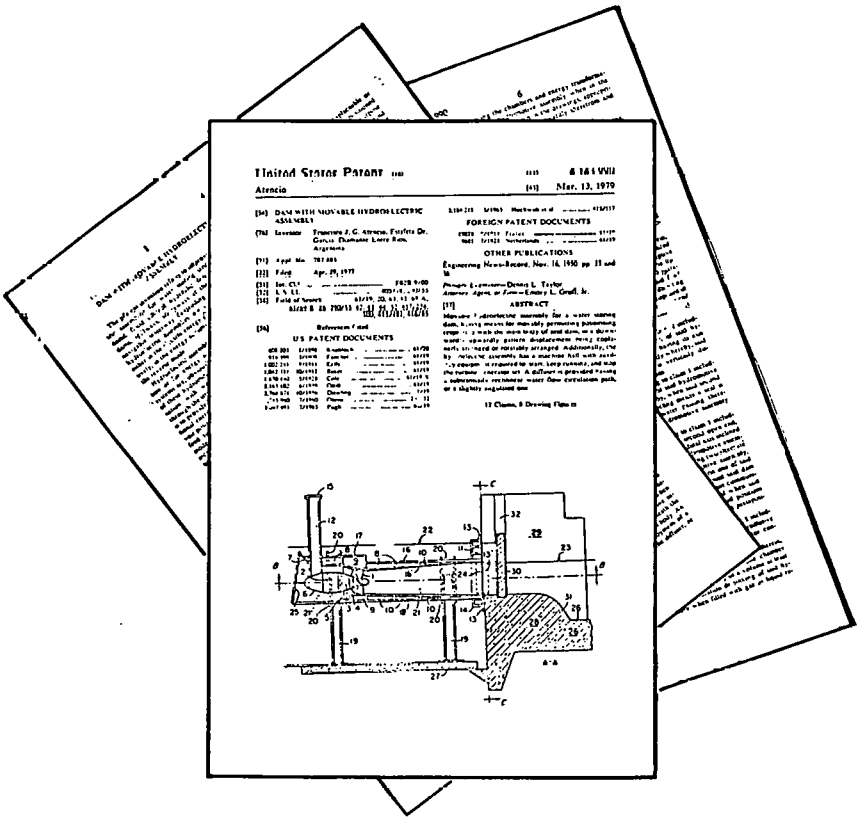


FIGURE H-4.1 Typical U.S. Patent

Patent Trends

Recent trends in patent application filing and grant-rates for U.S. inventors as compared to those for foreign resident inventors give cause for concern.

Figure H-4.2 illustrates recent overall trends in U.S. patent application filings. It is significant to note that U.S. residents are responsible for a decreasing share of the total filings (19% drop since the peak year of 1970), while the foreign share has risen to more than 38% . Patent grant-rates reflect the same general picture. Since 1970, residents of foreign countries (from Algeria to Zambia) have received nearly a quarter-million U.S. patents. The average foreign share of U.S. patenting is expected to reach 46% by 1983. As you will see, this high level of foreign activity is evident in hydropower technology, as well.

Patent Trends in Selected Hydropower Fields

"Hydropower technology," of course, covers a considerable range of components and structural combinations—from major dam structures and turbogenerator systems to pump-and-valve components, conduits, electrical control and storage systems. Let us look at patent activity in the following selected U.S. patent classes identified as pertinent, though not limited to hydropower:

U.S. PATENT CLASS (No. & Title)	RECENT GROWTH (Avg. Pats./Year)	RECENT FOREIGN SHARE *
310: Electrical Generator or Motor Structure	450	47%
307: Electrical Transmission Systems	540	36%
417: Pumps	500	33%

In certain categories defining features generally limited only to entire hydropower generation systems, (both large-scale and small-scale) patent activity has been much lower. Most patented improvements are in the subsystem and component areas—technologies with general application beyond just hydropower. Nonetheless, a microscopic glance at a selected few of the subcategories most pertinent to the hydropower industry might provide useful information.

Within Class 405, subclasses 75-78 involve hydraulic and earth engineering developments for extracting power from moving fluid. Selected areas of Class 290 (e.g., subclasses 43, 52 and 54) deal with turbogenerators and fluid current motors, and Class 415 provides for reversible kinetic fluid current motor/pump systems within subclass 500. Power plants utilizing natural energy systems are categorized in Class 60, subclass 398. A look at the overall patenting activity in these areas not only reveals a great deal of potentially useful technical information, but some interesting trends as well.

During the 1963-1978 period a total of 110 distinct patents were issued and categorized in these areas. More than 56% of the patents were granted to foreign residents (higher than the current 38% average for all technologies).

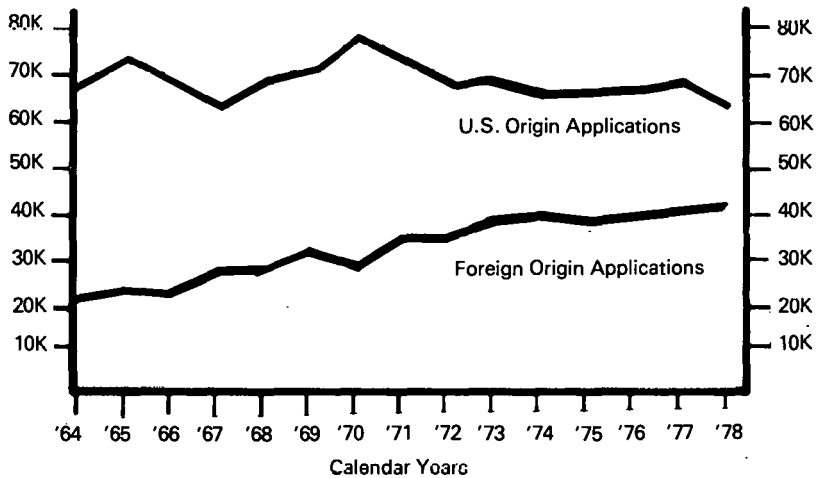


FIGURE H-4.2 U.S. Patent Application Filings ('64-'78)

Switzerland, U.K. and Japan were the principal foreign actors. Significantly, less than 37% of the inventions patented during the ten-year period covered by 1969-1978 were corporate-owned at time of grant, (less than half the average for all patented technologies). Furthermore, of all those corporations involved during the most recent ten-year period, none held assignments for more than five patents in this area. The obvious indications are that recent patentable inventions in these selected areas have been produced largely through individualized (non-corporate) efforts, with significant interest abroad.

More importantly, for the purposes of this conference, patenting activities in these hydropower oriented areas are not very high. While interest has picked up in the 1976-1978 period, with a relative 48% growth rate in patenting, it lags higher growth rates in other energy-related fields such as: solar heaters and collectors (86% and 67%, respectively); solar cells and panels (54%), and windmill systems (74%).

Recent hydropower system developments are directed, for the most part, toward increasing power output efficiency and ease of handling or assembly of components. Turbogenerator technology has advanced with inventions ranging from runner seal arrangements designed to prevent heat-expansion seizure (U.S. Pat. No. 4,049,361), to refinements in designs for minimizing runner pressure variations in switching between spinning reserve and normal running (No. 3,943,374). Recent hydroelectric system patents focus a great deal of attention on low-head and variable-head situations with inventions which introduce: improved modular hydrostations of the type wherein an entire capsule-type hydromotive assembly may be selectively flipped 180 degrees about a vertical axis to transform modes between pumping and generation (No. 4,159,188); improved guide-mounted, moveable hydroelectric assemblies to adjust to head change (No. 4,143,990). Handling and assembly ease is a target in patents introducing improvements in improved submersible hydromotor assemblies with chambers designed to be filled alternatively with water or gas for sink-float capability (No. 4,078,388), and similarly submersible diffuser designs (No. 4,073,146).

Conclusion

While patent activity in hydropower systems and major components has not been great, there has been a moderate upturn in more recent years. Additonally, the patented improvements in the smaller power-system components (with multi-industry application) are many. Taken together, this growing collection of patent information (from both this country and abroad) is a source which should be consulted for appropriate technology in hydropower systems development to insure that all the best technology for any particular hydropower project will be explored.

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

PLANNING, INFORMATION AND METHODS SESSIONS

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

Session Seven

PLANNING, INFORMATION AND METHODS

Topic: Social and Environmental Analyses I

Chairman: Mr. Bernhard Richert
Economic Development Planning Specialist
Economic Development Administration
Department of Commerce
Washington, D.C. 20230

COMMUNITY AND SOCIAL IMPACTS FROM HYDROPOWER DEVELOPMENT

Shirlene Clemence

Earlier this year, President Carter, in his series of energy speeches, stressed the need to develop our nation's energy resources—both renewable and nonrenewable—as expeditiously as possible. Immediately following this announcement, many public interest groups expressed concern that environmental and social considerations would decline under the impetus to develop national energy resources.

Certainly, many energy-rich regions are not only environmentally sensitive but are cherished by local residents. But the recipients of new power generation are often not local residents, but rather people residing in dense population centers sometimes hundreds of miles away. This is just one of many factors that has caused public opposition to energy production projects. The public today is asking tough questions: Are the projects necessary? Why in our backyards instead of yours? Why do we have to suffer so that you can live comfortably? Aren't there other ways to produce this energy?

There are no easy answers, and no doubt projects will continue to be questioned and possibly delayed. But there is a way to minimize public dissatisfaction and opposition. Actually, it is very simple. If you've ever had a Big Mac at the McDonald's hamburger chain you've seen it in practice. What is McDonald's key to success? They "Do It Right." McDonald's management does not just listen to their customers, they actively consult with them and are responsive not only to food preferences and dining atmosphere, but also consider local traditions and values and endeavor to enhance local communities. Before elaborating on the "McDonald's method," I am going to suggest to you a perspective as to why communities may be reluctant about adjacent energy projects.

Let's start with a story about Mossyrock, a small, rural town in Washington State. Until the 1960's, residents of Mossyrock were often loggers and farmers. Farms were family-owned and were often passed down from father to son. Crime was not a problem. As is typical in small towns, everyone knew everyone else and what they were doing. In short, it was a quiet, peaceful town. In the sixties, a public electric utility in the state proceeded to build a hydroelectric project a few miles away. For about 5 years, over a thousand construction workers and their families lived in or near Mossyrock.

The utility did little planning for potential community or social impacts on Mossyrock. The result was dramatic. A former Mossyrock resident recalled that of the 30 plus female classmates in his high school class, half had dropped out prior to graduation and, of the 15 that graduated, 14 were either pregnant or married at the time of graduation. All but one of the fathers or husbands were construction workers. After the project was completed, many young women followed their husbands or boyfriends out of town. Many of

---

Ms. Clemence is on the staff of the U.S. Army Corps of Engineers, Seattle District, Seattle, Washington, and is an assistant study manager for several flood control studies.

Mossyrock's young men also left town. With the departure of so many young people, a number of family—owned farms either went bankrupt or were sold.

Vandalism became a problem during the construction period. Prior to this time, the population was small enough to, in effect, police itself. Small towns typically have strong internal security networks which are dependent upon their small populations. Simply stated, it is difficult to escape detection when every resident is aware of everyone else's activities. Increasing the population, however, diminishes the effectiveness of this internal security network.

Mossyrock had another internal security network for an elk herd. Elk hunting was a highly valued tradition among local residents. The herd had been carefully maintained over the years by local residents. Only a certain number were killed each year to maintain the herd size. Construction workers, perhaps not knowing or caring about the informal herd maintenance system, decimated the herd.

Perhaps to some, the teenage pregnancies, family business decline, vandalism, and elk herd demise do not seem important, but if it happened in *your* town or *your* neighborhood, I think you would be more concerned. If you knew *ahead of time* that it was likely to happen, I suspect you'd *oppose* the project.

Of course, the situation at Mossyrock happened over a decade ago. Since then, new laws, such as the National Environmental Policy Act have required consideration of impacts from major actions, such as construction of hydropower projects. Public participation has also been mandated. So we shouldn't have to worry about future Mossyrocks. Or should we?

Just a few weeks ago I read an article in the *New York Times* about Lake Placid, New York, the site of the 1980 Winter Olympics. The article described impacts on this small town. I'd like to share a few excerpts from the article with you.

> With the Games starting 6 months from today, . . . more and more Placidians are voicing concern and regret. Their lives have been disrupted and their population divided.
>
> About a dozen Main Street shops have been rented at monthly prices ranging from $25,000 to $65,000 to such tenants as Adidas and Spalding. Homes have been rented for up to $55,000 to news organizations, corporations, such as Mobil and General Electric, and individuals such as the King of Sweden and the Crown Prince of Norway.
> . . . low-rent tenants without leases (are) being forced out of their apartments by landlords who can get thousands of dollars for the month.
>
> Farther down the serpentine main thoroughfare, Johanna Conway stands in the doorway of her tiny, cluttered sporting goods shop, the Tradewind, and scowls at the construction cross the street. She points to the Lake Placid High School, an elegant Gothic building set back on a lawn that now holds the 400-meter speedskating oval. Running along the sidewalk, partly obscuring Mrs. Conway's view of the school she attended some 50 years ago, are a series of shed-like structures that will hold the ticket office, restrooms, and Zamboni machines next winter.
>
> Mrs. Conway had attended a school-board meeting to approve the closing of the village schools for 5 weeks while the facilities are rented to the committee. At the meeting, she asked if her view would be obstructed and was assured that it would not. 'The next day I looked out and they've cut the

maples down and are digging,' she says. 'Most of us went to that school and are proud of it. Everything has changed. You'd have to have been here to know. Everything is so commercial, built up, and everybody's looking for a buck.'

Social impacts like those experienced by residents in Mossyrock, Lake Placid, and elsewhere do not have to occur or at least not to the same degree. If we are to go forward in developing our energy resources with minimal delay, we must be aware of impacts on local communities and deal appropriately with them. Effective interaction with those most knowledgeable about local values and environmental quality can lead to early identification of problems which might later needlessly delay development and can offer an opportunity for imaginative resolution of conflicts. Two major hydropower producing organizations in Washington State have recognized this opportunity and have incorporated community and social impact concerns in their respective study processes.

The Army Corps of Engineers, Seattle District, in its study of impacts associated with adding generation units to Chief Joseph Dam, analyzed the adequacy of local public services which could be expected following the influx of 2,000 construction workers and their families. Public services included police and fire protection, water supply, school capacity and others. The Seattle District was able to identify insufficient levels of public services to deal with the population influx and thus made it possible for the local communities to plan for the additonal demand. Some communities, for example, did not have enough classroom space. The Corps helped these communities by designing additional classroom facilities which would be useable and easily maintained after the construction workers left.

The Corp studies also contributed to the state-of-the-art of community impact analysis. Impacts were projected prior to construction, observed during construction, and evaluated after construction. This study procedure allowed the Seattle District to refine original estimates and compare them with other energy facility projects.

One interesting discovery had to do with residential preferences of the construction workers. It was initially predicted that workers would choose to live in a town with community services and amenities at 10 to 25 miles from the construction site rather than in one with fewer services and amenities, but adjacent to the site. Later in the study, it became evident that distance rather than amenities was a more dominant factor with regard to choice of residence location.

The second organization, Seattle City Light, is a city-owned electric utility. Its studies focused on local communities' social fabric stresses which could be expected should the proposed Copper Creek Dam in the Skagit Valley be constructed. Attitudes, values, and traditions of Skagit Valley residents were incorporated in the study process. For the first time, issues which concerned local residents most were identified. City Light management addressed those concerns, rather than ones which *they* thought residents were interested in. Most importantly, though, mitigating measures which could preserve community cohesion were identified. For example, it was discovered that towns located nearest the construction site are also least able to absorb large population increases. City Light's consultant suggested the transient population would likely locate in the larger communities farther from the site, thus laying

the groundwork for ignoring the inadequate capacity of public services at the local level. But the Corps study, you recall, concluded just the opposite. As a result of early consideration of this problem, and the incorporation of community impact analysis into project planning, there is a potential solution. The utility still maintains and uses two company towns at the Skagit Hydroelectric Project located only 10 miles upstream of the new damsite. Most of the housing is vacant because the facility was recently automated. During construction, Seattle City Light could arrange for workers to live in the two company towns.

The efforts of the Seattle electric utility and the Army Corps of Engineers, Seattle District, partially form the basis for the conclusions that I arrived at conducting my master's work, that adverse social impacts from hydropower, and other energy resource development, can be prevented or at least minimized. There is a lot of potential in small-scale hydropower development. Since each project is relatively small, there are probably smaller problems for you and me. However, problems associated with a smaller project may be just as great for someone who would be potentially impacted by the project. This is occurring today in Maine. Local residents are opposed to the alteration of an existing small dam to include power production. Residents enjoy the lake-like qualities of the reservoir and were dismayed when they learned that the water level would be fluctuating to accommodate power production. Because a larger number of small-scale hydroprojects are needed to generate the same amount of power that one large one could, there are more chances for things to go wrong.

The point that I want to stress is that we can no longer concentrate on the end product. It is not just how well-designed a dam is, it is the process by which we arrive at the design, construction and operation of the dam. This is being process-oriented, rather than product-oriented. Having a good product may never be realized.

Earlier, I said that if you have ever had a Big Mac, you have witnessed an organization paying as much attention to the process as to the product. The crux of process-orientation is public involvement in the evolution of the product. McDonald's is a prime example of the success of this cognizance. While some people here may not like McDonald's products, millions of Americans are satisfied enough to make McDonald's the leader in an extremely competitive industry.

McDonald's has captured 20 percent of the market. The nearest competitor has only 9 percent. In 1976, McDonald's brought in $2.7 billion in food sales. The nearest competitor brought in $1.2 billion. If we look at these dollar figures as votes, then one might think that the American public has voted overwhelmingly in favor of the McDonald's technique.

One difference between McDonald's and its competitors is McDonald's concentraiton on its customers and its changing products and policy based on customer input. Five percent of all store revenues go into advertising, promotion, and charitable projects. Efforts have revolved around customers' desires and concerns. In a time in which disintegration of the family unit is a concern, McDonald's has held contests in which the prize is a family reunion. In a time in which inflation is the number one problem facing Americans, McDonald's has reduced the price of two of its most popular products.

McDonald's does not stop at community activities directly related to business.

There are "activity representatives" who organize programs for children and senior citizens and who also manage nearby playgrounds. There is the Ronald McDonald House at which families may stay, free of charge, while a family member is receiving cancer treatment at a nearby hospital. McDonald's has demonstrated concern for local communities. In fact, to quote from a feature article in *Time* magazine, "this approach has disarmed communities that initially objected to a McDonald's in the neighborhood."

In sum, McDonald's corporation has not solely focused its attention and efforts on its products, but rather has ventured into the public service arena. Although there are no direct monetary benefits to donation of time and money, McDonald's is rewarded with a heightened positive image. This rationale is readily applicable to energy resource development.

Before expanding this concept further, I would like to answer a question you may have. Why bother, especially if you know that you have a well engineered project? First, I am sure that you are all aware that many projects have been delayed and even terminated by public opposition. People are demanding to be legitimate partners in the decision-making process. They are no longer content to have decisions affecting their lives being made by a few "experts."

Secondly, project delays are staggeringly expensive today. For example, if Seattle City Light's proposed Copper Creek Dam is under construction and delayed in 1985, the delay would cost Seattle citizens approximately $350,000 per week or $19 million per year. This may appear to be a considerable sum, but for other energy-producing facilities, such as nuclear powerplants, delays can cost over $3 million per week. At these kinds of costs for today's delays, a considerable expenditure can be justified trying to improve the process of implementing a project.

A study conducted last year for Petro-Canada, the equivalent of our Department of Energy, and York University in Ontario supports the contention that adequate environment and social management of a project can avoid unnecessary costs and delays. Eight major projects in the United States and Canada which had been delayed or cancelled for environmental reasons were investigated. Excessive costs due to inadequate environmental and social considerations were estimated and the results are staggering:

Garrison Diversion Unit	$400 million
Staten Island Liquid Natural Gas Terminal	$35 million
Pt. Conception Liquid Natural Gas Terminal	$150-180 million
Dodds/Roundhill Coal Mine	$5 million
Trans-Alaska Pipeline	$800 million
Birch Island Uranium Mine	$6-23 million

The three projects which were not cancelled or delayed indefinitely were delayed at least four years. The study authors estimated what the potential savings would be if the projects had had adequate environmental management. Again, the results are dramatic. Let me cite a few examples:

Project	Total Project Cost	Lost	Adequate Environmental Management	Potential Savings
Staten Island Liquid Natural Gas Terminal	$35 million	$35 million	$150,000	$34.75 million
Dodds Roundhill Coal Mine	$200 million	$5 million	$1.15 million	$3.85 million
Garrison Diversion Unit	$632 million	$400 million	$500,000 - $1.15 million	$398.5 - $399.5 million

Most importantly, though, the study concluded that "the earlier the environmental management is included in a project's development, the lower the potential relative loss . . . to a company should environmental problems occur." And I should add that by environmental management the authors emphasize that they not only refer to "the immediate biophysical effects of a project, but also to the whole continuum of issues from ecosystem dynamics to community and social impact questions."

The Petro-Canada study conclusions support the basic tenets alluded to earlier. First of all, involve the public, particularly local residents most likely to be impacted by the project. Public participation has long been a practice of many organizations, but generally this has meant presentations at formal public meetings after decisions have been made.

What I am advocating is that local resident involvement begin at the scoping meeting level. Basically, this is an extrapolation of the new Council on Environmental Quality's regulations that require affected governmental agencies to be included in Environmental Impact Statement scoping meetings. In addition to agencies, I suggest that local residents should be apprised of potential projects and actively consulted for their expertise on community concerns, values and attitudes, and on local environmental quality. It is important to emphasize active consultation. This means actually going into these communities and, on an informal basis, talking with, and especially listening to, residents in order to discern what issues are concerning them most.

One immediate advantage is avoiding surprises further along in the project assessment process. For example, an organization may perceive a community's concerns to revolve solely around its local fisheries' industry and focus studies in that direction. However, that community may value even more the high quality of its deer and elk hunting. As we have seen from Mossyrock, it is not just the number of deer that are likely to be eliminated by the project, a number that is not too difficult to determine, but rather the way in which this activity is likely to be impacted by inadequate early consideration. Early identification of the importance of this community value would allow project planners to incorporate methods of avoiding the impact.

Creative public involvement does not necessarily mean that the public will support a project. However, a very important result often is improved relations between the project organization and the public. A good relationship can lead to good communication, avoid misunderstandings, and often result in adverse impacts being prevented or adequately mitigated. This is desirable, particularly if the organization has frequent contact with the people involved or if it intends to propose other projects in that area.

Thus far, I have focused on the importance of listening to local residents early, at the scoping level, of an energy facility decision-making process. Additionally, the energy developer must be sensitive, flexible, and responsive to the concerns voiced by local residents.

Basically, responsiveness implies action. An energy developer may be sensitive and flexible without being responsive. For example, a community has a high unemployment rate and its young people are leaving to find employment elsewhere. The residents express concern to the energy developer about the loss of young people. The developer demonstrates sensitivity by listening and flexibility by expanding employment studies. Exhibiting responsiveness requires more definitive action. In this example, the developer can use the results of study to determine the required skills for project construction or operations and available local skills. The developer can be responsive in at least two ways. One, if local residents have the required skills, the developer can agree to preferentially hire them. Two, and more significantly, if they do not have the required skills, the developer could set up a training program to insure residents that those who want to acquire those skills will be trained.

In conclusion, the challenge before us is clear: to develop our energy resources with minimal delay. However, this cannot be accomplished by traditional means. In addition to assessing the technical, economic, and even biophysical aspects of a project, the human element has to be included. Involving the local residents early in the process at the scoping level, and demonstrating sensitivity, flexibility, and responsiveness, can result in fewer project delays, decreased cost overruns and can bring us closer to achieving our national goal of energy independence.

FISH PASSAGE AND SMALL HYDROELECTRIC TECHNOLOGY: A STATE OF THE ART REVIEW

Milo C. Bell and Stephen G. Hildebrand

Introduction

One of the most frequently raised environmental issues that may affect the development of small hydroelectric technology is the possible requirement of fish passage facilities at existing dams. The need for these facilities may be a significant factor in determining the economic feasibility of small hydro projects. This paper describes some preliminary results of an ongoing study reviewing fish passage technology relating to small hydro development. A full report covering this subject will be issued by the U.S. Department of Energy in early 1980. For this conference, we describe types of structures available to move upstream migrating fish around dams, and we mention downstream passage facilities. We present some basic design considerations for successful operation of upstream passage facilities and offer basic cost figures. A list of references is included that will serve as an entry into the literature.

Types Of Fish Passage Facilities

Upstream Passage

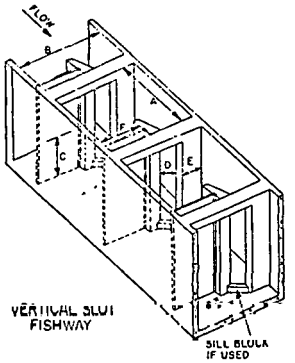
Three types of facilities are available to move fish upstream around small head dams: 1) fishways, 2) fish locks, and 3) fish lifts (Figure I-2.1). In a fishway, fish swim up a series of pools to facilitate passage. In a fish lock, fish are crowded into a lock chamber, raised above the dam by filling the chamber with water, and released over the dam. A fish lift works similarly to a fish lock, except that the former employs a waterfilled mechanical hopper to raise fish above the dam (Figure I-2.1).

Downstream Passage

There are a number of devices proposed to pass fish downstream around dams, but two types (louvers and angled screens) are most likely cost effective and have the highest likelihood of success (Figure I-2.2). Both louvers and angled screens are intended to guide downstream migrants to a bypass channel for passage around the dam. Both devices require close maintenance during times of high debris, and neither device is functional during the ice season.

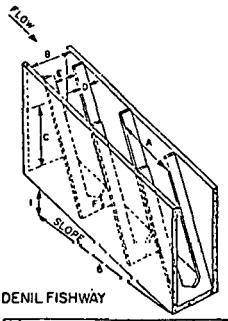
Professor Bell is Professor Emeritus, University of Washington, College of Fisheries, Seattle, Washington.

Dr. Hildebrand is a member of the Research Staff, Environmental Sciences Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

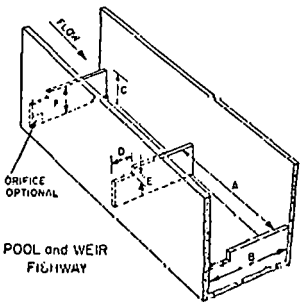


A	POOL LENGTH	6'	8'	10'
B	POOL WIDTH	4'	6'	8'
C	WATER DEPTH (MIN)	2'	3'	3'
D	SLOT WIDTH	.5"	.75"	1.0"
E	WING BAFFLE LENGTH	9"	1'-3 3/8"	1'-3 3/8"
F	WING BAFFLE DISTANCE	2'	3'-1"	3'-7"
G	DISPLACEMENT OF BAFFLE	4'	5'-½"	5'-½"
	DISCHARGE PER FOOT OF DEPTH ABOVE BLOCK IN CFS	3.2	4.8	6.4
	DROP PER POOL	1'	1'	1'

*SILL BLOCK IN PLACE

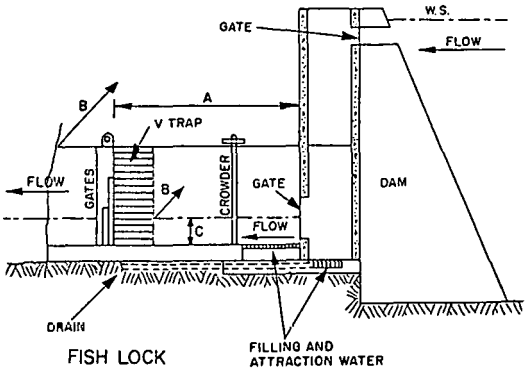


A	POOL LENGTH	2'
B	POOL WIDTH	3'
C	WATER DEPTH	3'
D	BAFFLE WIDTH	7.5"
E	SLOT WIDTH	1.75'
F	BOTTOM BAFFLE NOTCH HT.	7"
	DISCHARGE VARIABLE CFS – 21	
	AV. VEL. 4 FPS	



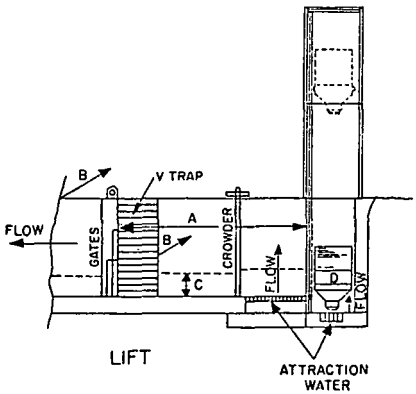
A	POOL LENGTH	6'	8'	10'
B	POOL WIDTH	4'	6'	8'
C	WATER DEPTH	3'	4'	6'
D	SLOT WIDTH	.5'	1.5'	1.5'
E	SLOT DEPTH	.5'	.6'	.5'
F	BAFFLE HEIGHT	2.5'	3.5'	5.25'
	WATER DEPTH IN NOTCH	12"	12"	15"
	DISCHARGE IN CFS MIN	1.65	4.0	4.0
	NORMAL	5.0	12.3	25.0
	MAX	24.0	36.0	48.0
	DROP PER POOL	1'	1'	1'

FIGURE I-2.1 Schematic representation of typical fishways, fish locks, and fish lifts used to pass fish upstream over a dam.



FISH LOCK

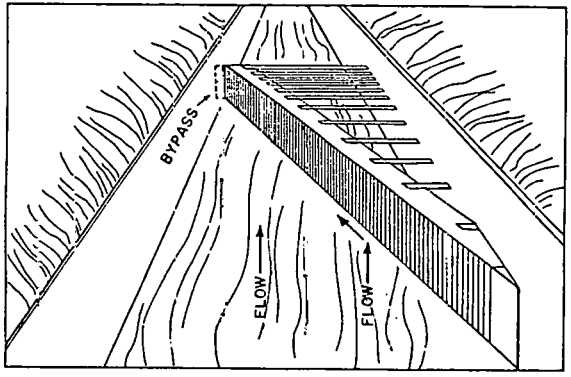
A	POOL LENGTH	8'	12'	16'
B	POOL WIDTH	4'	6'	8'
C	WATER DEPTH (MIN)	3'	3'	3'
D	LOCK CHAMBER	24°'	36°'	64°'
DISCHARGE VARIABLE (MIN)		30	30	30



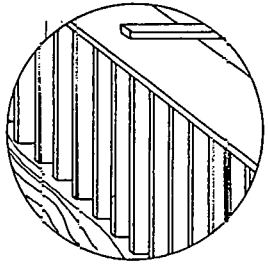
LIFT

A	POOL LENGTH	8'	12'	16'
B	POOL WIDTH	4'	6'	8'
C	WATER DEPTH (MIN)	3'	3'	3'
D	HOPPER SIZE (GAL)	250	500	750
DISCHARGE VARIABLE (MIN)		30	30	30

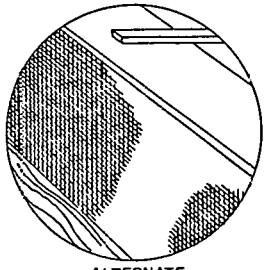
Figure I-2.1, cont. Schematic representation of typical fishways, fish locks and fish lifts used to pass fish upstream over a dam.



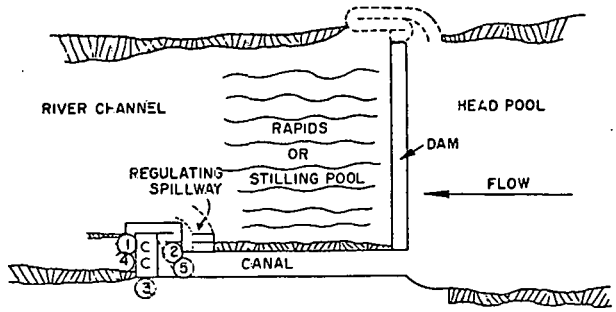
LOUVER BARRIER



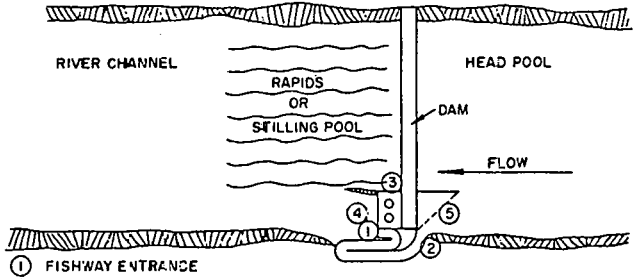
LOUVER BARRIER DETAIL



ALTERNATE ANGLE SCREEN BARRIER DETAIL



POWER PLANT WITH A CANAL



① FISHWAY ENTRANCE
② FISHWAY EXIT
③ POWERHOUSE
④ TAILRACE
⑤ SCREEN

POWER PLANT AT DAM FACE

FIGURE 2.2 Schematic representation of a louver and angled screen system to pass fish downstream around a dam. Typical locations of an angled screen are also shown.

Basic Design Considerations

General

If fish passage facilities are required at a given site, their design must be optimized to meet requirements of the dominant species of fish requiring passage. Fish species in the United States vary as to abundance, distribution, swimming capability, behavior, spawning requirements, and environmental requirements such as water temperature, water quality, and food preference. Any or all of these factors may influence the ability of a given species to negotiate a passage facility. Site specific analyses of habitat conditions upstream from a dam are necessary to insure that proper habitat is available to warrant passage.

The general water quality at a site must be known, because degradation in water quality can affect the performance of a fish in negotiating a facility. Water temperatures must be within a species range and dissolved oxygen levels should be sufficient to sustain adequate performance (near saturation desirable). The presence of toxicants could also affect the success of fish passage.

Current Velocities, Depth, and Holding Volume

The ability of a fish to swim against the current velocity present in a passage facility is important for successful passage. Current velocities must be established in a facility based on species specific swimming speed, which varies with fish size. A general rule of thumb for estimating swimming speed is speed (ft/sec) = fish length (inches) x 1 foot per inch per second (not to exceed 20 ft/sec regardless of length). To ensure reasonable passage, current velocities in a facility should not exceed 50% of the swimming speed of the fish to be passed, up to a maximum of 8 ft/sec. If design velocities exceed this value, resting areas may be required that the fish can reach in 15 seconds, or additional pools will be required to reduce the design velocity. Since cost of a fishway is based on the number of pools required, adding pools to decrease velocities may necessitate a closer look at fish locks and lifts. To insure successful passage, the passage facility should be deep enough to encompass the normal swimming depth of the fish.

Fish locks and lifts must include adequate space in storage or holding areas to eliminate adverse effects of crowding. As fish become crowded, oxygen uptake may increase and the dissolved oxygen level in water may decrease to the point where fish become stressed. Experience indicates at least 0.2^3 ft of space per pound of fish should be provided in holding or trapping areas.

Attraction Water

Regardless of the type of passage system used, attraction water must be available to encourage the fish to leave the normal river flow and enter the device. The entrances to fish passage facilities are usually located at the point of farthest upstream travel of a fish adjacent to spillways or turbine discharges. Discharge through fishways usually requires flow augmentation by gravity or

pumping to supply attraction water. An approximation of the amount of attraction water that is required is 3% of the flow adjacent to the fishway. At small projects, 3% of the average annual flow during the time of fish passage should provide adequate attraction flows.

Forebay Water-Level Fluctuation

Forebay pool fluctuations of one foot or less are not considered to be a problem. If fluctuations greater than one foot are predicted, forebay pool regulation may be required for successful fish passage.

Cost Analysis

A summary of a generalized cost analysis is presented here. Details of the basis for these estimates will be available in the complete report of this study to be issued by DOE in early 1980. The costs presented do not include any special site-specific civil works that may be required.

The basic cost of a fishway using one foot drop per pool and supplied with an entrance and exit pool and a head regulating section, would range from $6000 to $8000 per pool. The number of one foot drop pools required equals the head difference in feet. The equivalent basic cost for a fish lock would be approximately 11% less than for a fishway. The equivalent cost for a fish lift would be approximately 27% less than for a fishway. Maintenance costs on an annual basis, expressed as a percentage of basic cost, would be 3% for a fishway, 5% for a fish lock, and 14% for a fish lift. All of these costs, of course, are subject to inflation and interest rates on borrowed capital.

The power penalty cost of the water diverted through a fish passage facility can only be determined when project economics are known. Assuming a 10 cfs passage unit under 10 ft of head, with a power value of $0.05 per kWh for a 90-day period, a loss of potential power valued at $900 would result. If attraction water must be supplied (not supplied by forebay) to a level of 4 ft above tailwater level, 10 cfs of such water would result in a power value loss of $1,127. If a pumping system is required to supply the above amount of attraction water, such a system would cost approximately $6,400.

A very general estimate of the cost of a louver screening system for downstream passage would be $50 per square foot of screening surface. Using a passage unit of 1000 cfs and a design approach velocity of 1 foot per second, the base price would be approximately $50,000. The annual cost of maintenance would be 8.5% of base cost, again subject to inflation and interest rate escalation. It is possible to reduce annual maintenance costs of louver screens by adding mechanical cleaning devices, but this obviously would increase the capital cost. A louver system may offer some overall cost efficiency since the louvers may serve as trash racks. Also, louver by-pass water could be diverted to a fishway to supply some of the fishway water requirements.

Conclusion

We have presented some of the basic design factors and cost estimates for fish passage facilities applicable to small-scale hydroelectric systems. We

emphasize that if fish passage facilities are required at a given site, a developer should consult with the U.S. Fish and Wildlife Service, state agencies, and other appropriate expertise to properly design a facility. A careful site-specific analysis is required to ensure that the facility installed will successfully pass fish species to the level required.

REFERENCES

Bell, Milo C., *Fisheries Handbook of Engineering Requirements and Biological Criteria.* Report for U.S. Army Corps of Engineers, North Pacific Division, Fisheries-Engineering Research Program, Contract No. DACW57-68-C-0086. Portland, Oregon. February 1973.

Bell, Milo C., and Allan C. DeLacy, *A Compendium on the Survival of Fish Passage Through Spillways and Conduits* with a special section on stilling basin hydraulics and downstream fish migration by Howard D. Copp. Report for the U.S. Army Corps of Engineers, North Pacific District, Contract No. DACW57-67-C-0105. Portland, Oregon. January 1972.

Bell, Milo C., Allan DeLacy, and Gerald J. Paulik, *A Compendium on the Success of Passage of Small Fish Through Turbines.* Report for the U.S. Army Corps of Engineers, North Pacific District, Contract No. DA-35-026-Civeng-66-16. Portland, Oregon. May, 1967.

Clay, C. H., *Design of Fishways and Other Fish Facilities.* Canada Department of Fisheries. Ottawa, Canada, January, 1961.

Kerr, James E., "Studies on fish preservation at the Contra Costa steam plant of the Pacific Gas and Electric Company." California Department of Fish and Game, *Fish Bulletin,* 92. 1953.

Kipper, Z. M., and I. V. Mileiko, *Fishways in Hydro Developments of the USSR.* Rybnoe Khozyaistvo, Moscow. 1962. Translated by A. Wald, Israel Program for Scientific Translations, Ltd. U. S. Department of Commerce, Clearinghouse for Federal Scientific and Technical Information, Springfield, Virginia. 1967.

Ruggles, C. P., and P. Ryan, "An investigation of Louvers as a Method of Guiding Juvenile Pacific Salmon." *The Canadian Fish Culturist,* No. 33:7-68. November, 1964.

Thompson, John S., and G. J. Paulik, *An Evaluation of Louvers and Bypass Facilities for Guiding Seaward Migrant Salmonids Past Mayfield Dam in Western Washington.* Washington Department of Fisheries, Olympia, Washington. September, 1967.

Institution of Civil Engineers, Institution Research Committee, Report of the Committee on Fish-Passes. London. 1942.

SMALL-SCALE HYDRO - AN OPPORTUNITY FOR HISTORIC PRESERVATION

William J. Novak and Richard T. Heiderstadt

Nearly a century has passed since the construction of the first hydroelectric power station in the world. This first plant—built in 1882 in Appleton, Wisconsin—generated 200 watts and transmitted electric power one mile at 110 volts. Following the successful operation of this first plant, construction of other small-scale plants began throughout the U.S. with the East witnessing the greatest activity. Many of these plants were constructed at new dam sites while others, especially in the Northeast, were constructed at sites previously used for generation of mechanical power. In both cases the Industrial Revolution in the United States was given greater impetus as a source of cheap power was made available to manufacturing, as well as residential uses. More importantly, industrial activities at a large scale no longer had to be located adjacent to rivers or streams. This mobility freed industry to locate in response to market, raw material and transportation factors thus stimulating the geographic dispersion of economic growth within the country. Today we would like to present several ideas relating to the historic significance of older small-scale hydro stations, their renovation as historic resources, and the renewed or increased generation of power which is being addressed within the context of this conference.

The National Program of Inspection of Dams, as compiled by the U.S. Corps of Engineers in 1975, indicates that nearly 12% of the 2259 dams constructed before 1920 in 12 eastern states are now being used for hydroelectric production.[1] A few of these states have over 20% of these older dams producing electricity today, with New York operating 40% , Vermont 35% , Maine 22% and New Hampshire 20% (see Figure I-3.1).

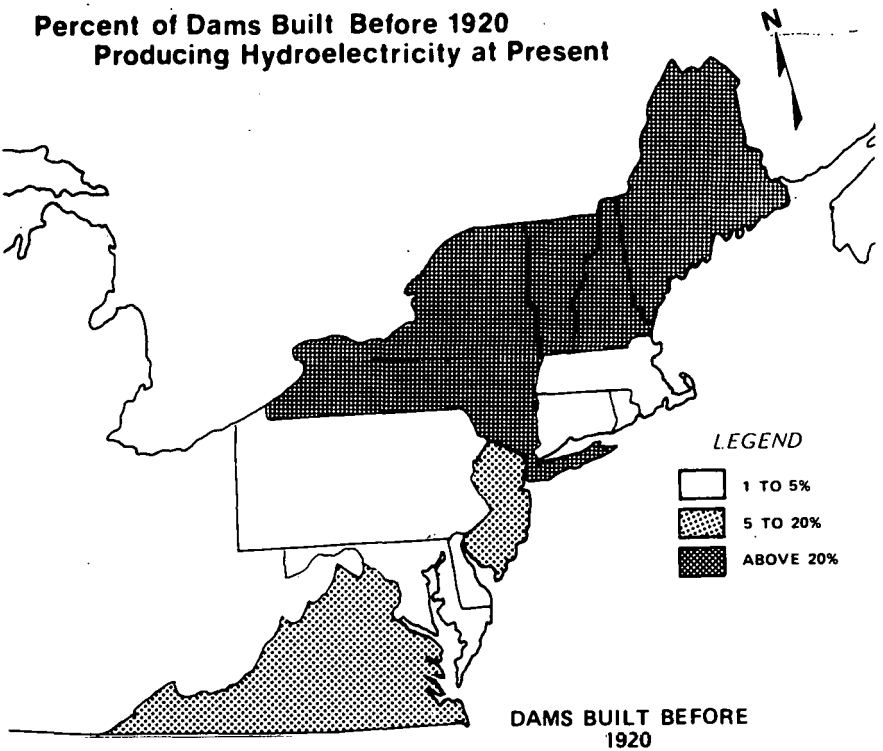
The Department of Energy is now in the process of completing its small hydro feasibility assessment of 54 installations nationwide. Twenty-one of the facilities studied are located in the twelve states under discussion and of these twenty-one dams eight (or 38%) were constructed before 1920.

Clearly, the evidence points to the continued viability of many of these older small-scale hydroelectric facilities. As historic resources in an environmentally conscious society and as sources of power in an energy hungry nation, these facilities provide an opportunity for the preservation of an important element of our industrial heritage with the simultaneous improvement of our energy self-reliance.

Understandably, utilities seek to avoid delays and complications in licensing procedures. Calling attention, it may be feared, to the historic significance of a powerhouse or dam may only bring into play a myriad of rules and regulations not to mention generation of concern by local historic groups.

Mr. Novak is Senior Environmental Planner, Tippetts-Abbett-McCarthy-Stratton, Washington, D.C. and Mr. Heiderstadt is Principal Ecology and Environmental Planner, Tippetts-Abbett-McCarthy-Stratton, Buffalo, N.Y.

[1]The twelve states considered in this study are: Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, and Virginia.



DAMS BUILT BEFORE 1920

STATE	TOTAL DAMS	WITH HYDROELECTRIC
CONNECTICUT	318	8
DELAWARE	16	0
MAINE	263	58
MARYLAND	22	1
MASSACHUSETTS	687	18
NEW HAMPSHIRE	93	19
NEW JERSEY	61	4
NEW YORK	264	106
PENNSYLVANIA	313	9
RHODE ISLAND	66	0
VERMONT	93	33
VIRGINIA	63	10
TOTAL	2259	266

FIGURE I-3.1 Percent of Dams Built Before 1920 Producing Hydroelectricity at Present

Before FERC can issue a license, the Advisory Council on Historic Preservation and the State Historic Preservation Officer must be consulted to assure that no historic or cultural sites will be adversely affected. These procedures, however, are usually limited to sites having significance warranting inclusion on the National Registry of Historic Places. Many older hydro power sites, while not of national significance, have played an important role in the local history of an area and are thus important enough to stimulate local concerns.

Review of the DOE feasibility assessments shows that concern is usually expressed for the impact of a project on other historic resources but little attention is focused on the impact—beneficial as well as adverse—on the historic powerhouse or dam itself. But why emphasize historic preservation of locally significant sites if not required to do so by FERC? Perhaps the answer to this question is twofold.

First is the obvious concern we should all have for the preservation of our heritage. This is not to say that every old structure in the country must be preserved but only that those of significant local or national value must be considered when renovation of industrial facilities takes place.

The second part of the answer revolves around the public relations aspects of a utility's operation. We do not have to expound on the defensive position utilities have been forced into by the energy crisis. The public at large as the end of the energy cost chain, sees only the high bills and often not the reasoning behind them. Utilities, as the second to last link in that chain have to face the brunt of public criticism. What we advocate here today is using preservation of historic dams and powerhouses as a means for improving public relations and as a means of providing local communities with a better understanding and appreciation of their history.

How can a utility develop such a "good neighbor" program? First, instead of a defensive posture on the historic significance of a hydro site, a utility could take the initiative by approaching local historical authorities and societies and seeking suggestions for input into the appropriate renovation or preservation of the structures. Additions and other needed alterations of the exterior of a structure should be designed in keeping with the historic and aesthetic value of the area especially if other historic structures are in close proximity.

Other, less costly measures are also possible. Again in cooperation with local historians it may be possible to research, design and display interpretive signs and exhibits which are accessible to the public. Such exhibits can present the history of the hydro site and serve to illustrate the utility's concern for historic preservation. Access to the facilities may also be possible. Perhaps a Saturday afternoon tour a few times a month led by a local historian and utility "old timer" may be feasible for many sites. Such a firsthand visual experience can prove extremely helpful in understanding not only the operational aspects of a hydroelectric facility but also the role the site has played in local development. With emphasis placed on the provision of recreational activities by FERC, it may also be possible to integrate a historic interpretation or tour program, or both, into the exhibit requirements.

Although certain of these programs and actions will result in added cost for renovation, others will cost very little. Construction materials complimenting the original facade of a structure could result in significant extra costs. Increased insurance costs resulting from access to the facility by the public may

be of significant proportions. On the other hand interpretive exhibits can probably be assembled relatively cheaply. Realizing the marginal economics involved with small-scale hydro, costs will have to be carefully considered in any preservation program. However, it will be most important to weigh these costs against the intangible benefits realized from improved community relations and the pride that a utility can take in preserving an important element of America's industrial heritage.

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

Session Eight

PLANNING, INFORMATION AND METHODS

Topic: Planning for Development I

Chairman: Dr. David Zoellner
Institute for Water Resources
U.S. Army Corps of Engineers
Kingman Complex
Ft. Belvoir, Virginia 22060

LOW-HEAD HYDROELECTRIC EVALUATION AND INVENTORY

Nelson J. Jacobs

Introduction

The Bureau of Reclamation is, perhaps, best known for development of irrigation works in the Western United States. These developments have had a tremendous impact on the economic and social life of westerners over the past 75 years by providing a firm agricultural base for a growing population. In addition to irrigated agriculture, however, Reclamation's water resource developments have provided the population of the Western States with hydroelectric power, municipal and industrial water supply, flood control, improvement in water quality, river regulation, fish and wildlife enhancement, and recreation. All of these have contributed to the high quality of life enjoyed in the West. Low-cost hydroelectric power, even though it is usually considered as only a by-product of water resource development for other uses, has had a far-reaching economic impact on developing and maintaining the quality of life in the West. The Federal Government, primarily the Bureau of Reclamation and Corps of Engineers, is a major producer of electrical power and energy in the West, all produced with a clean, pollution free, renewable resource-water. This power and energy has been provided often at a fraction of the cost experienced in other areas of the country.

Historically, most of the hydropower in the West has been provided by large, high-head dams. It is generally felt that most of the remaining large, high-head sites in the West are not practical for development due to today's environmental and social concerns criteria. Until recently little effort has been made to determine the potential for small, low-head hydroelectric power development in the West. Although once a major contributor of power and energy in this country, this type of development was deemphasized and many plants were abandoned as power generation from large fossil-fuel fired thermal-power plants became more economical. The changing economics of thermal power development, due to escalating capital costs and fuel costs, is once more making small, low-head hydropower an economically attractive source of power and energy. In addition, it is generally regarded as less environmentally objectionable than most alternatives and is, therefore, considered more acceptable.

Reclamation's DPTS undertook evaluation of some low-head hydroelectric potentials several years ago as part of an investigation called the Western Energy Expansion Study. Although many of these potentials were not economically feasible at that time, it was recognized that, with our rapidly changing economy and an increasing emphasis on use of renewable resources, low-head hydropower was a resource worthy of consideration. Therefore, one of the recommendations resulting from the Western Energy

---

Mr. Jacobs is a power planning coordinator, Water and Power Resources Service (formerly Bureau of Reclamation) Denver, Colorado.

Expansion Study was the initiation of an inventory of the potential for low-head development in the 17 Western States. That study, the Low-Head Hydroelectric Evaluation and Inventory, was begun during fiscal year 1979.

Description of the Study

The study is projected to be a 3-year effort and is expected to provide a comprehensive indication of the potential for low-head hydroelectric development in the West. For purposes of this study, low-head is defined as having a normal operating water surface differential of not more than 20 meters (approximately 66 feet). The study effort is being closely coordinated with the Corps of Engineers National Hydropower Study to preclude duplication of effort and to insure compatibility of study methodology and results. The study is being performed in three phases, as shown in Figure J-1.1.

Phase I. - The initial phase is being accomplished by a five-man multidisciplinary Reclamation team with the assistance of Reclamation's seven regional offices and the Engineering and Research Center. Phase I will be limited to evaluation of potential additions of hydroelectric generation at existing Reclamation facilities such as dams, diversion dams, and canal drops. No head limitation is included in Phase I. This phase of the study is an attempt to identify some developments with which Reclamation could readily make an early contribution to power and energy production.

Phase I began with a site identification and data collection effort by Reclamation's seven regional planning offices. DPTS requested the regional planning offices to identify potential sites at Reclamation dams, diversion dams, and canal drops which could develop a minimum of 10 feet of hydraulic head and were capable of producing a minimum of 500 kW of power based on average annual flows. For sites meeting these criteria the regional planning offices collected monthly flow data and monthly average head data as available. These data were obtained from USGS flow-station data, if appropriate, or from Reclamation annual operating reports. Generally, a minimum of 10 years of flow records was used for the analysis. A total of 141 sites were identified by the regional offices and submitted to DPTS. The geographical locations of these sites are shown on Figure J-1.2. The data collected from the regions were analyzed using the well known duration curve technique.

DPTS developed a computer program which computes and plots a power duration curve based on the recorded monthly flows and heads. The computer selected 20 installed capacities for each site in equal increments. For each installed capacity the computer determined the annual energy produced, the dependable capacity, and the annual plant factor. Dependable capacity was assumed to be that capacity available more than 90 percent of the time. All sites were analyzed as single-unit and two-unit plants.

Cost curves developed by Tudor Engineering Company were computerized and used to estimate powerplant costs for the 20 plant sizes at each site. The generalized cost curves used are shown as Figure J-1.3. Also, a rough estimate of the cost of penstocks, tailrace, switchyards, and transmission lines was added, as were appropriate contingencies and fixed costs.

Based on the potential energy produced by the 20 selected plant sizes and the costs associated with each, the energy cost in $/kWh was calculated and

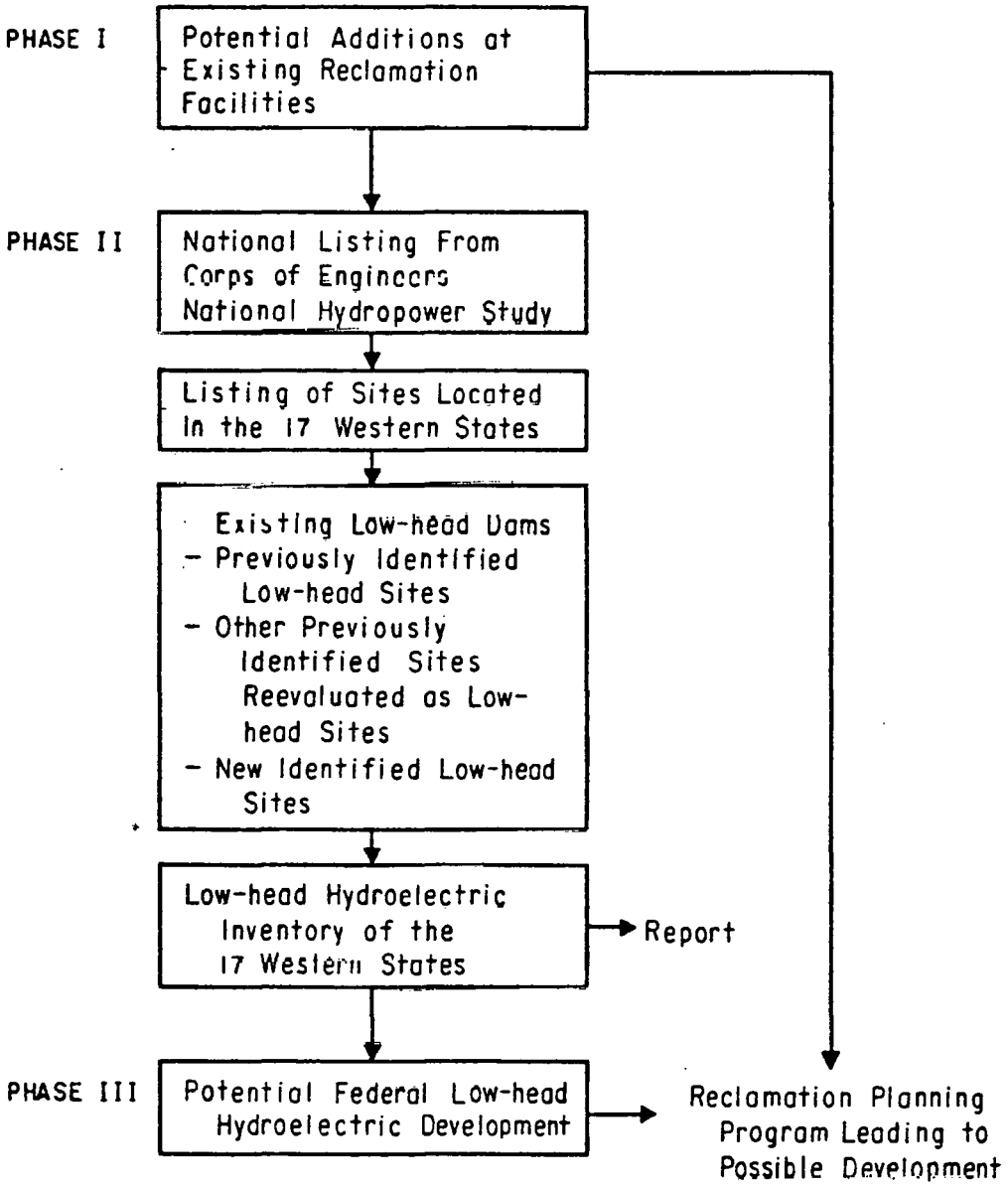


FIGURE J-1.1 Low-Head Hydroelectric Evaluation and Inventory Study Plan

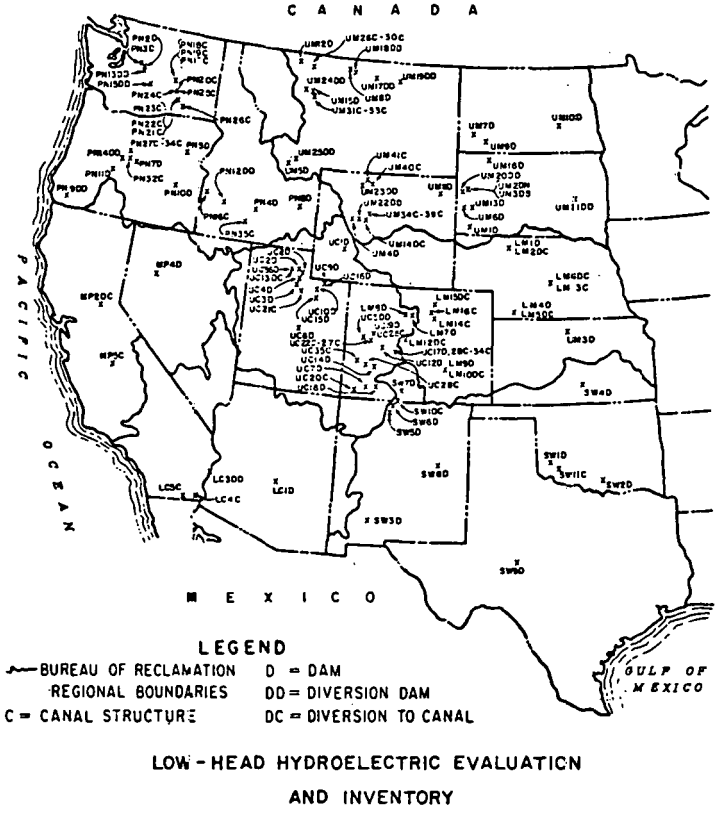


FIGURE J-1.2 Geographical Distribution of Sites Evaluated

LOW-HEAD HYDROELECTRIC EVALUATION
AND INVENTORY

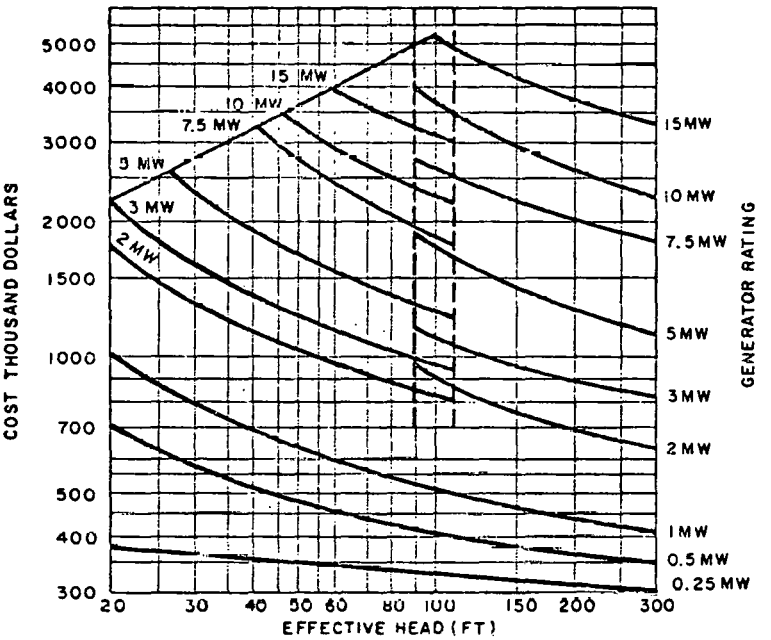


FIGURE J-1.3 Power features cost-reconnaissance

plotted. The computer then selected the plant size which resulted in the lowest energy cost for each site.

An initial screening of the 141 sites was made on the basis of energy cost. Based on a comparison of energy cost and updated FERC regional power values, 46 potential developments were selected for more detailed analysis.

For further analysis of the 46 selected sites, the same computer program was used to make capacity and energy computations and cost estimates using slightly refined data. Monthly flow records and recorded average monthly head figures for the individual sites were reexamined and, when necessary, additional data were collected from USGS stream gaging station records and Reclamation annual operating reports. The same generalized cost curves were used to estimate powerplant costs; however, a more accurate estimate of site-specific costs for such features as penstocks, tailrace, switchyard, and transmission lines was made using specification' drawings of the existing structures. An economic analysis of each site will be made comparing total investment costs with site-specific power benefits—both capacity and energy values.

The second-stage analysis of the selected sites will also include a very preliminary evaluation of environmental and social impacts which would result from the development of the site. Data collection and evaluation of environmental and social impacts are presently being done by Reclamation's regional planning offices. A second-stage screening of the sites will be based on a weighted consideration of the economic factors and environmental and social considerations. This screening will be completed in the near future. Based on the results of this screening, a number of sites will be selected and recommendations will be made for further, more detailed planning studies and possible early development.

Phase II. - This phase of the study will consist of a more general inventory which will result in a comprehensive listing of potential low-head hydroelectric development sites in the 17 Western States. As a starting point, Phase II will begin with the Corps of Engineers inventory data base assembled as part of their National Hydropower Study. This total nationwide listing of existing dams and identified potential sites will be initially screened to isolate all those in the 17 Western States. All existing dams in this resulting listing with more than 20 meters of head will be eliminated since they could not qualify under our definition of low-head hydroelectric development. Undeveloped sites with more than 20 meters of head will be reanalyzed as a potential development with 20 meters of head. In addition, the listing will be augmented by identifying as many additional undeveloped low-head sites as is practicable considering limitations of time and funding.

Sites in this total listing will be analyzed using the Corps computer routines developed for the National Hydropower Study, and will be screened on the basis of powerplant economics to identify a limited number that appear to be possible Federal low-head hydroelectric developments. The total listing of potential low-head sites and the results of the evaluation will be made available to the public. Phase II will be completed in about 1 year. Due to overall program workload and limitations of manpower, a decision was made to contract for Phase II of the study. The selection of a contractor is presently in progress and it is hoped to award a contract in the month of November.

Phase III. - Phase III of the study will commence at the completion of

Phase II. In this phase, the sites selected as a result of Phase II will be analyzed and evaluated in more detail. Work under Phase III will also be accomplished by the contractor selected for the Phase II work and will be completed during fiscal year 1981. The hydrology will be reviewed for these sites and, if necessary, the potential power and energy will be reanalyzed. Designs and cost estimates roughly equivalent to Reclamation's appraisal study level will be developed, and economic analyses will be performed. As an indication of energy efficiency of the sites, analyses will be performed to indicate the relationship of primary energy invested in development of the site and energy returned through power generation. A preliminary evaluation of the environmental and social impacts resulting from development will be made. Based on the factors of economics, energy efficiency, environmental impacts, and social impacts, a final screening of these sites will be made with the anticipation that some will be recommended for inclusion in Reclamation's planning program for more detailed study and possible development.

METHODOLOGY FOR CONDUCTING A RESOURCE ASSESSMENT OF SMALL-SCALE HYDROPOWER POTENTIAL

Thomas E. Klock

Introduction

> Surely among the events of our time that do not make future planning easy are the sharp rise in foreign oil prices and (the) resulting blow to our economy, especially here in New England. But the pressures of these events have also created some new thinking about an old energy stand-by: electricity produced by flowing water.[1]

Serious thinking about looking back to streams and rivers for a means to reduce regional dependency on foreign oil began several years ago in New England. An urgency had developed to reconsider waterpower, as New Englanders had allowed themselves to become extremely vulnerable to oil price hikes and supply disruptions. The region had become 80-percent dependent on oil for energy, and more than three fourths of this oil was being supplied by OPEC sources.

An immediate opportunity for reducing oil dependency was through reuse of the region's numerous small-scale dams. However, the extent of this opportunity was unknown, as most of these dams had become either economic or environmental liabilities. New Englanders were unsure if the changing economic situation meant that repairing and retooling these dams for producing energy from a renewable resource was worth the investment required. Moreover, they were unable to gauge whether the added energy produced would reduce oil dependency sufficiently to offset the environmental problems that could be created. What New Englanders needed was a means of obtaining a concise understanding of the region's hydropower potential so that prudent decisions could be made about the value of power generation at small-scale dams.

NERBC Hydropower Expansion Study

The New England River Basins Commission (NERBC) committed itself to the responsibility of furnishing New England with a resource assessment of the region's hydropower potential. The Commission assumed this task because of its mandate to comprehensively plan for the region's use of water

---

Mr. Klock is Hydropower Study Manager, New England River Basins Commission, Boston, Massachusetts.

[1]New England River Basins Commission, *Hydropower in New England: New Lease on an Old Stand-By?*, page 1.

and related land resources. To fulfill this commitment, the Commission decided that it would need to:

1. Quantify, in terms of energy and cost, the extent that New England's oil dependency could be reduced through feasible hydropower expansion;
2. Identify the complications that expanded use of hydropower would add to the management of competing water uses;
3. Obtain and evaluate public opinion about the consequences of these complications; and
4. Set forth policy and action recommendations which acknowledge public opinion about hydropower expansion.

Resource Assessment Strategy

The challenge facing NERBC in meeting these goals was in choosing an appropriate methodology for conducting the resource assessment. Technical information about the hydropower potential and water use complications had to be specific enough to insure product credibility but general enough to support policy formulation activities. Therefore, the following four principles were chosen as a framework around which to design the study:

(1) A minimal amount of data would be assembled;
(2) Readily-available information sources would be depended upon to the maximum extent possible;
(3) Computer processing would be utilized for record maintenance and for ease in evaluating effects of alternative recommendations; and
(4) Federal, state, and regional agency personnel would be relied upon for their technical expertise as well as for their capability in conducting special study tasks.

The study framework set by these principles would provide the following long-term benefits to New England:

1. Continual refinement and updating of the data base could be actively pursued with minimum support;
2. Effects of future changes in economic conditions could easily be checked against study projections; and
3. Educational byproducts from association of federal and state agency personnel with study activities would augment their capability to review specific hydropower development proposals.

Assumptions for Planning Purposes

Use of the four principles required that assumptions be made and values selected for the many variables associated with hydropower development including the following:

Hydrologic Characteristics - To deal with the problem of examining the power potential at a large number of dams, the basic hydropower equation ($P_{KW} = E_{tg}H_nQ/11.8$) had to be simplified. This equation calls for the use of site-specific streamflow data, which is very costly as well as difficult to obtain. Instead, assumptions were made that the discharge Q (in cfs) could be expressed as the product of:

1. A unit mean runoff per square mile of drainage area,
2. The drainage area above the dam in square miles, and
3. The ratio of energy-productive water to total mean discharge at the dam. This ratio was introduced to account for flows that would occur in excess of turbine capacities and is termed a spillage factor (F_s). The values selected for F_s were .7 and .9 for plant factors of 70 and 40 percent, respectively. These values were derived from curves constructed to reflect streamflow and power plant operational characteristics in a representative New England river basin (the Connecticut River Basin). Values for unit mean runoff were developed from representative stream gauges for 44 hydrologic basins in New England, each of which was delineated on the basis of displaying substantially uniform runoff characteristics (average value of 1.8 csm).

Use of assumptions concerning the basic hydropower equation and the values selected meant that the only hydrologic variable for each dam site was the upstream drainage area. This measurement was obtained by state agency personnel (entry level) through one of three methods: using available records, planimetering areas on appropriate maps, or counting overlay squares. The accuracy requested was to the nearest mile.

The other variables in the power equation which had to be simplified (for data collection purposes) were net head (H_n) and combined turbine-generator efficiency (E_{tg}). The assumption was made that hydraulic head losses would approximate 5 percent of the gross head; thus, with the use of a coefficient of .95, the height of the dam above tailwater could be used as the head measurement in place of net head. For a combined turbine-generator efficiency, the value of .88 was selected on the basis that generators are about 97 percent efficient, and the efficiency for turbines is about 90 percent.

Use of these assumptions and selected values meant that only one easily obtainable variable was needed—height of dam above tailwater. This was also furnished by state personnel, primarily from available records.

Water Storage Capability - With practically all the dams being small-scale, the assumption was made that no storage capability would be available. Admittedly, this could have been overly conservative; however, these dams were not originally designed with extended storage features because of streamflow variations. An added benefit from using this conservative assumption is that environmental concerns normally associated with variable pondage and flow releases would be minimized.

Type of Power to be Produced - For the purpose of comparing the amount of power that could be produced under different facility designs, two plant factors were selected. A 40 percent plant factor was chosen as typical of peaking/intermediate power generation (based on the average plant factor for ex-

isting facilities on the Connecticut River), and a 70 percent plant factor was considered typical of a baseload operation.

Projected Regional Power Needs - The extent of energy that hydropower could contribute to regional needs was determined by comparing study findings on regional hydropower potential with the 10-year regional load demand projections furnished by the New England Power Pool. Seasonal or daily load demand variations were not considered at this stage of the study.

Degree of Reliability of Hydropower to Meet These Needs - Concern has been expressed over information credibility concerning energy potential when hydropower facilities are sized on the basis of average annual flows. Undoubtedly, some distortion does exist between seasonal or daily load demands and the energy and system capacity that can be attributed to hydropower. It was felt that use of 40 and 70 percent plant factors, as well as the spillage factor, would offset the margin of error sufficiently so that the resulting information base would be acceptable for planning purposes.

Generation Equipment Capability and Availability - Five feet of head was selected as the minimum acceptable for efficient equipment operation, and 50 kilowatts was selected as the minimum generation capacity based on the availability of equipment for commercial generation.

Cost of Facility Construction - Sets of curves were developed for computer calibration purposes in determining construction costs. These curves were based on empirical data from various categories of dams, and were grouped into three sets:

(1) Cost for complete redevelopment of dam, powerhouse and related power equipment;
(2) Cost for package unit including turbine, generator, and related components; and
(3) Cost for refurbishing existing facility.

Other miscellaneous construction costs (for intake gates, tailraces, etc.) were considered rather minor components of overall costs and were assigned percentage values rather than values which were site specific. Percentages were also derived for engineering and design, operation and maintenance, taxes, insurance, and interim replacement.

Use of these assumptions meant that dams had to be checked in the field for only three variables: length of dam, type of dam, and condition of the facilities. This information was readily obtainable through site visitations by state personnel who were not required to possess extensive background in dam evaluation.

Variable for Economic Conditions - Two economic variables were used to provide a computer capability for testing the sensitivity of hydropower development to changing economic conditions. There variables were:

(1) Financing cost in terms of a range of interest rates; and
(2) Capital recovery energy cost. This represents the return needed by a developer for each unit of electricity produced to cover the total investment. This return is expressed in mills per kilowatt hour.

The four interest rates chosen to represent a range of financing arrangements were:

1. 14 percent to reflect the interest rate available to potential private developers who do not qualify for prime interest rate. Recent increases in the prime rate mean that 14 percent may be conservative for this representation.
2. 10 1/2 percent to reflect the prime interest rate in late 1978 and today's level of below-market rates that might be available.
3. 6 7/8 percent, which is the fiscal year 1979 discount rate for federal water projects.
4. 3 percent to reflect a possible government subsidized rate to achieve low-cost financing.

Project life was estimated at 50 years for all interest rates except 6 7/8 percent. For this rate, a 100-year evaluation period was used for consistency with the National Hydropower Study. The distortion in capital recovery factor between 50 and 100 years is minimal (0.25 percent).

For the needed return, or capital recovery energy cost, four values were selected:

1. 25 mills/kWh to represent the wholesale rate paid to hydropower producers in late 1978 (and in many instances, the going rate today).
2. 45 mills/kWh which reflects a recent decision by New Hampshire Public Utilities Commission (NHPUC) setting the rate which utilities are to pay developers for hydropower with firm capacity. This compares closely with FERC's power value for equivalent energy from oil-fired plants at a $16/barrel fuel price.
3. 67 mills/kWh which reflects the power value equivalent for $27 per barrel oil (the current market price for #2 distillate which is used in plants with a 40 percent plant factor).
4. 90 mills/kWh which is an arbitrarily chosen rate of twice the NHPUC rate-setting decision. If the price of oil would reach $42/barrel, this would be the break-even return required for oil-fired power generation.

Assessment Techniques

Before an attempt at quantifying New England's hydropower potential could be made, an accurate inventory of dams had to be prepared, as a wide disparity in numbers existed among previously conducted inventories. This was accomplished through intensive work performed by the six New England States to assemble composite lists of dams and compile technical information about them. Included in the inventory are those dams which:

1. Are currently being operated for power generation;
2. Are currently being operated for other water management purposes;
3. Are idle; and
4. Are breached (broken through).

The next stage of the assessment was directed toward identifying those existing non-generating dams which warranted further evaluation for power generation purposes. This was accomplished through a computer screening process which eliminated dams with heads of under five feet and with power generating capacities of less than 50 kilowatts.

The subsequent task was to rank, according to economic feasibility, those dams warranting further evaluation. This also was accomplished by computer using selected values for economic conditions (listed previously). The rankings were displayed in two forms: (1) Ascending order according to capital recovery energy cost; and (2) Descending order according to benefit-to-cost ratio.

Remaining work tasks to complete the methodology are currently being initiated. These address the complications that hydropower expansion could pose to other water uses. A pilot study is currently under way to determine which social and environmental factors should be considered in regionally-oriented resource assessment. Most likely these factors would be used to evaluate only those sites which demonstrate a favorable economic ranking. Completion of these remaining tasks is scheduled for 1980.

Physical and Economic Findings

The value in utilizing the described methodology to conduct a resource assessment is demonstrated by the results obtained thus far. A wide range of information has been compiled which already can support decision-making processes, as illustrated by the following representative findings:

- The inventory shows that, for all of the dam categories, a total of 10,670 dams exist in New England. Of this total, nearly 15 percent (1,445) are either partially breached or require total reconstruction, and 363 are currently being used for power generation.
- Further evaluation is warranted for 1750 dams, based on practicability for generating power. At a 40 percent plant factor, the maximum power potential of these dams is 1,000,000 kilowatts capacity and 3,500,000 megawatt hours annual energy. This is about 4 percent of New England's 1979 electrical energy demand, 8 percent of the additional electrical energy needed over the next 10 years, and 15 percent of the additional capacity needed.
- In terms of reducing oil dependency, the maximum power potential would be equivalent to a savings of 5 million barrels of oil annually—worth $130 million at current prices.

To aid New England in policy formulation, two graphs (see pages 9 and 10) have been prepared to show the sensitivity of hydropower development to economic conditions. The following findings are derived from these graphs:

- Under present economic conditions, New England could anticipate commercial development of only 15 percent (600,000 mWh annually) of the region's hydropower potential at existing dams. Only

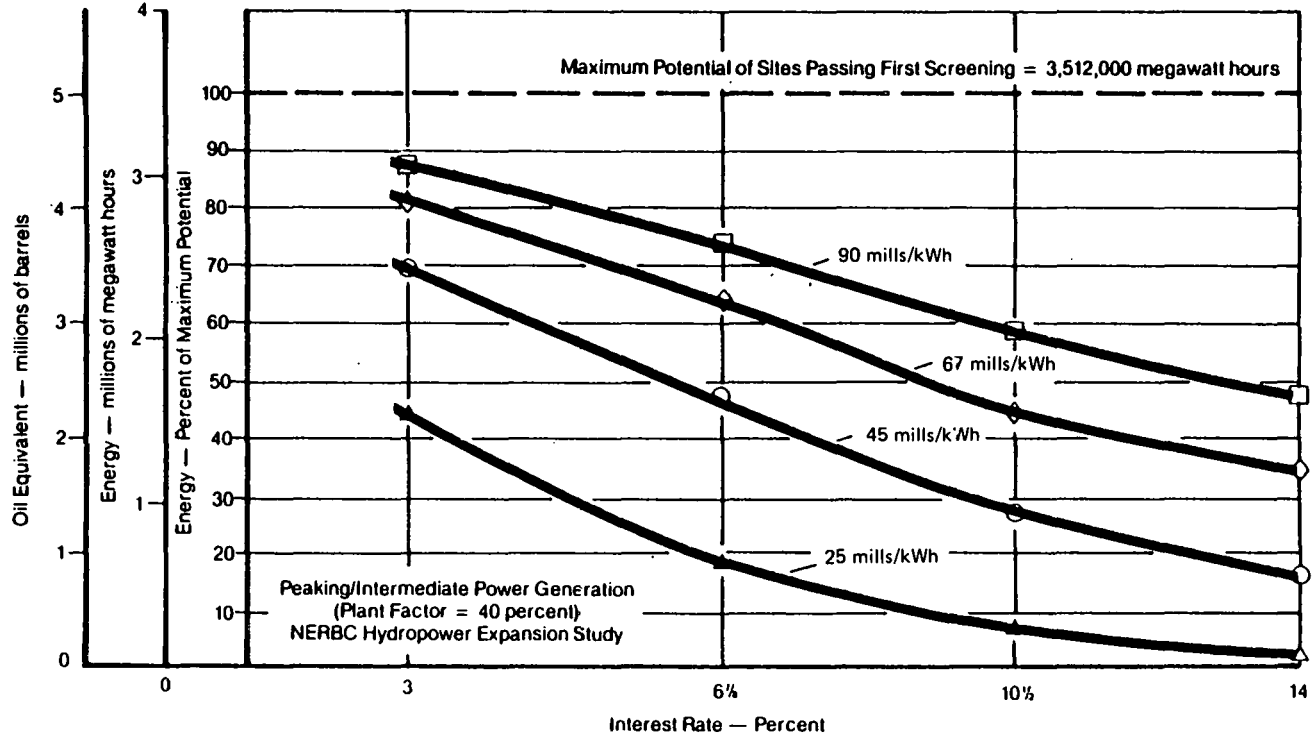


FIGURE J-2.1 Effect of Interest Rate on Potential for Hydropower Development at Existing Dams in New England

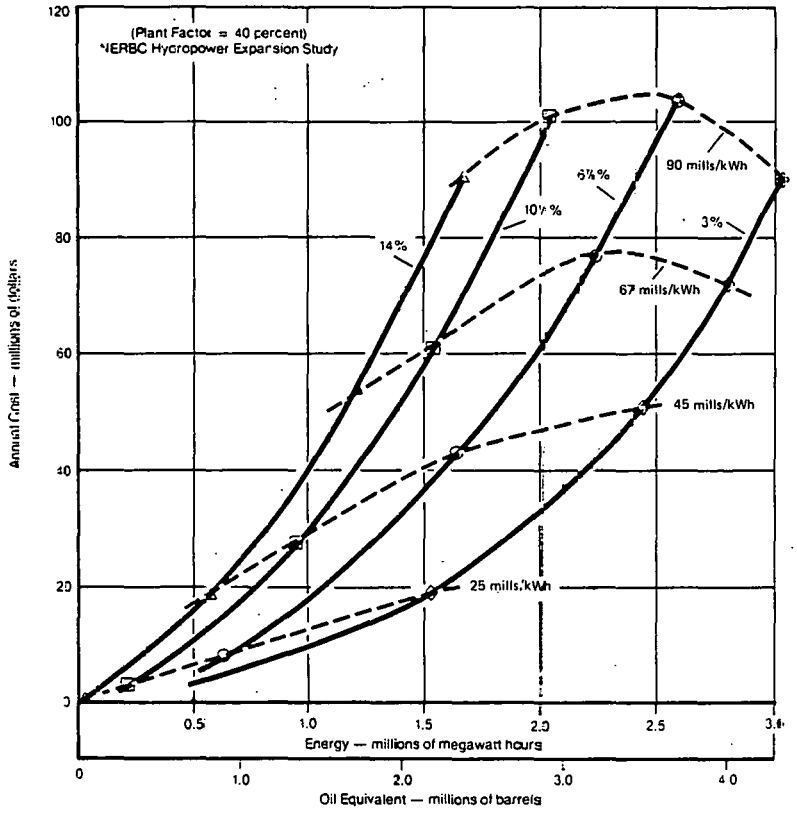


FIGURE J-2.2 Annual Cost for Developing Peaking/Intermediate Power Generation at Existing Dams in New England

82 sites would be economically attractive, at an annual cost of about $20 million.

- If the return were 67 mills per kilowatt hour (equivalent to the current power value for oil-fired intermediate generation), the amount of energy that would be economically attractive to produce at existing dams would double (1,200,000 mWh annually at a total of 148 sites). The annual cost would be about $50 million.
- If the return remained at 45 mills per kWh, and if financing could be made available at the federal discount rate, nearly 50 percent of the hydropower potential at existing dams would become economically attractive (1,600 mWh annually at 209 sites). The annual cost for development would be slightly more than $40 million.
- To achieve economic attractiveness for 80 percent (2,8000,000 MWh annually at 581 sites) of the region's hydropower potential at existing dams, the return would have to be 67 mills per kilowatt hour and the interest rate reduced further still to 3 percent. The annual cost for this level of development would be about $70 million.
- Current policies put forth by federal assistance programs could actually deter rather than accelerate commercialization of small-scale hydropower. If these programs were designed to better account for market conditions, incentives could be provided which would strengthen the economic feasibility of currently marginal or economically unattractive sites. If this is not done, the number of economically attractive sites will quickly be depleted, and federal programs will not achieve their intended goal of reducing New England's oil dependency.

Summation

Even though New England is still in the process of conducting a resource assessment of its hydropower potential, already the methodology used has enabled the region to acquire a substantial amount of information for policy formulation purposes. The remaining task is to complete the methodology by conducting a socio-environmental assessment. When finished next year, the total cost for utilizing the regional methodology is anticipated to be in the range of $500-$700 per site. For this investment, New England will have gained a concise understanding of the hydropower potential as well as the consequences of the development. A dynamic planning and information tool will be available to guide state and local efforts in selecting priority areas and sites. In addition, New England will be in a front-line position to both influence and benefit from national policy on small-scale hydropower development.

REFERENCES

Klock, Thomas, and Dennis Waskiewicz, *Potential for Hydropower Development at Existing Dams in New England: Physical and Economic Findings,* New England River Basins Commission, October 1979.

Le Blanc, Robert, "Current Studies Investigating Small Hydroelectric Power Facilities in New England," presented to the American Society of Civil Engineers Convention and Exposition, Boston, Mass., 6 April 1979.

Parker, Stephen, "Memo on Derivation of Power Computation Formulas," New England Division of the U.S. Army Corps of Engineers, Waltham, Mass., July 1978.

New England River Basins Commission, "Hydropower in New England: New Lease on an Old Stand-By?," *Regional Report* Vol. 7, Issue 3, Boston, Mass., August 1979.

SCREENING STUDIES FOR SMALL-SCALE HYDROPOWER POTENTIAL

Alexander C. George

The purpose of this discussion is to review methods that permit a rapid and inexpensive screening of a large number of dam sites to identify those that are potentially viable under the economic criteria which govern the selection procedures of a potential developer. The aim is to develop a short list of sites which appear to offer the best chance of proving viable and warrant the added cost of a brief reconnaissance study.

Only after the completion of these steps can a decision to commit the "front-end risk" money be made with a reasonable chance that the proposed project will not prove to be hopelessly uneconomic or impractical. The generation of hydroelectric energy is a relatively simple mechanical-electrical process. Recoverable energy and power depend on time, usable head and flow of water in a natural or man-made watercourse. Further variables are added to these parameters as a result of natural or man-made storage.

Analysis of hydrology and hydraulics as related to hydroelectric energy generation is not particularly complicated with modern techniques. Fortunately, stream flow records of substantial duration exist in most parts of this country. We believe that an area which will require attention to establish an optimum match of resources and needs is the full utilization of at-site and upstream storage. The importance of seasonal storage is that the reservoir can be filled at times of high flow when spillage and waste of energy would occur and the water released at times when the natural flow is insufficient to drive the turbine at full power. If the stream flow drops below that required to operate the turbine at its minimum power a relatively small volume of at-site storage can allow part day opeation, thus, allowing energy to be recovered which would otherwise be lost.

Superimposed on these variables are those of turbine capability. Many manufacturers produce turbines of various types which will recover energy; however, each type and brand has variations in peak efficiency, efficiency at maximum load, efficiency at minimum load, and ratio of maximum load to minimum load. Each of these variables affects the recoverable annual energy at a given site. As a result, in developing a simplified analytical procedure to provide a reliable screening methodology for hydroelectric generation potential, many variables have to be considered.

An important factor is the availability of standardized units. Therefore, the designer instead of asking for a custom unit to fit his site can use a standardized unit or combination of units which would achieve the same purpose at lower cost. Consideration of economic factors introduces a completely new range of variable factors. For example, the cost of mechanical, electrical and civil engineering equipment and construction vary throughout the U.S. on a regional basis; the value of energy and capacity varies on a state and system

---

Mr. George is Principal Civil Engineer, Tippetts-Abbett-McCarthy-Stratton, New York, New York.

basis. The value of capacity and energy is also greatly affected if generation can be coordinated with peak daily load demand. This latter variable is not expected to affect the economics of small capacity run-of-river hydro plants; however, in the case of a site with usable daily storage capacity, it can become meaningful, especially if large volume regulated upstream storage exists.

Hydroelectric project construction is a capital expenditure-intensive source of energy. However, once the project is complete, operation and maintenance changes are relatively small. The alternate sources of capacity and energy require a lower level of capital expenditure, but fuel must be purchased throughout the life of the plant. Therefore, the cost of capacity and energy from a hydro plant is affected greatly by the interest rate for money and the cost escalations between initiation and completion of the project. The alternate source costs contain these same variables, but in addition the future cost of fuel over the life of the station must be estimated. Thus, this comparison of hydro versus an alternate source is highly sensitive to the accuracy of predictions of the future cost of money and long-term future price of fuel.

All of the above cost and economic factors must be estimated or provided for by the use of sound engineering and economic judgment. However, the analysis is still incomplete until some allowance has been made for indirect costs such as contingencies, engineering, legal, administrative and an allowance for funds used during construction. Therefore, for a preliminary screening evaluation of the potential of a particular site for development of a hydroelectric power plant, it is necessary to know approximately the practicable installed capacity, average annual energy generation to be expected, the gross project investment required to construct the plant, the monetary value of capacity and energy and the annual fixed charges, plus the operation and maintenance charges to be used, so that annual cost can be compared to annual revenue. For screening a multitude of sites, it is necessary to develop rapid methods of evaluating these parameters with sufficient accuracy to distinguish between sites requiring further review and those that could be discarded immediately as nonviable.

Fortunately, on a regional basis a flow-duration curve which, when expressed in terms of the ratio of the mean flow, fits all river curves, within that region, with only minor variance. Energy is proportional to the area under the curve at any given maximum turbine discharge; however, due to limitations of turbine operating range, not all of the energy under the curve can be recovered. Energy curves can be developed from these unit-flow duration curves for a one-unit plant, a two-unit plant, and a plant where daily storage was available. From these curves, energy and capacity coefficients can be obtained which estimate these values with sufficient accuracy.

In order to evaluate gross plant investment required, curves were developed for the direct cost of turbine-generator tube unit packages from information obtained from the manufacturers. These curves allow for all electrical-mechanical equipment in the powerhouse, freight and erection, civil works to house the equipment and indirect costs. Other costs such as waterways, dam construction or repair, spillway, transmission line, access road, land acquisition, etc., remained to be added; however, in order to avoid deleting a viable site, and to allow for cases of existing dams where these facilities already existed, initial screening can be conducted assuming that no work other than the power plant would be required.

The only remaining unknowns are now the value of capacity and energy, annual fixed charge and operation and maintenance charge rates to compare annual cost with revenue. Values can be selected which lie in the region of those that will apply to the type of developer performing the study.

For a first screening a computer program was written to evaluate capacity, average annual energy, the annual value of this energy and capacity and the gross project investment that these values could support. In order to retain marginal sites rather than delete viable sites, the program then compared the allowable gross project investment with the estimated cost of the smallest available standard tube unit. Sites which do not provide at least 50% of this required value can be deleted. In a recent study involving an initial 11,000 sites this step deleted approximately 90% of those recorded. The remaining evaluation procedure is illustrated on Figures J-3.1, J-3.2. Use of these three figures, with suitable adjustments, permits a graphic solution to the economic evaluation of all sites within each typical area. The flow-duration curve at the lower right of Figure J-3.1 is the typical curve for the region within which the site is located.

Immediately to the left are plots of mean head times mean flow, against mean head times maximum turbine discharge. These lines, for the three cases indicated, represent the selected optimization results. This plot is entered with mean head times mean flow for each site, proceeding upward until the appropriate optimization line is reached. One then proceeds horizontally to the left to the next plot which determines plant capacity for the maximum turbine discharge and mean head.

However, rather than use the theoretical value, we have displayed the performance curves for the entire line of Allis-Chalmers standard tube turbines. Therefore at this point we can select the nearest standard wheel size (either one or two units) for the mean head available. Moving vertically to this point we then proceed horizontally to the left and read maximum, rated and minimum installed capacity for the site.

Continuing further to the left to the appropriate mean head times mean flow line, we then move vertically upward to the function curve in the upper left hand corner, then horizontally to the right to the appropriate energy curve, then vertically downward to read the energy coefficient. With this operation, we have determined the average annual energy available for the selected installed capacity.

As a result of the foregoing simple procedure, we have selected a standard unit (or units) appropriate to each site and determined the installed capacity and average annual energy output. The same procedure can be readily adapted to determining incremental capacity and output at existing hydro plants.

The procedure described applies to run-of-river situations modified only by the daily storage case. If daily storage is available, it is assumed that the units can run at best efficiency until daily storage is consumed and then shut down until storage is replenished. This permits efficient recovery of all available energy at the lower flows.

If seasonal storage is available either at the site or upstream, the additional energy available is estimated by a simple side calculation. Basically, it is assumed that energy represented by stored flows in excess of maximum turbine discharge is seasonally transferred to the lower part of the flow-duration

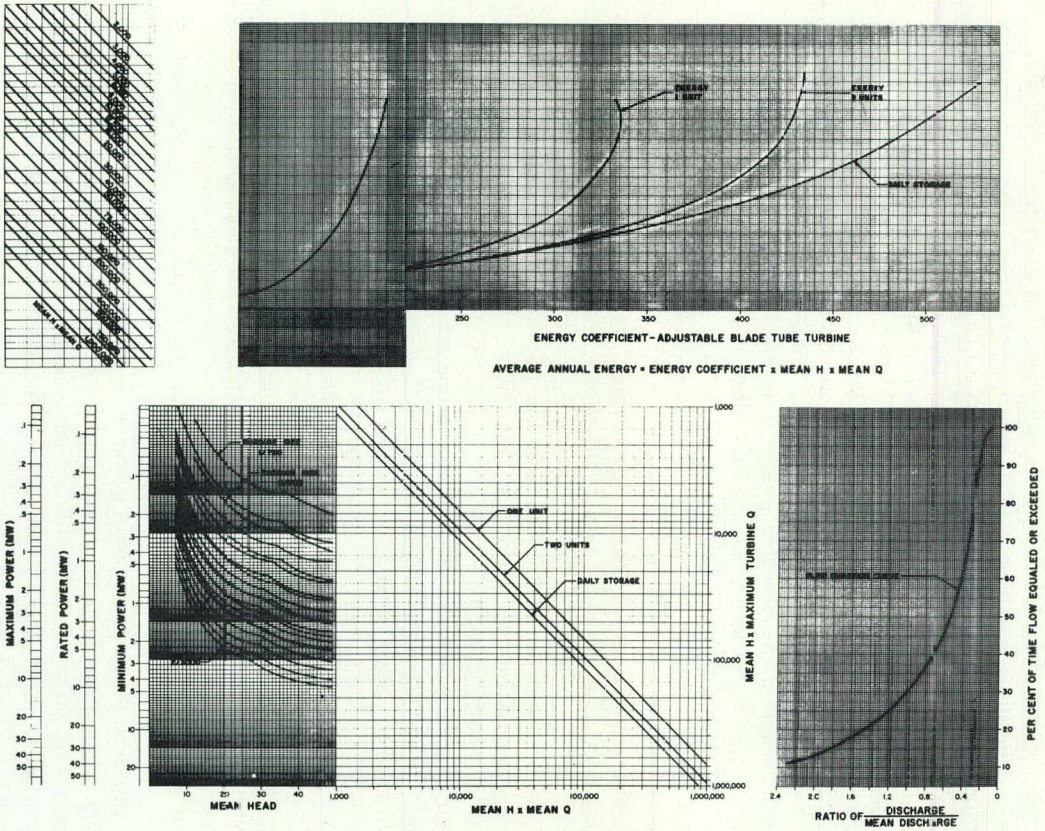


FIGURE J-3.1 Energy Coefficient - Adjustable Blade Tube Turbine

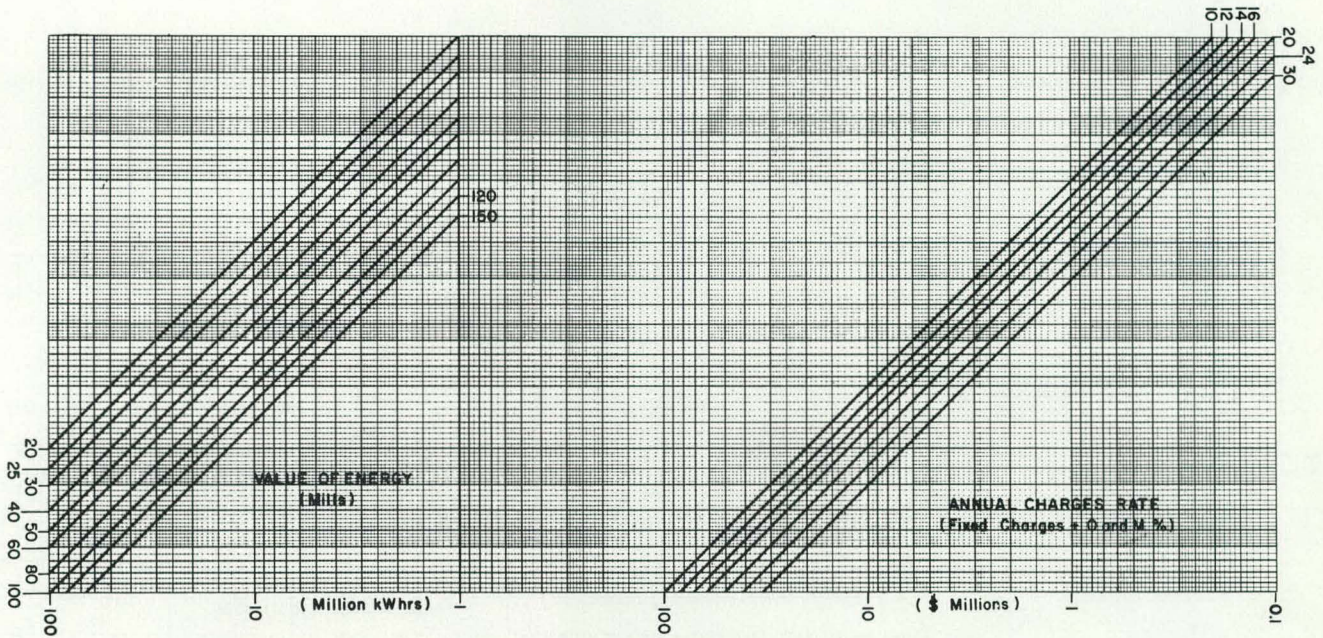
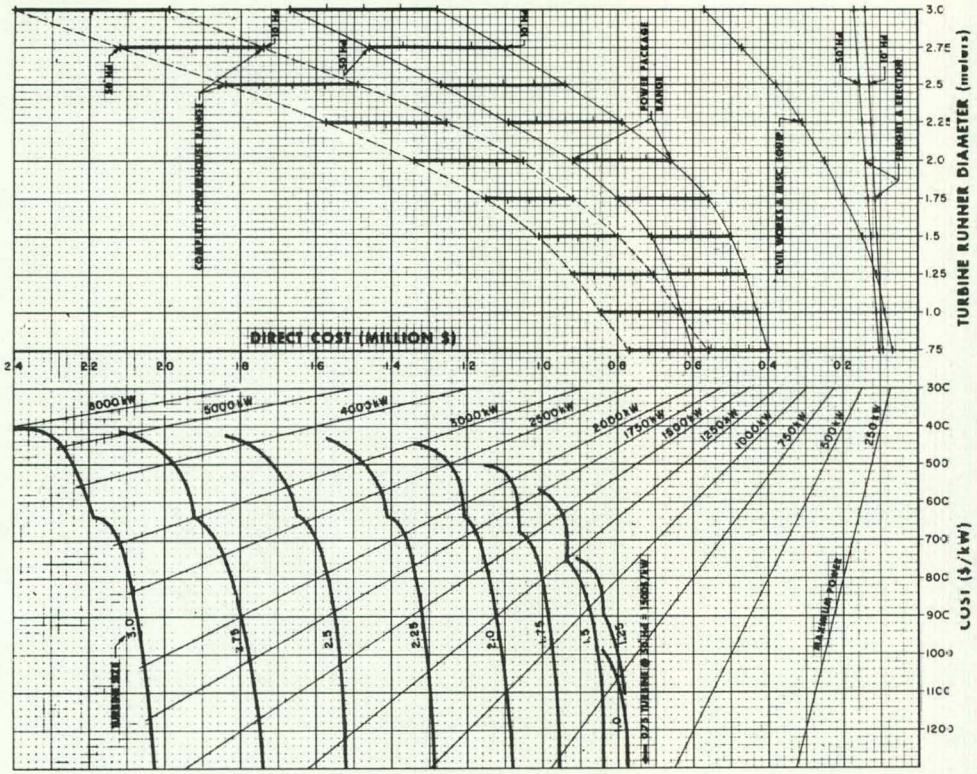


FIGURE 2

FIGURE J-3.2a Average Annual Energy and J-3.2 b Maximum Gross Plant Investment



BASIC ASSUMPTIONS:-

1) JANUARY 1979 PRICES.
2) DIRECT COST ONLY.
3) NO ALLOWANCE FOR CONTINGENCIES.
4) ASSUMES STANDARDIZED ADJUSTABLE BLADE TUBE UNIT.
5) FOR HEADS BETWEEN LIMITS USE DIRECT INTERPOLATION.
6) PRICE INCLUDES ONLY POWERHOUSE STRUCTURE-TURBINE GENERATOR PACKAGE-CONTROLS-MISC. EQUIPMENT-4.16/34kV TRANSFORMER AND HV SWITCH GEAR.
7) ASSUMES NO COFFERDAM REQ'D.
8) COST SHOWN IS FOR ONE UNIT FOR TWO UNITS MULTIPLY BY 1.65 (TOTAL COST ONLY).
9) SUGGESTED ALLOWANCE FOR TOTAL INDIRECT COST +50%.

FIGURE J-3.3a Tube Turbine Powerplant Cost Estimating Curve, and J-3.3b Turbine Runner Diameter (in meters)

curve. Therefore, for sites with seasonal storage this increment of energy is added to the average annual energy determined by the basic procedure. In this connection, we have found that unless peaking operation is possible, which is very site-specific, the availability of seasonal storage does not affect the selection of optimum installed capacity. It can however, have substantial effect on the firm capacity value of the plant.

The next step in the evaluation is illustrated in Figure J-3.2 which represents a calculation of the worth of the average annual energy expressed in terms of justifiable gross plant investment. With the average annual energy for each site calculated by Figure J-3.1 procedures (and including that due to seasonal storage) the plot is entered vertically to the energy value levelized over the life of the project. Then one proceeds horizontally to the right to the appropriate annual charges rate and then downward to read maximum gross project investment.

This amount is based upon energy value only. If the site also has firm capacity, the regional value of this capacity is determined in terms of justifiable gross project investment and added to the energy component. This total gross project investment represents the total amount that one can afford to spend at each particular site.

The worth of the site can then be compared to the estimated cost of the powerplant, illustrated in Figure J-3.2, for the unit size selected from Figure J-3.1. If the worth of the site exceeds the cost of the powerhouse alone further study can be justified to determine the potential magnitude of other project costs.

INTERAGENCY COORDINATION FOR SMALL HYDROELECTRIC POWER DEVELOPMENT IN ALASKA

Loran R. Baxter and Weldon A. Opp

Spiraling fuel prices, rising transportations costs, storage problems, and increasing energy demands—these are just a few of the factors which are making small hydropower increasingly more attractive as an alternative energy source. In remote areas of Alaska where heating fuel prices have soared to 2.50 per gallon and electricity rates of 35 to 40 cents/kWh are fast becoming the rule, the need for alternative energy sources is critical. These problems have become the primary catalyst in motivating state and Federal agencies involved with power development in Alaska to work cooperatively to fulfill these needs.

With the help of Alaska's congressional delegation, the Public Works Committee of Congress passed a resolution in October 1976 directing the Corps of Engineers to assess the hydropower potential for small isolated communities throughout the State. This laid the groundwork for joint Federal-State cooperation between the four primary agencies involved in power development in Alaska. The Division of Energy and Power Development, the Alaska Power Authority, the Alaska Power Administration and the Corps of Engineers, are working together to avoid duplication of effort in meeting the problems and needs of the State of Alaska in a more timely and efficient manner. A brief description of each agency's role in power development is contained in the following paragraphs, followed by examples of interagency coordination and the resulting programs for small hydropower development.

The role of the Division of Energy and Power Developement under Alaska's Department of Commerce and Economic Development is basically one of planning. The Division is currently in the process of formulating a long-term power development plan for the State. They also have the authority to sponsor energy development demonstration projects.

The Alaska Power Authority is a public corporation of the State, created with the idea that it would provide "a means of constructing, acquiring, financing and operating hydroelectric and fossil fuel generating projects."[1] The Power Authority is empowered to make loans for feasibility studies and project design as well as issue revenue bonds for construction.

The Alaska Power Administration represents the United States Department of Energy (DOE) in Alaska. The Power Administration is responsible for comprehensive planning, marketability studies for proposed hydropower projects, as well as for the operation and maintainence of Federal facilities.

Mr. Baxter is a water resources planner for the Alaska District, Corps of Engineers, Anchorage, Alaska, and is a project manager for a hydropower study and also the manager of a hydropower feasibility study at Valdez, Alaska. Mr. Opp is the Chief of the Planning Branch, Alaska District, Anchorage, Alaska.

[1]Alaska, *An Act Creating the Alaska Power Authority* (1976), Sec. 44.56.070.

Other responsibilities include administering various grants for demonstration projects.

The Corps of Engineers, represented by the Alaska District is responsible for planning, design and construction of hydroelectric projects specifically authorized by Congress. In the case of small hydropower however, the Corps is authorized to study the potential but no provisions have been made for construction short of Congressional authorization of projects.

Periodic meetings held between these agencies afford the opportunity to discuss current programs, provide input to other agency's studies, and set priorities for future investigations. This type of coordination is essential due to the overlapping authorities of the agencies. Due to this overlap, each agency has the ability to pick up a study where another left off. This provides for maximum efficiency in the utilization of both State and Federal funds, as well as a full sharing of responsibility for the welfare of the State. One project having the potential to reduce exisitng electrical rates in bush Alaska is a single wire ground return transmission system. Sponsored by the Division of Energy and Power Development as a demonstration project, it may reduce transmission costs to one-third that of a conventional three-phase system.[2] Basically, the system consists of a single energized wire supported by an A-frame structure of local spruce poles, with the earth acting as the return circuit.

Two single wire projects are scheduled for completion this winter. The villages of Bethel, Napakiak, and Akiachuk in southwest Alaska will be intertied as well as Kobuk and Shungak in northwest Alaska. With the aid of snow machines and local villagers for construction, the transmission systems should be functional by spring. If the single wire ground return proves successful, it will improve the economic feasibility of small hydropower development in Alaska.

Partially in anticipation of the success of the single wire system, but primarily due to increasing diesel generation costs, the Alaska Power Authority is undertaking a study to determine the feasibility of developing a project at either Grant Lake (1.5 MW) or Lake Elva (2.25 MW), in the Bristol Bay region. The Power Authority has picked up where the Alaska Power Administration left off with its reconnaissance of the two sites. Their initial findings did not show either project as economically justified at that time; however, recent cost increases in petroleum have prompted a second look.

The Corps of Engineers small hydro study is designed to assess the hydropower potential for small communities statewide. Regions of the State are being systematically evaluated for potential projects having up to five megawatt capacity. Additional provisions, providing for investigations of specific areas by community request or through recommendations by other agencies having allowed flexibility in meeting the problems and needs of Alaska.

During fiscal year 1979 the Corps has assessed the small hydropower potential at all isolated communities in Southeast Alaska not previously investigated. This information is being combined with the Alaska Power Authority's earlier studies of ten communities to provide a comprehensive planning document for hydropower development in the Southeast.

In addition, site investigations were conducted on the island of Unalaska,

---

[2]Projection based upon estimates by Robert W. Retherford Associates of Anchorage, the engineering firm responsible for design and construction of the project.

Akutan and Umnak in the Aleutian Chain at the request of the Division of Energy and Power Development and the Aleutian Pribilof Native Corporation. Preliminary evaluations at Akutan show that approximately 90 kW may be developed at the site which would serve the village of approximately 70 people. Although this development may sound insignificant, the increase is substantial when compared to the existing system consisting of only a direct current hydro development and a 10 kW diesel generator used for the school.

Approximately 25 requests were received for site evaluation during 1979. Regretfully they could not all be evaluated due to funding limitations during this first year of the study. However, through coordination with the Alaska Power Administration, it was possible to incorporate several of these villages into their small hydro assessment plans for the year.

As a result of the Power Administration's investigations this year, a number of potential sites were identified. The coastal villages of Scammon Bay and Elim show a particularly high potential for development, and have been recommended to the Corps for feasibility studies.

Presently, the Alaska Power Authority is the only agency that has the authority to administer funds for construction. There are three means available to them in obtaining funds: direct State legislative appropriations, moneys through the state permanent loan fund from nonrenewable resource taxes, and sale of revenue bonds. Some funds may be available through the Department of Energy's program for retrofitting existing small dams. This program may have great potential in the lower-48; however, for Alaska, with its few existing dams, the program has been of limited value. Efforts are underway to expand this program to include natural dams at the mouths of perched lakes. This modification would have far greater promise for Alaska.

Agencies of the Federal Government are restricted in their construction effort of obtaining specific authorization and appropriation by Congress and the President. Upon favorable findings of a feasibility study, the report must be renewed by the Water Resource Council and the Office of Management and Budget before it can be transmitted to Congress. If Congress concurs in the report's recommendation, they must authorize the project through legislative documentation allowing appropriations to be made. This action then requires another legislative action and Presidential approval.

A bill recently introduced in the Senate is an encouraging step towards construction of small hydroelectric power facilities and the displacement of diesel fired generation. The concept of the bill would allow for construction of small hydroelectric power facilities without specific project authorization by Congress. This concept is similar to the Small Project Continuing Authority Program approved by Congress for small flood control and navigation projects. If this proposal is enacted into law, it will provide a means for the most viable hydroelectric projects to be constructed in a timely manner. This will result in a decreased dependence on our nations non-renewable resources.

Session Nine

PLANNING, INFORMATION AND METHODS

Topic: Case Studies and Demonstration Projects I

Chairman: Mr. Charles Gilmore
Director, Advanced Technology
Idaho Operations Office
U.S. Department of Energy
Idaho Falls, Idaho 83401

FEASIBILITY INVESTIGATIONS OF FIVE LOW-HEAD HYDROELECTRIC PROJECTS UNDER DEPARTMENT OF ENERGY GRANT PROGRAM

James V. Williamson and A. Wayne Pietz

Introduction

In 1978 the U.S. Department of Energy (DOE) made grants to study the feasibility of installing hydroelectric generating facilities at some 54 existing dams throughout the country. This paper will present the results of the feasibility studies for five of these sites.

The five sites compared in this paper are representative of the varying conditions which can be encountered in attempting to develop small-scale hydropower at existing dams in the United States. As shown in Table K-1.1, the proposed sites range in location from Kansas to Florida, and occur on small to large rivers. Further, the developable head ranges from about 2.5 meters to 20 meters and the installed capacity from 400 kW to almost 15,000 kW. Two of the projects are located at Corps of Engineers dams; two are at installations which have, or have had, hydroelectric power generation in the past; and the other is at a dam which impounds a thermal plant cooling pond. The methods of financing available range from tax exempt municipal revenue bonds to Rural Electrification Administration (REA) type financing. The alternatives to a project are either continued wholesale power purchase or construction of new thermal generation, depending on the location.

The projects also cover a range of equipment characteristics and arrangements. This includes both horizontal and vertical mountings and types of turbines which include Francis, fixed-blade propeller, adjustable-blade propeller, and diagonal flow. In addition, the settings include Allis-Chalmers standard TUBEs, modified open flume, and concrete spiral case.

Project Arrangements

The proposed arrangement for the Tuttle Creek Project includes a steel liner placed inside one of the existing outlet works conduits, a wye at the downstream end with one branch leading to the powerhouse, located at the stilling basin, and one fitted with a butterfly valve to allow flood releases. The powerhouse would contain three Allis-Chalmers standardized 4,750-kW TUBE units, and one 500-kW TUBE unit, for a total installed capacity of 14,750 kW operating under a rated head of 60 feet.

The proposed development at Zumbro consists of installing a third unit in the empty stall in the existing powerhouse, adding two feet of flashboards to the spillway, and the installation of a new three-phase transformer. Provision was made when the powerhouse was constructed in 1919 for addition of the

Mr. Williamson is a partner and Mr. Pietz is Supervising Engineer, R. W. Beck and Associates, Seattle, Washington.

TABLE K-1.1

Hydroelectric Project Statistics

Project/Instal. Capacity/Rated Head	**Investigating Agency**	**Type Of Existing Facility**	**Turbine Mounting/ Turbine Type/ Setting**	**River** Name; Average Discharge	**Financing** Type; Interest; Terms	**Alternative To Project**
Tuttle Creek 14,750 kW 60 feet	Kansas Electric Power Cooperative, Inc. Topeka, Kansas	Corps Flood Control Dam	Horizontal; Adjustable blade propeller; AC standard TUBE	Big Blue 2,120 cfs	REA 7% ; 9-1/2% — 35 yr DOE 7-1/8% & 9-1/2% — 30 yr	Wholesale Power Purchase
Zumbro 1,800 kW[1] 52 feet	City of Rochester, Minnesota	City Hydro Dam	Vertical; Francis; Concrete spiral case	South Fork Zumbro 361 cfs	Revenue Bonds 7% — 40 yr	Hydro & New Thermal Generation
Piqua 400 kW 8 feet	City of Piqua, Ohio	City Thermal Cooling Pond	Horizontal; Adjustable blade propeller; AC standard TUBE	Great Miami 759 cfs	Revenue Bonds 6.5% — 40 yr	Fuel Replacement
Maxwell 8,000 kW 17 feet	Allegheny Electric Cooperative, Inc. Harrisburg, Pennsylvania	Corps Locks and Dam	Vertical; Fixed blade propeller; Modified open flume	Monongahela 8,769 cfs	REA 7% ; 9% — 35 yr DOE 7-1/8% & 9% — 30 yr	Wholesale Power Purchase
Jackson Bluff 8,800 kW 32 feet	City of Tallahassee, Florida	State Owned — Originally Licensed Power Project	Vertical; Fixed blade propeller or diagonal flow; Concrete spiral case	Ochlockonee 1,692 cfs	Revenue Bonds 6.5% — 30 yr	New Thermal Generation

[1] — Third Unit Only

third generating unit but it was never installed. The third unit would be a Francis-type turbine with an installed capacity of 1,800 kW under a rated head of 52 feet.

The Piqua Project would consist of the installation on the east bank of the existing dam of a power intake, power conduit, powerhouse, tailrace channel, access road, and transmission line which would interconnect directly to the City's existing distribution system. The Project would operate under a rated head of 8 feet and have an installed capacity of 400 kW, consisting of two 200-kW standardized TUBE units.

The arrangement at Maxwell would consist of an intake structure, open canal and powerhouse, located on the east side of the existing Maxwell Locks and Dam, and a transmission line about one mile in length which would connect to an existing line. The powerhouse would house four vertical units of 2,000 kW each in a modified open flume setting, operating under a 17-foot rated head.

The development at Jackson Bluff consists of the re-installation of power generating equipment at the existing powerhouse, addition of electrically driven hoists for five spillway gates, and the construction of a fuse-plug type auxiliary spillway. The project would operate with a rated head of 32 feet and have an installed capacity of 8,800 kW, consisting of two 3,200-kW units and one 2,400-kW unit, the same size as installed previously.

Power Output And Utilization

Reservoir Operation and Power Output

Reservoir operation and power studies for each project were generally conducted for the period of hydrological record which ranged from about 40 to 50 years. The results of the power output studies are shown on Table K-1.2. Ordinarily, a project would be operated as a daily peaking plant with storage in the reservoir being utilized whenever the amount of water required to sustain generation during the daily peaking period exceeds the natural inflow into the reservoir. The long-term average annual generation from a project was determined using this mode of operation.

The firm (prime) energy is that generated and delivered to the load center on an annual basis, during severe low-flow conditions. It was considered reasonable for these feasibility assessments to base the available firm energy of a project on the amount of energy which is generated under the hydrologic conditions corresponding to the second most adverse hydrologic year. These adverse conditions, then, have an expected recurrence interval of 20 to 25 years, which is about the life of an alternative thermal installation.

Dependable capacity was generally determined by operating a plant during the peak load period each weekday during a severe low-flow stream condition. The minimum capacity during this period of time, which most often corresponds to the peaking capability of the plant at the lowest reservoir elevation reached during this flow condition, was considered to be the dependable capacity in terms of comparison with the alternatives available for power generation.

TABLE K-1.2

Power Output[1]

PROJECT	INSTALLED CAPACITY (kW)	DEPENDABLE CAPACITY (kW)	AVERAGE ANNUAL ENERGY (Mwh)	FIRM ENERGY (Mwh)	SECONDARY ENERGY (Mwh)
Tuttle Creek	14,750	12,290	56,690	(2)	(2)
Zumbro					
All three units	3,640	3,227	10,661	3,652	7,009
Two existing units	1,840	1,712	7,986	3,092	4,894
Piqua	400	0	1,462	0	1,462
Maxwell	8,000	4,914	35,880	(2)	(2)
Jackson Bluff	8,800	6,659	24,920	6,753	18,167

(1) All values of power delivered at load center.
(2) Not applicable for power purchase alternatives.

Utilization of Power in System

With few exceptions, the hydroelectric sites in the country which have not been developed should be considered as peaking installations (low-plant factor), in order for them to be economically competitive with alternatives. This results from the projected high value of demand (peaking) in the future, particularly where such generation is oil-fired. Even the output from so-called "energy" installations on larger rivers can be expected to be used in the upper part of the load curve, to achieve maximum economies rather than displacing power from large baseload thermal generation.

Economic Analysis

Method of Economic Analysis

To establish the economic feasibility of a project it is necessary to compare costs with the most economic alternative source of generation to meet load. The two basic alternatives considered were: (1) a generic alternative consisting of the operation of a new thermal peaking generating plant (usually a simple-cycle combustion turbine) having an identical dependable capacity and firm energy capability as the hydro project, with the secondary energy generated assumed to replace energy that would otherwise be generated by older, oil-burning or coal-burning steam units; and (2) continuing power purchases from the current power supplier if this situation pertains.

The economic analyses in the feasibility assessment studies were based on comparing: (1) the estimated cost of power from the project during its first year of operation versus the cost of an equivalent amount of power from the alternative considered (value or benefit) from which the first year benefit-cost ratio is determined; and (2) the estimated total cost of power from the project during the first ten years of operation versus the estimated total cost of an equivalent amount of power from the alternative considered for the same ten-year period, on a present-worth basis. If the net result (benefits less costs) was a surplus over this period then the project was considered economically feasible.

Results of Economic Analysis

Table K-1.3 summarizes the results of the economic analysis for each project. As can be seen, Tuttle Creek shows economic feasibility based on the ten-year analysis, assuming 7% interest, REA type financing, since it shows savings in cost over the alternative over the period of $1,166,000. This is so even though the first year benefit-cost ratio is only 0.84. However, with 9-1/2% REA financing the project is not considered economically feasible since over the ten-year period it would cost $2,592,000 more for power from the project than it would from the alternative of continued power purchases. The economic feasibility of the Tuttle Creek Project will be totally negative, even with 7% REA financing, if reservoir use charges tentatively suggested by

TABLE K-1.3

Results Of Economic Analysis

PROJECT	INSTALLED CAPACITY	ESTIMATED TOTAL INVESTMENT[1]			ECONOMICS First Year	Ten Year (Present Worth)	
	(kW)	On-Line Date	Cost ($1000)	$/kW	B-C Ratio	PW Date	Total PW Savings (Deficit) ($1000)
Tuttle Creek[6]	14,750	7/84	19,192[3] 19,662[4]	1,301[3] 1,333[4]	0.84[3] 0.67[4]	7/84	1,166[3] (2,592)[4]
Zumbro	1,800[2]	10/83	1,718	955	1.27	10/83	805
Piqua	400	1/84	2,828	7,070	0.19	1/84	(1,807)
Maxwell[6]	8,000	1/85	17,801[3] 18,134[5]	2,225[3] 2,267[5]	0.88[3] 0.70[5]	1/85	108[3] (2,525)[5]
Jackson Bluff	8,800	10/83	9,882	1,123	1.27	10/83	4,486

(1) Escalated to on-line date
(2) Third unit only
(3) 7% REA financing
(4) 9-1/2% REA financing
(5) 9% REA financing
(6) No Federal dam use charges included

the Corps of Engineers are imposed. A result similar to Tuttle Creek occurs for the Maxwell Project although the amount of savings with 7% REA financing is less than with the Tuttle Creek Project. Again, it shows that with 9% REA financing the project is not economic even on a ten-year analysis basis. The Zumbro and Jackson Bluff Projects, which consist of installation of equipment in existing stalls, show first year benefit-cost ratios which are greater than unity and substantial savings over the ten-year period when compared to the most economic alternative of generating the same amount of power.

Environmental Effects

Since all of the proposed projects are at existing dams, the installation of hydroelectric generation facilities is expected to produce minimal adverse impacts. An assessment of the environmental effects which could be expected to occur from the development of each project revealed no potential impacts which are anticipated to preclude development.

Conclusions

The feasibility assessment studies demonstrate conclusively that the Jackson Bluff and Zumbro Hydroelectric Projects have economic feasibility. The Maxwell and Tuttle Creek Projects are economically feasible if suitable low interest (7% or less) financing can be obtained, such as is commonly available to municipalities under revenue bond financing, and if no Federal dam charges are imposed. The Piqua Project is infeasible.

General conclusions which can be arrived at from these studies are as follows:

1. Very low head (probably less than 15 feet), small-hydro installations will usually not prove feasible even with attractive financing terms.
2. Low-interest long-term financing is imperative for economic development of small-scale hydroelectric projects.
3. It is necessary to have available some reservoir regulation, or even daily pondage, to enable the capacity from a project to be developed as dependable and hence credited with that value for the alternative.
4. For the size of project involved (less than 15 MW) feasibility can only be obtained if the necessary waterways are nominal in cost. This is particularly so for low heads (say 6 meters) but also applies for the upper limit of 20 meters
5. Although advantages occur with large rivers (flows) much of this advantage is lost due to spill unless upstream regulation is available. Further, existing locks and dams on such large rivers of necessity only have low heads available and often have difficult physical constraints for construction of hydro development.

6. Standardized equipment such as Allis-Chalmers TUBE units tend to reduce equipment costs, but are not applicable to some of the head ranges and sizes considered. Further, the civil works costs associated with these standardized units may be increased, and can result in an unacceptable powerhouse arrangement. Bulb type units are very expensive for small installations.
7. In position of substantial Federal Dam Users Fees will generally result in rendering a small-scale hydro development infeasible.

POWERHOUSE RESTORATION AT HAGLEY

Lee DeHeer

Introduction

The purpose of this paper is to give a short history of one of the early small hydropower installations in the United States and to relate some of the experiences associated with restoring this powerhouse.

The Hagley Museum is located on 200 acres along the banks of the Brandywine river, approximately 2 miles north of Wilmington, Delaware. It was established in 1952 on the 150th anniversary of the DuPont Company. Many of the original stone powder mills and other buildings built by the DuPont family in the early 1800's are still in existence on the grounds.

The DuPont powder works was located alongside the Brandywine river to make use of the hydraulic power provided by the river. Two small dams were built on the Brandywine river in the Hagley Museum area which direct water into the upper and lower canals on the museum grounds. These canals were originally constructed to carry water to the various powder, flour and textile mills and tanneries located on the grounds. Gate structures were located at the upstream ends of the canals to control the flow, and overflow spillways were located along the canals to prevent flooding during high-river flows. Water wheels were originally constructed along the canal to provide power for the mills. Roll mills, used in the processing of black power, were most common in the DuPont yard. These mills were originally powered by a waterwheel placed between each pair of mills, but they were later converted to hydro turbine power. At the Birkenhead Mills, where black powder was once incorporated, a sixteen foot breast wheel has now been restored.

Beginning in the 1840's the water wheels used by the DuPont Company were gradually replaced with more efficient and durable water turbines. Ellwood Morris, a Philadelphia engineer, installed the first turbines in use in the powder yards. By the 1880's turbines had replaced all of the waterwheels in the company's Brandywine Mills.

The New Century Powerhouse

The power potential of the Brandywine continued to intrigue the DuPonts, and in the 1890's the company began construction of a hydroelectric plant which was completed and placed in operation as the nineteenth century came to a close. This powerhouse contained three forty-four inch Rechard turbines and three generators which were capable of producing 150 kilowatts. For a dozen years the electricity from this plant provided power for the mills and nearby residences until the mills closed in 1921.

Mr. DeHeer is Managing Engineer, O'Brien and Gere Engineers, Inc., Philadelphia, Pennsylvania.

In 1957, when the Hagley Museum opened, the only evidence of the hydroelectric plant was the foundation. Solid stone walls, sixteen feet high and two feet thick were still intact. During the summer of 1974, the staff archaeologist and others began to excavate the site, removing the dirt and rubble from inside the foundation.

Plans to reconstruct the New Century Powerhouse were made. The reconstructed powerhouse was to be similar in appearance to the original powerhouse, was to contain an exhibit of the early use of electricity and, if feasible, was to house a small turbine and generator to produce electricity. The growing energy crisis of 1974 prompted the initiation of a feasibility study for enlarging the capacity of the powerhouse to meet the electrical needs of the Foundation. In 1974, the Foundation's annual electrical demand was slightly over one million kilowatt hours, which cost the Foundation about $45,000. The Foundation's demand in 1994 was projected to be about 7 million kilowatt hours costing an estimated $800,000.

One of the first conclusions of the study was that the nine foot fall of water at the Hagley dam, which was adequate for the small power requirements of the early 1900's could not be economically redeveloped, and even if it could, it would not provide a very large part of the Foundation's needs. However, an intriguing variation of the original installation was suggested. A half mile upstream was the Birkenhead Dam, which diverted water into the upper canal, which terminated about 500 feet from the New Century Powerhouse. This canal was originally used to provide water wheels located along the canal. By connecting the upper canal to the powerhouse with a six-foot diameter penstock, the gross head available at the powerhouse would be increased from nine to 28 feet and the capacity of the powerhouse increased sufficiently to supply the requirements of the Foundation until about 1980. After 1980, load growth was recommended to be supplied by the restoration of another powerhouse.

This plan was accepted by the Foundation's board of Trustees, and construction began in October of 1975. An agreement was also made with Delmarva Power & Light Company wherby the New Century Powerhouse would be in parallel operation with the utility to insure an uninterupted power supply to the Foundation, even during periods of low flow in the Brandywine. The Delmarva agreement also stated that when the powerhouse produced more electricity than the Foundation could use, it could be fed into the Delmarva system and the Foundation would receive a credit of about 10 mills per kilowatt hour for this energy.

Since the powerhouse was to resemble an old installation, a search was made for an existing turbine and generator rather than for new equipment. A fifty-four inch Smith-Kaplan turbine and a 300-kilowatt General Electric generator made for the 1932 Winter Olympics in Lake Placid, New York were located in storage in Watertown, New York. This equipment was purchased, the generator was rewound for 500-kilowatt production, and both were installed in the powerhouse. The canal was cleared of sediment and the penstock was installed in a trench excavated out of Brandywine granite.

On October 4, 1976 the powerhouse was placed in service and the Brandywine was again producing electricity for the first time in more than half a century. The cost of the powerhouse reconstruction, installation of the

penstock, trubine and generator and other miscellaneous work connected with the project was slightly over one million dollars, or about $2,000 per installed kilowatt of capacity. Construction took approximately 12 months.

Operational Problems

Initial operation of the powerhouse at the design output of 500 kilowatts was not possible during the first year, even though the flow was available in the canal. The maximum generation possible was about 220 kilowatts due to the fact that pulsating flow would occur in the penstock at this rate. In June of 1977, Justin & Courtney (now part of O'Brien & Gere Engineers, Inc.) was contacted to study the system and recommend improvements to increase the output of the system. The study consisted of a hydraulic analysis of the penstock and canal, evaluation of the conditions at the entrance to the penstock, and an evaluation of the gate structure at the upper end of the canal.

Current meter measurements were made of the velocity in the canal to estimate the discharge in the canal at various power generation rates. These measurements were limited to rather low flows because of the limitation caused by the pulsating flow in the penstock. The purpose of these measurements was to provide data to establish a head-discharge-power relationship for the system. The hydraulic capacity of the canal was estimated to be about 350 cubic feet per second (cfs) which meant that if the hydraulic losses in the penstock were not excessive, the system should be capable of producing 500 kilowatts.

Difficulty was encountered in estimating the head loss in a reinforced concrete box transition constructed between the penstock and the turbine pressure case. Because of the fact that the penstock had to be constructed beneath the lower canal, which is between the upper canal and the powerhouse, the penstock elevation at the powerhouse is about three feet lower than the entrance to the turbine pressure case. This difference in elevation is taken up by the concrete box. The loss in this box was estimated by subtracting the theoretical net head on the unit at various generation rates from the measured gross head between the canal water surface elevation and the tailwater elevation, minus the friction loss in the penstock. Extrapolating the results of these measurements to the capacity of the system was difficult since only a few data points at relatively low discharges were obtained. However, since the hydraulic losses in the box increased so rapidly at higher flows due to the high velocities in the penstock, it was estimated that a maximum output of only about 350 kilowatts could be attained with the existing arrangement. The hydraulic losses in the box created a severe limitation on the operation of the powerhouse.

The source of the hydraulic problem causing the pulsating flow in the penstock was determined to be the configuration of the penstock entrance. Due to the restrictions of topography, the penstock invert at the upstream end was about six feet below the upper canal invert. This drop restricted the amount of flow which could enter the penstock and created a condition of partial flow in the upper end of the penstock and the formation of a hydraulic jump inside the pipe. The entrained air in the pipe would accumulate into

large bubbles and periodically blow back mud and water with terrific force.

The solution to the problem was to slope the canal for a distance of about 150 feet upstream of the penstock to provide a hydraulically smooth transition between the canal and the penstock. This was a rather touchy operation because the excavation had to be accomplished by blasting the Brandywine granite rock immediately adjacent to the masonry canal walls. This work was successfully completed in the winter of 1978 and resulted in an increase in the output capacity of the powerhouse to 350 kilowatts.

Further studies were made on the effect of the upper gate structure on the flow into the canal. Records of daily flow in the Brandywine river at the USGS gage located near Birkenhead dam were used to develop a flow-duration curve. These records showed that the average flow in the Brandywine river at this location is 430 cfs, which is about 1.4 cfs per square mile. According to an agreement between the Hagley Foundation and the State of Delaware, the flow in the Brandywine cannot be reduced to less than 100 cfs by diversion into the canals. Therefore, flow in the Brandywine river must be at least 450 cfs in order to operate the powerhouse at capacity. This discharge is equalled or exceeded about 37 percent of the time, based on the records.

The upstream gate structure near the Birkenhead dam is a concrete structure approximately 10 feet high by 25 feet wide with four 42 inch diameter gated openings in the bottom of the structure. This structure has a considerable effect on the flow in the canal. In order to obtain the required head on the gate structure to produce a flow of 350 cfs in the canal, a discharge of over 2,000 cfs would be required in the Brandywine river. This flow usually occurs only a couple of days a year. It was estimated that the installation of a new structure with gate openings 50% larger than those in the existing structure would increase the energy output by about 180,000 kWh per year. This would result in a savings in energy cost of over $7,000 a year at present rates. With an increase in cost of 6% per year, the annual savings in energy cost would exceed the annual cost of the improvement in about 7 years. It is anticipated that this structure will be constructed within the next few years.

Plans are presently being made to improve the hydraulic efficiency of the entrance to the turbine pressure case by construction of a smooth transition section between the penstock and the turbine pressure case. This work should begin in a few weeks. When all of the work is completed, it is expected that the maximum practical efficiency of this hydroelectric system will be reached.

REFERENCES

The Hagley Museum Guide, published by the Eleutherian Mills - Hagley Foundation Inc.

Eleutherian Mills - Hagley Foundation 1976 Annual Report.

IDAHO FALLS LOW-HEAD HYDROELECTRIC DEMONSTRATION PROJECT

Pablo Chavez

Mr. Chairman, Ladies and Gentlemen, I am very glad to be here to have the opportunity to participate in this very important conference. We at IECO are excited about a project on which we have been working for the past three years. This project is the Idaho Falls Low-Head Hydroelectric Demonstration Project.

The Idaho Falls Project consists of the redevelopment of three existing run-of-river power plants and associated diversion dams on the Snake River near Idaho Falls in Eastern Idaho, using bulb turbine-generators. The gross head at each of the plants is approximately twenty feet. All three plants are owned and operated by the city of Idaho Falls. Under a cooperative agreement signed in January, 1978, by the United States Department of Energy (DOE) and the city of Idaho Falls, DOE agreed to participate and assist in the project. It is a principal feature of DOE's national Low-Head Hydroelectric Demonstration Program. The objectives of this demonstration project are: 1) for the city to increase energy generation at their three hydroelectric plants and, 2) for DOE to obtain detailed information on an existing technology that may have applicability to the development of the nation's low-head hydro reserves. Financing available for the project consists of $48 million of revenue bonds authorized by the city and $7.3 million obligated by DOE.

The most unique thing about this project is that small bulb units were selected for installation at these sites. The first project in the United States where bulb units have been installed is the Rock Island Project on the Columbia River near Wenatchee, Washington. The eight units at Rock Island are the largest in the world at 54 MW each. The Idaho Falls Project where we expect the first unit to go on line in December 1981, may very well be the second installation in the United States using bulb units. The three Idaho Falls units will be 8 MW each.

This type of turbine is essentially an axial (or horizontal) turbine. The unit is arranged in a horizontal water passage with the axis of the turbine coaxial with the water passage. The runner and the generator are enclosed within the water passage. The name is derived from the steel capsule (or bulb) that encloses the generator. The reliability of bulb units has been well demonstrated in Europe. Under appropriate conditions the application of bulb turbine-generator technology is an economically viable and environmentally acceptable means of developing new sites, or upgrading existing hydroelectric facilities to increase their energy projection. This technology can be applied immediately without prior research and development.

The city of Idaho Falls has operated a municipal electric utility system since 1901 and is a typical small municipal energy producer and distributor.

Mr. Chavez is the Project Manager, Idaho Falls Hydroelectric Project, Idaho Falls, Idaho.

The city's generation system comprises three hydroelectric plants, which together supply about 5% of the city's energy requirements. The city purchases energy to meet the remainder of its requirements from the Bonneville Power Administration. Idaho Falls is currently experiencing rapid load growth (more than 7% per year) in its service area, as a result of significant population increases and increasing commercial development in the area. Energy deficits are anticipated, starting in 1983, because of Bonneville Power Administration's forecasted inability to provide energy for load growth beyond that date (See Figure K-3.1).

The city has considered a number of alternatives for obtaining the energy required to meet this load growth and found upgrading of its three hydroelectric plants to be the most attractive alternative. These plants, built between 1913 and 1946, are not quite deteriorated and inefficient. The Upper Plant has been demolished and removed. At the City Plant, one of the four existing machines is out of service, and all the concrete structures are in need of immediate replacement. The Lower Plant is back in operation following a 10-month shutdown, during which certain facilities destroyed during the flood that followed the failure of the Teton Dam in June 1976 were replaced.

To determine the feasibility of upgrading these three plants, the City retained IECO in 1976-77 to study several possible alternatives for rehabilitating each site. The studies showed that:

- Rehabilitation and upgrading of the three existing plants are technically and economically feasible.
- Bulb turbine-generators are the most favorable units for the low-head, high-flow-rate, run-of-river conditions at the three sites.
- The use of bulb turbine-generators, combined with improved utilization of the available streamflows, will increase energy production about threefold over the amount generated by the existing plants.
- The estimated energy cost is 21 mills per kilowatt-hour, which is substantially lower than the cost of new thermally generated energy.

Bulb units were selected for the Idaho Falls installations based on comparison with vertical Kaplan turbines. This comparison (K-3.2, K-3.3) which was based on the same rated output, efficiencies, and head, showed that at the Idaho Falls sites, the bulb turbine has numerous advantages over the Kaplan. Layouts of powerhouses at one of the sites for both types of machines showed that a savings of more than 40 percent in the cost of the civil works would result. The main economic advantage of using bulb turbines at Idaho Falls, therefore, is the large savings possible in the initial construction costs.

An application for licensing of the three plants was filed with Federal Energy Regulatory Commission (FERC), on 5 July 1978. The license for the proposed Idaho Falls Hydroelectric Project (FERC Project No. 2842) was issued in February, 1979 by the Commission. Environmental baseline studies and technical assistance for the preparation of the application were furnished

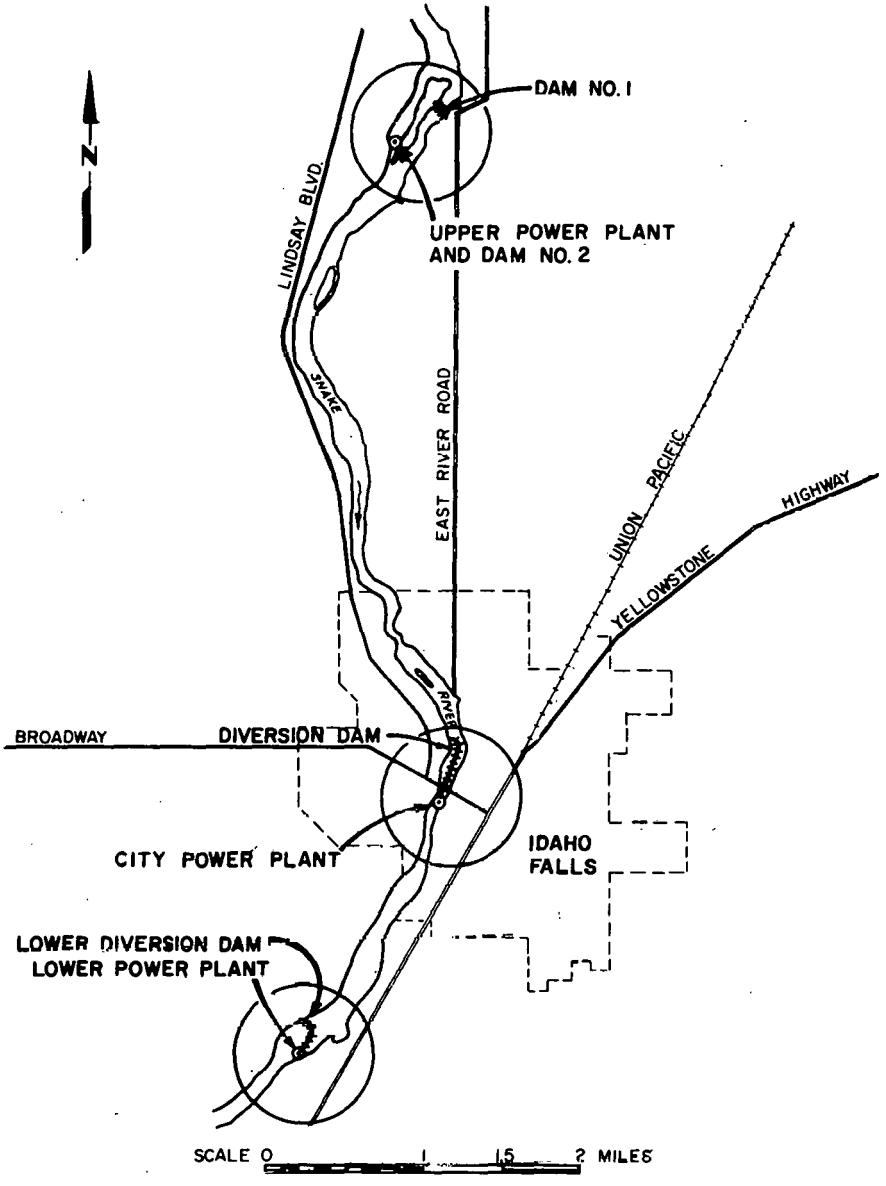


FIGURE K-3.1 Location Map

to the city by IECO. The Project will not significantly affect the quality of the environment for the following reasons:

- The sites of the proposed action are the sites of the existing power plants.
- Operation of the plants will not consume any water or change downstream water levels or streamflows in the river.
- Water quality is not expected to be altered.
- The plants will have no significant effect on the fishery.
- No significant loss of habitat important to existing wildlife is expected to occur.
- No significant impact will occur to protected rare or endangered species as a result of the proposed action.

In determining the unit size for final turbine and generator specifications, we considered the following factors: water availability; site interrelationships and system operation; estimated costs provided by manufacturers for furnishing and installing the units; the value of benefits established for the project; unit efficiencies determined from typical model curves; and estimated construction costs.

Monthly streamflow data for the Snake River at Idaho Falls obtained from the Idaho Department of Water Resources were used in the studies. The flow-duration curve for these streamflow data are presented on (Figure K-3.4). These streamflows were the basis for the power estimate and represent 45 years of record from water year 1928 through water year 1972, adjusted to 1975 upstream development conditions. These flows can be considered representative of long-term conditions since both wet and dry periods are included. The average annual energy estimated in this manner reflects what can be expected, but not guaranteed, in the future.

Four sizes of units were selected by judgment as probably covering the range within which the optimum size would fall, namely units with flow capacities of 5000, 6000, 7000, and 8000 cfs, respectively. The flow-duration curve and Figure K-3.5 show the availability of these flows at each of the three Idaho Falls plants. This means, for example, that if a unit capable of passing only 5000 cubic feet per second were installed, it would utilize for power generation all water passing down the river 55% of the time; for 45% of the time the flow would exceed the unit capacity, and the excess would pass over the spillway, wasted as far as energy is concerned. For a substantially larger investment, a unit capable of passing 8000 cfs could be installed, reducing the period of wastage over the spillway to 17% of the time. The objective was to study the tradeoff between increasing capital investment and decreasing spillage (energy waste) to determine the economic installation.

Tailwater rating curves for each of the 3 plants were prepared as input for the operation studies for use in determining the hydraulic head available for power generation Figure K-3.6. Power operation studies were performed for plants with 5000, 6000, 7000 amd 8000 cfs installations, respectively, to determine their average annual generation in kilowatt-hours. In making these studies the following criteria were observed:

ITEM	UNIT	KAPLAN TURBINE QUANTITY	BULB TURBINE QUANTITY
ROCK EXCAVATION	CY	16,500	8800
CONCRETE	CY	10,200	5000
REINFORCEMENT	TON	510	250

FIGURE K-3.2 Kaplan Turbine and Bulb Turbine Quantity

ITEM	UNIT COST	KAPLAN TURBINE TOTAL COST $	BULB TURBINE TOTAL COST $
ROCK EXCAVATION	12	198,000	105,600
CONCRETE	20	1,224,000	600,000
REINFORCEMENT	1000	510,000	250,000
SUBTOTAL		1,832,000	955,600
CONTINGENCIES (20%)		366,400	191,100
TOTAL CONSTRUCTION COST		2,198,400	1,146,700
SAVINGS (EQUALS DIFFERENCE)		2,198,400 -1,146,700 1,051,700	

FIGURE K-3.3 Kaplan Turbine and Bulb Turbine Cost

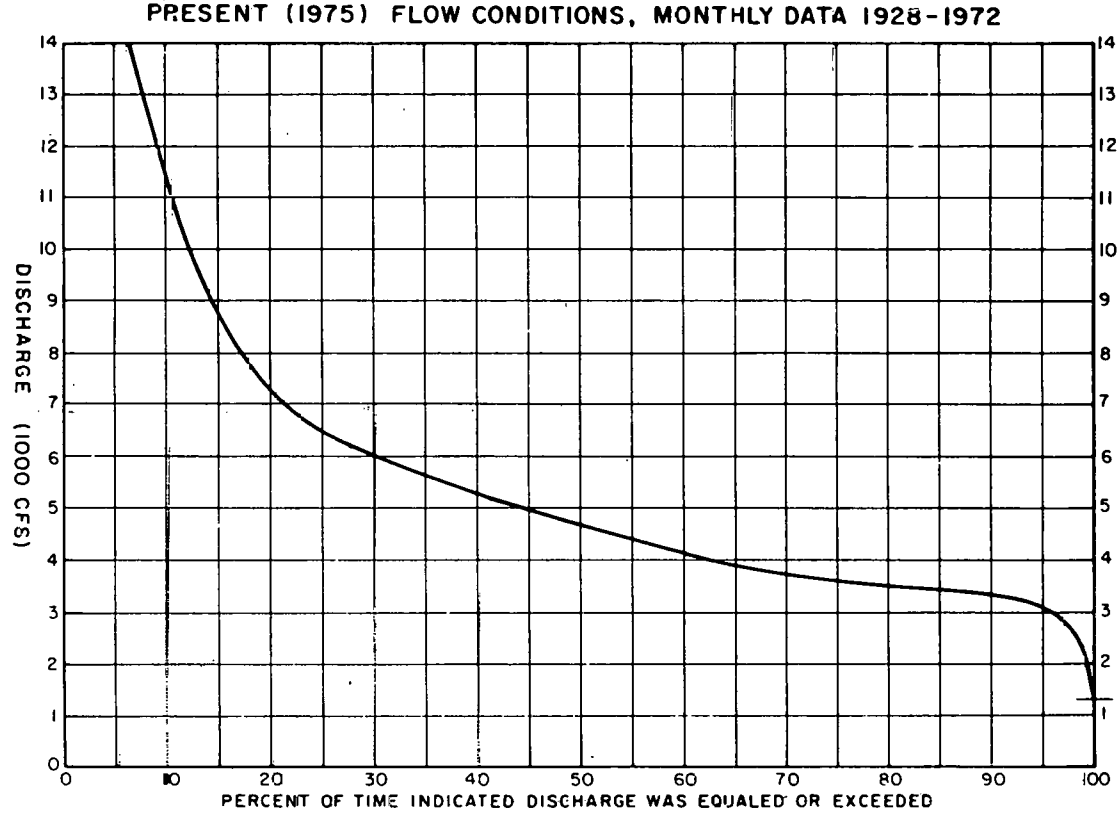


FIGURE K-3.4 Snake River Near Idaho Falls - Flow Duration Curve

- The plants will operate as run-of-river plants and will utilize water only as it comes to them from upstream lakes and reservoirs.
- The plants will operate as baseload plants.
- The operation study was on a monthly basis, based on average monthly streamflow data.
- At the Upper Plant, fish water requirements were assumed to be 100 cfs. Streamflows available for power generations were reduced accordingly.
- The minimum net head for power generation is 13 feet.
- The minimum river discharge for power generation is 1600 cfs.

The results of the operation studies are shown on Figure K-3.7.

The head developed at each site (Figure K-3.8) is dictated by existing topographic conditions. In each case, low diversion dams will divert flows to the power plants and maintain the desired water levels upstream from the plants. The proposed headwater at the Lower Plant will reach the tailwater of the City Plant, approximately 2 miles upstream. However, the upper pool of the City Plant will not affect the tailwater of the Upper Plant, 4 miles upstream from the City Plant. The flows at the three plants are essentially equal most of the year.

The equipment costs for the Idaho Falls installations, as with any lowhead hydroelectric project, will be a high percentage of the total project cost. The estimated prices received from five manufacturers (in April 1978) were adjusted for rate of exchange, transportation to the jobsite, customs duty, and installation. To minimize possible inaccuracies, the prices were averaged.

Bids for the equipment were received from manufacturers located in Europe, Japan, and the United States. Therefore, the future value of the dollar in foreign exchange was a factor in the bidding. No special provisions for this contingency were made in the Idaho Falls studies. Estimated costs used in this study are based on the rate of exchange existing in April 1978, when they were received from manufacturers. Bids were received in U.S. dollars.
to determine total annual energy were based on data furnished by eight bulb turbine generator manufacturers in their prequalification proposals. An average efficiency curve was used at the three plants for each size unit. This method provided a minimum acceptable unit efficiency which is a conservative estimate for determining total energy output. (Figure K-3.9).

Cost estimates were developed for plants with alternative size units. All costs were then reduced to the annual cost of ownership and operation. The unit cost of energy was estimated based on the estimated average annual energy generation at each plant. The estimated project costs, and benefits for the four alternatives investigated are shown on Figures K-3.10, K-3.11 and K-3.12.

Estimated energy benefits are based on the cost of providing equivalent energy by the most economical alternative means. A value of 30 mills per kWh was used. This value furnished by the Idaho Falls Electric Division, represents the present cost of alternative source energy.

To ensure that the total investment required for the project is consistent with the funds available for the project, escalation throughout the planned

FLOW (cfs)	PERCENT OF TIME FLOW IS EQUALED OR EXCEEDED
5000	45
6000	30
7000	21
8000	17

FIGURE K-3.5 Availability of Flow

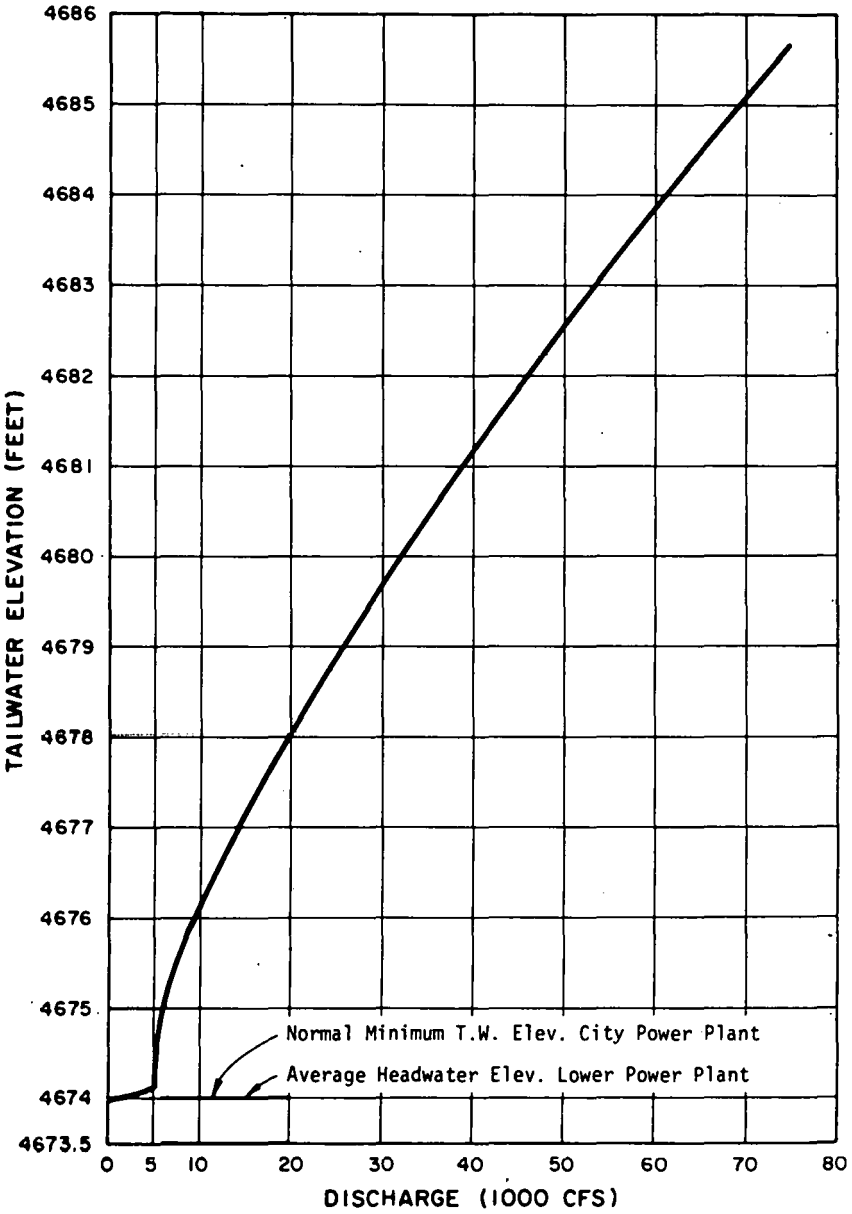


FIGURE K-3.6 City Power plant - Tailwater Rating Curve

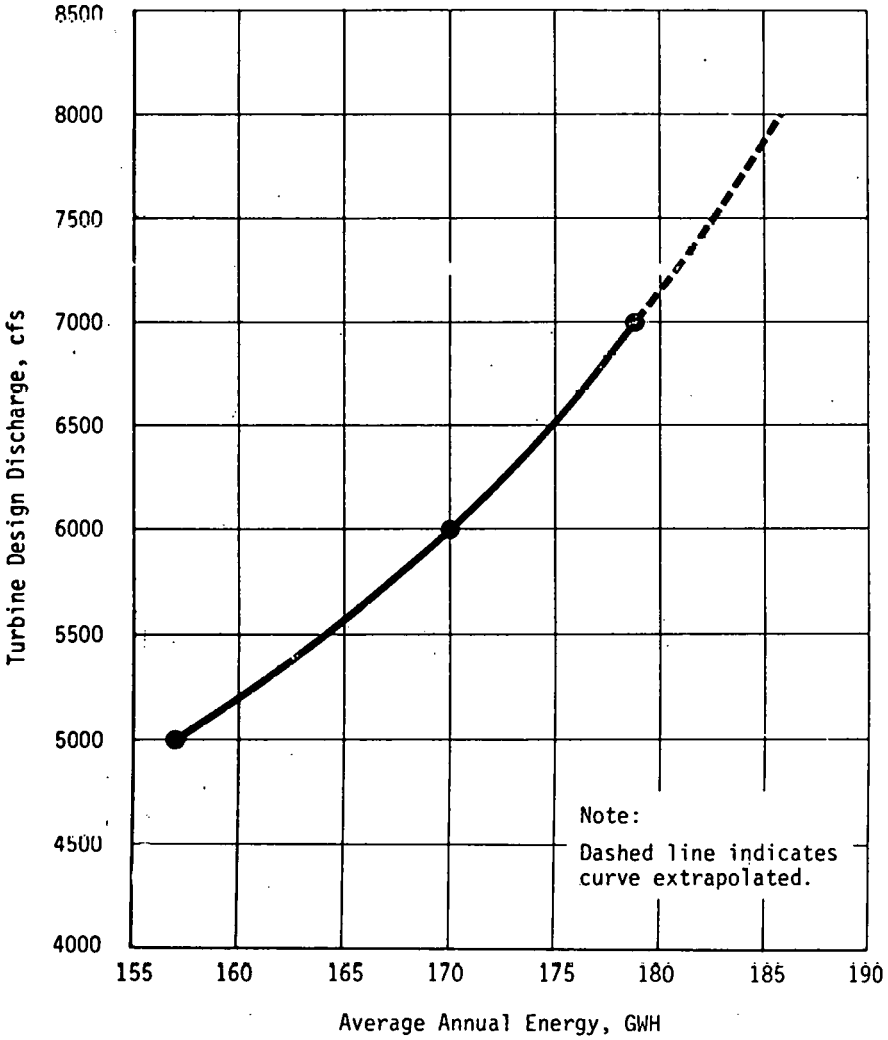


FIGURE K-3.7 Average Annual Energy

ITEM	UPPER PLANT	CITY PLANT	LOWER PLANT
AVERAGE HEADWATER ELEVATION FT.	4734.0	4694.25	4674.0
AVERAGE TAILWATER ELEVATION FT. (Q = 4700 cfs)	4713.5	4674.10	4653.6
GROSS HEAD (FT)	20.5	20.1	20.4

FIGURE K-3.8 Head Developed at Each Site

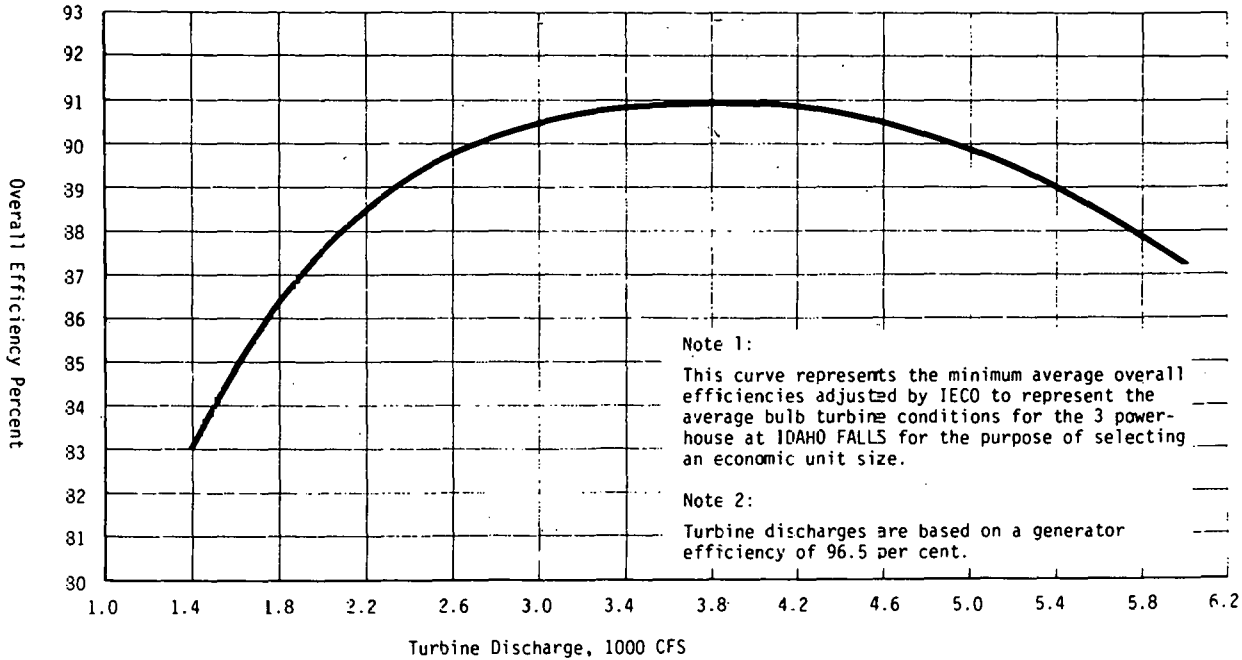


FIGURE K-3.9 Overall Turbine-Generator Efficiency in Percent vs. Turbine Discharge in CFS (Head Varies) Nominal 6000 CFS Units

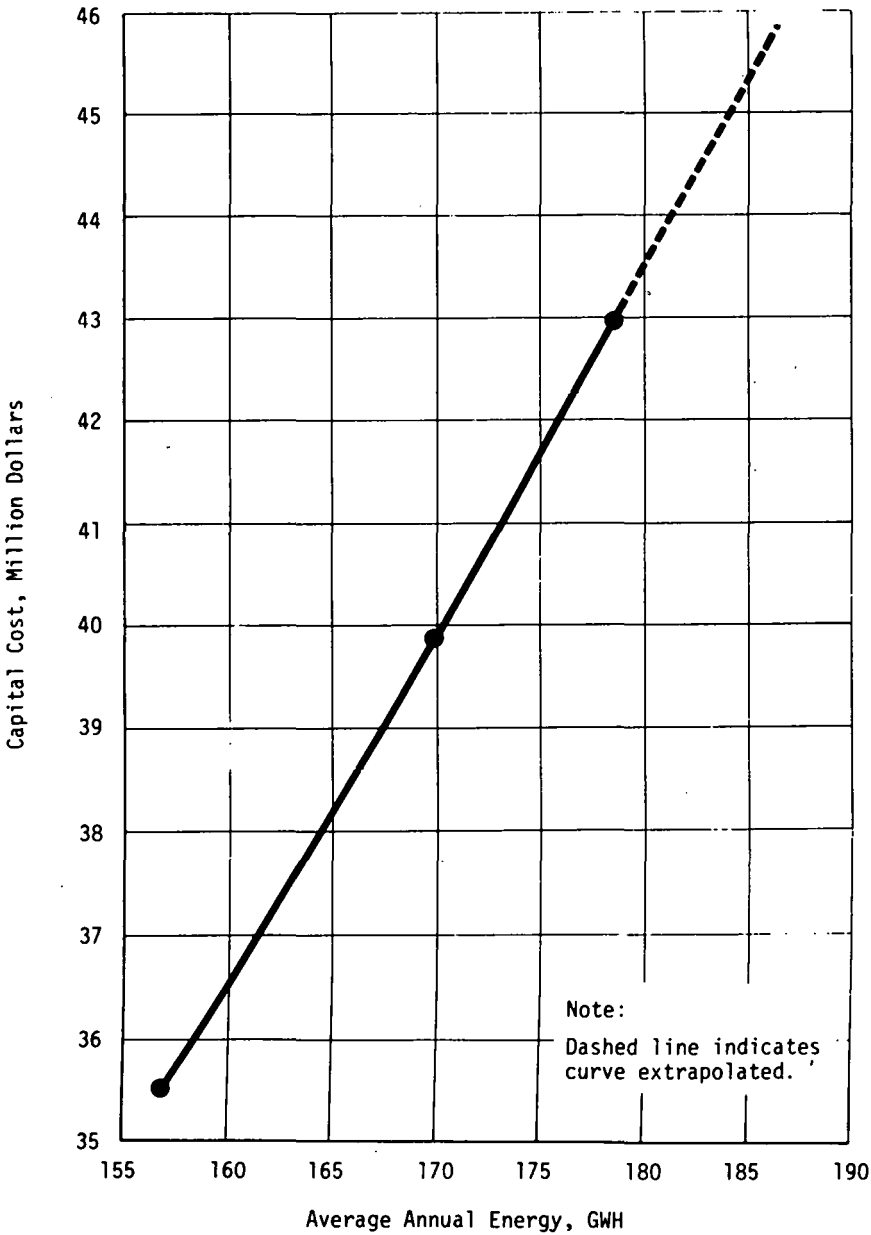


FIGURE K-3.10 Capital Cost

construction period and the effects of possible delays were considered. The amount of revenue bonds authorized is $48 million. When the DOE contribution of $7.3 million is added, this financing covers an estimated $38.2 million capital cost in 1978 dollars plus 10% escalation per year thereafter and contingency of a 2-year delay in the start of construction, Figure K-3.13.

Comparison of the annual benefits and annual costs permitted selection of the economic installation—that is, the one that will maximize the net benefits (excess of annual benefits over annual costs). The criteria selected for the comparison are:

- Any benefits that may be derived from the existing units at the Lower Plant are not included in the economic analysis.
- The economic analysis is based on annual benefits and annual costs for the three plants operating as one system.
- The economic installed capacity is the one that will give the maximum benefits-minus-costs.
- The benefit-to-cost ratio shall be greater than one.
- The total investment shall be consistent with the amount of revenue bonds authorized by the voters and DOE's contribution, considering the possible escalation due to delays.

The estimated benefits minus costs for the four alternatives investigated are shown on Figure K-3.14.

Selection of the optimum unit size is very sensitive to both project costs and the value assigned to the energy benefits. Figure K-3.14 shows the relationship between annual net benefits (at 30 mills per kWh for the energy benefits) and average annual energy generation for the three plants operating as a system. Although the curve is very flat, it does show that maximum net benefits will be obtained at an average annual energy generation of 170 GWh (million kilowatt-hours). This generation level corresponds to a unit size of 8.0 MW (6000 cfs discharge capacity), which is the most favorable unit size. (Figures K-3.7 and .15). With units of this size, the total estimated capital investment required for the project will be $39.9 million, (1978 dollars) and the energy cost will be 21 mills per kWh.

After establishing 8.0 MW as the most favorable unit size, we considered a slightly larger unit size of 8.4 MW, at an incremental energy cost of 30 mills per kWh for the additional energy produced by these units. With 8.4-MW units, the three plants, operating as a system, would generate an additional 2 GWh of energy a year at an additional cost of 30 mills per kWh. The total estimated capital investment required for the project with units of this size is $40.6 million (1978 dollars).

As shown on Figure K-3.14, if average annual energy is increased beyond 170 GWh, each dollar of costs will return less than a dollar of benefits. The reason for this is that the substantially higher costs associated with larger units, to obtain increasingly smaller increments of additional energy, are not justified on the basis of net benefits. Thus, the additional capital investment required for 8.4-MW units (172 GWh average annual energy) would be justified only if alternative source energy would be displaced early in the life of the project. However, alternative source energy will probably not be required at Idaho Falls for at least 10 to 15 years after the completion of project

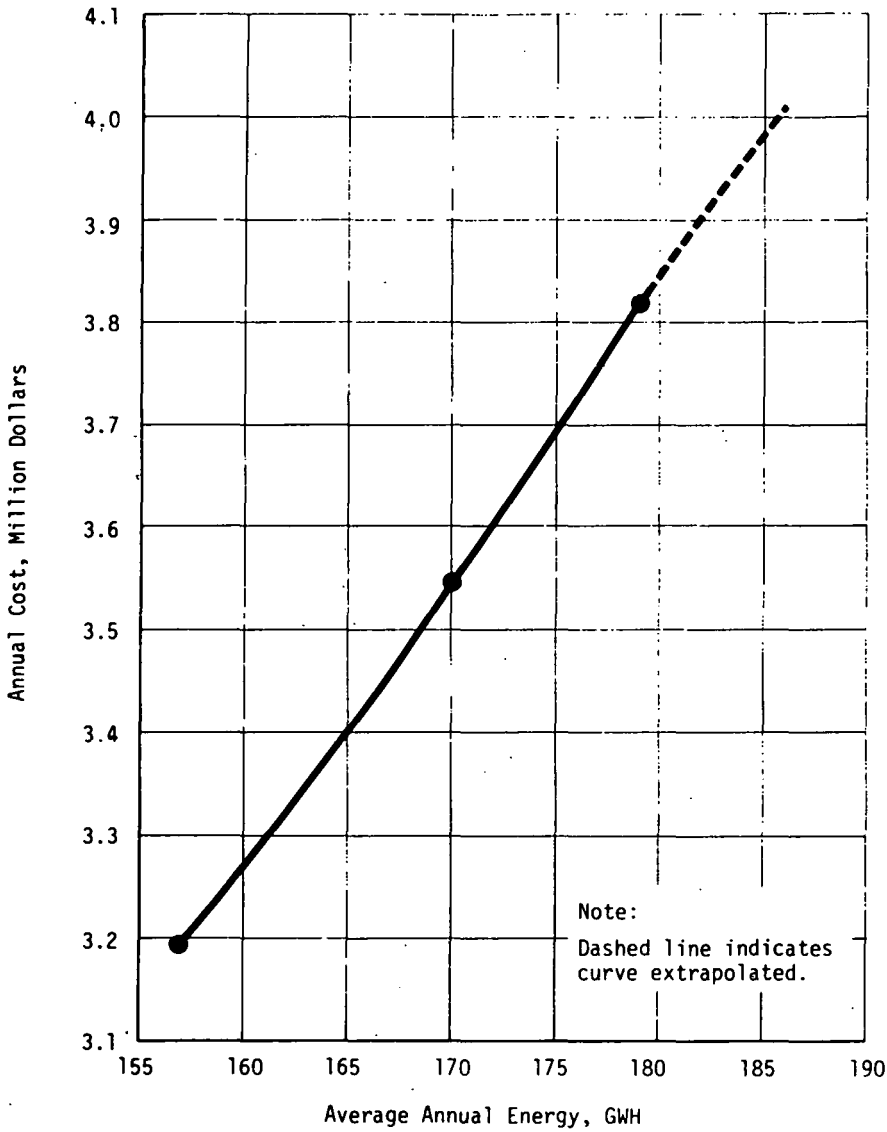


FIGURE K-3.11 Annual Cost

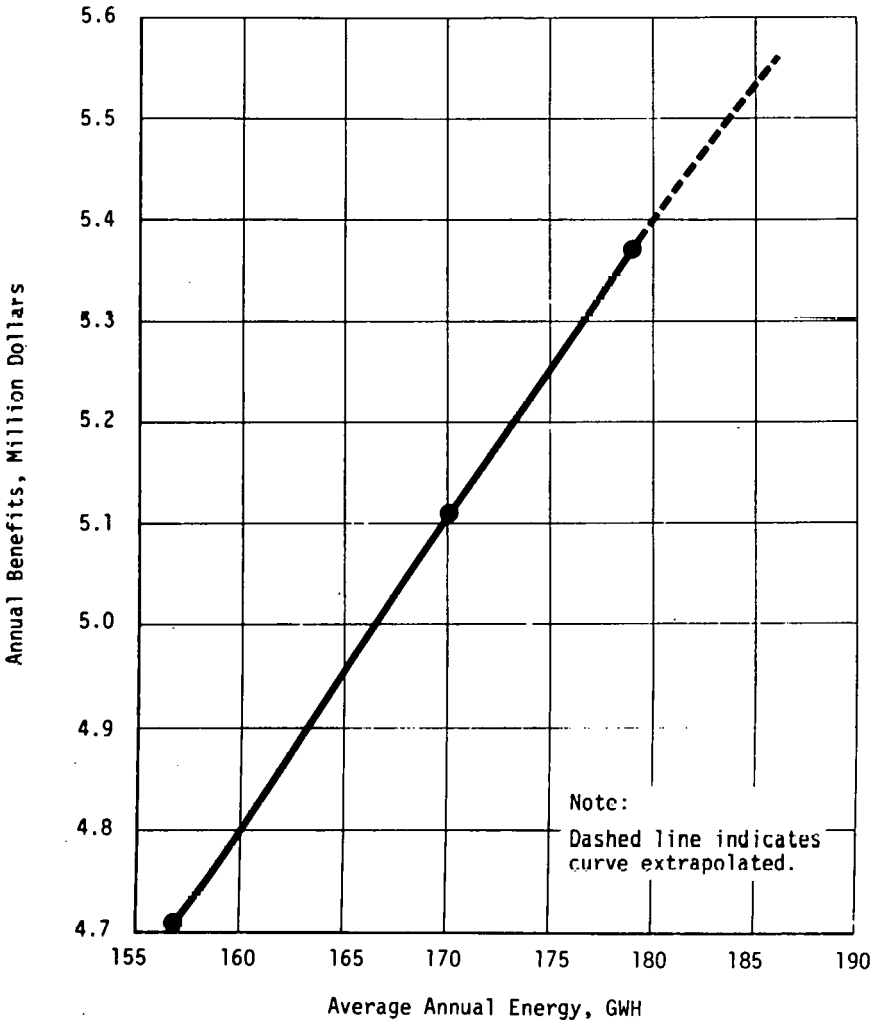


FIGURE K-3.12 Annual Benefits

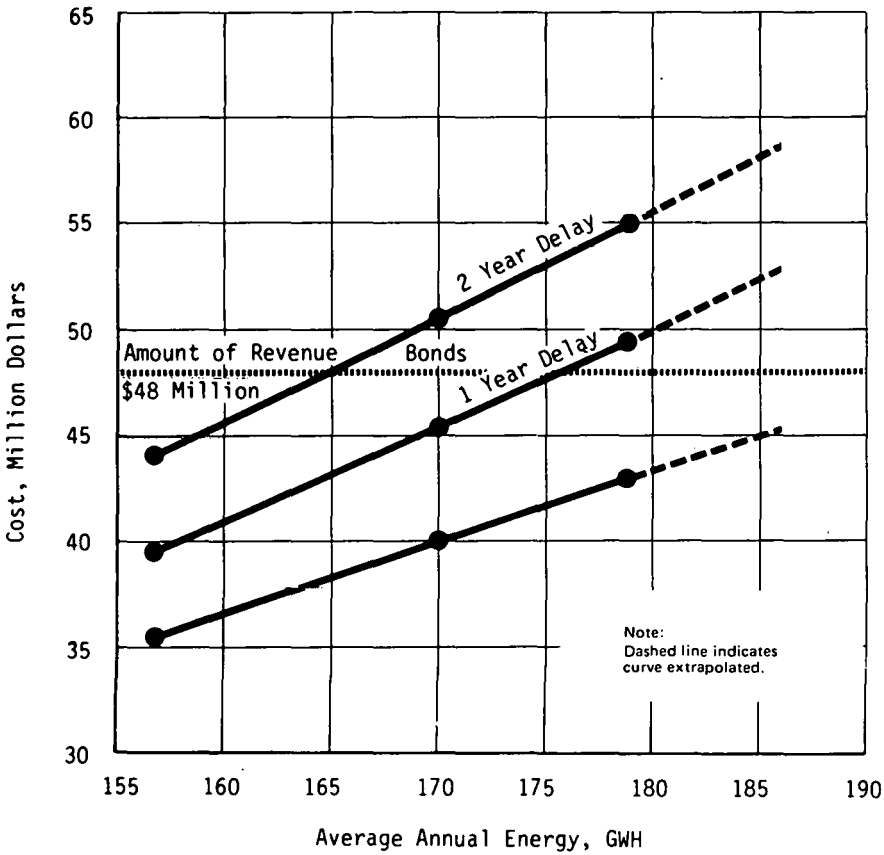


FIGURE K-3.13 Cost to the Owner

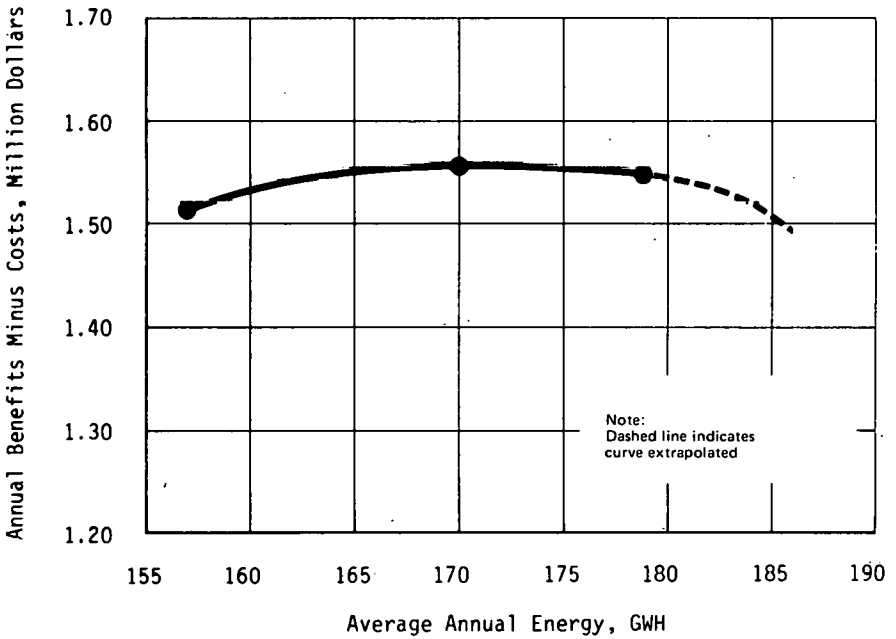


FIGURE K-3.14 Annual Benefits Minus Costs

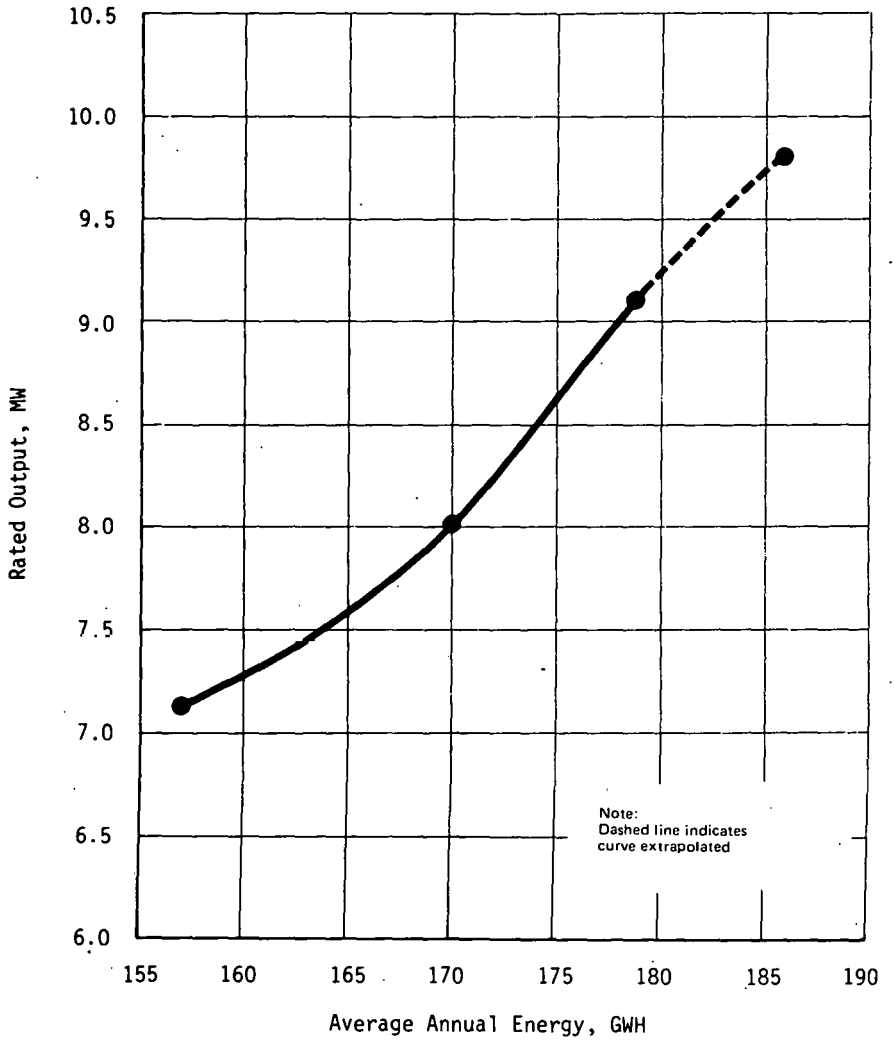


FIGURE K-3.15 Average Annual Energy

construction. Therefore, the optimum unit size of 8.0 MW was selected for the Idaho Falls Hydroelectric Project. With units of this size, the project can be constructed within the funds available from both the authorized revenue bonds and the Department of Energy, provided delays during construction do not exceed about 1 year. (Normally, 2 to 3 years' contingency is recommended).

In closing I would like to acknowledge the guidance and support of the City of Idaho Falls through its Power Committee (of the City Council), Mr. Steve Harrison, Manager of the Idaho Falls Electric Division and Mr. Jeff Paine, Chief Electrical Engineer.

Session Fifteen

PLANNING, INFORMATION AND METHODS

Topic: Social and Environmental Analyses II

Chairman: Dr. Allan Hirsch
- Director, Office of Biological Services
U.S. Fish and Wildlife Service
Department of the Interior
Washington, D.C. 20240

TAPPING THE BOUNDLESS RESOURCE TO SOLVE ENERGY PROBLEMS

Roger E. Hamlin

Introduction

In a era of energy and resource shortages, society seeks a resource which is highly renewable. One resource can most nearly be called the boundless resource. Not only is this resource easily accessible, but it is waiting to be tapped. It is the human resource.

Human effort is called boundless because, instead of depleting with consumption, it improves when appropriately utilized and perishes when underutilized. When individuals are properly employed, they apply their mental capacities, gain experience and learn new skills. Human effort is called perishable because, if an individual spends one week unemployed or underemployed, that man-week of work, expertise and training can never be recaptured.

Despite the nature and existence of the boundless resource, millions of individuals remain unemployed, while countless others are only employed part time and are seeking full-time employment. Still others are fully employed in jobs which are below their ability. At this time of resource shortages, the physical and mental energies of the boundless resource must be more fully employed.

We are now entering a period of stagflation, or a situation in which high unemployment and rapid inflation occur simultaneously. This economic phenomenon is relatively new in the United States and is primarily a product of resource shortages. When inflation was predominately demand-driven, inflation and high unemployment occurred at opposite ends of the business cycle. But now that a major component of inflation is the increased cost of scarce energy and raw materials, inflation and unemployment are driven by the same forces. Not only can they operate simultaneously, but they exacerbate one another.

One multi-dimensional solution to the nation's domestic problems, therefore, is to pursue projects which lower the cost of energy while employing and training unemployed individuals. One such project idea which can offer a small but meaningful contribution to the solution of the problem discussed above is to employ and train unemployed individuals in the retrofitting of abandoned small-scale hydroelectric facilities.

As many are discovering, the task of small hydro rehabilitation is a difficult one involving labor problems, licensing problems and other legal problems, special engineering issues and difficulties in finding suitable equipment. At the same time, any effort to employ and train unemployed individuals is more

---

Dr. Hamlin is an associate professor of Urban Planning at Michigan State University, and also Vice President of Proaction Institute, where he is directing the Youth and Energy Project.

difficult than first appears. The interfacing of these two problem sets makes for a complicated endeavor.

The purpose of this paper is to describe the problems and potentials for the rehabilitation of small hydroelectric facilities while promoting the utilization of the boundless resource. The first part of the paper discusses the background and history of both relevant problems with emphasis on how unemployment and small hydro potential are geographically and economically related. Part two provides a how-to-do-it approach to project implementation.

Background: The Relationship of Hydropower Potential and Unemployment

The history and background of hydropower should be well known by individuals attending Waterpower '79. The nature and scope of unemployment and the geographic relationship between unemployment and small hydro may not be so familiar. Unemployment in the United States is approximately 6 percent, and minority youth unemployment is over 30 percent. In past decades, unemployment in the United States has been a cyclical phenomenon resulting from the temporary need to reduce excess business inventories by laying off workers. A certain percentage of difficult-to-employ individuals were always on the employment service roles, but high levels of unemployment were succeeded by economic upturns resulting from increased economic activity.

Although business cycles clearly continue to exist, unemployment is taking on new dimensions. In the two business cycles of this decade, unemployment has remained relatively high even during economic peaks. This phenomenon is not totally understood, but it appears to be caused in part by the entrance of the second breadwinner into the labor market and technological changes which displace workers. Constant high unemployment has created a large pool of chronically unemployed, and this group is not equally distributed across the population. Rather, the chronically unemployed are more concentrated in certain geographic areas, age groups and ethnic groups. Unemployment has increasingly become a structural problem rather than a cyclical one.

Geographically, low worker mobility and the changing industrial structure have caused unemployment to rise and become more fluctuating in the industrial Northeast and Great Lakes area. The Northeast and Great Lakes suffer because of labor problems, taxes and increased energy costs. The malady of the old industrial zone is not uniform either; it tends to be worse in medium-sized older cities and some rural pocket areas. Because of the history of small-dam development, these older mill towns and rural backwaters are often the location of small dams with hydropower potential.

How To Combine Hydropower and Employment Stimulation

The next question to be answered is how does one go about employing unemployed individuals in a small-scale hydropower redevelopment project.

Two basic issues to be addressed are (1) expertise and (2) funding. This section addressed these two issues.

Expertise

The issue of expertise is the most difficult. Dams are not uncomplicated entities and are occasionally dangerous. The inherent danger applies not only to the people working on the dam, but also to the people downstream who might suffer from any damage to the dam. Expertise is a problem at two levels, engineering and craftsmanship. Clearly both are badly needed. How does this need for expertise relate to the notion of employing unemployed individuals? There are several different kinds of unemployed individuals, some of whom are highly skilled in many of the trades. Finding unemployed engineers may not be a significant possibility, but employing and training people as draftsmen and research aids to take water and soil samples may be possible.

A primary strategy in designing any such community improvement employment project is to estimate the strata of technical skills required for each job. Then, determine the strata of skills that exist among unemployed and underemployed individuals in the community. Finally, evaluate the capacity of the project to provide training necessary to bring individual skills up to needed levels. This capacity is a function of the general preparation of the unemployed individuals, the capacity to find trainers, and the time required for training. Clearly all aspects of the job on a dam cannot be done by unemployed individuals, but such individuals in combination with skilled craftsmen who provide on-the-job training can, by themselves, complete much of the work.

A major problem associated with unemployment individuals, given the type of unemployment we suffer today, is that many are not accustomed to the world of work. Their lack of skill not only includes the specific skills required to complete the tasks, but it includes what are often labeled "employability skills." These skills involve such things as getting along with peers and supervisors, work regularity, and following instructions. One of the best ways to promote the development of employability skills is through a form of supervised work experience where individuals are given a job which is meaningful and real, but of fairly low skill. In this job the individual would concentrate on the development of work habits with the guidance of the work supervisor and a work experience counselor. Such a work experience program can be integrated into a dam rehabilitation project by having individuals spend several weeks in low-skill activities such as site clean up prior to entry into an intensive on-the-job training program coupled with actual work on the dam.

A second major problem associated with the employment of unemployed individuals is that many such individuals lack fundamental language and computational skills necessary not only for successful work on the site, but also for successful training. Several solutions exist for this problem. One is to have pre-project basic skills training. A second is not only to have basic skill development included into other training, but to design task instructions so as

to teach reading, counting, and measuring on the job. No matter what the skill level of project participants, work specifications must be written in a language which is simpler than normal.

Funding

The second major issue in attempting to employ unemployed individuals in a small-scale hydro redevelopment project is funding. The major source of funding which relates is the Comprehensive Employment and Training Act. The Comprehensive Employment and Training Act is a Federal program originally adopted as one of the special revenue sharing packages of the Nixon revenue sharing program. It distributes money on a formula basis to local agencies called prime sponsors.

The most visible component of the original CETA act is called public service employment. This provision is mainly a revenue and job supplement to local governments. A less visible but increasingly more important part of the Act is the provision of training and other services which prepare people for work. These services include classroom training, on-the-job training, career counseling and guidance, necessary health services and employability skills development. The purpose of these services is to take an individual who is difficult to employ in the private sector and prepare him/her for entry into private sector employment. Often community improvement activities are encouraged as a way of providing employment and on-the-job training. Some monies are available not only for employing eligible individuals, but also for training costs, and purchase of materials and equipment.

A paticularly good example of this type of funding is the Youth Community Conservation and Improvement Project (YCCIP) section of Title IV, "Youth Programs." This section, which was originally adopted as part of the Youth Employment and Demonstration Projects Act of 1977, especially encourages the use of CETA funds for community improvement projects. Youth and appropriate supervisory personnel can be employed for such projects as the rehabilitation of public facilities (including school buildings), neighborhood improvements, weatherization and basic repairs to low-income housing, energy conservation (including solar energy techniques), barrier-free and natural resource improvements. Repair of municipally-owned dams is an eligible community improvement activity. Applications from organizations, agencies and institutions interested in providing jobs for youth through the program must be submitted to and approved by the local prime sponsor. In applying for funds under this subpart, project applicants describe the work they are proposing, the jobs to be filled, the duration (no job may last longer than 12 months) and the wages or salaries to be paid. Applicants must assure the Department of Labor that an adequate number of supervisory personnel, who are trained in the skills needed to instruct the youth will be available. The project should be labor intensive to the maximum extent possible.

The Community Development Act can also be a major source of funds for a variety of projects within a community, but of the eight titles contained in the Act, only two appear relevant to dam renovation, Title I, Community Development Block Grants and Title VIII, Miscellaneous Grants. The Com-

munity Development Block Grant Program provides funds for community development, innovative projects, and discretionary grants. Funds are distributed to qualifying units of government on a formula basis. Application procedures include the submission of a community development plan. Community development funds are to be used for a variety of purposes and a community's allocation is normally divided among several projects. Although a hydropower redevelopment project can obtain financial assistance in this way, community development funds should be viewed as a portion of the project's financing plan and not as a sole source. A small amount of community development money used to buy materials and equipment may leverage a very large amount of the labor money described above.

Innovative projects money is allocated on a competitive basis. The grant program is designed to strengthen local governments by developing, through individual demonstration projects, innovative approaches to the solution of longstanding or widespread urban problems. Categories of funding applicable to a hydropower project include training and manpower development. The innovative use of education and vocational training through coordination of manpower and training funds to promote neighborhood preservation, or the rehabilitation of public facilities is one approach. The availability of these funds is largely dependent on annual funding appropriations, program objectives, and the quality of competing applications.

The Economic Development Administration (EDA) has a public works program that could apply to retrofitting dam sites. There are two critical prerequisites for eligibility in the program. The applicant must have an approved economic development plan before applying for Title I assistance; and the connection between the proposed project and the creation or preservation of jobs in the community must be well documented. Carefully planned dam projects have qualified. For example, if a dam deteriorated to the point where a reservoir was lost, the loss could destroy tourism and related commercial activity that had developed around the reservoir. Saving the dam would thus preserve existing jobs and eliminate a safety hazard. Communities may be able to develop other linkages following the requirement and there may be a connection between the project and private sector jobs.

Funds for the public works program are somewhat limited. A 1979 budget of $26 million was appropriated for the seven state Chicago Region. Project grants can cover 50-80 percent of the project budget. To be eligible for 1979 assistance, an overall economic development plan must have been submitted by June 30, 1978. The 1980 fiscal year started October 1, 1979 and funds are distributed throughout the year. If the project in question is not included in the Overall Economic Development Plan, it will not be considered. While there is a midcycle adjustment process for projects that arise within the distribution period, funding may be more difficult.

Summary

Two major interrelated domestic issues are energy and unemployment. One approach to providing a partial solution to both problems is to use

governmental problems to employ unemployed individuals in the production of energy. Because of the labor intensive nature of projects to rehabilitate old dams and prepare them to produce hydroelectric power, such projects offer an opportunity for a joint purpose project.

Two problems associated with creating a joint hydropower employment stimulation project are expertise and funding. The issue of expertise or skill level can be resolved by carefully cataloging the skills required to do the job, analyzing the skills offered by unemployed individuals in the community and designing a training program to raise skill levels. Substantial funding is available through the Comprehensive Employment and Training Act. When these funds are leveraged with smaller amounts of money from community development, the Economic Development Act, the Department of Energy Hydro Program and various loan programs, viable hydro-employment projects can be developed.

Clearly utilizing the boundless resource to increase our energy production capacity is a feasible and important concept.

ENVIRONMENTAL IMPACT ASSESSMENT METHODOLOGY OF SMALL-SCALE HYDROELECTRIC PROJECTS

Richard K. Carlisle and Donald W. Lystra

Background

In 1978, Ayres, Lewis, Norris and May, Inc. was selected by the U.S. Department of Energy (DOE) to study the feasibility of recommissioning two small-scale hydroelectric facilities located on the Huron River in southeastern Michigan. A necessary component of the DOE studies was the evaluation of the environmental impact of hydroelectric development at subject sites. While conducting the Huron River studies, we were retained by Antrim County in northern Michigan, to evaluate a facility under their jurisdiction. After finding the development of the project to be feasible, we embarked upon the Federal Energy Regulatory Commission (FERC) licensing process. FERC also requires an environmental report detailing the consequences of the proposed activity.

Aside from satisfying DOE and FERC requirements, there is an obligation to adequately address the environmental issues associated with any project which affects waterways. Michigan, like many other states, is rich in natural resources. People derive considerable enjoyment from water-related recreational activities, and many lakes and streams are bordered with both seasonal and permanent residences. Real or perceived threats to inland waters are scrutinized not only by regulatory agencies but by the citizens themselves.

The purpose of this paper is to discuss the methodology used by the authors to evaluate the environmental impacts of the small-scale hydroelectric facilities. Further, the actual application of the environmental impact assessment methodology to a case study project is discussed.

Environmental Impact Assessment Methodology

A key component in the assessment of the feasibility of small-scale hydroelectric projects is the evaluation of environmental impacts related to alternative design or operational strategies or development versus non-development options. Environmental impact assessment is often complicated by the consideration of a number of proposed construction and operation activities and their attendant impact upon a multitude of natural and cultural factors. With two projects in the feasibility study stage, one in the FERC licensing stage, and several prospective projects, the need for a uniform impact assessment methodology was felt to be essential. Time and budgetary

Mr. Carlisle is Head, Planning Department, and Mr. Lystra is Head, Electrical Department, Ayres, Lewis, Morris & May, Inc., Ann Arbor, Michigan.

constraints of small-scale hydro projects also point to the need for an impact assessment to be performed in a timely but thorough manner.

An environmental impact matrix having universal applicability to ongoing and prospecitve hydroelectric projects was developed. The purpose of using the matrix approach was twofold:

(1) To assist in the identification and organization of the numerous construction and operational activities and equally numerous natural and cultural factors which could be potentially impacted.
(2) To serve as a tool to screen the relative impacts of project activities on environmental factors so that impacts of a more significant nature could be more fully addressed.

The environmental impact matrix that our firm developed and used is shown in Figure L-2.1. The matrix charts proposed actions on the vertical axis and natural and cultural environmental factors on the horizontal matrix. Proposed actions are divided into construction with nine sub-activities and physical plant and operation with seven sub-activities. Natural factors are divided into terrestrial, hydrological, biological, and atmospheric which are further divided into eleven sub-factors. Cultural factors are divided into social, economy, land use-land value, infrastructure and recreation with twenty-eight sub-factors. It should be noted that impact matrices are not a new tool and, in the course of developing the small-scale hydro impact matrix, a number of the standard works were consulted.

Applying the environmental impact matrix involves a three-step process. Step 1 establishes the environmental setting in which the project is to be conducted. The environmental setting is a statement of the existing natural, social, economic and legal/institutional environment of the project area. The description of current environmental conditions serves as a baseline against which the impacts of project alternatives are assessed. Step 2 involves the use of the impact matrix to screen the impact of proposed actions on the natural and cultural factors. The effect of proposed actions on the environment are rated as having significant, limited or insignificant or no impact. Based upon Step 2, more significant impacts are further analyzed and detailed in Step 3. The screening of impacts in Step 2 allows further concentraiton of effort in addressing more significant issues in Step 3.

Case Study Application

The impact matrix has been used by the authors to assess the environmental impacts of various design alternatives on three small-scale hydroelectric projects. The use of the impact matrix for the French Landing Dam in Wayne County, Michigan will be discussed as a case study for this paper. The French Landing Dam and Hydroelectric Facility is located on the Huron River in Van Buren Township of Wayne County, Michigan. The facility was constructed in 1925 by the Detroit Edison Company and produced power until 1962. Average available head at the dam site is 32 feet, mean annual streamflow is 518 cubic feet per second, and the impoundment, called Belleville Lake, has a surface area of 1,425 acres. Restoration of the aban-

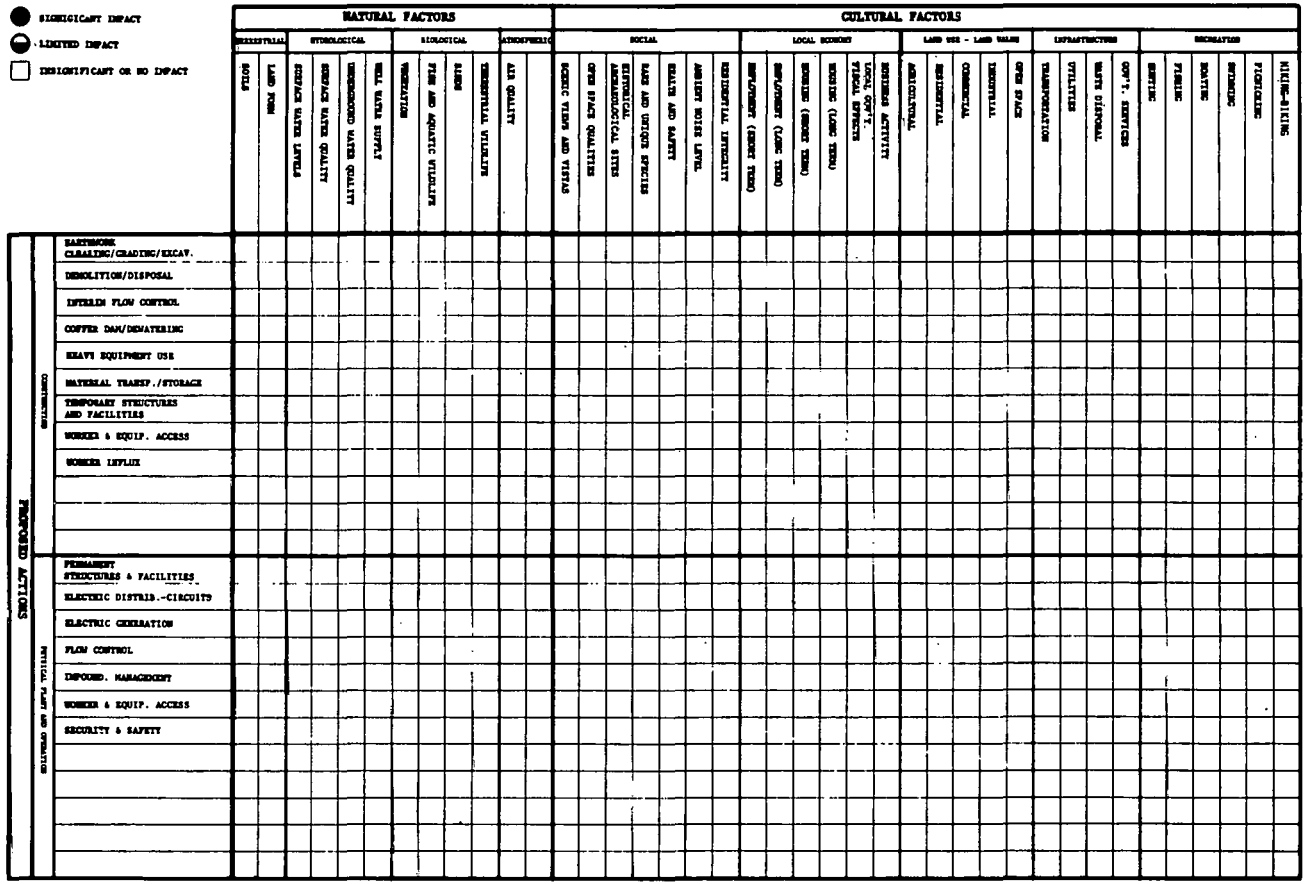


FIGURE L-2.1 Environmental Impact Matrix Small-Scale Hydroelectric Plant

doned hydroelectric facility would require the installation of new turbines, either in the existing powerhouse or some other configuration, as well as extensive structural repairs to the dam, flood gates, and powerhouse structure.

In conducting the feasibility study for this dam site, the environmental impact assessment procedure previously discussed in this paper was used. The environmental setting was described, environmental impact matrix applied, and significant impacts were further addressed. Using the environmental impact matrix to screen all possible effects of the project on the environment, impacts of a more significant nature were identified for further investigation. The completed impact matrix for this project is shown in Figure L-2.2. The significant environmental issues which emerged included impoundment level management, flow control, fishery management, and condition of the dam. Construction activities were felt to be so localized and short-term that the attendant impacts were deemed minor.

Located in heavily populated southeastern Michigan, Belleville Lake serves as an important residential setting and recreational resource. Perhaps the single most critical issue to lake residents regarding the restoration of the hydroelectric facility is the regulation of impoundment levels. Current policy calls for the lowering of the lake level by 3.5 to 5 feet during the winter months to allow shoreline work, prevent ice damage to shoreline structures, and provide capacity for spring runoff. The extreme lowering of the lake level has resulted in extensive damage to steel sheet piling and concrete seawalls due to groundwater movement behind the seawalls. The improved flow management due to restoration of the hydroelectric facility would require only a 12 to 18 inch drop in lake levels during the winter months to prevent ice damage to shoreline structures. Our studies indicated that a less extreme lowering of the lake would minimize shoreline damage, provide sufficient spring flood capacity, and allow for operation of the hydroelectric facility. Of course, shoreline dock and pier work would be a little more difficult.

Issues related to the management of the impoundment include flow control and fishery management. While several Michigan statutes protect the environmental quality of inland lakes and streams, authority over streamflow has been largely confined to the placement of new structures in a lake or stream. The management of water release from an existing impoundment is not regulated by any known state statutes. However, concern was expressed by state agencies over minimum flow release to accommodate downstream recreational activities and fishery habitat. Flow management proposed for the restored hydroelectric facility would be based upon a "run-of-river" operation. No attempt would be made to store and deplete waters from Belleville Lake to allow increased production during peak periods. The schedule of production would be based entirely on natural stream flow characteristics.

Current impoundment management policies calling for large manipulations of lake levels also has an impact on fishery management policies for Belleville Lake. An extensive fisheries management program was initiated in 1972 by the Michigan Department of Natural Resources. Extreme lowering of the lake level can alter fish habitat and spawning areas and strand young and adult fish. The impoundment management policy prescribed by the restoration of the hydroelectric facility would improve conditions for fishery resources.

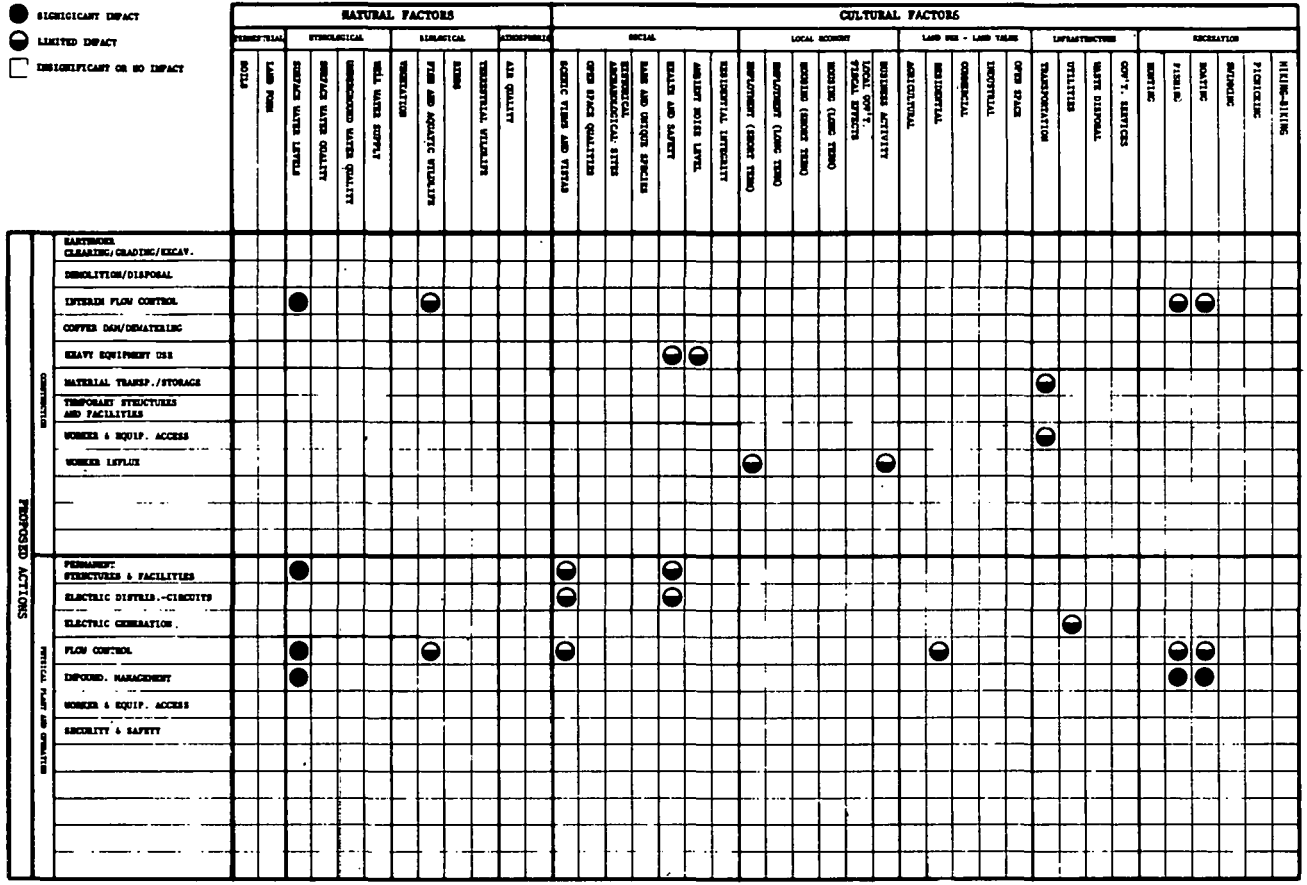


FIGURE L-2.2 Environmental Impact Matrix French Landing Hydroelectric Facility

Another significant issue which emerged was the condition of the dam and lake level control mechanism. Allowed to gradually deteriorate, the dam could pose a threat to health and safety. A failure in the lake level control mechanism or the dam itself would cause the rapid release of water potentially inflicting damage on downstream property and structures. Restoration of the hydroelectric facility and dam would alleviate the immediate threat. The restoration project would require not only replacement of the turbines, but repair of the lake level control mechanism and dam. Therefore, the hydroelectric restoration would alleviate the threat to health and safety created by existing conditions.

Conclusion

The environmental impact assessment procedure described by this paper has been found adequate to address environmental issues associated with the restoration of small-scale hydroelectric facilities. The environmental impact matrix can be of assistance in identifying activities associated with restoration and the environmental factors potentially impacted. Further, the matrix provides a useful tool for initial screening of relative environmental impacts.

The experience of our firm in conducting the feasibility studies at three hydroelectric sites indicates that the identifiable adverse environmental impacts associated with restoration of the three facilities are relatively minor, as illustrated in this paper with the French Landing Hydroelectric Facility Case Study. Significant environmental issues which have been identified, such as impoundment management, are largely independent concerns. The analysis of the small-scale hydroelectric sites has focused attention on facilities which have been abandoned and largely ignored. The conduct of the feasibility studies have forced the consideration of a host of dam-related environmental concerns which otherwise would not be addressed.

ANALYSIS OF ENVIRONMENTAL IMPACTS OF WATER LEVEL FLUCTUATION IN RESERVOIRS AT HYDROELECTRIC SITES

Adam T. Szluha, James M. Loar, Ralph R. Turner and Stephen G. Hildebrand

Introduction

The operation of dams for generation of electricity may result in unnatural fluctuations in water level in both the reservoir and the river below the dam. Such fluctuations can affect the physical, chemical, and biological components of aquatic environments. We discuss our review of pertinent literature on the nature and environmental significance of water level fluctuation in reservoirs due to hydroelectric operation.

Both the amplitude and frequency of water level fluctuation affect the nature and potential significance of the environmental impact on reservoir systems. The amplitude and frequency of fluctuations at a given hydroelectric site depend on the mode of operation of the facility. If a facility is operated in a run-of-river mode, the discharge rate of water released through the turbines is approximately equal to the discharge rate of water entering the basin above the dam. Thus, hydropower generation in a run-of-river mode should not significantly alter the natural amplitude or frequency of reservoir water level fluctuation. Conversely, operation of a hydroelectric facility in a peaking mode requires the storage of water in the reservoir for periodic power generation on a daily, weekly, or seasonal schedule. This mode of operation can result in large water level fluctuations in the reservoir (e.g., > 3 meters). The balance of our discussion will focus on the potential adverse physical, chemical, and biological effects on reservoirs due to water level fluctuation at peaking hydroelectric facilities.

The vast majority of information available on the impacts of water level fluctuation discussed below comes from studies of large dam/impoundment systems. The significance of these issues at small hydro sites will have to be determined on a site specific basis.

Physicochemical Effects

The primary physicochemical effects of water level fluctuations within reservoirs not formerly exposed to such fluctuations, or exposed to different temporal patterns and ranges of fluctuations, are expected to involve shoreline substrate stability and water quality. Specifically, these effects may be summarized as follows:

Dr. Szluha, Dr. Loar, Dr. Turner, and Dr. Hildebrand have been actively involved in environmental research and assessment of fossil, nuclear, and hydroelectric energy technologies. All four authors are employed at the Oak Ridge National Laboratory, Oak Ridge, Tennessee.

1. Resuspension and redistribution of bed and bank sediment.
2. Leaching of soluble matter from sediment in the littoral zone as water moves into and out of the interstices (bank storage) of this substrate in response to water level fluctuations.
3. Changes in (a) sediment and nutrient retention (trap efficiency) of the impoundment, as a consequence of hydro-imposed changes in circulation patterns and hydraulic efficiency, and (b) water quality which is coupled to circulation pattern and hydraulic efficiency.

When water level fluctuates due to hydro peaking operations, continual resuspension and redistribution of poorly consolidated bank and substrate materials will occur. The net results of this resuspension is the preferential removal of the finer, less dense, particles (silt, clay, organic matter) from the littoral zone and either redeposition in deeper and more quiescent water or complete loss from the reservoir in the outflow. The material remaining in the littoral zone after extended exposure to a fluctuating water level is, therefore, of coarser particle size than would be the case with a stable water level.

Occasionally, alluvium, when exposed periodically by a fluctuating water level, will contain very little coarse material that can withstand the erosive forces associated with waves and currents. In this case, banks exposed at low water levels may be subjected to continuous undercutting and collapse. The material eroded can contribute to increased turbidity of the water column and accelerated sedimentation in deeper water.

Regular reservoir drawdowns can also have profound effects on the longitudinal and lateral distribution of sediment (Lara, 1973). These effects may sometimes be beneficial in the context of prolonged reservoir life since previously deposited sediments might be sluiced out of the reservoir (ordinarily requires a deep outlet) or deleterious in the context of the excessive resuspension of sediments into the water column and potential clogging of outlet structures (TVA, 1978).

The alternate inundation and drainage to which soils and sediments in the littoral zone are exposed when water levels fluctuate may lead to increased leaching of soluble matter from the exposed substrate. In shallow water where aerobic (chemically oxidized) conditions are likely to prevail in the water overlying flooded soils and sediments, a sharp gradient in the concentrations of nutrients and metals is likely to exist across the substrate-water interface (Lee, 1970). When the water level is lowered, some portion of the interstitial water containing higher concentrations of nutrients and metals may drain out onto the surface of the substrate or enter the adjacent surface water body. If this drainage water is highly enriched in soluble plant nutrients or deleterious substances, such as heavy metals, the near-shore water quality may be adversely affected.

The ability of a reservoir to trap and retain sediment is known as the 'trap efficiency' and is expressed as the percent of the total inflowing sediment which is retained (deposited) in the basin. The degree to which a reservoir traps inflowing sediment is the prime determinant of the useful lifespan of the reservoir and is an important factor affecting both reservoir and downstream water quality, especially turbidity. In general, sediment trap efficiency decreases with:

1. A decrease in water retention time,
2. A decrease in sediment particle size, and
3. A change from surface water withdrawal to deep water withdrawal.

Imposing water level fluctuations on a reservoir would directly affect the water retention time as a consequence of the changes in average storage volume. The overall effect would be a probable reduction in sediment trap efficiency. In addition, the periodic lowering of water level may permit coarser-grained sediments to reach, and be transported farther into, the reservoir basin, thereby initially increasing the trap efficiency. However, the latter effect would also lead to a somewhat faster loss of reservoir storage capacity. Thus, any apparent increase in trap efficiency due to the input of coarser sediment may ultimately be offset by the decrease in retention time caused by the decrease in storage volume.

The term 'trap efficiency' has also been used in the context of nutrient retention by reservoirs (Glymph, 1973; Rausch and Schreiber, 1977). The efficiency with which impoundments trap inflowing nutrients is an important environmental issue because water quality and productivity, both within and downstream of impoundments, is partially determined by trap efficiency. Nutrient trap efficiency appears to vary in response to the same factors which affect the trap efficiency for sediment (Prochazkova, 1975; Gill et al., 1976; Rausch, and Schreiber, 1977). Thus any significant change in water retention time, the primary determinant of sediment trap efficiency (Glymph, 1973), will also affect nutrient trap efficiency.

Biological Effects

The effects of water level fluctuation on reservoir biota are, in part, a result of changes in the physicochemical environment discussed above. General effects of water level fluctuations on reservoir biota include:

1. Habitat destruction resulting in partial or total loss of organisms,
2. Changes in habitat quality resulting in reduced standing crop and production, and/or
3. Shifts in species diversity. The effects of water level fluctuations on the biological communities of reservoirs can be best described in the context of the communities occupying major habitats or ecological zones in a reservoir. Beach Zone (landwater interface)

The most important biological components of the beach zone community are the aquatic marsh vegetation and semi-aquatic plants, and their associated invertebrate fauna. The beach zone plant community requires considerably more soil moisture (derived from interstitial reservoir water) than purely terrestrial plants. A well developed and stable plant community not only protects the beach zone from both sheet erosion due to precipitation and bank erosion due to storm waves, but also prevents sedimentation and leaching of chemical compounds from the beach zone soil. The terrestrial invertebrate fauna associated with the beach zone vegetation provides an important food source to the reservoir fish fauna. Water level fluctuation could reduce ie interstitial water available for beach zone vegetation and thus indirectly affect productivity of reservoir biota dependent on this vegetation.

Water level fluctuation could reduce interstitial water available for beach zone vegetation and thus indirectly affect productivity of reservoir biota dependent on this vegetation.

Littoral and/or Shore Zone (water depth of rooted plants): A distinction is made here between a littoral zone with characteristic emergent and submergent aquatic macrophytes and the shore zone without any aquatic macrophytes. The importance of the littoral and/or shore zone to biological production is well established, although a littoral zone with aquatic macrophytes may be more productive, with higher species diversity, than a shore zone without aquatic macrophytes (Reid, 1961; Hynes, 1972).

Water level fluctuation imposed on the littoral or shore zone of a reservoir can change species diversity, eliminating those species which are unable to migrate, aestivate, or rapidly recolonize the draw-down zone (Hynes, 1961). Littoral benthic invertebrates stranded above receding water for longer than a few hours may be lost (Hynes, 1961; Hunt and Jones, 1972). However, chironomid larvae and oligochaetes are able to retreat deeper into the substrate and survive for periods of 50-100 days (Grimas, 1961; Paterson and Fernando, 1969; Kaster and Jacobi, 1978). Benthic invertebrate populations that recolonize the littoral zone upon rising water levels may be less diverse and possibly more abundant than those of undisturbed systems. Such effects of water level fluctuation (decreased diversity and increased standing crop) may be a stress on the ecosystem (Spence and Hynes, 1971).

With few exceptions, most reservoir fishes are closely associated with the littoral and shore zones of reservoirs throughout a significant portion of their life cycle. Specifically, spawning, incubation and hatching of eggs, and the development of larvae, postlarvae and juveniles occur in shallow littoral and shore zones. The basic requirements for successful spawning, development and growth are adequate spawning habitat, stable water level, and adequate food supply. Water level fluctuation can significantly affect all of these requirements. Il'ina (1962) observed that gravid females of some species reabsorbed their spawn due to the lack of adequate spawning grounds in Rybinsk Reservoir. Nelson (1978) reported similar findings in Lake Oahe, a mainstream reservoir of the Missouri River. Based on several years of observations on the fish populations of numerous reservoirs, Puddubny (1971) identified water level fluctuation as one of the major factors affecting optimum fish production. Similar conclusions were drawn by Aggus (1979) who indicated that variations in water level produce a constantly changing food source and hence contribute to the instability in carrying capacity and population structures of reservoir fishes.

Limnetic (Open Water) Zone: Water level fluctuation most likely will not directly affect aquatic species in the deep open water areas of reservoirs. However, drops in water level are ultimately reflected in increased discharge from the reservoir. Thus planktonic species (algae and zooplankton), early life history stages of fish, and some benthic invertebrate species could potentially be lost from the reservoir ecosystem. Such losses could adversely affect reservoir food webs and productivity. Cowell and Hudson (1967) estimated a loss of 44 metric tons of benthic invertebrates through the turbines at Lewis and Clark Lake. Walburg (1971) observed a strong negative correlation between flushing rate and abundance of young fishes in Lewis and Clark Lake.

Conclusion

The potential significance, on a site-specific basis, of water level fluctuation impacts discussed above range from benign (run-of-river plants) to possible significant enough to require mitigation. We emphasize that efforts to develop small hydroelectric sites that entail water level fluctuation should include a careful analysis of the types of impacts described. The potential significance of these impacts should be evaluated as an integral part of initial studies of site feasibility.

This research was funded by the U.S. Department of Energy, Assistant Secretary for Resource Applications, Division of Hydroelectric Resources Development under Contract W-7405-ENG-26 with the Union Carbide Corporation. This manuscript is publication 1433 of the Environmental Sciences Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

REFERENCES

Auggus, L. R., "Effects of Weather on Freshwater Fish Predator Prey Dynamics." Henry Clepper (Ed.), *Symposium on Predator-Prey Systems in Fisheries Management.* Sport Fishing Institute, Washington, D.C., 1979, pp. 47-54.

Cowell, B. C. and P. L. Hudson, "Some Environmental Factors Influencing Benthic Invertebrates in Two Missouri River Reservoirs." In: C. E. Lane, Jr. (Ed.), *Reservoir Fishery Resources Symposium, American Fisheries Society,* 1967, pp. 541-555.

Gill, A. C., J. R. McHenry and J. C. Ritchie, "Efficiency of Nitrogen, Carbon and Phosphorus Retention by Small Agricultural Reservoirs." *Journal of Environmental Quality,* 5, 1976, pp. 310-315.

Glymph, L. M., "Summary: Sedimentation of Reservoirs," In: W. C. Ackemann, G. F. White and E. B. Worthington (Eds.), *Man-Made Lakes: Their Problems and Environmental Effects,* Geophysical Monograph Ser., 17, American Geophysical Union, Washington, D.C., 1973, pp. 342-348.

Grimas, U., The Bottom Fauna of Natural and Impounded Lakes in Northern Sweden, Drottingholm Institute of Freshwater Research, Report, 44, 1961, pp. 14-41.

Hunt, P. C. and F. W. Jones, "The Effects of Water Level Fluctuation on a Littoral Fauna. *Journal of Fish Biology,* Vol. 4, 1972, pp. 385-394.

Hynes, H. B. N., *The Effects of Water Level Fluctuation on Littoral Fauna.* Verhandlungen Internationale Verinigung fur Theoretische and Angewandte Limnologie, 14 (2), 1961, pp. 652-656.

Hynes, H. B. N., *The Ecology of Running Waters.* University of Toronto Press. 1972, 555 p.

Il'ina, L. K., The Influence of Water Level on Fish Spawning in Rybinsk Reservoir in 1960. *Byulleten Instituta Biologii Vodakhranilishch,* 1962, 13, pp. 26-30.

Kaster, J. L. and G. Z. Jacobi, Benthic Invertebrates of a Fluctuating Reservoir. *Freshwater Biology,* 8, 1978, pp. 283-290.

Lara, J. M., "A Unique Sediment Depositional Pattern." In: W. C. Ackermann, G. F. White and E. B. Worthington (Eds.), *Man-Made Lakes: Their Problems and Environmental Effects,* Geophysical Monograph. Ser., Vol. 17, American Geophysical Union, Washington, D.C., 1973, pp. 387-394.

Lee, G. F., "Factors Affecting the Transfer of Materials Between Water and Sediments." *Literature Review,* No. 1, Water Resources Center, University of Wisconsin, Madison, Wisconsin, 1970, 50 p.

Nelson, W. R., "Implications of Water Management in Lake Oahe for the Spawning Success of Coolwater Fishes." *American Fishery Society Special Publication 11,* 1978, pp. 154-158.

Paterson, C. G. and C. H. Fernando. "Macroinvertebrate Colonization of the Marginal Zone of a Small Impoundment in Eastern Canada." *Canadian Journal of Zoology, Vol. 47651,* 1969, pp. 1229-1238.

Prochazkova, L., "Balances in Man-Made Lakes (Bohemia)." In: A. D. Hasler (Ed.), *Coupling of Land and Water Systems,* Springer-Verlag, New York, New York, 1975, pp. 65-72.

Puddubny, A. G., *Ecological Topography of Fish Populations in Reservoirs.* Nauka Publishers, Leningrad, 1971, 414 p.

Kausch, D. L. and J. D. Schreiber, "Callahan Reservoir: I. Sediment and Nutrient Trap Efficiency." *Transactions of American Society of Agricultural Engineers,* 20, 1977, pp. 281-290.

Reid, G. K., *Ecology of Inland Waters and Estuaries.* Reinhold Publishing Corporation, New York, 1961, 375 p.

Spence, J. A. and H. B. N. Hynes, "Differences in Benthos Upstream and Downstream of an Impoundment." *Journal of Fisheries, Research Board of Canada,* Vol. 28 (1), 1971, pp. 35-43.

Tennessee Valley Authority, "Impact of Reservoir Releases on Downstream Water Quality and Uses." Special Executive Report, Division of Environmental Planning, Chattanooga, Tennessee, 1978.

Walburg, C. H., "Loss of Young Fish in Reservoir Discharge and Year-Class Survivial, Lewis and Clark Lake, Missouri River. *American Fishery Society Special Publication, No. 8,* 1971, pp. 441-448.

THREE-AGENCY CONTROL FOR CO-DEPENDENT HYDROELECTRIC FACILITY

Samuel E. Barnes

For over 50 years the Columbus Division of Water (DOW) has used two dams on the Scioto River to impound water for the City's municipal water needs. For many years, until the late 1950's, these dams (Griggs and O'Shaughnessy) were the only source of municipal water. Both dams were originally designed by far-sighted early 20th century planners with provisions for the eventual installation of hydroelectric machinery. Now, it seems, the time has come to implement their dreams.

O'Shaughnessy Dam, about 16 miles north of Columbus, is approximately 65 feet high, impounds 16,900 acre-feet of water when full, and controls a drainage area of 980 square miles. Griggs Dam, about 8 miles downstream from O'Shaughnessy Dam, is about 35 feet high, impounding 4,200 acre-feet of water. It controls a drainage area of 1,044 square miles. Both reservoirs are primarily for water supply, and are heavily used for recreation by area residents. About 5 miles downstream from Griggs Dam are the Dublin Road water treatment plant and a small intake-pool which stores about 200 acre-feet of water. Taken together, the three dams impound a relatively small proportion of basin runoff—about four percent.

For the hydrologic analysis, duration curves of annual and monthly discharge and headwater elevation were developed based on records from 1921 through 1978. Tailwater elevations were defined by discharge-elevation rating curves, which were in turn developed by numerical modeling of hydraulic stream profiles. Flood levels were determined primarily from flood water surface profiles by others. The duration curves indicated discharge in excess of water supply needs during 85 percent of the time, and 20 times water supply about 20 percent of the time.

Table L-4.1, below, summarizes the cost and performance factors expected for the co-dependent projects.

Table L-4.1
COST AND PERFORMANCE FACTORS

	Capacity	Project Cost	Unit Cost	Benefit Cost Ratio	Current Energy Cost*
O'Shaughnessy Dam	5 MW	$4,080,000	$ 800/kW	2.31	$0.031/kWh
Griggs Dam	2 MW	3,625,000	$1,800/kW	1.37	$0.056/kWh
Combined	7 MW	7,705,000	$1,100/kW	1.91	$0.038/kWh

*Includes financing

Mr. Barnes is Manager of the Technical Services Group, City of Columbus, Division of Water, Columbus, Ohio.

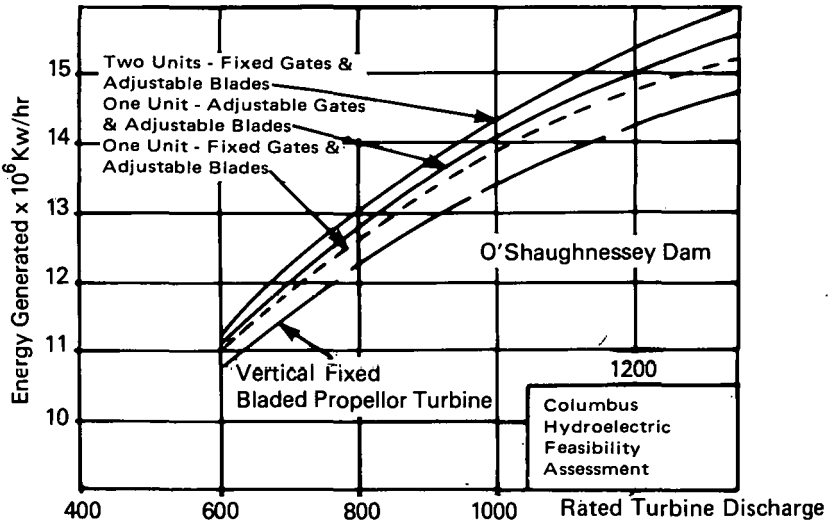


FIGURE L-4.1 Typical Year Energy Generated

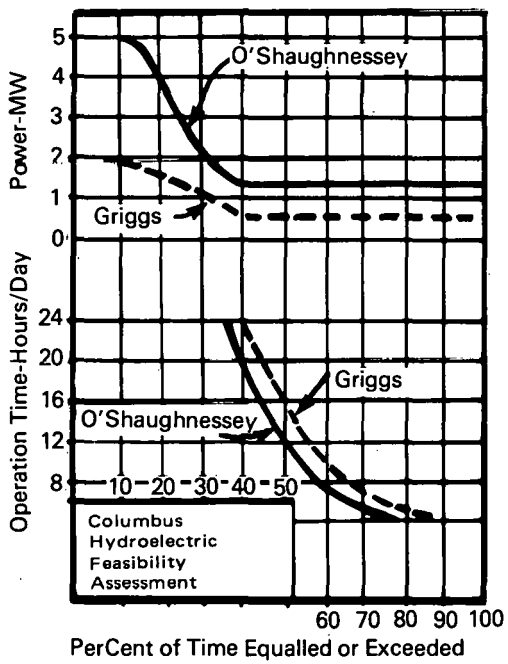


FIGURE L-4.2 Power and Time Duration Curves

Operations

Fortuitously, the Dublin Road Water Plant (DRWP), which purifies the water impounded by the dams, normally requires an amount of power roughly equal to what the dams can be expected to produce. Getting the power to DRWP, and providing energy back up for the plant, however, presents some distribution and control problems with unusually interesting concepts. Three independent agencies are involved, and superficially it appears that each has paramount motives and a primary mandate for direct control of the generating facilities. For example:

A. Division of Water employs sophisticated control strategies to optimize cost-effectiveness of the service provided to its consumers. Simultaneously, the same kinds of complex control strategies are employed for risk-vs-safe-yield management of water resources. Daily city-wide maximization schemes for water resources using simulation and gradient searches ("hill climbing") means that the DRWP (which now provides about 30% of total demand) has to vary output as required. Plant operating personnel, therefore, must have some means of controlling flow-of-water through the dams. Because potable water use is the primary function of the Griggs and O'Shaughnessy Reservoirs, DOW operations personnel must maintain "over-ride" control of hydroelectric operations.

B. Division of Electricity routinely provides all electrical power required by the DRWP. Normal load, 1 to 4 kVA, is provided via redundant lines from the DOE main switchyard near the old coal-fired electrical plant (no longer in use) on Dublin Road. At the present time, all DOE electrical power is purchased from a complex of C&SOE lines which feed the main switchyard. In 1981, however, the City's 90 MW trash-burning power plant in southern Columbus will provide a major portion of the load. For load dispatching and system management, it is essential that DOE personnel have access to a man-machine interface controller of the hydroelectric generation facility.

C. Columbus & Southern Ohio Electric Co. (C&SOE) has a well-developed local power grid. There are C&SOE access nodes which are conveniently almost contiguous with the output gear of the planned hydro facilities and C&SOE will "wheel" power to the DOE's main distribution switchyard: C&SOE officials have committed their distribution resources to the spirit of this endeavor. For many years, the City's Division of Electricity has been interfacing their generators with the C&SOE power grid, so the two agencies have developed a mutual trust based on carefully developed manuals of procedure. C&SOE relies on DOE employees for synchronization and switching, so C&SOE does not require control capability of the hydroelectric generator. However, schedules, forecasts, and status reports available on the CRT would be invaluable to C&SOE dispatchers.

Control System

A unique control system, using a distributed hierarchy, is proposed for direct digital control (DDC) of generators and switchgear. It will be a dis-

tributed system in that a host computer, located at the Dublin Road Water Plant, will be the "boss" of several satellites—three of which will be graphic generators for CRT displays at DRWP, DOE, and C&SOE. Two satellites will perform DDC at the dam sites. Other satellites may be required for other functions. The control system hierarchy will be discussed by comparing control functions with operational organizations, beginning with a chart prepared for overall project implementation, Figure L-4.3.

Selection of Operating Mode

At any one instant in time, the Division of Water can predict their expected daily water demand for periods in the near future. With reasonable accuracy we can even predict the hourly demand pattern for several weeks to come, Figure L-4.4. The Division of Electricity, it is expected, can also come up with predictions which will establish near-term electrical demand patterns.

Armed with these two pieces of data, representatives from the Divisions of Water and Electricity should be able to establish 7-day schedules for the next week's operation of the hydroelectric facility. The schedule thus established would trade-off the amount of water that is predicted to be going over the dam against expected revenues which could be gained by operating to meet C&SOE peaks. Or, if the water reservoirs are operating in an "in storage" condition predicted municipal water requirements could be scheduled to maximize electrical revenue. In any event, it is expected that it will not be a difficult feat for the representatives to come up with a mutually agreeable weekly schedule.

On-Line Control of Operations

This block represents the actual operation and primary control of the hydroelectric facility. As a matter of routine operation, the Division of Water, with the aid of digital computers, employs sophisticated control strategies to optimize the cost-effectiveness of the service provided to its consumer customers. The same kinds of complex control strategies are employed for risk-vs-safe yield management of water resources in a dynamic simulation program with gradient searches; the optimum solution could change hourly, Figure L-4.3.

All of this means that output of the Dublin Road Water Plant may have to change from hour-to-hour. O'Shaughnessy and Griggs impoundments, which furnish the raw water for the Dublin Road Water Plant (DRWP) nominally contribute about 30% of the municipal supply, but optimization strategies require that this proportion vary as required. Plant operating personnel at DRWP, therefore, must have primary and "over-ride" control of water through or over the dams.

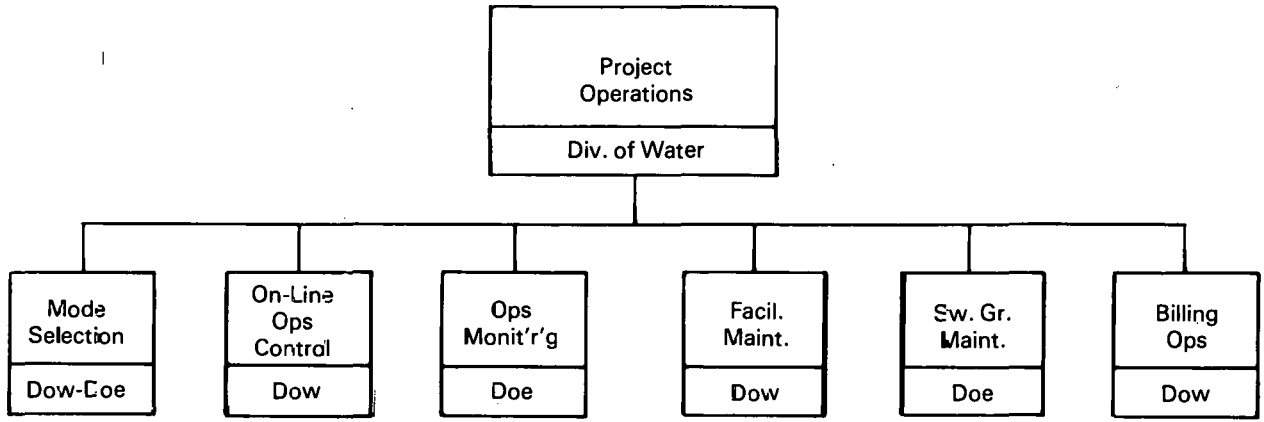


FIGURE L-4.3 Organization Chart of Control Strategies

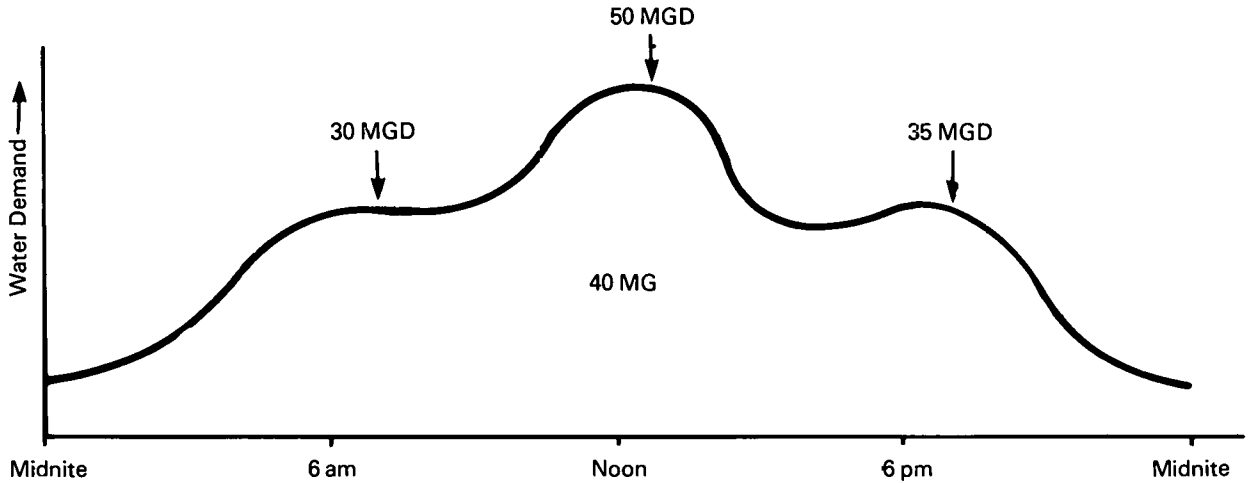


FIGURE L-4.4 Management of Water Resources

Operations Monitoring

The Division of Electricity routinely provides all electrical power required by DRWP, which is normally 2000 to 4000 kVA. This is done via redundant transmission lines, Figure L-4.5. At the present time, all electrical power sold by the Division of Electricity is purchased at "wholesale" prices from the Columbus and Southern Ohio Electric Co. and distributed as required from their main switchyard near the old municipal coal-fired electrical plant (no longer in use). The ring-type configuration of this sub-station is inherently redundant—multiple sources of power input are available as is multiple means of power egress.

In 1981, the city's 90 MW trash-burning plant is expected to come on line to provide energy to service a major portion of the Division of Electricity customers. Some power will still have to be purchased, even though the hydroelectric facility will probably be in service. As can readily be seen, load management of such a system requires that Division of Electricity personnel continually monitor hydroelectric operations. In fact, it is expected that the DOE load dispatcher will be contacting the DRWP several times daily for load scheduling.

Electrical Equipment & Facility Maintenance

Since the controls, rotating machinery, and civil works associated with the hydroelectric installation will be generically similar (and of similar magnitude) to that type of facility which is routinely operated and maintained by the Division of Water, it is expected that Division personnel will have no maintenance difficulty. Though different in function, the hardware similarities between a turbine and a variable-speed finished-water pump are obvious; a likewise similarity exists between finished-water pump motors and hydroelectric generators.

The control system visualized will expedite facility maintenance in the same manner it will be employed for normal water equipment maintenance at the plants. When assigning daily tasks, the foreman or supervisor queries the central computer, which would elicit a print out of the items needing accomplishment. A work-order system helps keep track of those tasks which have been completely or partially performed.

Switchgear Maintenance

Switchgear and distribution lines are elements of the hydroelectric system with which the Division of Electricity has a great deal of experience. Maintenance and trouble shooting of this equipment will be well within the purview of existing Division of Electricity crews, since the equipment is exactly like that used in the DOE system. DOE crews will also be responsible for maintaining interface connections between the DOE system and the Columbus and Southern Ohio Electric system.

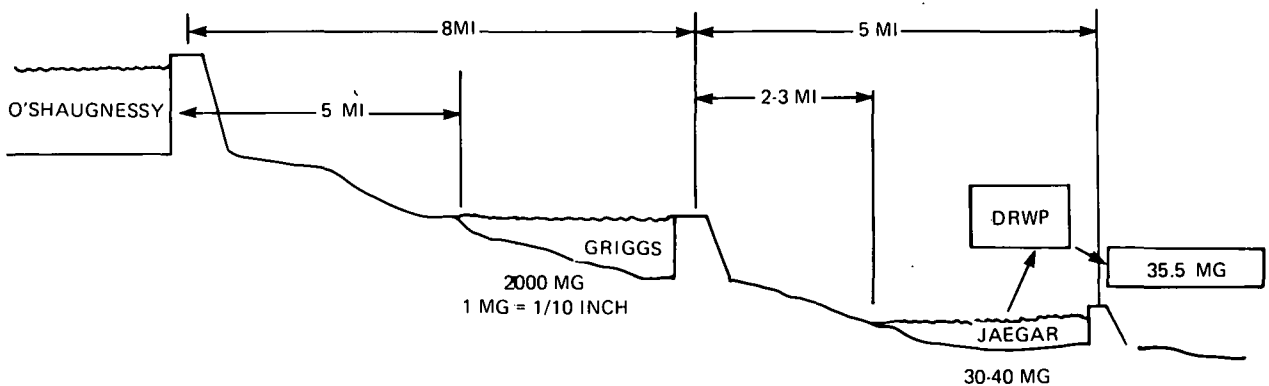


FIGURE L-4.5 Hydroelectric Power - Columbus Water System

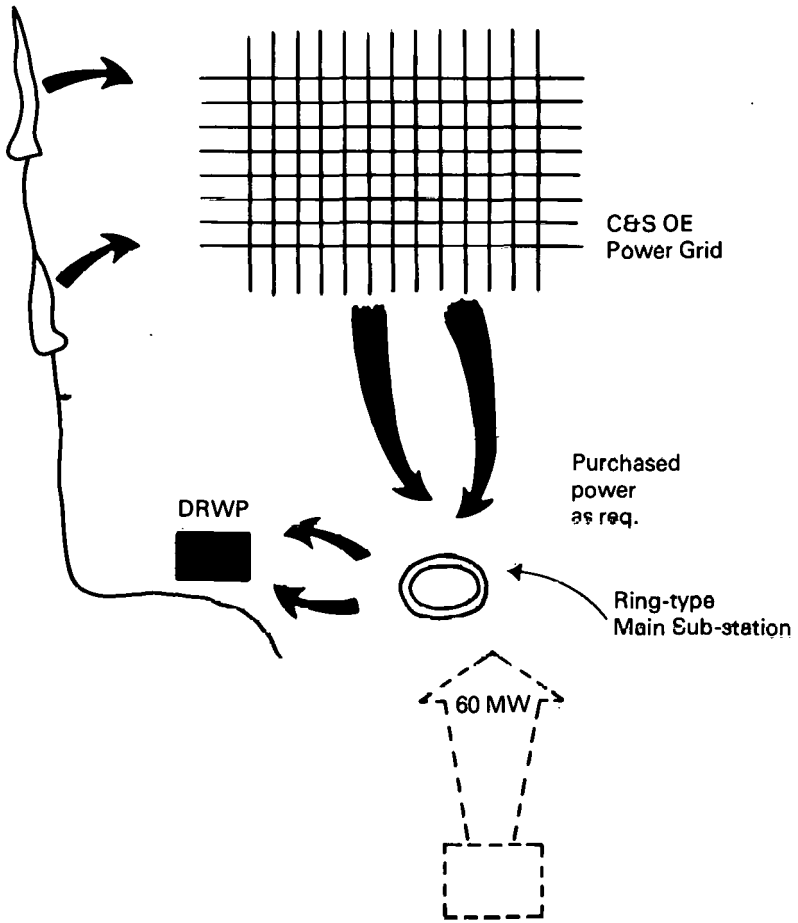


FIGURE L-4.5a Redundant Transmission Lines

Division of Electricity personnel have operated generating plants over a period of many years and have much experience in synchronizing their rotating machinery with the C&SOE system. The trust and mutual respect established over this long period is such that C&SOE dispatchers prefer that city crews "close the switches" when synchronizing is being accomplished. Actually, from a safety standpoint, it is important that the Division of Electricity have final and absolute control over all switching. If, for some reason, DOE crews have some switches open and/or "Red-Tagged", such switches must remain in that position (until an authorized DOE person changes them) regardless of how much water might be going to waste by passing over the dams or regardless of what normal or emergency power demands might be. The DOE dispatcher (or delegate) is the ultimate source of knowledge about safe switching in the system.

Billing Operations

Keeping track of energy and power produced by the facility will be the function of several agencies.

1. C&SOE will probably want their own metering equipment at the dams so that they will have a basis for billing "wheeling costs."
2. The Division of Electricity needs to credit the Division of Water for power and energy produced. These credits will be applied to power consumption costs at the DRWP and Parsons Avenue Water Plant, and so the Division of Electricity obviously has a need for metering equipment.
3. To ensure that proper credits and debits are being applied, the Division of Water has a proprietary need for metering.

There is no reason why all of these metering needs cannot be met by the same instruments and the digital control system which will be operating the facility. The control system being planned provides each agency with an identical CRT terminal with an operator keyboard, Figure L-4.6 and 6a. One will be in the Master Control Room at the Dublin Road Water Plant (DRWP), one will be in the office of the Division of Electricity (DOE) dispatcher, and one will be provided for C&SOE. Each of the terminals will be identical from a hardware standpoint, and most of the software will be identical also. From any terminal, by use of the keyboard, observers will be able to call up:

1. Displays which show power and energy produced in tabular, chart or pictorial formats.
2. Schedules of power to be produced, trends, historical data, etc.
3. Maintenance requirements, periodic maintenance schedules, etc.
4. Current operating data and alarm conditions in several formats.

In other words, all the CRTs will be identical in the information they are able to provide. Via software coding, however, one of the terminals will be a "master" controller and the operator will have a full man-machine interface which will allow him to interact with the hydroelectric facility. He will be

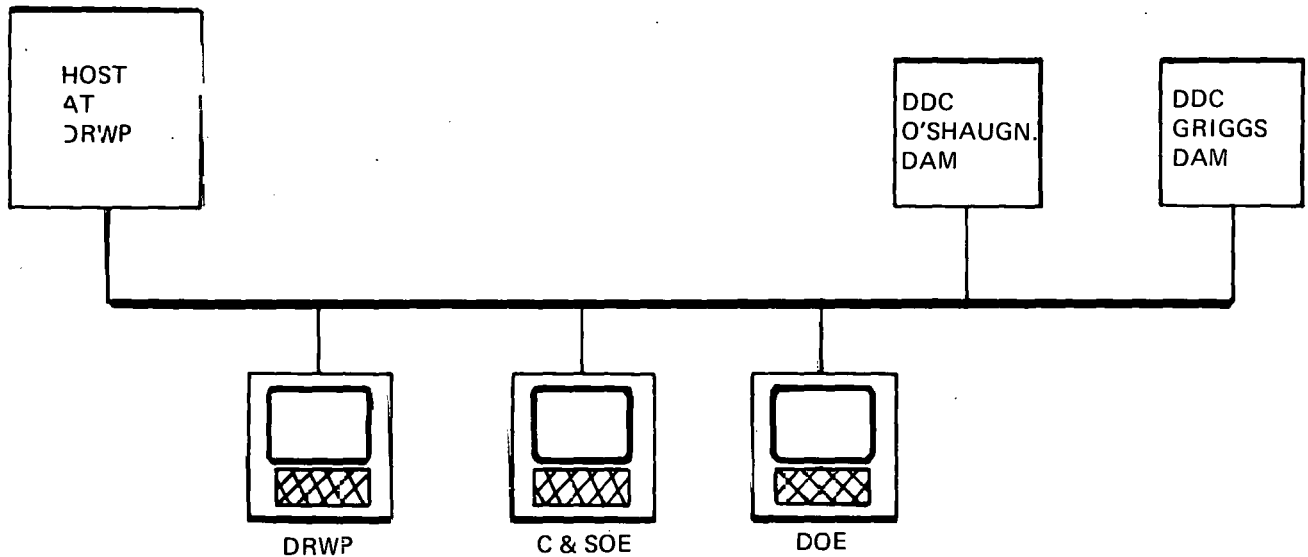


FIGURE L-4.6 Control Systems

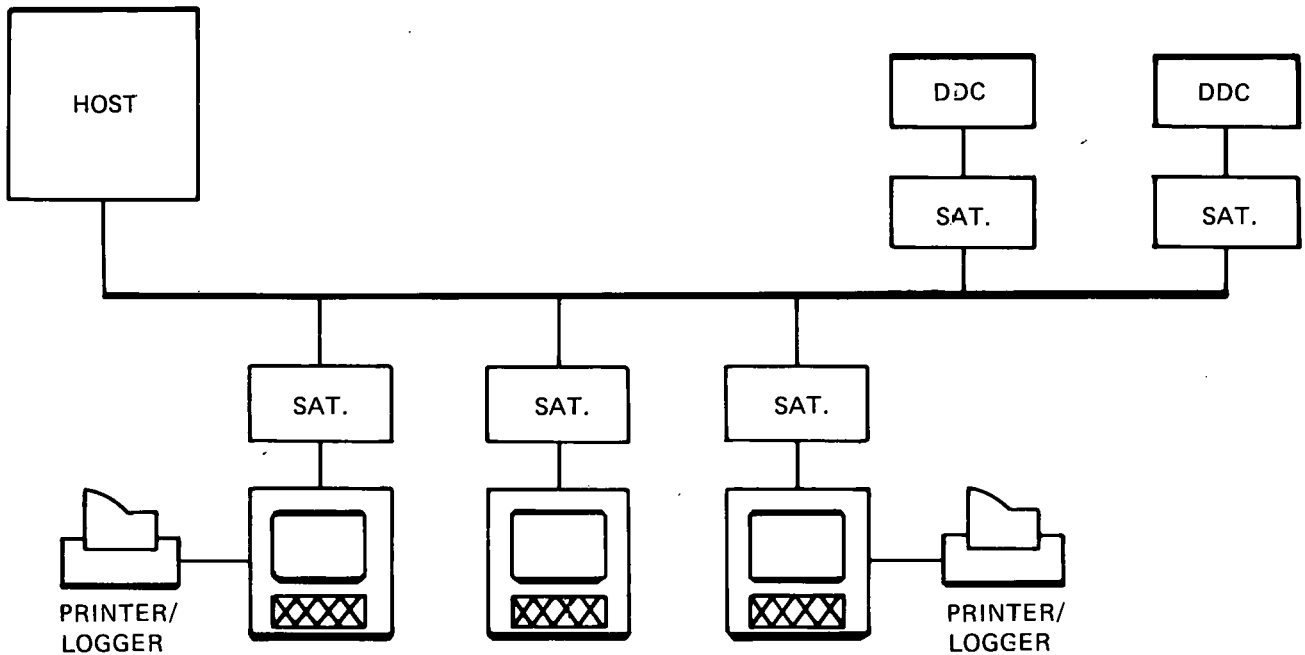


FIGURE L-4.6a Control System with Printing Ability

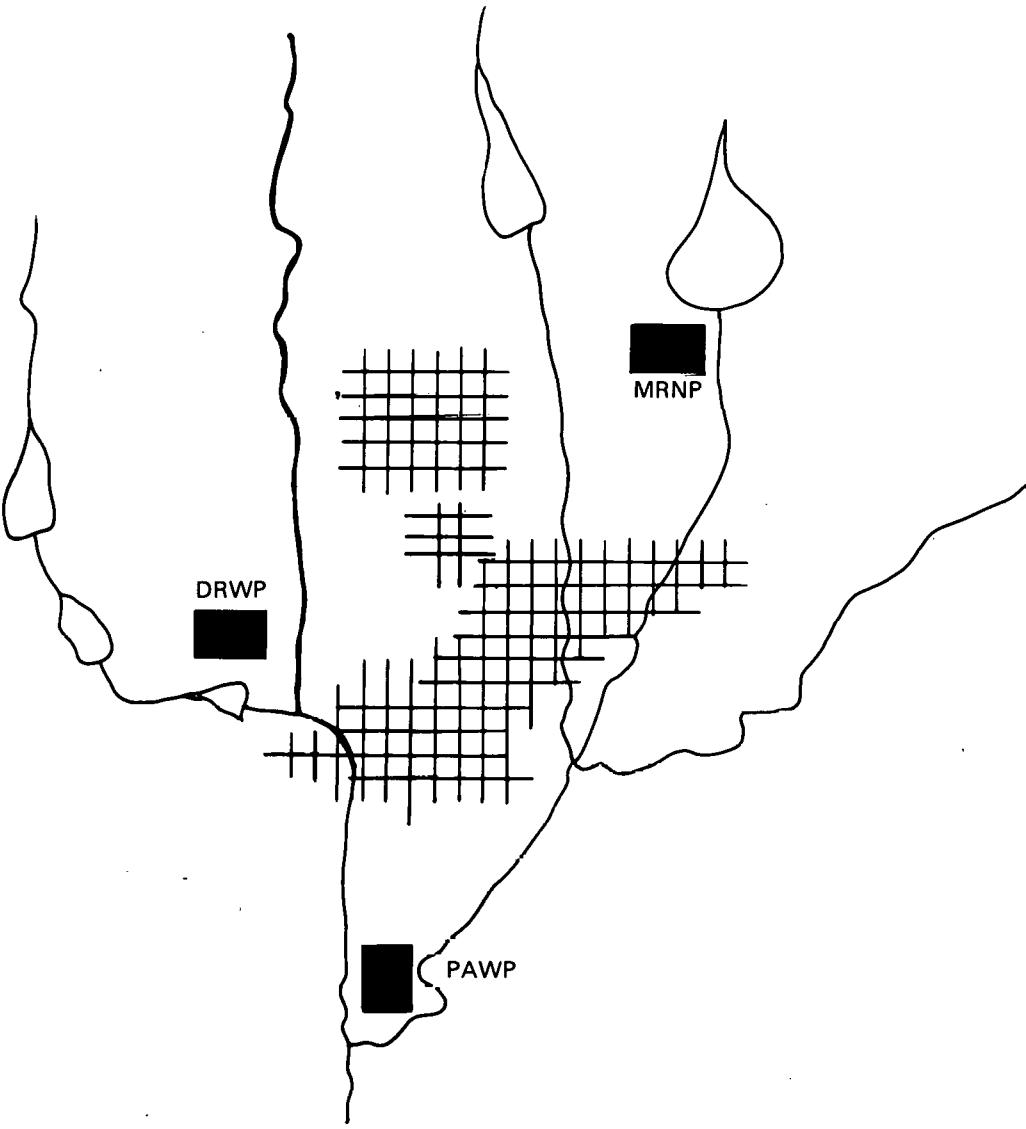


FIGURE L-4.7 Water Supplies — Columbus, Ohio

able to open and close valves, switches, modulate performance, etc. Other terminals can call up the displays that the "master" uses for control purposes, but they can not interact with the control system. The "master" software codes will normally be available only to the DRWP Operator. The Division of Electricity dispatcher will also have unique software codes which will allow him limited interaction with the control system. He will be able to open and close intra-system switches, and he will be able to modulate fine-speed control for synchroneity during switch-over.

As mentioned, C&SOE will have all of the above information at their disposal, but, lacking the proper software codes, they cannot effect any control changes. Since the control system will be instrumented for power and energy production, C&SOE can use this information for billing. If they need printed data for billing, a video copier (or printer) can be added to their terminal. If they insist on "sealed" metering instruments, so let it be—control system sensing can be accomplished through sealed C&SOE primary sensors if they are of adequate quality and accuracy.

Control System Design

The Division of Water is already engaged in implementation of a distributed control system requiring a similar degree of state-of-the-art progress. This control system is being implemented at the new Parsons Avenue Water Plant, (PAWP, Figure L-4.7) which will be on line in mid 1981. Details are in literature References 2, 3, and 4.

REFERENCES

Feasibility Assessment for Hydro Power Development at O'Shaughnessy Dam and Griggs Dam, City of Columbus, Division of Water, Burgess & Niple, Ltd., Columbus, Ohio, August, 1979.

Barnes, Sam, Task Force Checks Out Computers. . . . . , *Water and Wastes Engineering,* June, 1977.

Control System Evaluation and Recommendation for the Parsons Avenue Water Plant, EMA, Inc., January, 1978.

Barnes, Sam, et.al. "Using Cost Benefit Analyses to Select Digital Control Systems," *Instrumentation Technology,* October, 1978.

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

Session Sixteen

PLANNING, INFORMATION AND METHODS

Topic: Planning for Development II

Chairman: Mr. John S. Gladwell
Director, Idaho Water Resources Research Institute
University of Idaho
Moscow, Idaho 83843

PLANNING SMALL-SCALE HYDROPOWER ADDITIONS

Darryl W. Davis

Introduction

Small-scale hydropower development is receiving significant renewed attention as one of our national, underdeveloped energy resources. Public institutions and private organizations are examining the potential that exists at many existing reservoir sites presently not producing power. To aid these groups in their efforts, the Hydrologic Engineering Center of the Corps of Engineers has prepared a manual providing guidance in the study of the feasibility of adding small hydroelectric power features to existing facilities. The manual preparation was sponsored by the U.S. Department of Energy through the Corps' Institute for Water Resources. The manual is designed for use by public agencies (Federal, state and local), public and private utilities, and private investors. The focus is upon the technology, concepts, and economic and financial issues unique to small-scale hydropower additions. The manual includes data and discussions on the topical subjects of cost escalation in economic and financial analysis, feature component selection for reconnaissance and feasibility levels of study, and time, costs, and resources required to perform the investigations. This paper discusses significant findings and conclusions of studies that were performed for the project and presents an overview of the manual.

Characteristics of Small Hydropower

Small hydropower projects include installations that have 15,000 kilowatts (kW) or less capacity. "Small hydro" and "low-head hydro" are not synonomous. Small hydro as defined above has been an informal breaking point used for various Federal and other agency statistical tabulations and informal communications. The concept has now been defined by the Public Utility Regulatory Policies Act (PL 95-617, November 1978) to be 15 megawatts (MW) for purposes of special handling for licensing, loans, incentives, and other promotional programs. Low-head hydro is a term associated with a research and development program managed by the Department of Energy that is designed to advance the technology for generating hydropower from sites with heads of less than 20 meters (66 feet). A significant number of the presently identified small-hydro addition sites fall within the low-head criteria.

The fundamental thesis for small hydro as a concept (apart from hydropower in general) is that the impacts of implementation (especially for an

Mr. Davis is Chief, Planning Analysis Branch, The Hydrologic Engineering Center, U.S. Army Corps of Engineers, Davis, California.

addition to an existing impoundment) are likely to be modest; thus, projects will be essentially non-controversial so that simpler license and permit granting programs are appropriate and physical facilities can be kept simple and functional. Implementation should, therefore, be possible in relatively short time frames.

Existing and Future Development

A significant number of existing hydropower installations in the United States could be classified as small hydro. Installed or under construction hydropower capacity is near 65 million kW in about 1,400 plants, which results in an average installed capacity of about 40 MW per plant. The latest published inventory (Federal Power Commission, 1976) lists 142 plants as having installed capacities greater than 100 MW. Deducting the sum of the capacities for plants in excess of 100 MW from the total results in the average plant size for the remaining 1,260 plants dropping to 12 MW.

Initial estimates of power potential at existing non-hydropower dams indicated that about 30,000 MW and 95 billion kWh per year (McDonald, 1977) exist at several thousand sites. These sites are among the 50,000 dams identified in the national dam inventory prepared by the Corps of Engineers and range in size from retired small-hydro plants in the New England area to major Federal reclamation projects in the West. Other potential sites not identified in previous studies include irrigation canal drops, municipal water supply delivery systems, and wastewater management systems. Preliminary results from an improved resource assessment (IWR-HEC, 1979) indicate the gross potential at existing dams lies in the 6,000 to 10,000 MW range at upwards of 5,000 sites. The gross potential annual energy at existing dams lies in the 18 billion to 25 billion kWh range, which is equivalent to a savings of 80,000 to 140,000 barrels of oil per day. Rising costs of fossil fuels are increasing the economic attractiveness of hydropower in general, particularly small hydropower. Within the next ten years, upwards of 2,000 sites are likely to be found feasible for implementation.

Implementation Issues

A significant major positive feature of small hydro is that many of the important environmental and other site issues have been previously resolved (e.g., the impoundment site exists and is presently in service). The lag time from conception to implementation could be as little as three years compared to the often 10-15 years for major projects. The significant trend in small hydro is to take advantage of the head and existing flow release patterns to avoid the environmental and legal complexities that would ensue from alteration of present use. In effect, the trust is "let's develop what's presently lost through energy dissipation structures and get it on line quickly since we are at least aiding in meeting near term energy requirements."

There will, however, be instances of important environmental issues surfacing. An alteration of the flow pattern and released water quality will re-

quire careful documentation and analysis. Also, past mitigation omissions (such as anadromous fisheries' passage) will likely need to be corrected. Small hydro offers an opportunity for engineers to provide the leadership early in project development to identify and formulate solutions to potential environmental problems.

Factors Important for Feasibility

The reasons underlying the major national attention that is focussed on small hydro, an admittedly small element of the national energy array, is important in establishing the conceptual base for feasibility study methodology. Simply stated, they seem to be the national desire to move to energy independence, the current national concern for resource conservation and use of renewable resources, the potential for quick results from public and private efforts (an increasingly rare commodity in today's world), and most assuredly, the demand for nonfirm energy presently valued in many areas at 15 to upwards of 40 mills per kWh as compared to 1 to 2 mills per kWh several years ago.

The sites typically have major civil works in place, are in non-Federal ownership (about one-half of existing hydropower plants are in non-Federal ownership), and are often in the low-head range (under 20 meters), with a significant number falling in the head ranges of less than 30 feet. The marketable output will most often only be energy with little, if any, dependable capacity and the value will therefore be due to fuel and operating cost savings rather than offsetting the need for new plants.

The feasibility of projects is expected to be quite sensitive to site-specific conditions. The modest project benefits will not likely support an extensive array of ancillary features such as long transmission lines, access roads, or significant site preparation. The nature of the market area load characteristics and present generating facilities servicing the load are critical elements in valuing power output. Areas served with major fossil fuel plants, or systems with high operating cost plants will be more attractive for small-hydro development. Investigation, design, construction management, and administration (the non-hardware elements of a project) are a major project cost burden. The feasibility study itself can be viewed as a significant financial burden warranting an investment type decision by the project sponsor prior to initiation of the study.

Small-Hydro Addition Planning Studies

The guide manual has adopted a standard sequence of preconstruction studies as follows:

1. Reconnaissance (should a feasibility study be performed?),
2. Feasibility (should an investment commitment be made?), and
3. Definite plan (The collective group of studies that are performed between an implementation commitment and construction initia-

tion that result in permit applications, preparation of marketing agreements and financial arrangements, and definition of design parameters). The manual is specifically designed to aid in the execution of the reconnaissance and feasibility studies.

Reconnaissance Study

The reconnaissance study is designed to reduce the potential chance of a subsequent unfavorable feasibility finding and maximize the potential for identifying and moving forward to implementation of the attractive projects. It is a relatively complete small-scale feasibility study in which the important feasibility stage issues are raised. A reconnaissance study should either recommend proceeding with a feasibility study or recommend termination of further investigations.

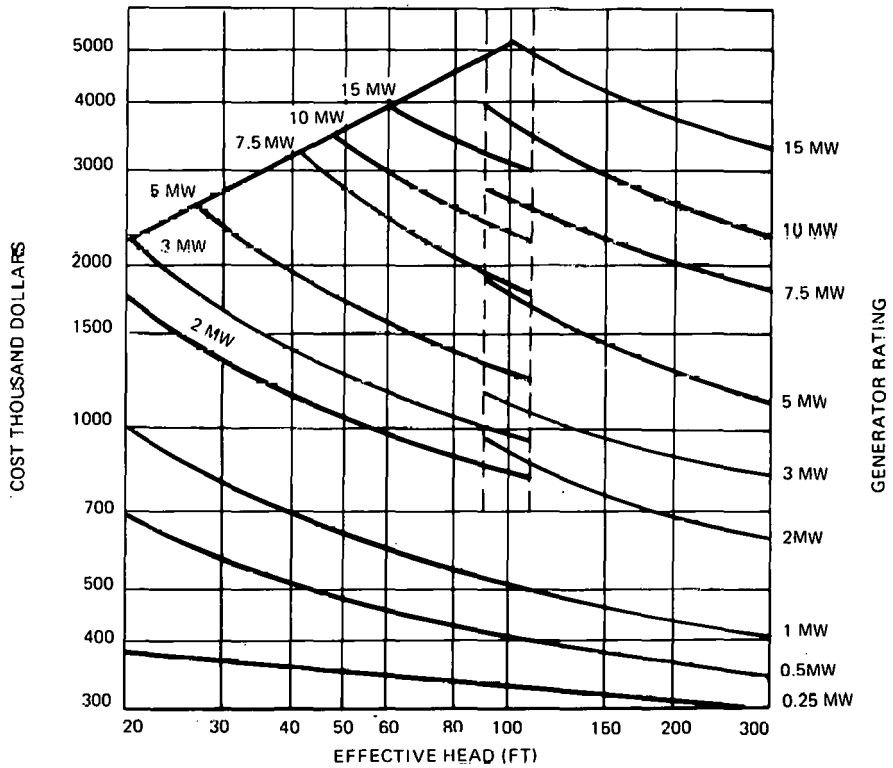
The strategy of performing a reconnaissance study is first to perform a preliminary economic analysis; and then identify and assess the issues that may be critical to implementation. The formulation of project features and determination of costs were determined to be a critical major task. The information for the feasibility analysis was consolidated into one chart (Figure M-1.1) to provide a basis for estimating construction costs at the reconnaissance level. Projects approaching the upper limits of the small-hydro capacity (15 MW) probably warrant using the more detailed and specific charts in the manual even for the reconnaissance estimate.

The value of power is the amount that the project proponent could reasonably expect to receive for the sale of the project output. A benchmark value is the fuel replacement cost that is usually reported by utilities to the FERC regional offices. A generous value in the range of 20 to 40 mills per kWh is considered reasonable in light of presently escalating fuel and operation costs. Economic feasibility is positive when the project benefits exceed the costs. The manual encourages adoption of the internal rate of return method of characterizing project feasibility.

Feasibility Study

The feasibility study is designed to formulate a viable small-hydro project, develop an implementation strategy and provide the basis for an implementation commitment. The significant legal, institutional, engineering, environmental, marketing, economic and financial aspects are to be identified, investigated, and definitively assessed in support of an investment decision. The objective is to formulate a power addition project that is economically attractive and consistent with modern concepts of resource planning and management. The findings of a feasibility study should be whether or not a commitment to implementation is warranted; and should the finding to positive, define the steps needed to assure implementation.

The selection of the installed capacity, the number of units, and the supporting ancillary physical works are the specific objectives of project formulation designed to develop one or more proposals with the greatest economic



NOTES:

1. Estimated costs are based upon a typical or standardized turbine coupled to a generator either directly or through a speed increaser, depending on the type turbine used.
2. Costs include turbine/generator and appurtenent equipment, station electric equipment, miscellaneous powerplant equipment, powerhouse, powerhouse excavation, switchyard civil works, an upstream slide gate, and construction and installation.
3. Costs not included are transmission line, penstock, tailrace construction and switchyard equipment.
4. Cost base July 1978.
5. The transition zone occurs as unit types change due to increased head.
6. For a Multiple Unit powerhouse, additional station equipment costs are $20,000+$58,000 (n-1) where n is the tital number of units.
7. Data for this figure was obtained from figures and tables in Volume V and VI.

FIGURE M-1.1 Power features cost - reconnaissance

value consistent with the array of development constraints. A project formulation strategy that progresses through three progressive stages of feature sizing and selection is suggested, beginning with a reconnaissance formulation as discussed previously, which yields a preliminary estimate of the project's installed capacity. The second stage incorporates machine performance characteristics in the formulation of several refined alternatives and yields a selection of the number and type of turbine units that consider site conditions and tradeoffs. The final stage of project formulation examines the performance of the more promising one or more alternatives in a sequential power routing analysis.

Economic and financial analysis have been carefully defined as having distinctly different purposes, and consequently, distinctly different (although very much similar) cost data. Economic feasibility analysis compares economic costs with project economic benefits while financial feasibility analysis develops the specific cash flow and assesses financing and repayment issues. The inclusion of cost and value changes in economic analysis should forecast the change in value for all aspects of the feasibility assessment, both the cost side and its several components, and the benefit side (e.g., alternative fuel costs) and its several components.

Guide Manual Overview

The manual *Feasibility Studies For Small Hydropower Additions* (HEC) 1979, is comprised of six volumes: Volume I, *Technical Guide,* overviews the investigation process for reconnaissance and feasibility studies, provides implementation guidance, coordinates use of the supporting five volumes and documents two case study applications. (The material comprising the substantive part of this paper was extracted from Volume I.) Volume II, *Economic and Financial Analysis,* includes criteria and procedures for marketing and valuing power output, determining economic feasibility, and analyzing financial requirements and issues critical to implementation; Volume III, *Hydrologic Studies,* describes investigations necessary to evaluate the hydrologic integrity of an impoundment and to estimate the power output of plant additions; Volume IV, *Existing Facility Integrity,* provides guidance for assessing the ability of a site to safely accommodate a power addition. (The volume is a rather complete guide to dam safety investigations.) Volume V, *Electromechanical Features,* describes selection criteria, performance characteristics and costs of small-hydro generation and ancillary equipment; and Volume VI, *Civil Features,* provides preliminary design and cost guidelines for the civil features of power additions. A glossary of hydropower terms is included as an appendix to the manual.

The manual is designed for use by the variety of organizations and private individuals that might study small hydropower projects for feasibility. The document is a guide, not a cookbook. A structure is presented within which the majority of studies are expected to fall. A feasibility investigation of sufficient quality to provide a basis for investment decisions requires the services of qualified professional engineers.

Status of Manual

The manual is presently (September 1979) undergoing final typesetting, and printing for public distribution. Priority distribution of advance copies have been made to the Department of Energy, Corps of Engineers field office libraries, and participants in the White House Rural Energy Initiative. General distribution is expected to be available in November.

Acknowledgments

The manual preparation was the responsibility of the Hydrologic Engineering Center, Bill S. Eichert, Director. The Corps' Institute for Water Resources sponsored the manual preparation as a complimentary task to the management of the National Hydropower Plan activities for which they are responsible. The Department of Energy provided funding support under their small-scale hydropower commercialization program. The preparation of the manual was a joint effort by staff of the HEC and several private consultants. The principal-in-charge was Mr. Darryl Davis of the HEC. The *Technical Guide* volume was written by the principal-in-charge aided by Mr Brian Smith, a member of his staff. The *Hydrologic Studies* was written by Mr. Dale Bernett of the HEC and aided by his staff. The remaining volumes were prepared under contract to the HEC as follows: *Civil Features* and *Electromechanical Features*—Tudor Engineering Co., San Francisco, CA; *Existing Facilities Integrity*—W. A. Wahler & Assoc., Palo Alto, CA; *Economic and Financial Analysis*—Development and Resources Corporation, Sacramento, CA.

REFERENCES

McDonald, Richard J., *Estimate of National Hydroelectric Power Potential at Existing Dams*, Institute for Water Resources, U.S. Army Corps of Engineers, July 1977.

Federal Power Commission, "Hydroelectric Power Resources of the United States, Developed and Underdeveloped," January 1976.

The Hydrologic Engineering Center and Institute for Water Resources, Davis, California, *Preliminary Inventory of Hydropower Resources*, 6 volumes, July 1979.

The Hydrologic Engineering Center (HEC), Davis, California, *Feasibility Studies for Small Hydropower Additions*, 6 volumes, July 1979.

Public Law 95-617, 95th Congress, 2nd Session, *Public Utilities Regulatory Policies Act*, November 1978.

MARKETABILITY OF LOW-HEAD HYDROPOWER

Stephen T. Lee, G. Paul Grimsrud, Man-Loong Chan, Eric Marsh, Glenn H. Masters, J. Randall Threadgill, and Abner W. Watts

Introduction

In these days of energy shortage and inflation, hydropower is an attractive indigenous energy source which is clean, renewable, and a shelter against future inflation. The Federal government has developed a major part of existing hydropower capacity and is able to expand that effort swiftly and effectively. But few premium sites for large-scale hydroplants, such as Grand Coulee, Hoover and Glen Canyon, remain to be developed. Therefore, future hydropower development will come largely from small-scale plants, which can be used for auxiliary power or be blended into existing power systems.

The Bureau of Reclamation is actively pursuing large and small hydropower developments. Currently, Reclamation has 31 appraisal and feasibility power study proposals underway in the 17 Western States. It is undertaking a Western States low-head hydro evaluation and inventory study, in coordination with the Corps of Engineers' National Hydropower Study.

Reclamation is also involved with the Department of Energy in several special studies to determine the potentials of small-scale hydropower. One study, by Tudor Engineering Company, will provide cost data for small hydroplants. An in-house study deals with design standardization of water passages to reduce cost, while another deals with the power system operation effects due to a large number of small-scale plants. A joint study with the National Marine Fisheries Service and Idaho Power Company investigates fish mortality caused by passage through low-head turbines. These are all important studies related to the supply side of small hydro. However, in order to fully understand the potentials of low-head hydropower, a market study looking at the demand side must be done. For that purpose, Systems Control, Inc. was selected. The result of that study is the subject of this paper.

The study was conducted in two phases. The first phase was a cursory screening of the nine reliability council areas of the United States, further subdivided into 12 regions, in order to select four geographically-dispersed areas which seemed to offer the most potential. These regions are shown in Figure M-2.1. The second phase was a more detailed study of these four selected areas - New England Power Pool, Mid-Continent Area Reliability Coordination Agreement (MARCA), Southeastern Electric Reliability Council (SERC), and the California portion of the Western System Coordinating Council. The rest of this paper will be a discussion of methodology used in the study and the most important results and findings.

Messrs. Lee, Grimsrud, Chan, and Marsh are associated with Systems Control, Inc., Palo Alto, California.

Messrs. Masters, Threadgill, and Watts are associated with Bureau of Reclamation, Engineering and Research Center, Denver, Colarado.

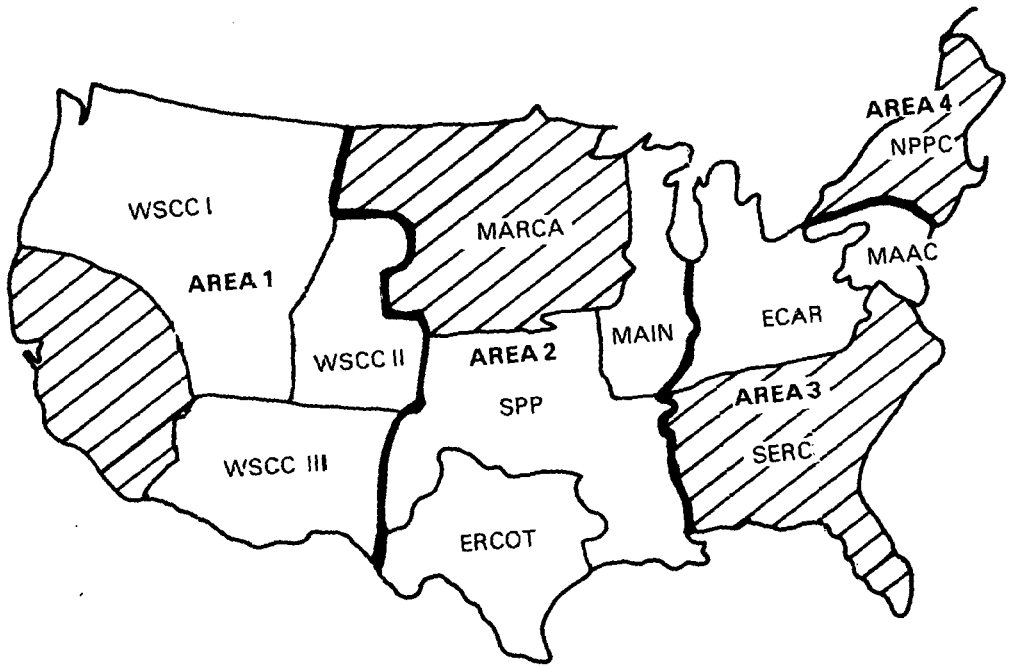


FIGURE M-2.1 Regions Selected for Phase II Analysis

Phase I Method of Approach

In Phase I, the 12 regions are ranked according to two criteria. The first is the total annual energy and capacity credit. The second is the average annual energy and capacity credit per potentially-installed low-head hydro capacity. The energy credit is based on average annual streamflow data for the river basins or portions thereof in the region. The potential hydro energy in each region is then given an average energy value based on the average fuel cost in the region.

The capacity credit defined in Phase I is the value of the firm capacity available during the month when the electric load in the region is at its annual peak. Furthermore, firm capacity is defined as that capacity for which there is a 90 percent confidence level of realization given the historical uncertainties of streamflow. Thus, conservatism is included in this evaluation.

To complete the valuation of firm capacity, the capacity value is obtained by averaging the annual fixed charges of the generation mix planned to be installed between 1977 and 1986 for each region. The results of the Phase I ranking are shown in an IEEE paper (1) as well as in the Final Report (2).

Phase II Method of Approach

Whereas the Phase I approach is adequate for a relative regional assessment and ranking, it is not suitable for the evaluation of specific hydro installations. Instead, a system analysis approach using a generation-expansion planning-model is adopted in Phase II.

This computer model called PUPS (Planning Unconventional Power Supplies) was originally developed by Systems Control, Inc. for the economic analysis of tidal power in the Bay of Fundy (3). It is ideal for estimating the market value of a new energy technology from the electric utilities' perspective. To the utilities, the value of low-head hydropower is measured by the savings in their revenue requirement if its power is available to them free of cost. In the cost-benefit analysis framework, these savings are the benefit to be compared with the cost of installation.

The best way to estimate the savings in revenue requirement is by comparing two long-term generation expansion plans. The base case is an expansion plan without low-head hydro in which the generation alternatives are the conventional ones available to the utility. The other case includes the fixed installation of a certain amount of low-head hydro, with the rest of the generation requirement supplied by the conventional alternatives.

The present worth of the revenue requirement is computed for each case. In the case with low-head hydro, the costs of hydro are excluded. Thus, subtracting the present worth of the hydro case from that of the base case gives the present-worth savings due to the low-head hydro installation.

Furthermore, to account for the life-cycle cost and benefit of hydro, the expansion plans are optimized by PUPS annually for 15 years (1985-2000) and their costs are extrapolated without real escalation for 34 more years, resulting in a 50-year life-cycle evaluation.

PUPS performs two main functions for each snapshot year: planning and simulation. Figure M-2.2 shows the block diagram for a snapshot-year analysis. The planning function is to optimize the generation mix for achieving minimum fixed and variable costs and to satisfy a reliability criterion. The reliability is measured by the Loss of Load Probability (LOLP) criterion commonly accepted by electric utilities. Therefore, the capacity credit of low-head hydro is evaluated within the utilities' planning framework.

The simulation function is to dispatch the generation resources to serve the electric load over the year. Hydro and pumped storage are dispatched hour by hour. The remaining load is subsequently served by the thermal generation. From this simulation, the production cost (fuel and operating costs) is computed. Because of the hourly dispatch of hydro over a year, the seasonal as well as the daily coincidence between hydro generation and the system load can be captured accurately.

The analysis of low-head hydropower benefits was performed for several sites in each of the four regions. They are classified as firm flow, seasonal flow and random flow. The generation expansion planning was carried out for each market area using aggregate information for the region. A description of each market in terms of present and future loads, generation mix, capital and fuel costs, etc. was established using the best readily-available data. All costs were computed in terms of constant dollars, including any real cost escalation, e.g., for fuel. Private financing was assumed for both market values and low-head hydro costs. Basic economic parameters and discounting procedures were consistent with the recommendation of the Electric Power Research Institute (4).

In addition to the PUPS analysis, the fuel cost savings due to low-head hydro's potential spinning reserve contribution are estimated by interpreting previous work. Extrapolating the results of other studies also provides an estimate of the potential transmission and distribution credit associated with hydro sites that are close to some local load centers (5).

Finally, the effects of different interest rates and different real escalation rates for fuel costs on the cost and benefit of low-head hydro are investigated using PUPS.

Conclusions

From this study, the following conclusions were drawn:

- The break-even capital cost for low-head hydro is in the range of $600 to $1780 per kW (in 1979 dollars), with private financing. The higher credits are associated with the firm-flow sites having a high capacity factor while the lower credits are given to sites with seasonal flow and low capacity factor.
- Based on the Tudor Engineering Company's analysis, the capital cost of low-head hydro ranges between $480 and $2880 per kW (in 1979 dollars), depending on the site and flow characteristics. This range overlaps the range of break-even capital cost.

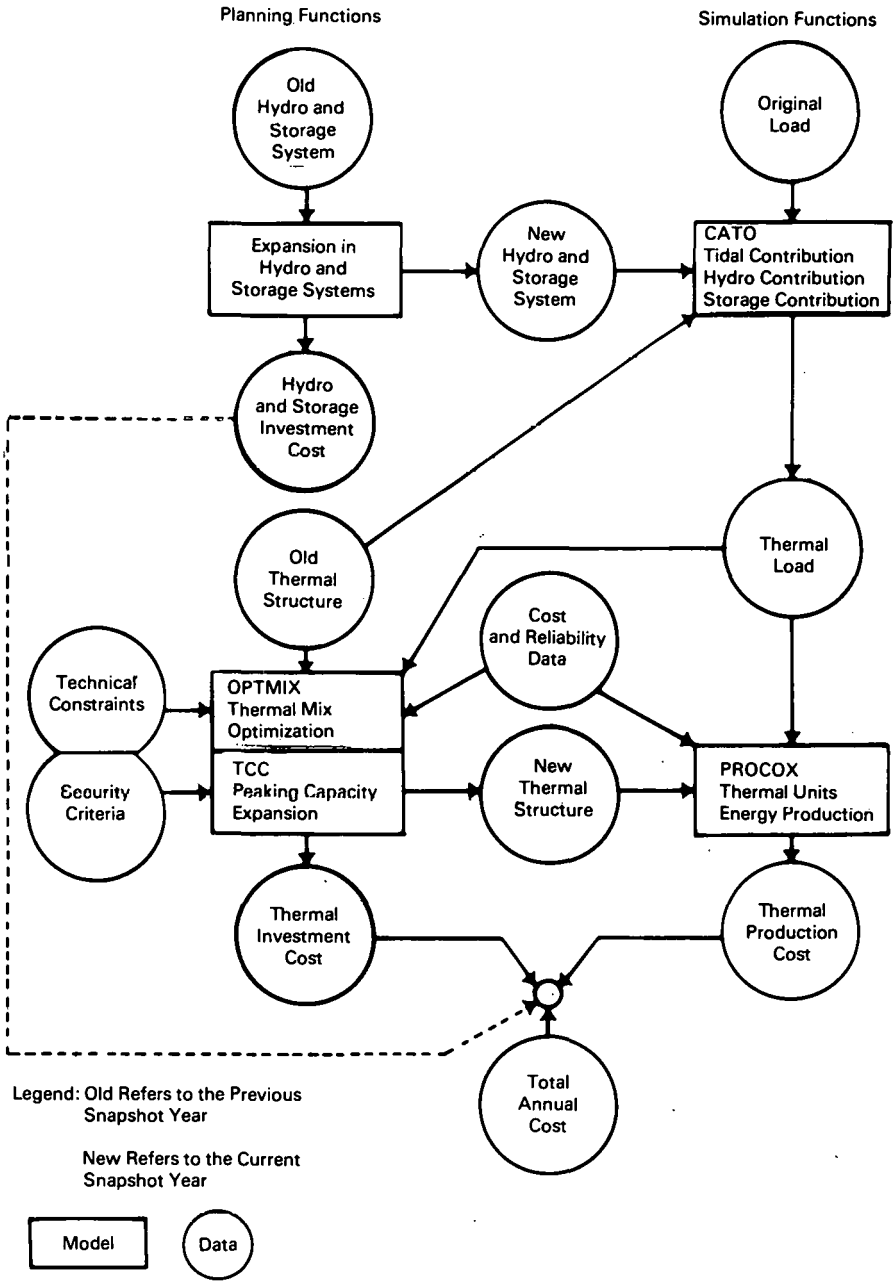


FIGURE M-2.2 Functional Relationships for Generation Planning and Simulation in a Snapshot Year

- The average benefits of low-head hydro expressed in 1979 values are 43, 42, 32 and 31 mills/kWh in California, New England, SERC and MARCA, respectively.
- The benefits due to spinning reserve contribution could amount to $20 - $70 of capital cost credit per kW of low-head hydro capacity.
- The capital cost credit due to transmission and distribution savings for some suitably located low-head hydro sites could be $100 - $300 per kW of hydro capacity
- The sensitivity analyses show that the benefit-cost ratio of low-head hydro would be improved by about 5% for every percentage point increase in the fuel cost real escalation rate, and by about 6% for every percentage point drop in the interest rate.

REFERENCES

Grimsrud, G. P., M. L. Chan, L. Isaksen, and S. T. Lee, "Marketability of Low-Head Hydropower," IEEE Paper F79826-9 presented at the 1979 Joint Power Generation Conference, Charlotte, North Carolina, October 7-11, 1979.

Lee, S. T., G. P. Grimsrud, and M. L. Chan. *Marketability of Low-Head Hydropower.* Systems Control, Inc., Palo Alto, California, prepared for Bureau of Reclamation under Contract No. 8-07-83-V-706, July 1979.

Lee, S. T., C. Dechamps, "Mathematical Model for Economic Evaluation of Tidal Power in the Bay of Fundy," IEEE Transactions on Power Apparatus and Systems, Vol. PAS-97, No. 5, September/October 1978, pp. 1769-1778.

Lee, S. T., J. Peschon, "Impact of Dispersed Generation on Transmission and Subtransmission Requirements," presented at the 1979 Joint Power Generation Conference, Charlotte, North Carolina, October 7-11, 1979.

Electric Power Research Institute. *Technical Assessment Guide.* Special Report PS-866-SR, EPRI, Palo Alto, California, June 1978.

SMALL-SCALE HYDROPOWER DEVELOPMENT: HOW NEW HAMPSHIRE IS MAKING IT HAPPEN

Louis H. Klotz, Fred K. Manasse, and David B. Master

The State of New Hampshire is first in more than just the presidential primary. Along with other New England States, New Hampshire led the way in developing its rivers' small-hydro potential throughout the 17th, 18th, and 19th centuries. As late as 1948, 68 percent of the State's installed electrical generating capacity was hydroelectric power. Now, as interest throughout the country is growing, New Hampshire citizens have gone further ahead in creating a political, economic, and regulatory environment which encourages the development of small-scale hydro resources.

Late in April of 1977, a special commission set up by the Governor of New Hampshire concluded its study on the potential of small-scale hydropower development in the State with the statement:

> The resulting economical and financial feasibility of reactivation is presently not sound and small hydro stations will not help to significantly alleviate the energy crises . . . capital can be invested in more viable projects (energy or otherwise) then reactivation of small hydroelectric stations.

At the time it might have seemed that the Governor's commission had reached a sound conclusion: The resource base was unknown, the actual number of developments had been minimal and there had been little concerned public or private effort to suggest a contradictory conclusion. However, shortly after the report was published, a series of activities began or "surfaced" across the State that indicated a much different conclusion by other profesionals and the citizenry at large.

In September of 1977, a long planned national workshop on policy involved with small-hydro development throughout the country was held at the University of New Hampshire in Durham. The meeting was sponsored by ERDA, now Department of Energy (DOE), and its principal aims were to identify needs and to suggest a suitable Federal program for redevelopment of small-scale hydro.

Some 120 experts from all parts of the United States and a select representation from foreign countries sat down to the first comprehensive discussion of development problems and policy options. Topics ranged from an examination of the adequacy of available technology to the development barriers created by various types of government regulation. The resulting policy recommendations laid the groundwork for most of the newly-formed Department of Energy's hydro commercialization program.

Shortly after the hydro conference in Durham, New Hampshire's Senator John Durkin introduced a number of pieces of legislation in Congress

Dr. Klotz is Associate Professor of Civil Engineering at the University of New Hampshire.
Dr. Manasse is Vice President of AETA Corporation, a private consulting firm.
Mr. Master is Staff Associate at the University of New Hampshire and is Associate Director of New Perspectives, Inc.

designed to promote the country's small-hydro development. The most important of these measures, which were eventually passed as part of the Public Utilities Regulatory Policies Act of 1978 (part of the National Energy Act of 1978), included the present DOE loan program for both feasibility studies and actual development as well as regulatory changes in the Federal Power Act.

Simultaneous to these matters of national importance, an undergraduate study project, begun at Dartmouth College in Hanover, New Hampshire, began to develop information contrary to the resource and economic assessment found in the Governor's commission's report. This effort eventually developed into a public outreach activity involving two state-wide organizations: The New Hampshire Environmental Coalition and the Northern New England Center for Appropriate Technology. A state-wide conference in December of 1977, sponsored by both of these organizations, brought together a diverse group of academics, legislators, environmentalists, and government officials and helped catalyze and give coherence to the growing public support for small hydro throughout the state.

Simultaneous to these efforts, the Energy Law Institute at the Franklin Pierce Law Center in Concord, New Hampshire began a major DOE-sponsored study project on legislation, government policy, and other institutional considerations relevant to small-hydro development in 19 Northeastern States. To date, the results of this study project have been a series of documents which clearly delineate the Federal and relevant state regulatory processes, some cogent economic analyses of small-hydro development, a modeling effort performed by the Resource Policy Center at Darmouth College related to SSH market penetration in New England, and a series of regional conferences which have helped spur more private and public interest activity throughout the Northeast.

After the national conference in Durham, the University of New Hampshire continued to explore issues in small-scale hydro development and lend technical assistance to developers in the State. Feasibility work had already been conducted on a number of sites on the Salmon Falls River and a feasibility study on a North River site in Lee was also begun (as part of an EDA-sponsored business assistance program). Student projects which included preliminary feasibility study work, computer-based streamflow analysis, and an assessment of penstock options were conducted in conjunction with private studies on dams in Bethlehem and Union. Most recently, as part of a grant from the Public Service Company of New Hampshire to the Center for Industrial and Institutional Development for the publication of ten state-of-the-art reports on energy technologies; "Water Power, Its Promises and Problems" was written and will be publicly available in November, 1979.

In the fall of 1978, a major new piece of legislation, introduced by a state representative from a town with one of the few privately-owned sites selling power to an investor-owned utility, passed the New Hampshire Legislature. This law was entitled the Limited Electrical Energy Producers Act, and was designed to diversify the supply base of the State's electrical energy system by encouraging the production of electricity from small sites not using nuclear or fossil fuels. Specifically, the legislation exempted all such producers with a

developed output capacity of less than 5 megawatts from regulation as a public utility and mandated that franchised public utilities must buy the power from such sites if it is offered for sale. The price to be paid for such power and the resolution of disputes was left up to the State Public Utilities Commission.

Eight months after the bill had taken effect, in April of 1979, the Public Utilities Commission (PUC) issued a ruling concerning the rate structure for the purchase of electricity from limited electrical energy producers. After listening to testimony from the two major utilities in the state (which argued for a rate around 2¢/kWh), and that of representatives of small producers, and others in favor of developing small hydro (who argued for a broad definition of "incremental" costs and a higher price for power) the PUC set a rate of 4¢/kWh for "non-dependable capacity." Many people felt this to be a significant step forward in providing economic incentive for development, although some sentiment suggested that a higher price was justified. The PUC countered criticism of the set price with a statement that prices would be reviewed periodically. The only major issue which has yet to be resolved relative to the ruling is just what is meant by "dependable and non-dependable." This may be subject to interpretation on a case-by-case basis.

In 1978, DOE awarded four PRDA contracts for feasibility studies in the State at Bethlehem, Goffstown, Sewell's Falls in Concord, and Northumberland. In 1979, the Brown Paper Company in Berlin, New Hampshire was one of eight national recipients of a Program Opportunity Notice award to assist in actual reactivation of a 2700 kW site on the Androscoggin River. Lastly, the town of Ashland was granted feasibility study money under the recent Appropriate Technologies grant program which was sponsored by DOE in the Northeast. For a state with a population of only 830,000 people such federal support seems extraordinary.

Simultaneous to some of the activities indicated above were three additional information/citizen-involvement efforts made by in-state groups. First, the League of Women Voters of Durham held an evening program on small hydro in March of 1979. The program had a panel format in which presentations were made and questions solicited from the audience. Some 100 interested people were present, including representatives from the major state utilities and the state legislature. The presence of state legislators was significant in light of additional legislation described below.

Next, the New Hampshire Environmental Network sponsored a Statewide conference in renewable energy policy on May 5, 1979, which was held before members of a mock State legislative subcommittee on energy. The Policy recommendations agreed to by the conference panel on small hydro included:

1. Support for rehabilitation of existing sites and the construction of new small hydropower facilities.
2. Creation of a State level, lead agency concept for obtaining rehabilitation and construction approvals and permits.

Finally, on June 12, the Governor's Council on Energy held a Statewide meeting for developers and bankers; an important effort in trying to bring together projects and financial backing.

In June of 1979, another major piece of legislation was enacted which has had a direct bearing on the economic climate for small-hydro development. The Limited Electrical Energy Producers Act was modified to allow for the direct retail sale of power by small producers for up to three purchasers other than a franchised electrical utility and to open up the option of wheeling along utility lines. Both these provisions were tempered with clauses which provide for the New Hampshire Public Utilities Commission's (PUC) determination that the public interest is being served and that all parties are reasonably compensated for any real costs. This bill may have very positive impact for small-hydro producers who can find buyers interested in negotiating long-term contracts at a fixed or slowly inflating rate.

In an interesting attempt to solicit local resource into national policy formulation on small hydro, Senator John Durkin held a formal U.S. Senate Subcommittee Hearing (the Subcommittee on Energy Conservation and Supply of the Committee on Energy and Natural Resources) in Nashua, New Hampshire on June 15th, 1979. This hearing drew responses from over thirty interested parties, representing every sector from developers to utilities to the environmental community.

The newest experiment in New Hampshire is the recently-formed Salmon Falls Hydropower Association. The Association is an independent organization with membership of diverse entities which own or have interest in small-hydro sites along the Salmon Falls River in the eastern part of the State. Its goals are to generate revenue from the sale of power, to produce power for on-site consumption, to increase or stablilize local property tax bases through hydro development, and, in general, to help support existing levels of industrial development in the region. Specifically, the agreement provides for the following scope of activities:

1. Provide a mechanism for ongoing communication and negotiation among members of the Association in order to facilitate the development process.
2. Explore methods whereby the management of the Salmon Falls River Basin might be improved for the mutual benefit of existing and potential hydropower producers and all parties utilizing the Salmon Falls River and watershed.
3. Determine and undertake appropriate cooperative development efforts for the purpose of reducing costs, facilitating the regulatory process and maximizing economic return from hydropower generation.

Membership in the Salmon Falls Hydropower Association does not imply any contractual obligations, but allows for participation in what is hoped to become an eventual effort to develop the entire river basin. The Strafford Regional Planning Commission is providing the member towns, cities, and private businesses with organizational assistance. The Center for Industrial and Institutional Development of the University of New Hampshire is providing technical coordination and support. Additionally, the town of Rollinsford and UNH have a written agreement whereby the University will be investigating the options of obtaining electrical energy from their redeveloped hydroelectric site.

The benefits of this small hydropower association became evident with the very first organizational meeting; that of focusing enlightened self-interest in small hydropower for the entire basin. This very local approach to unified action could well provide a model for the creation of a sectional focal point for the private sector to promote its desired actions in small hydro. A founder's committee has been organized to develop such an organization for future presentation to the small hydropower community.

REFERENCES

Klotz, Louis H., *Water Power, Its Promises and Problems,* Durham, New Hampshire.

Klotz, Louis H., "Notation for Series", *Energy Sources, Their Promises and Problems,* University of New Hampshire, Durham.

Master, David B., *Small-Scale Hydroelectric Power Redevelopment in New Hampshire,* Dartmouth College, June, 1978.

Brown, Peter W. and Anthony W. Buxton, *Legal and Institutional Obstacles and Incentives to the Development of Small-Scale Hydroelectric Power in New England and in the Mid-Atlantic States,* Executive Summary, University of New Hampshire, Durham.

Brown, Peter W. and Anthony W. Buxton, *Preliminary Report of Legal Obstacles to the Development of Low-Head Hydroelectric Power in the Northeastern United States,* University of New Hampshire, Durham.

Brown, Peter W. and Anthony W. Buxton, *Federal, Legal, and Institutional Obstacles and Incentives to the Development of Small-Scale Hydroelectric Power in the Northeastern United States,* Report and Executive Summary, University of New Hampshire, Durham.

Brown, Peter W. and Anthony W. Buxton, *Fundamental Economic Issues Involving Small-Scale Hydroelectric Power,* University of New Hampshire, Durham.

Brown, Peter W. and Anthony W. Buxton, *Monopsony and the Supply of Power from Small Generating Stations,* University of New Hampshire, Durham.

Klotz, Louis H. and Fred R. Manasse, *Low-Head/Small Hydro-Electric Workshop,* Durham, New Hampshire, September 6-9, 1977.

Banker/Developers Conference on Small-Scale Hydroelectric Development, Franklin Pierce Law Center, Sponsored by the Governor's Council on Energy (GCOE), June 12, 1979.

New Hampshire's Energy Plan: A Role for Alternative Energy, St. Anselm's College, Goffstown, New Hampshire.

"Salmon Falls Hydropower Association Agreements," University of New Hampshire, Durham, August, 1979.

Public Service Company of New Hampshire Notes For Sale of Power by Limited Electrical Energy Producers, New Hampshire Cooperative, Inc.

Public Utility Regulatory Policies Act of 1978 (Title II), pp 95-117.

Report on Hydroelectric Energy in New Hampshire Existing and Potential Development, New Hampshire Governor's Commission on Hydroelectric Energy, April, 1977.

Revised Statutes Annotated, DE 78-232, DE 78-233, Chap. 263-A.

State of New Hampshire House Bill 771-362-2-a.

THE OPTIMIZATION OF CIVIL WORKS DESIGN FOR SMALL-SCALE HYDROPOWER PROJECTS

Kenneth R. Broome and Howard A. Mayo, Jr.

Introduction

The overriding distinction between small-scale installations at existing dams and typical larger hydropower projects is the much smaller proportion of money spent on civil works. This point is well illustrated by "Comparison of Cost Breakdown for Large Hydro vs Mini Hydro," from a paper by G. E. Pfafflin[1]. The percentage of cost for civil construction and equipment installation is shown as 80% for the large hydro project at Bonneville (626 MW, 16 M Head) compared to a range of 30-35% for the Mini Hydro project at Barker's Mill in Maine (1.5 MW, 16 M Head). The challenge in small-scale hydro work, of course, is of finding ways to reduce the total cost to a figure that will be competitive with alternative means of power generation. Equipment manufacturers have been actively developing programs of standardization that have made significant reductions in equipment costs possible over the last few years. Civil engineers have been equally concerned to find the lowest cost approaches to the design of the civil works aspects at each particular site but have not taken the same opportunity to standardize their portion of the design.

The difficulty in minimizing the cost of the civil works is that there is a much greater range of design alternatives and site conditions to be considered than is the case with the equipment design problem. A range of standard hydro-turbines can be developed with adaptors to suit either vertical or horizontal installation. Such machines can then be used to satisfy the requirements of every site within the size range. Generators and electrical equipment are already available as standard items. The very nature of the concept of retrofitting existing dams results in the need to consider unique Civil Works designs. Each dam was designed individually to suit the particular site conditions. (e.g., hydrology, geology, and topography). The purpose of this paper is to describe a systematic method of selecting the lowest cost approaches to the design of the Civil Works for Small-Scale Hydro power projects at existing dams, that recognizes the inherent diversity of site conditions.

Optimization Methodology

It is assumed for the purpose of this paper that a pre-feasibility study has

Mr. Broome is Principal Project Manager, Environmental Division, Gilbert Associates, Inc., Reading, PA.

Mr. Mayo is Manager Product Promotion, Standard Products Dept., Allis-Chalmers Hydro-Turbine Division, York, PA.

[1]Pfafflin, G. E., "The Importance of Standardization in the Development of Small Hydroelectric Sites," Canadian Electrical Association, Vancouver, B.C., March 1979.

already been carried out that determined a potentially feasible site having adequate head and flow and the existence of a market for using the power at that location at a particular selling price. The question that remains is: "Can hydro equipment be installed at this site, able to produce power at production costs sufficiently less than the selling price of competitive power over the life of the project to make it financially feasible?"

A methodology for determining the answer to this question is described in the following five steps:

1. *Identify and Quantify Applicable Constraints*
   Representative constraints are shown on Table M-4.1 grouped into Physical, Environmental, Economic, and Institutional categories. Where practical, these constraints should be quantified as criteria for comparing the design concepts to be developed in Steps 2 and 3.

2. *Develop Likely Alternative Design Concepts*
   A list of the most frequently used design concepts is shown in Table M-4.2 under headings of Forebay, Hydroturbines, and Tailwater Alternatives. Selections are made from those development alternatives that are compatible with the site constraints. The three or four most likely combinations are selected on the basis of professional judgment as candidates for further evaluation in Steps 3 and 4. (All the alternatives may be at one place at the site or may be situated at various locations.)

3. *Estimating Cost Differences for Candidate Concepts*
   Order of Magnitude cost estimates are made for the variable construction and operating cost aspects of each candidate concept. Aspects that are common to all concepts need not be considered in this step. Table M-4.3 shows a typical listing of variable construction costs. The only operating cost variables needing to be considered in this step are amortization of capital and average annual power output.

4. *Compare Candidate Design Concepts*
   The candidate design concepts are then compared with respect to conformity with constraints and cost of power. A numerical rating system can be used for evaluation of intangible factors as shown on Table M-4.4. One concept that best satisfies both intangible and economic considerations can then be selected.

5. *Develop and Analyze Selected Design Concept*
   The selected design concept is further developed to the stage where a complete conceptual construction cost estimate and time schedule can be prepared and the economic and financial analysis finalized. Any adequate contingency in the order of 15 to 25% of the estimated Civil Works costs and 5% of the equipment costs should be included.

TABLE M-4.1

TYPICAL CONSTRAINTS FOR DESIGN OF SMALL-SCALE HYDROPOWER

PHYSICAL CONSTRAINTS
- — CLIMATIC CONDITIONS
- — VARIATIONS IN HEAD DIFFERENCE
- — DAM TYPE AND CONFIGURATION
- — CONDITION OF DAM
- — HEADWATER POOL SHAPE, DEPTH, & VOLUME
- — FLOW DURATION DATA
- — TAILWATER CONDITIONS
- — TOPOGRAPHICAL LIMITS FOR SITING OF POWERHOUSE
- — CONSTRUCTION ACCESS
- — SPILLWAY SIZE AND LOCATION
- — FLOODWAY REQUIREMENTS

ENVIRONMENTAL CONSTRAINTS
- — NEED FOR FISH PASSAGE
- — LOW FLOW MAINTENANCE CRITERIA
- — PROXIMITY TO HISTORIC SITES
- — SUITABILITY OF IMMEDIATE SITE AREA AS A HABITAT FOR THREATENED OR ENDANGERED SPECIES
- — IMPACT ON EXISTING RECREATIONAL FACILITIES
- — NEED FOR FURTHER RECREATIONAL FACILITIES

ECONOMIC CONSTRAINTS
- — COST OF POWER FROM OTHER SOURCES
- — DEMAND FOR POWER IN THE VICINITY OF THE DAM
- — PROXIMITY TO TRANSMISSION LINES

INSTITUTIONAL CONSTRAINTS
- — EXISTANCE OR OTHERWISE OF LEGAL AND REGULATORY PROCEDURES TO ESTABLISH AN ECONOMIC RATE FOR PURCHASE OF POWER BY A PUBLIC UTILITY OR BY AN INDUSTRIAL CUSTOMER WITH BACK UP FROM A PUBLIC UTILITY
- — AVAILABILITY OF TAX EXEMPT FINANCING
- — EXEMPTION FROM OR LIABILITY FOR PAYMENT OF REAL ESTATE TAXES
- — EXEMPTION FROM WATER USE CHARGES

TABLE M-4 2

TYPICAL DESIGN CONCEPTS FOR SMALL-SCALE HYDROPOWER

FOREBAY		- DIRECT INTAKE THROUGH DAM - GRAVITY FLUME - OPEN TO ATMOSPHERE - CLOSED PENSTOCKS - SIPHON OVER DAM
HYDROTURBINES	HORIZONTAL	- TUBE TYPE BULB UNIT CROSS FLOW (OSSBERGER) REIN GENERATOR
	VERTICAL	- TUBE TYPE KAPLAN FRANCIS CROSS FLOW (OSSBERGER)
	INCLINED	- TUBE TYPE
	IMPULSE	- PELTON WHEEL
TAIL WATER	DRAFT-TUBE	- CIRCULAR CONE SHAPE RECTANGULAR CONE SHAPE STEEL & MASS CONCRETE PRECASE CONCRETE
	TAIL-RACE	- ASPHALT LINED CHANNEL CONCRETE LINED CHANNEL EXCAVATED ROCK CHANNEL

TABLE M-4.3

TYPICAL VARIABLE CONSTRUCTION COSTS FOR COMPARISON
OF CANDIDATE DESIGN CONCEPTS

DESCRIPTION	SCHEME "A"	SCHEME "B"	SCHEME "C"	SCHEME "D"
EXCAVATION & DEMOLITION	386,000	$ 413,000	$ 366,000	$ 379,000
CONCRETE WORK	390,000	471,000	537,000	527,000
SUPERSTRUCTURE CONSTRUCTION	35,000	75,000	103,000	75,000
MECHANICAL & ELECTRICAL EQUIPMENT	2,374,000	3,403,000	3,403,000	3,164,000
TEMPORARY CONSTRUCTION FACILITIES	81,000	74,000	95,000	74,000
TOTALS	$3,266,000	$4,436,000	$4,504,000	$4,219,000

NOTE: COST SHOWN ARE FOR COMPARISON ONLY, ITEMS COMMON TO ALL SCHEMES HAVE BEEN OMITTED.

TABLE M-4.4

TYPICAL COMPARISON OF CANDIDATE DESIGN CONCEPTS

COMPARISON FACTORS	ALTERNATIVE SCHEMES A HORIZ D/S	B VERT D/S	C VERT U/S	D SIPHON D/S
1. ENVIRONMENTAL				
1.1 HUMAN				
A. PRESERVATION OF THE HISTORIC AREA	10	7	5	7
B. PRESERVATION OF RECREATIONAL AMEN.				
(1) CANOEING	5	5	5	5
(2) FISHING	5	5	5	5
(3) SCENIC	10	7	5	7
1.2 TERRESTRIAL & AQUATIC BIOLOGY				
A. FISH PASSAGE COMPATIBILITY	5	7	10	7
B. MAINTENANCE OF WATER QUALITY	5	5	5	5

Table M-4.4 continued

2. INSTITUTIONAL				
2.1 ACCESSABILITY	8	8	2	8
2.2 LICENSABILITY	10	10	10	10
2.3 MARKETABILITY	10	10	10	10
TOTALS	68	64	57	64
3. VARIABLE COSTS				
3.1 CONSTRUCTION COST $1,000's	3,266	4,436	4,504	4,219
3.2 DEVELOPMENT COST	-	-	-	250
TOTAL VARIABLE COSTS	3,266	4,436	4,504	4,469
ORDER OF PREFERENCE	1	2	4	3

Optimization Principles

While the selection methodology is quite straightforward, the identification of alternative concepts is surprisingly difficult. The best approach seems to be to check every possible alternative for each major portion of the system against the governing constraints. On several occasions, a minor variation of a basic concept has proven to be suitable even when the first trial did not appear to be so. The following principles apply when developing the candidate concepts:

- Minimize new construction and use as much of what is existing as can be relied upon and will serve the purpose.
- Avoid or minimize the use of temporary works such as cofferdams and bulkheads whenever possible.
- Eliminate buildings needed primarily for weather protection. (It can be provided more economically by integral equipment housings.)
- Eliminate personnel facilities.
  (These stations will be unattended most of the time.)
- Eliminate permanent cranes.
  (Mobile cranes are quite suitable for installation and infrequent overhauls.)
- Increase the available head and power generating potential by use of collapsible flashboards that do not increase upstream flood damage exposure.
- Increase project benefits by the inclusion of water supply improvements, the addition of recreational facilities, or the enhancement of downstream aquatic habitats by low flow augmentation and/or regulation.

There is a temptation in doing small-scale hydropower feasibility studies to take a short cut by using engineering judgment in selecting any physically suitable concept as likely to be representative of what will finally be designed. This approach is likely to be unduly conservative. Conversely, the desire to justify a project may induce over optimism. Shortage of funds for doing the feasibility study usually adds to the pressure. The answer to this dilemma is to use a systematic approach to the selection and comparison of the three or four most likely concepts as described above. It takes less time to identify all the likely alternatives, compare them and select the best, than it does to make premature selections based solely on intuitive judgment, then have second thoughts, and have to do all the estimating and analyses over again at the last minute.

TABLE M-4.5

SUMMARY OF PROJECT CHARACTERISTICS FOR SMALL-SCALE HYDROPOWER INSTALLATIONS AT FLAT ROCK DAM AND CARLISLE DAM, PENNSYLVANIA

PROJECT CHARACTERISTICS	FLAT ROCK DAM	CARLISLE DAM
HEAD RANGE	17-20 FT.	5.1-8.5 FT.* 5.1-7.5 FT.
MEAN ANNUAL FLOW	2691 CFS	578 CFS
MAXIMUM POWER OUTPUT	3531 kW	196 kW* 160 kW
AVERAGE ANNUAL POWER GENERATION	17,900 MWH	905 MWH* 735 MWH
AVERAGE COST OF GENERATION	42.6 MILLS* kWH	77.57 MILLS/kWH* 95.25 MILLS/kWH

*WITH 1 FT. FLASHBOARDS

Examples of Methodology Application

The feasibility studies for installation of small-scale hydropower used by the authors to develop the methodology described above are:

Flat Rock Dam - Schuylkill River, PA - Typical medium-size project.
Carlisle Dam - Conodoquinet Creek, PA - Typical small-size project.

Principal characteristics of the sites and results of these studies are shown on Table M-4.5. A commentary follows on the application of the suggested methodology to each site.

Flat Rock Dam

The entrance to the retired Manayunk Canal provides an extended forebay with several options for powerhouse locations providing various head differences, construction costs, and environmental impacts. Having selected a location immediately downstream of the Waste Weir, four different arrangements of forebay, hydro equipment, and tailrace were explored before selecting one. An enclosed powerhouse was chosen to provide adequate flood protection.

Carlisle Dam

There are extensive existing hydro facilities available at this very low head (less than 10 ft.) low flow (578 cfs average annual flow) site. Economics dictate, however, that they be abandoned in favor of mounting outdoor equipment right at the dam. A 60-inch diameter unit installed downstream of existing sluice gates and a 36-inch siphon unit mounted over the dam constitute the concept with the lowest construction cost. Excavation of rock to provide a tailrace in the creek bed maintains what little head difference exists. Use of flashboards to provide additional head also develops added storage needed for the water supply system. This project could only be considered feasible if the added benefit of the value of water storage is considered as well as the value of power generated.

Conclusions

Use of the methodology described in this paper may improve the Civil Works design approach, provided the full range of options for siting, waterways, equipment sizes and configurations, and housing are adequately considered. There is no way, however, to make sites feasible that have inadequate energy or market potential available. Use of the pre-feasibility study approach is recommended to avoid the expense and embarrassment of failure to achieve the impossible.

Session Seventeen

PLANNING, INFORMATION AND METHODS

Topic: Case Studies and Demonstration Projects II

Chairman: Mr. Farwell Smith
Acting Resource Manager
For Small-Scale Hydroelectric Applications
U.S. Department of Energy
Washington, D.C. 20461

THE ANNAPOLIS TIDAL POWER PILOT PROJECT

G. C. Baker, E. M. Wilson, H. Miller, R. A. Gibson and M. Balls

Introduction

In the early 1960's a barrier was built across the Annapolis River at Annapolis Royal (Figure N-1.1) to protect up-river farmlands from ingress of salt water at spring tides and to improve drainage of the heavy soils. The causeway was provided with sluice gates and fishway. The sluice gates are closed against high tides only when river flows are high, restricting the level of impounded water to 6.28m or less above local chart datum (cd).

The presence of this causeway and the range of the tide at the site present an opportunity for tidal energy generation. Such a development was considered when the works were designed but the costs appeared excessive and the idea was dropped. Since then the cost of energy has risen several times in real terms and new engineering ideas and techniques have appeared. So far as tidal energy in Canada is concerned, these new ideas have been thoroughly investigated during two series of studies into the Bay of Fundy and its tidal energy potential.

One of the innovations discussed in the Fundy reports is the straight-flow turbine with rim generator (Straflo). It became obvious that prototype demonstration of a large Straflo turbine would be advantageous for future Fundy schemes, in view of the potential saving in power station cost that might accrue. At least equally important is its relevance as a low-head river hydro-electric turbine. Detailed examination of its potential value in large low-head developments in Manitoba have been made and others in other Canadian provinces are pending. There are obvious advantages in combining both tidal and conventional prototypes in one machine, and since the salt water environment and tidal regime operation are the more demanding, a tidal installation is preferred.

In May 1977, the Tidal Power Corporation of Nova Scotia commissioned a study of a possible prototype Straflo plant at Annapolis Royal and a report was prepared in September 1977. Since that time, considerable further work has been undertaken by the Straflo Group in optimizing station design and energy output. Much of this work has been of an innovative nature and, although specifically for an ebb-generation tidal plant, the turbine specification and the variation of performance with the important parameters of speed, submergence and installed capacity, have relevance to low-head hydro projects. A longitudinal section of an earlier version of the one-unit Straflo station is shown in Figure N-1.2. The latest proposals involve somewhat deeper submergence.

Mr. Baker is Executive Vice President, Tidal Power Corporation of Nova Scotia.

Dr. Wilson is Professor of Hydraulic Engineering, University of Salford, Salford, United Kingdom.

Mr. Miller is Straflo Project Manager, Escher Wyss AG, Zurich, Switzerland.

Dr. Gibson is Systems Analyst, EPD Consultants, Sideup, United Kingdom.

Mr. Balls is Research Assistant, University of Salford, United Kingdom.

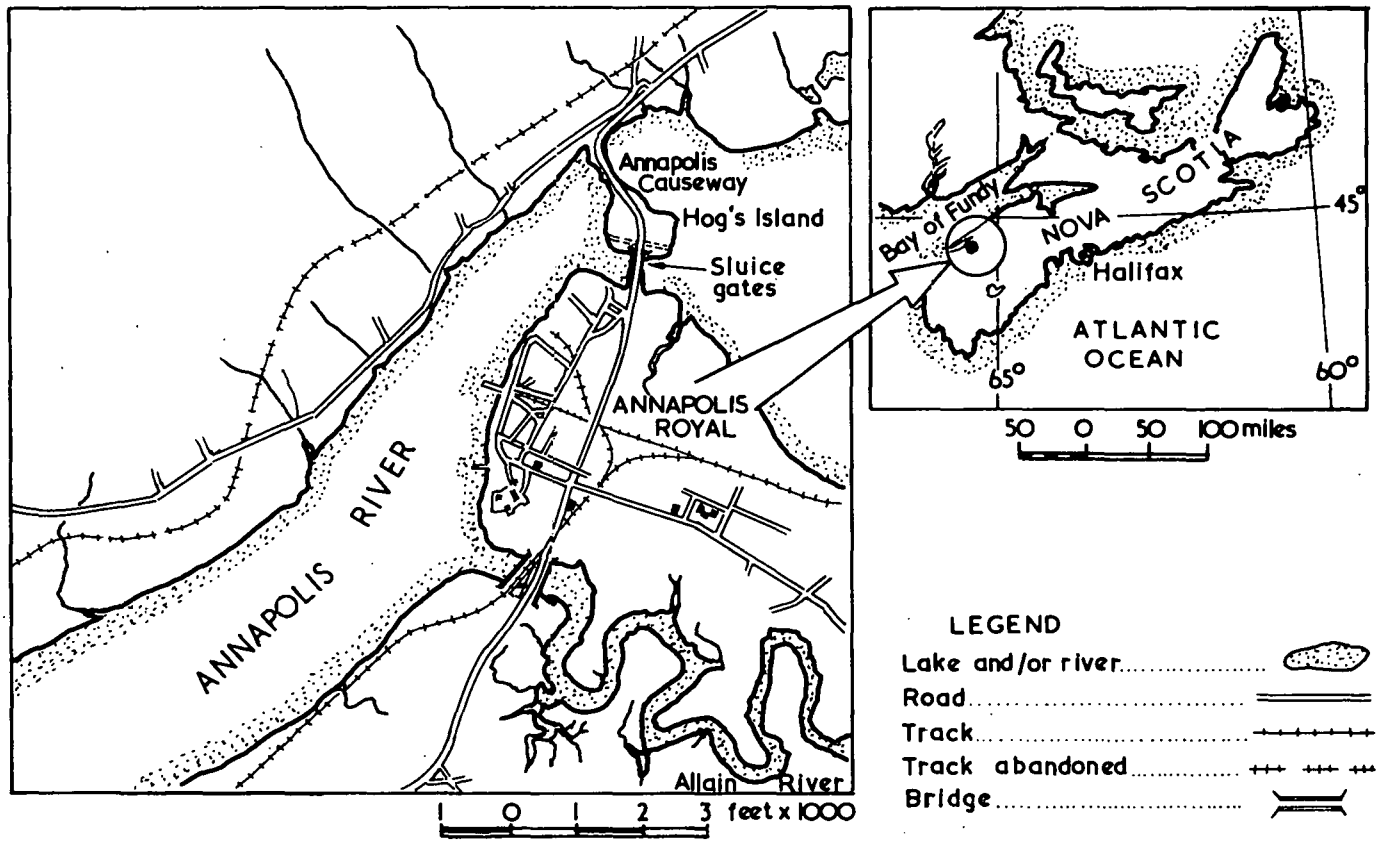


FIGURE N-1.1 Site Location

Generating Equipment

As proposed here, the Annapolis Royal tidal power station will consist of one Straflo turbine with fixed blades, adjustable guide vanes and a rim generator. The turbine runner will be 7.6m diameter.

The Straflo turbo-generator is a horizontal-shaft machine with the generator attached to the runner periphery which means that there is no driving shaft. The turbine and generator form a single unit, lying in one vertical plane, allowing easy erection and good access for maintenance. The compactness and orientation of the unit make for uncomplicated powerhouses of minimal volume, reduced construction time, and low cost.

The distinguishing characteristic of the Straflo unit is that the generator rotor is mounted on a rigid rim attached peripherally to the runner blades which gives the machine various advantages - no driving shaft; compactness; sufficient space on the rotor to accomodate the generator poles, even for large outputs and high frequencies; simple, efficient air cooling of the generator; very high inertia which ensures stable running and damping of power fluctuations. Hydraulic characteristics were supplied by the manufacturer, Escher-Wyss AG of Zurich. Generator efficiency was assumed to be 95% at all levels of production.

Computational Procedure

The computational work was undertaken using programs of the 'single tide optimization' type, that is where tides are considered one at a time as opposed to the consideration of successive cycles of naturally occurring tides. A year of tidal ranges was represented by a histogram containing ten bands. The central tidal range of each band was taken as being representative of that band. A computer program was used to determine the maximum energy output from each of the representative tidal ranges and the results were multiplied by the appropriate band frequency. The results for all bands were then summed to give the annual energy production. This single tide method has been shown to be almost as accurate as more sophisticated methods which use continuous tidal range simulation[4]. Programs of this type are efficient, easy to use and require limited computer time. Consequently, many combinations of machine blade angle, rotational speed and rated head may be studied.

It is also possible to study the effect of submergence of cavitation and energy availability at various setting levels. Programs were also written to determine the effect on energy production of varying the sluicing capacity, headpond level restriction and river inflow.

Discussion of Results

The results showed that an increase in the rated head leads to an increase in the generator capacity, hence increasing the annual energy output (Figure N-1.3). However, as the rated head and installed capacity increase, less and

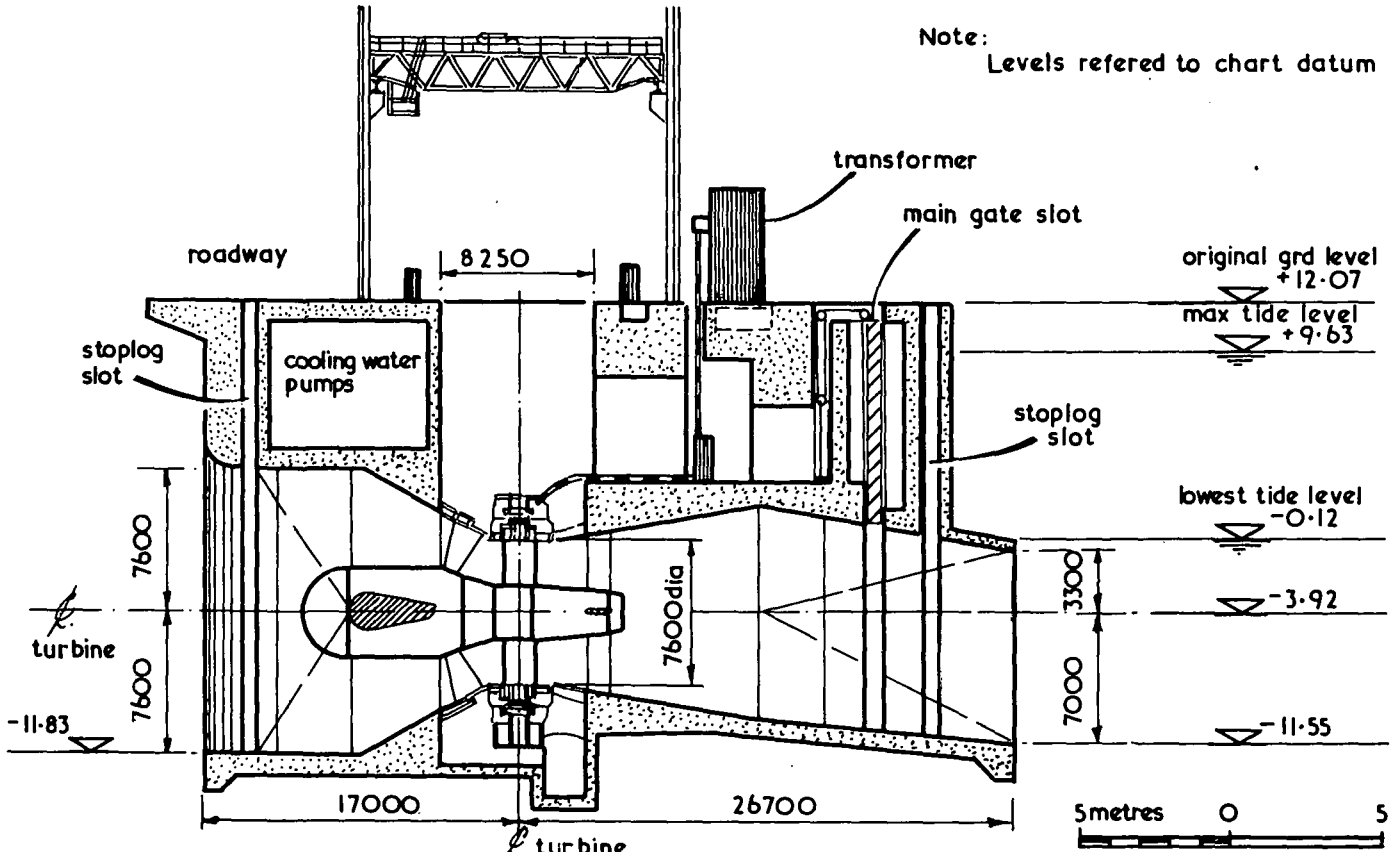


FIGURE N-1.2 Section Through Power Station

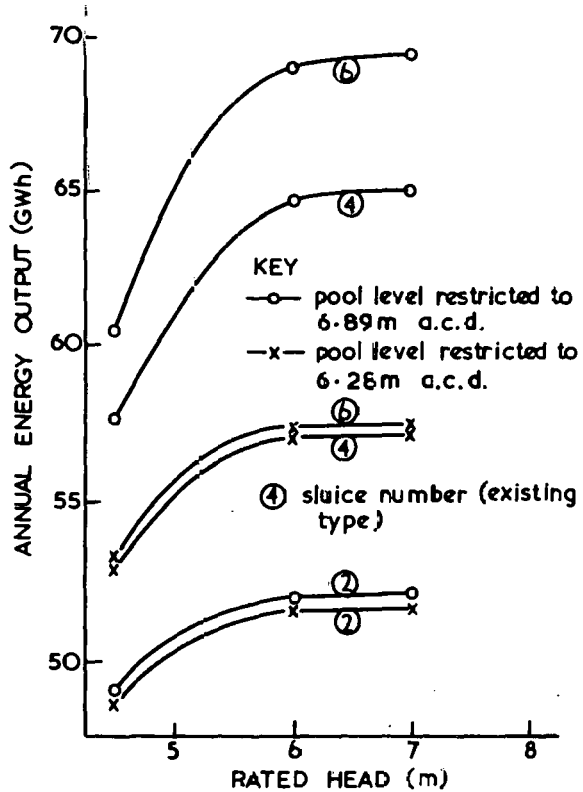


FIGURE N-1.3 Rated Head

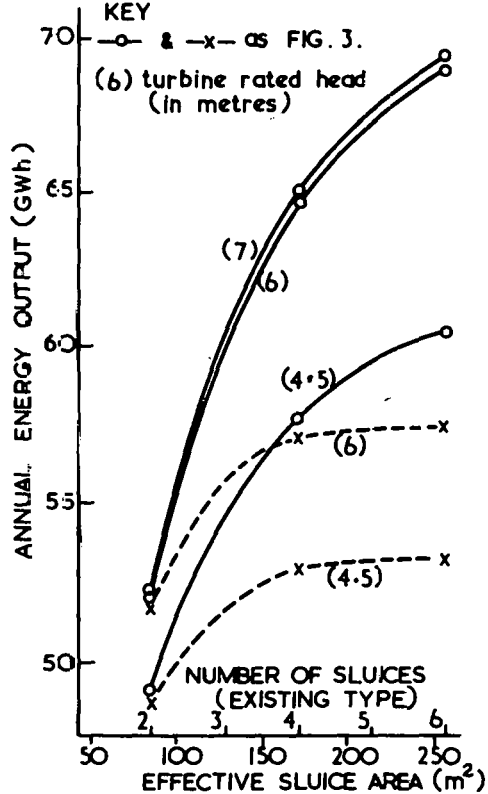


FIGURE N-1.4 Effective Sluice Area

less additional energy is realized for each incremental capital cost involved, and consequently, there is an optimum installation which minimizes the unit cost of energy.

It has become evident, as a result of current energy studies of ebb-generation tidal power schemes in the Severn Estuary (UK), that turbines of high specific discharge (which is dependent on widest acceptable blade angle, which is in turn dependent on depth of submergence) are desirable. Turbines of lower specific discharge, operated under similar conditions, invariably give lower annual energy outputs even though their hydraulic efficiency is better.

If rated head and blade angle are held constant and rotational speed is varied, that which maximizes the energy generation can be determined. In general, the optimum speeds were found to be between 50 and 60 rpm. Rotational synchronous speeds to maximize energy are given for various rated heads in Table N-1.1.

TABLE N-1.1
Annual Energy Production at Annapolis Royal

Headpond restriction m above cd	Rated Head (m)	Number of Sluices (Existing type) 2	4	6	
	4.5	48.5	52.9	53.3 GWh	
		16.5	17.0	17.0 MW	
		53.7	57.1	57.1 rpm	
6.28 (6ft amsl)	6	51.6	57.1	57.5	
		24.0	24.5	24.5	
		57.1	59.0	59.0	generator efficiency 95%
	7	51.6	57.2	57.6	
		27.5	28.5	28.5	
		57.1	59.0	59.0	
	4.5	48.9	57.7	60.5	
		16.5	17.0	17.5	There are currently two sluices
		52.9	57.1	58.1	whose total discharge capacity
6.89 (8ft amsl)	6	52.0	64.7	69.1	under 1ft head is assumed to be
		24.0	25.0	25.5	7,390ft³/s (209.3m³/s).
		56.3	60.0	61.0	
	7	52.1	65.1	69.5	
		27.5	29.0	29.5	
		56.3	60.0	62.0	

Table N-1.1 also shows the annual energy production that can be realized with headponds restricted to 6.28m and 6.89m cd respectively, with various sluicing capacities and rated heads, in each case. The same results are presented graphically in Figure N-1.4. River inflow was neglected when computing the values presented. Annual energy production increases with rated head, sluicing capacity and headpond level, but a sluicing capacity increase becomes worthwhile only when accompanied by a relaxation of the headpond restriction. This is because, on most tides, the existing two-sluice capacity is capable of refilling the headpond to 6.28m cd, but is inadequate to refill it to 6.89m cd.

The refilled and drawndown headpond levels are plotted against tidal range in Figure N-1.5 and Figure N-1.6 for the headpond restriction of 6.28m

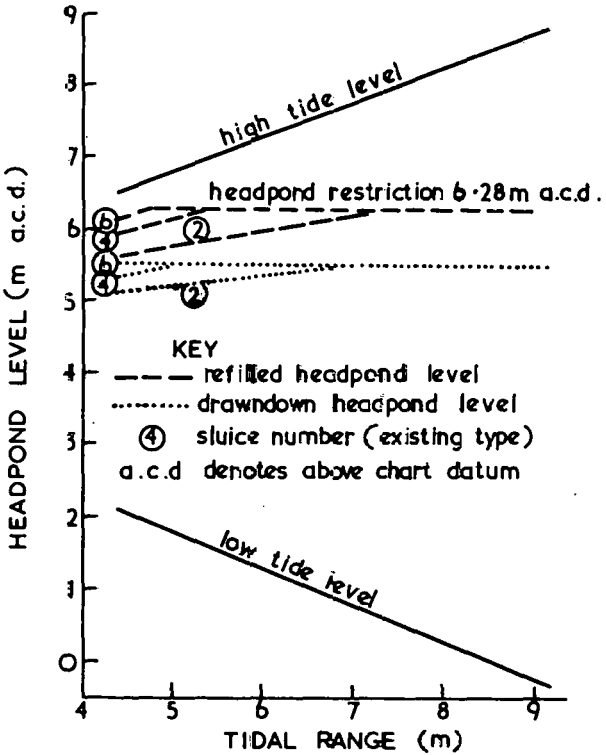


FIGURE N-1.5 Tidal Range for Headpond Restriction of 6.28m cd

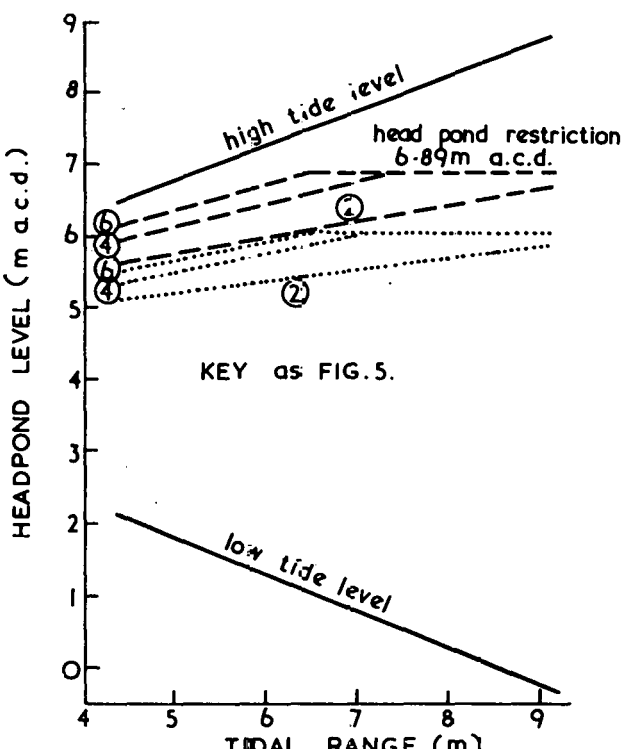


FIGURE N-1.6 Tidal Range for Headpond Restriction of 6.89m cd

and 6.89m cd respectively. It can be seen that for higher sluice capacities, the operation of the tidal power station is considerably influenced by the headpond restrictions. These two figures are plotted assuming a Straflo unit with a rated head of 6m.

To prevent cavitation, an adequate setting (measured to turbine centreline) is required for the units used for Table N-1.1. With a view to keeping excavation to a minimum, several computations were made using different turbine depth settings. The program was operated so that cavitation would not occur at any head or sea level. If cavitation was likely to occur, the specific discharge was reduced, which resulted in some energy loss. Turbine depth settings of 4, 5 and 6m below cd were studied. The results are shown in Table N-1.2 for headpond restriction of 6.28m cd.

TABLE N-1.2
Annual Energy Outputs in GWh/YR

Submergence	Speed (rpm)	Rated Head (m) 4.5	5.0	5.5	Assumptions:
-4m cd	45.0	46.0	47.3	48.0	1. Constant blade angle throughout.
	50.0	47.6	48.9*	49.6*	2. Turbines operated for maximum power
	55.4	47.9*	48.7*	48.7+	output.
					3. Existing sluices only.
-5m cd	50.0	47.6	48.9	49.6	* turbine operation partially restricted
	55.4	48.3*	49.6*	49.9*	due to cavitation
	60.0	45.3*	45.5+	45.5+	+ turbine operation completely restricted due to cavitation
-6m cd	50.0	47.6	48.9	49.6	
	55.4	48.3*	49.7*	50.4*	
	60.0	47.1*	48.0+	48.0+	

It may be seen from Table N-1.2 that cavitation becomes a limiting factor as the speed and rated head (and hence the specific discharge) of the unit increase. In some cases an increase in the speed and rated head would cause a decrease in energy output because of the need to restrict the operation of the turbine to avoid cavitation. Consequently, lower rotational speeds than those shown in Table N-1.2 were necessary to encompass the optimum energy production.

All energy computations discussed above neglected the effect of river flow into the headpond. In general, river flow is negligible in comparison to the mass of water brought into an estuary by the flooding tide. However, in the case of the scheme proposed here, where the estuary storage is comparatively small, the Annapolis River inflow is worth consideration. In an average water year, river flow would contribute approximately 9% of the total energy produced. The variation of annual energy output with average river flows is shown in Figure N-1.7. On the same figure the energy produced from representative tides is shown for a range of river flows. The unit in this case has a rotational speed of 50 rpm, a rated head of 5m and an installed capacity of 17.8MW. Appreciable gains from river flow are confined to tidal ranges below 6.9m for the low headpond.

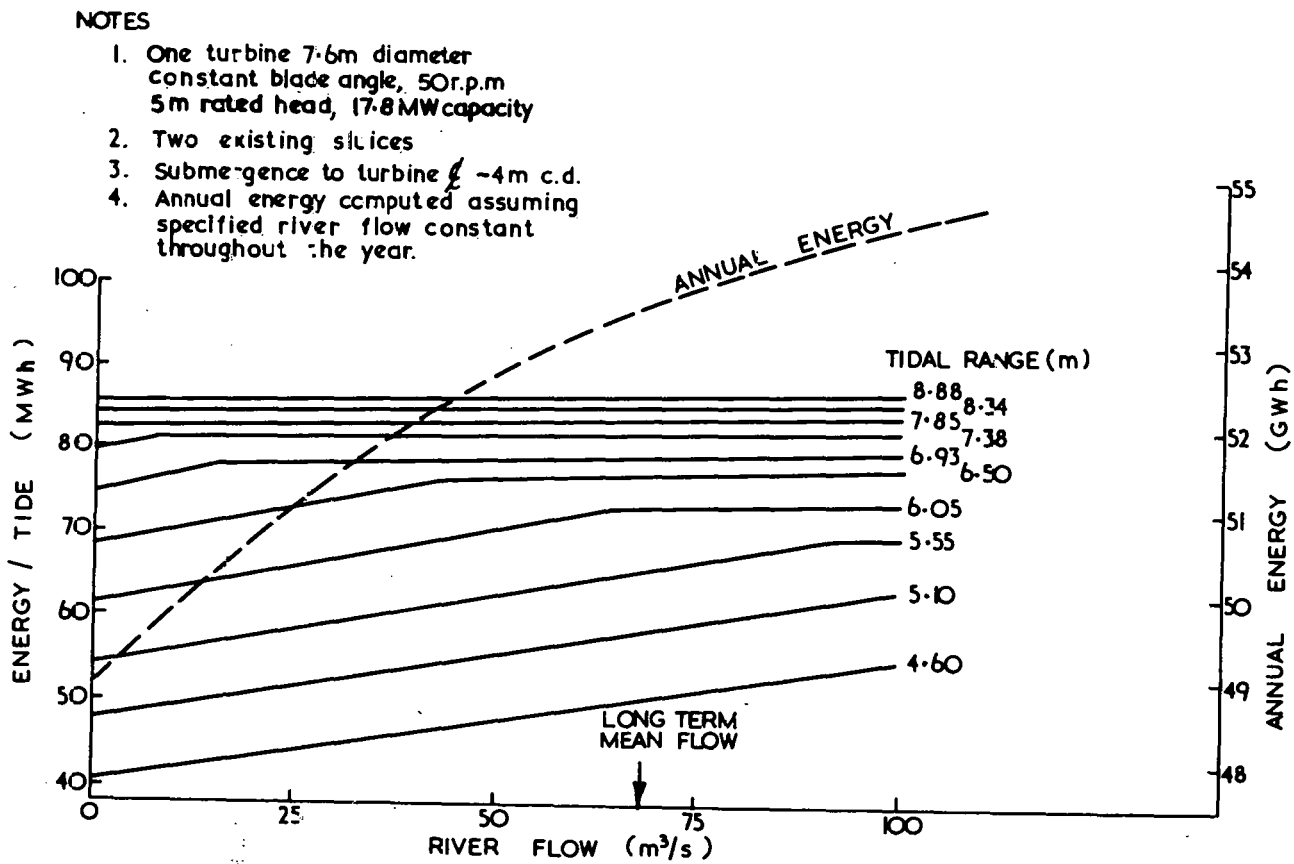


FIGURE N-1.7 Energy Output Including River Flow for Headpond Restriction of 6.28m cd

Relevance of these Studies to Low-Head River Projects with Daily Pondage

In plants with daily pondage which are used for peaking power, the advantages of high specific discharge (and hence high power output) may outweigh the costs of deeper submergence. In the case of Annapolis, for example, increasing the submergence from 4m below tail-water level to 8m allowed a power increase (for the same size turbine, headpond level and sluice capacity) of 35% . The effects on the cost of the power station was to increase it by 7.8% and to increase the project cost by 5.8% . Through increased energy production the cost per kWh is hardly affected. The power capacity in an ebb-flow tidal station is not firm, and so in this instance the deeper option has not been chosen. In a run-of-river station with pondage, however, the increase in power capacity could have substantial monetary value.

Conclusions

a) The need for some additional sluicing capacity arises if the headpond level restriction is relaxed as the existing sluices cannot refill the headpond to 6.89m cd on any tidal range.

b) Appreciable energy gains are possible if the headpond level restriction is relaxed from 6.28m to 6.89m cd. Such a relaxation should be accompanied by an increase in the rated head of the machine for best results.

c) Reducing the submergence of the turbine with a view to reducing the excavation costs leads to energy losses. Reduced submergence is also possible through reducing the specific speed of the unit. High specific speeds and/or high rated heads would lead to lower setting levels, which may be avoided by reducing the specific discharge over the critical range.

d) In an average water year the Annapolis River flow into the headpond would contribute approximately 9% of the total energy produced (53.2GWh) assuming a 17.8MW capacity unit.

REFERENCES

Atlantic Tidal Power Programming Board, "Feasibility of Tidal Power Development in the Bay of Fundy," Oct. 1969.

Bay of Fundy Tidal Power Review Board, Reassessment of Fundy Tidal Power, Dept of Supply and Services, Ottawa, Canada, Nov. 1977.

Hopper, H. T. et al, "Manitoba Hydro and Straflo Units," *Proceedings, 92nd EIC Annual Conference 1978,* St John's, Newfoundland.

Gibson R. A., "Optimal Production and Integration of Tidal Energy," PhD thesis, Univ of Salford 1978.

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

CASE STUDY - ROLLINS POWER PROJECT: BEAR RIVER, CALIFORNIA

David C. Willer

Rollins Hydroelectric Project, 11,000 kilowatts in size, now under construction in California, may be the premier small hydroelectric project of its kind at an existing dam that was conceived, designed and constructed as a result of the dramatic increase in energy cost after the Arab oil embargo. This plant will be generating power by the end of 1979. It is most interesting to note that the project was developed by a public district, Nevada Irrigation District, of Grass Valley, California, and, more importantly, was developed totally with private sources of funds; that is, no Federal, state or local taxes or loan funds were used. The existing and new project features are shown on Figure N-2.1.

In its role as a forerunner, the Rollins Project met and overcame many obstacles, thus paving the way for projects which are now following. Financially, the District had 7.8 million dollars in authorized but unissued revenue bonds remaining from the construction of the Yuba-Bear Project. These could be used for the Rollins Project, but if that amount was exceeded, other forms of financing the overrun, including possible additional authorization by the electorate to sell more bonds, would be necessary. Also, if the power were sold to an investor-owned utility, the bonds would take the form of Industrial Development Bonds (IDBs) and would lose their tax exempt status. The District's financial consultant indicated that the IDBs would carry an interest rate greater than the maximum allowed by California Irrigation District's law; i.e., eight percent. Therefore it was proposed, and later accomplished, that the District's law be amended to permit a higher interest rate, not to exceed 10 percent.

The most difficult physical constraint encountered was the necessity to pierce the plug in the original diversion tunnel for the penstock. There was no valve or control gate with which to close off the upstream side of the plug so that work could be performed without draining the reservoir. Several unique and challenging proposals were made for accomplishing the work under those adverse conditions. However, during the unprecedented drought in the summer of 1977, the reservoir water surface fell below the level of intake structure and the work schedule was accelerated to take advantage of the unexpected opportunity to pierce the plug in the dry. This work was approved and performed under the supervision of the Division of Safety of Dams, California Department of Water Resources.

The most unique aspect of the project was the procurement of the advance funds, and the marketing and disposal of the power. The District, using a feasibility study as a description of costs and benefits of the project, solicited

Mr. Willer is Manager, Water Resources Activities, Tudor Engineering Co., San Francisco, California.

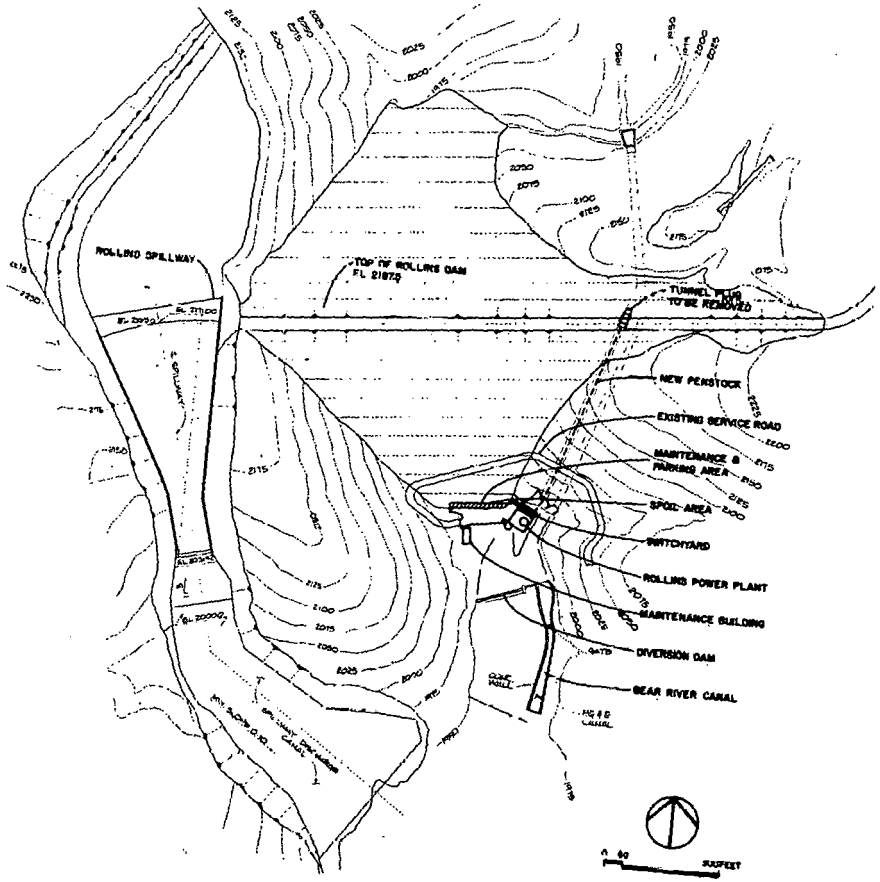


FIGURE N-2.1 Principal Features-Rollins Power Project

proposals from various public and investor-owned electrical utilities in the area. Certain minimum requirements were requested in each proposal. These requirements included:

1. a willingness to advance front end money;
2. guaranteed payment of debt service;
3. guaranteed payment of operation and maintenance costs;
4. an added incentive payment to the District of at least 4 mills per kilowatt-hour; and,
5. the willingness to escalate the added incentive payment as the wholesale value of power increases.

The Pacific Gas and Electric Company provided the most attractive overall offer to the District and subsequent negotiation resulted in a firm contract to sell power to them from the project. At the time of the offer, December 1975, the cost of the fuel oil being used to generate power resulted in a cost of energy of about 20 mills per kWh. This cost was considered the highest replacement value of energy in the PG&E system. The cost to develop power at Rollins was estimated to result in a cost of about 12 mills per kWh. Therefore, payment of 4 mills per kWh, one-half of the difference between the replacement value of energy and the cost to produce the energy, was approved as a fair royalty to the District.

Table N-2.1 shows the dates that the applications and permits were filed and when approvals were received. This table indicates that, with the exception of the time required to obtain water rights from the State of California, all other approvals were obtained in less than 12 months. The time required for water rights was due in part to slow processing by the State and to an intervention of a downstream irrigation district. The intervenor was eventually satisfied by the execution of a supplemental agreement between the two parties which primarily reiterated the District's intent not to cause harm to the other District.

Another significant aspect of the application process was the determination by the district and Federal Energy Regulatory Commission that no significant adverse environmental impact would be caused by the construction of the project. A negative declaration, prepared to fulfill the requirements of the California Environmental Quality Act, was submitted to Federal Energy Regulatory Commission by the District's Directors. This determination was reviewed by the staff of the Commission and, after further review and consultation, they recommended to the Council on Environmental Quality that no adverse impact would occur and a negative declaration should be issued.

The question of adverse impact on the local fisheries was not an issue. The release requirements from the dam were jointly developed 10 years previously with representatives of state and Federal governments to enhance the fisheries below Rollins Dam. (No fish passage facilities exist at Rollins because there are no migratory runs within the river.)

The construction cost for Phase II of the Project, bid by the joint venture of Nielsen Nickels Company and the Shirley Company in May, 1978, was $5,500,082 (($500/kW). The Phase I contract for piercing the tunnel plug amounted to $352,000. These costs are shown on Table N-2.2. The total cost

TABLE N-2.1

SCHEDULE OF APPLICATION AND PERMITS

Permits or Applications	Responsible Agency	Date Filed	Approval Granted	Months Before Approval
1. Water Right Application to Develop Power at the Site	State Water Resources Control Board	1/29/76	9/27/77	20
2. Environmental Impact Negative Declaration in Accordance with California Environmental Quality Act	Nevada Irrigation District	9/27/76	7/11/77	9
3. Amendment to License to Develop Power at the Site	Federal Energy Regulatory Commission (F.E.R.C.)	10/1/76	10/14/77	12
4. Water Quality Certificate (Sec 401 F.W.P.C.A.[1])	Regional Water Quality Control Board	2/20/77	5/11/77	3
5. Request to Lower Rollins Reservoir below Minimum Level	State Dept. of Fish and Game and F.E.R.C.	4/15/77	4/21/77	0
6. Application to Alter Permit Application No. 6333 (Sec. 404 F.W.P.C.A.[1] Permit)	Corps of Engineers Sacramento District	6/8/77	6/29/77[2]	1
7. Application to Make Alterations to a Dam	California Division of Safety of Dams	6/10/77	7/11/77	1

Table N-2.1 continued

8. Permission to Sell Phase I Bonds[3]	California Districts Security Commission	6/22/77	7/29/77	1
Phase II		1/11/78	9/20/78	8
9. Permission to Work in tunnel	California Division of Industrial Safety[4]		4/28/78	n/a

[1] Federal Water Pollution Control Act
[2] Not required
[3] For permission to sell revenue bonds
[4] Article 8422 D, Title 8, California Administration Code.
Classification of tunnel work required. Work was classified as non-gassy.

TABLE N-2.2

PROJECT COSTS — ROLLINS POWER PROJECT

Direct Costs: Account Number		Actual
331	Structures and Improvements	$ 876,000
332	Waterways	531,000
333	Turbine & Generator	2,479,000
334	Electrical	897,000
335	Mechanical	292,000
	SUBTOTAL	$5,075,000
Additional Work Items:		
	Road and Traffic Control	$ 110,000
	Toe Drainage for Dam	37,000
	Office and Warehouse Building	38,000
	Channel Diversion and Afterbay Excavation	90,000
	Remote Control (Including Equipment in Chicago Park Powerhouse)	150,000
	TOTAL PHASE II CONSTRUCTION CONTRACT	$5,500,000
Other Costs:		
	Tunnel Plug Contract (Phase I)	$ 352,000
	Turbine/Generator Purchase (PG&E)	112,000
	Contingencies	223,000
	TOTAL CONSTRUCTION COST	$6,187,000
Indirect Costs:		
	Development and Design	$ 640,000
	Construction Supervision, Surveys and Testing	425,000
	Legal Counsel	125,000
	Bond Issuance Costs	110,000
	State Treasurers Certification	28,000
	Funded Interest Less Accrued Interest (2 Yr.)	999,000
	TOTAL PROJECT COST	$8,514,000

of the project, including engineering, construction management, legal and financial consultation, and interest during construction, also shown on Table N-2.2, amounted to $8,514,000 ($774/kW).

The revenue bonds which were issued by the District for construction of the project were sold with an interest rate of 9-7/8 percent (taxable IDBs). The term of the bonds, 32 years, coincided with the years remaining on the District's FERC license for the Yuba-Bear Project. The total annual cost to PG&E is $1,243,000, including $884,000 for debt service on the bonds, $75,000 for estimated operation and maintenance costs, and $284,000 for the added incentive payment. With an annual energy production of 71.1 x 10^6 kWh, the cost of energy, delivered to Pacific Gas and Electric Company at the bus bar, is 17.5 mills per kWh.

To emphasize again, this project was developed by a public district, the Nevada Irrigation District in California, in partnership with Pacific Gas and Electric Company, and investor-owned utility, without the assistance of any Federal, state or local taxes or loan funds. It is believed that this type of arrangement can be repeated many times over for the benefit of our country's energy needs.

CASE STUDY - BROADWATER DAM POWER PROJECT: MISSOURI RIVER, MONTANA

Gordon E. Little

Introduction

Early in 1978 Tudor Engineering Company performed reconnaissance level feasibility studies for three small hydroelectric projects at existing dams in Montana. The dams were under the administration of Montana Department of Natural Resources and Conservation and had been selected from 40 projects for which statistical data had been compiled by the Department.

The most promising of the three sites studied was Broadwater Dam, located on the Missouri River near Toston, Montana. The dam was constructed by the WPA in the mid-1930s as a diversion dam for a 500,000-acre irrigation district. The dam has a concrete gravity overflow section 40 feet in height with seven 54-foot-wide bays. Flashboards are added during the irrigation season to raise the water level for diversion, but no active storage exists at the site. The annual average volume of flow is 3,700,000 acre-feet, and the average monthly flow is 5,200 cfs.

The PERDA Program of the United States Department of Energy (DOE) was announced about the same time that the study was completed. Under this program, grants for feasibility studies were to be made for selected low-head projects of less than 15MW. The State of Montana thereupon instructed Tudor to file a PERDA application for Broadwater Dam in order to investigate the project in more detail.

During the preparation of the application proposal, preliminary studies indicated that a powerplant with a very innovative design was considerably less costly than a conventionally-designed powerplant. The preliminary design used in the reconnaissance studies assumed a conventional out-of-channel location for the powerplant on the left abutment with excavated inlet and outlet channels.

The innovative design placed the powerplant on the downstream apron of the existing ogee crest dam. The turbines would be mounted vertically in the existing bays in an open flume configuration. Since the new powerplant would otherwise restrict the flood-carrying capacity of the dam, the rear wall of the plant would be removable and during periods of flooding the flows could pass over the turbine inlet and through the plant.

Inasmuch as it was felt that the apron-mounted alternative may have widespread application on many such existing dams throughout the United States, the Department of Energy was approached and agreed to fund the feasibility study wherein a detailed comparison would be made between the two alternative configurations. Owing to the unique apron-mounted configuration, a model study was included to identify any potential hydraulic problems during normal generation and to investigate the energy dissipation problems during the passage of flood flows through the powerplant.

Mr. Little is a Project Manager at Tudor Engineering Co., San Francisco, California.

Apron-Mounted Configuration

The apron-mounted configuration is presented on Figure N-3.1. For this alternative, two existing spillway bays near the left abutment would be split with a middle pier into two bays, each approximately twenty-four feet wide. Within each of the resulting smaller bays, a turbine-generator unit would be mounted, with the turbine shaft located approximately thirty-six feet downstream of the spillway crest. The turbine case and draft tube would be encased in a concrete spillway extension. The generators and other appurtenant plant facilities would be located in a superstructure mounted above the downstream spillway. An inspection gallery would be included immediately downstream of the turbine and a drainage and grouting gallery would be placed at the interface of the existing dam and the new structure.

The existing flashboard system, used to increase the water surface elevation in the reservoir during the summer months would be removed. Additional piers identical to those proposed for the turbine bays would be constructed. Radial gates, 24-feet wide by 12-feet high, would be installed in all bays to give better control of the upstream water level. A new service bridge with a movable gantry crane would be added for maintenance access to the gates.

In order for the flood flows to pass directly through the power bays, the rear wall of the powerhouse was designed as a fixed-wheel gate. During periods of high flow, the turbines would be stopped, and the fixed wheel gates raised to allow unhindered passage of the flood flows through the turbine bays.

Trashracks would be included upstream of the existing dam crest. They would be removed by the upstream gantry crane when the turbine bays were converted to spillway bays. A downstream, outside gantry crane would be included to facilitate the fixed-wheel gate removal and to insert stoplogs when necessary. The substation for the powerplant would be located on the left abutment. A new canal inlet structure would replace the existing structure on the left bank.

Selection of Turbine Size for Apron-Mounted Alternatives

The selection of a vertical shaft propeller turbine for the apron-mounted alternative was dictated by the physical constraints of the site; the low head required a propeller turbine and the placement of the unit on the downstream face of the spillway made a vertical shaft unit clearly the most suitable type.

The area of the inlet flume and the height of the water surface above the turbine entrance limited the size of the vertical turbine which could be installed and operated without vortices occurring in the entrance. The model

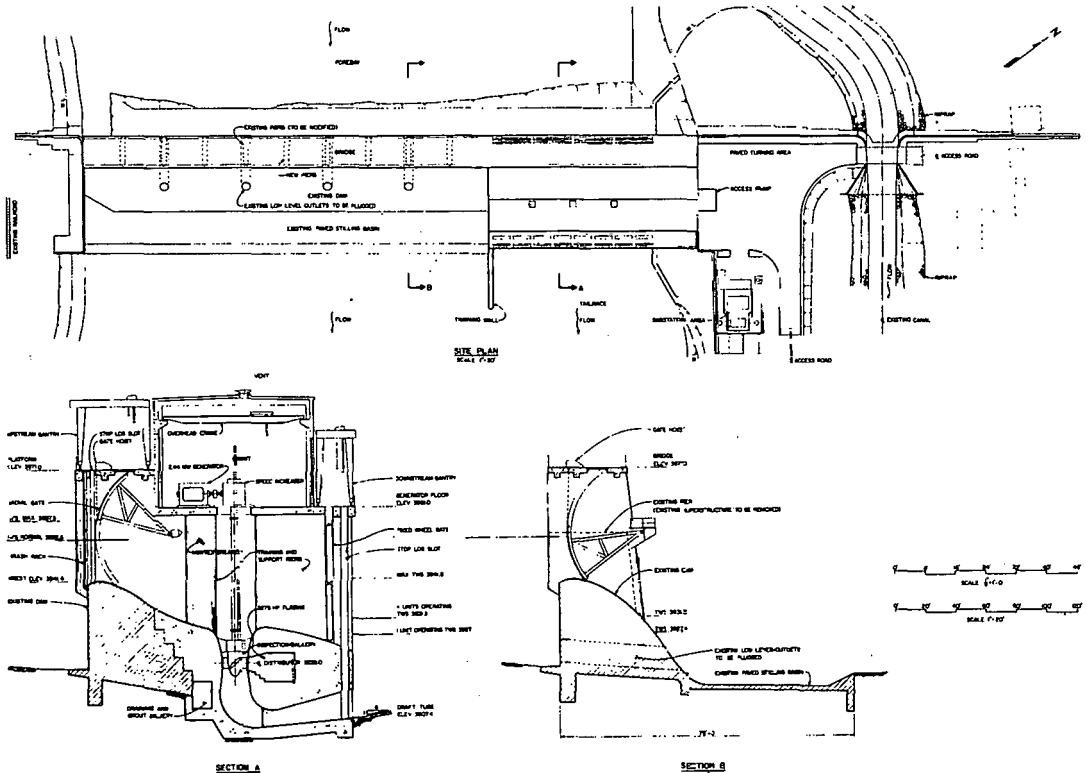


FIGURE N-3.1 Broadwater Dam Power Project Apron Mounted Alternative

tests established that vortices occurred with discharges above 1800 cfs through the turbine. A turbine with a maximum discharge of 1600 cfs was selected to provide a suitable margin of safety. The resulting turbine output at 22 feet of head is 2.44MW. Using these parameters, recommendations for turbine runner size were sought from turbine manufacturers. A standardized adjustable blade turbine runner with a runner diameter of 2750mm (9 feet) was found to meet these requirements. Installations of two, three, four and six turbines were then evaluated to determine the economically optimum number of units. The optimization analysis was based on the net present worth, the difference between the present worth of costs and the present worth of benefits over an assumed 50-year project life.

The optimization was very dependent on inflation. One feature of the economics of hydroelectric generation that is different from that of most other conventional sources of energy is the high ratio of initial capital cost to annual operating costs. There are no fuel costs, and little operating and maintenance expenses, so the annual cost is virtually constant over the life of the project. Thus, as inflation and the attendant escalation in the value of energy occurs, the increases in the value of the power are greater than the increases in the annual cost. The ultimate effect of this relationship is that, as the assumed inflation rate is increased, the optimum plant capacity also increases. The optimum number of units is therefore dependent upon the inflation rate assumed for the project life.

Cost estimates and average annual energy estimates were prepared for each combination of unit sizes considered. Based upon the estimates, discounted cash flow analyses were performed for various assumed rates of inflation, ranging from no inflation to eight percent inflation. It was found that under no conditions was the two-turbine installation optimal. For inflation rates under two percent, the three-turbine installation was optimal. At four percent, the four-unit installation became optimal and, above seven percent inflation, the six-unit installation became optimal.

Based on these considerations, the four-turbine installation with an installed capacity of 9.76MW was selected as optimum. If the future inflation rate later proves adding more units to be economical, they can easily be added because of the modular type of installation adopted.

Discussion of Model Studies

The model study for the project was performed by Hydro Research Science of Santa Clara, California. The results of the model study indicated that the proposed concept presented no major poblems. The study determined that the upstream pier within the power bay should be streamlined and that a vortex breaker should be added to smooth out the water surface at higher discharges. The location of the back power bay wall (fixed-wheel gate) was studied and the optimal location was determined.

It was found, under the flood mode condition, that the tailwater was sufficiently high to drown out the hydraulic jump of the water passing through the power bay, and the resulting turbulence was confined to the bay. It had been of some concern that the jump would occur downstream and that dissipation

and erosion problems would have resulted. The model study proved, however, that this would not be a problem.

Flood Mode Operation

It should be noted that the process of converting a power bay to a spillway bay would take about one hour. However, the necessity of such a conversion would be very infrequent. The hydrologic analyses indicate that with all other spillway gates open, one power bay would be necessary to pass a 20-year flood, two bays for a 33-year flood, three bays for a 53-year flood and all four bays for a 91-year or greater floods.

Conventional Alternative

The conventional configuration is presented on Figure N-3.2. The facility would consist of a powerhouse structure located outside of the river channel near the left abutment of the existing dam. Excavation would be necessary to provide an upstream approach channel to the powerhouse and a downstream tailrace. The dam would be fitted with radial gates, the same as proposed for the apron-mounted configuration. The existing headworks on the diversion canal would be removed and replaced by a new radial gate control structure located immediately adjacent to the new powerhouse. A breach crane would be located within the powerhouse structure for plant maintenance. The plant substation would be located on the left abutment of the dam.

Selection of Turbine Size

Because the conventional installation allows more flexibility in turbine selection, several configurations were evaluated. The turbine configurations assessed included one 10MW Kaplan turbine, two 5MW Kaplan turbines, one 10MW bulb turbine, two 5MW bulb turbines, four 2.5MW tube turbines, and five 2MW open flume vertical shaft propeller turbines.

Hypothetical operation studies using applicable efficiency curves were performed for each configuration to determine the power and energy generated. Since the turbine configurations studied required different civil features, preliminary designs and corresponding cost estimates were prepared for each. A present worth or net benefit analysis was then performed based on the cost estimate and estimated 50 year power revenues for each alternative. Based on this analysis, four tubular-type turbines at 2.5MW each were selected for the optimum conventional configuration.

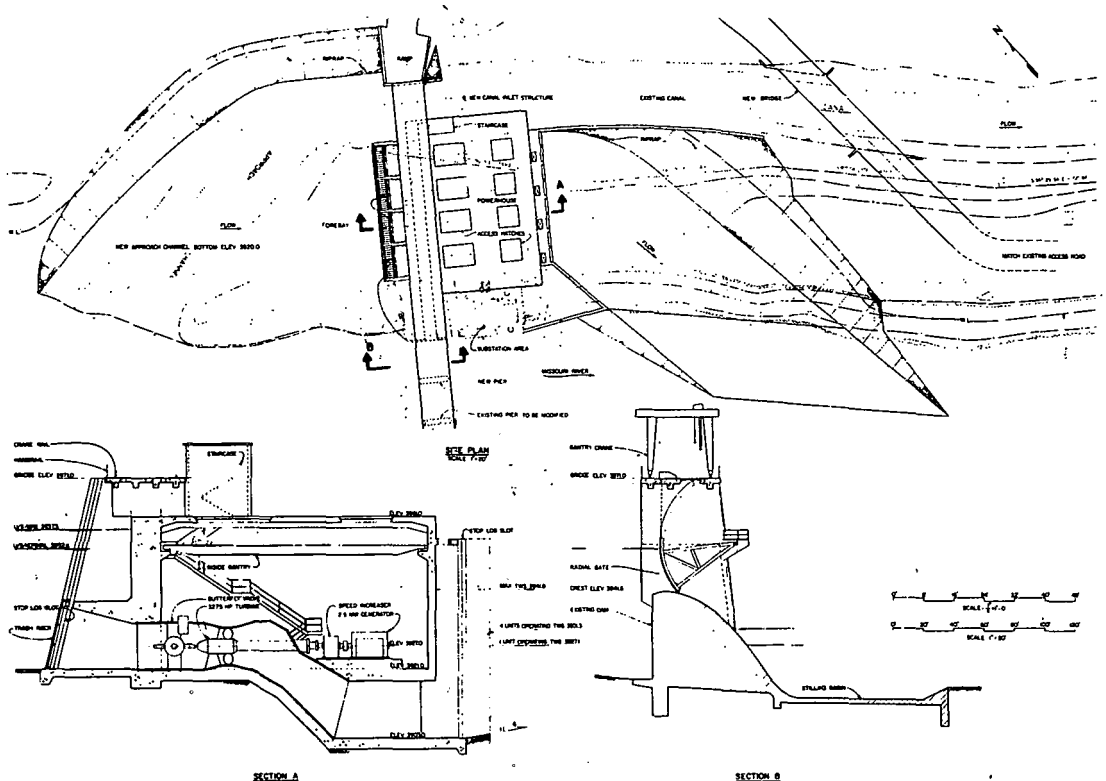


FIGURE N-3.2 Broadwater Dam Power Project Conventional Alternative

Project Financing

A number of possible financing sources for the project were investigated. These included taxable and non-taxable revenue bonds, DOE loans, and a USBR Public Law 984 loan. The net interest rates ranged from 6 7/8 to 10 percent and the loan terms from 30 to 40 years. All sources had their pros and cons and no single source was clearly desirable. The final method chosen will depend on the financial options available at the time the project is actually financed and whether the eventual power purchaser, is a tax-exempt or non-exempt power utility.

Project Power Production

Using a 50-year hypothetical operation study, the average annual energy production for both installations was 56 million kWh per year with a capacity factor of 66 percent. Based on the value of alternative power sources, the marketing analysis indicated that the project had a capacity value of $135.50 per kW per year and an energy value of 9.95 mills per kWh. These can be combined to a single project unit energy value of 34 mills per kWh.

Cost Benefit Analysis

The cost benefit analysis indicated that both alternatives were feasible. The apron-mounted alternative had an initial cost of $11,847,000 and a power production cost of 19.6 mills/kWh to 26.9 mills/kWh, depending on the financing alternative chosen. The benefit cost ratio was between 1.32 and 1.70 at a 6 percent discount rate and 1.29 to 1.63 at an 8 percent discount rate. The conventional alternative has an initial cost of $13,485,000 and a power production cost of 25.5 mills/kWh to 31.2 mills/kWh, again depending on the financing method. The benefit/cost ratio was between 1.14 and 1.47 at a 6 percent discount rate and 1.12 and 1.42 at an 8 percent discount rate.

Study Conclusions

A comparison of the study results indicates that the apron-mounted configuration is the most desirable installation at Broadwater Dam. It would generate the same amount of power as the conventional alternative and would cost $1,611,000 or 12 percent less. Therefore, this alternative was recommended and the State of Montana is proceeding with development of the apron-mounted alternative.

On a broader scale, the study demonstrated the technical and economic feasibility of the concept of constructing a powerplant directly below an existing ogee crest diversion dam and designing the powerplant to allow the passage of flood flows through the power bays. It is believed that this general concept may have wide applicability to many other existing overflow dams throughout the United States and other countries.

PRELIMINARY FEASIBILITY STUDY FOR HYDROPOWER AT BRANDON ROAD LOCK AND DAM

Gerald J. Stadler and Brian Moentenich

Purpose of Authority

The purpose of this report is to present a feasibility study for installing hydroelectric generating at Brandon Road Lock and Dam. Authority for funds for the study was authorized under House Resolution Number 1139, 95th Congress, Public Law 95-482 approved October 1978. Chicago District, Corps of Engineers requested and made funds available to North Pacific Division, Corps of Engineers to prepare the study.

History of the Illinois River Basin and Waterway

The Illinois Waterway extends from Lake Michigan at Chicago to the Mississippi River at Grafton, Illinois, a distance of 330 miles. A map of the Illinois Waterway is shown on Figure N-4.1. The natural drainage area of the waterway is about 29,000 square miles. This area includes about 673 square miles of former Lake Michigan Basin drainage which was added to the Illinois River drainage when the flow of the Chicago and Calumet Rivers was reversed and certain drainage areas intercepted along the lake shore.

At the present time, there are two private hydroelectric plants on the Illinois Waterway; one at the Lockport dam and the other near Marseilles Dam. The existing hydroelectric plant at the Lockport Dam generates approximately 13.5MW, which is sold to the local utility company, Commonwealth Edison. The hydroelectric generating plant at Marseilles is owned and operated by the local utility company, Illinois Power Co., and generates approximately 2MW.

Description of Existing Facility

The Brandon Road Lock and Dam is located at mile 286 of the Illinois Waterway on the Des Plaines River, in the City of Joliet, Illinois. This dam is used to maintain the navigation pool at elevation 539.0 msl (1912) between Brandon Road and Lockport through Joliet. Normal lift is 34 feet. The dam includes 21 tainter gates, a fixed spillway, 6 sluice gates, 16 head gates, and an overflow section.

Mr. Stadler is Chief, Hydrology and Hydraulics Branch, Engineering Division, Corps of Engineers, Chicago District, Chicago, Illinois.

Mr. Moentenich is a Mechanical Engineer, Hydropower Design Section, Engineering Division, Corps of Engineers, North Pacific Division, Portland, Oregon.

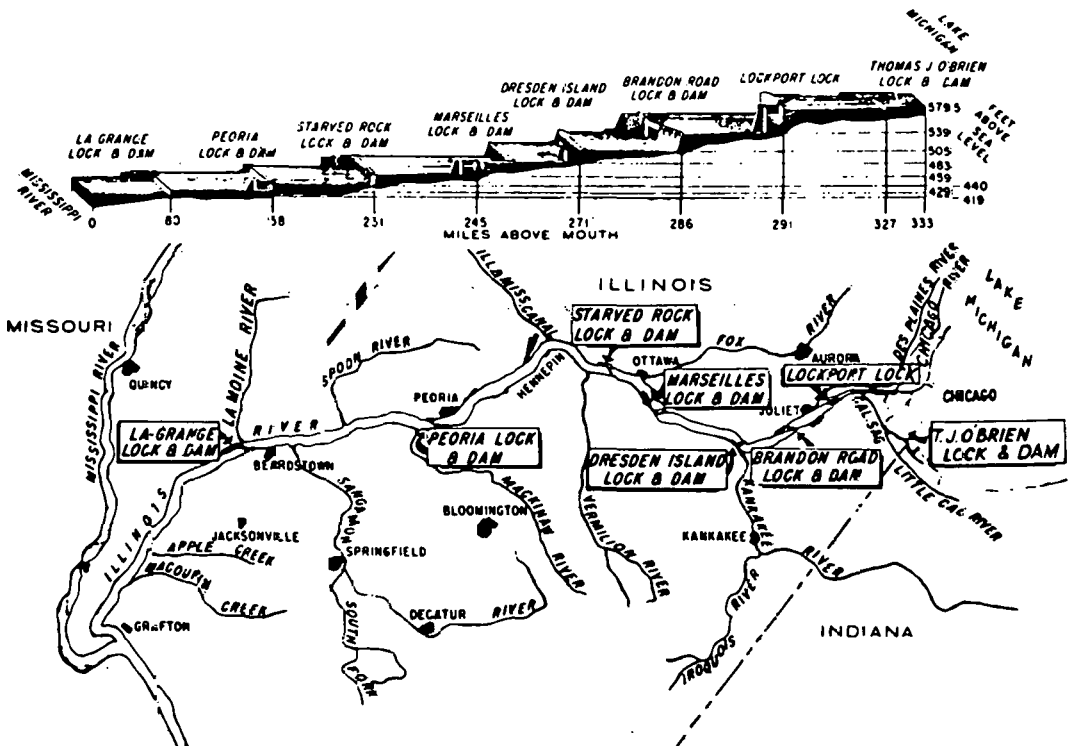


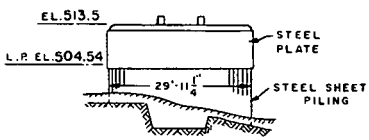
FIGURE N-1.1 The Illinois Waterway

BRANDON ROAD LOCK, DAM & POOL

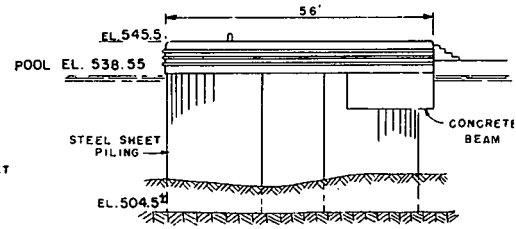
STRUCTURE DATA

Locks	Lock	Junction Lock
Available Length	600'	92'
Clear Width	110'	22'
Upper Miter Sill	El. 520.7	529.5 M.S.L. 1929
Lower Miter Sill	El. 490.7	520.5 M.S.L. 1929

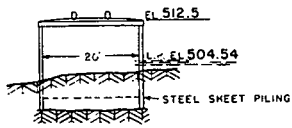
Dam	
Fixed (Embankment)	822'
Headgate Structure	320'
Ice Chute	30'
Sluice Gates	91'
Tainter Gates	1110'



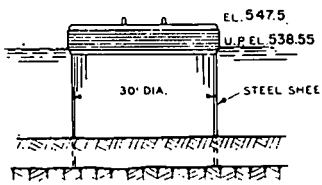
ELEVATION OF PROTECTION PIER AT U



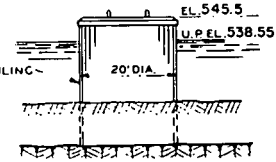
ELEVATION OF UPPER GUIDE WALL END PIER T



ELEVATION OF MOORING PIER AT Q



ELEVATION OF MOORING PIER AT R



ELEVATION OF MOORING PIER AT P

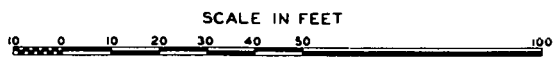
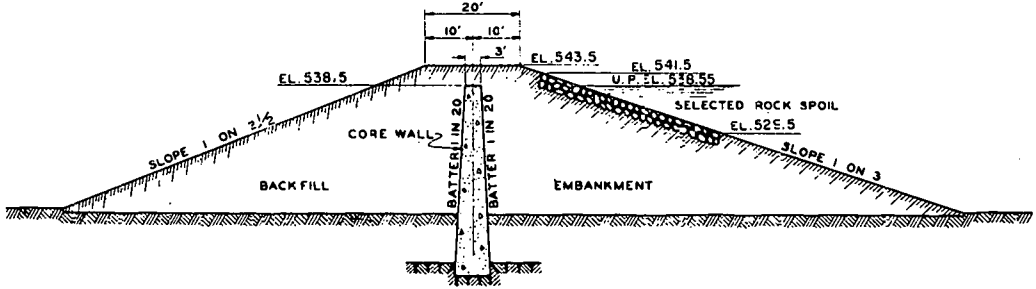
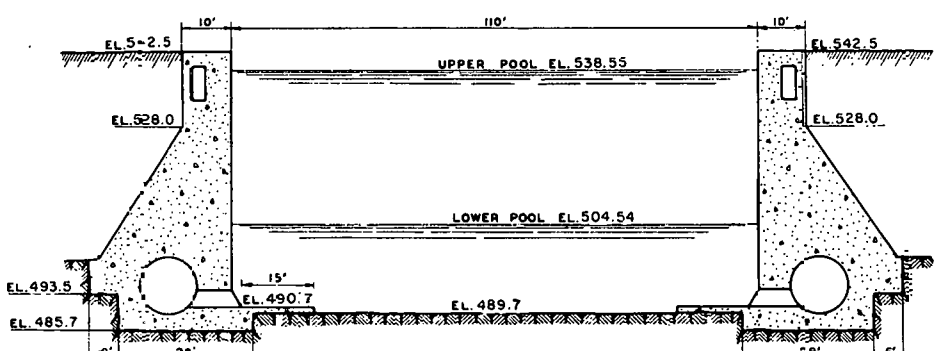


FIGURE N-4.2 Brandon Road Lock and Dam

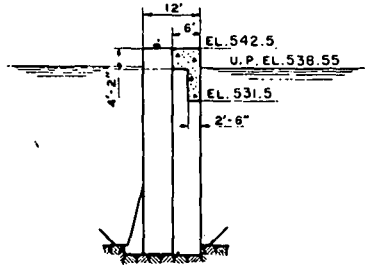


CROSS SECTION OF EMBANKMENT
AT A-A

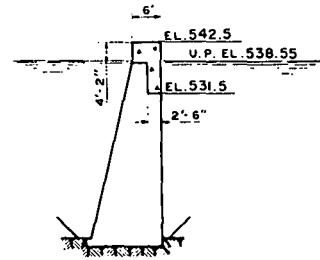


CROSS SECTION OF LOCK
AT B-B

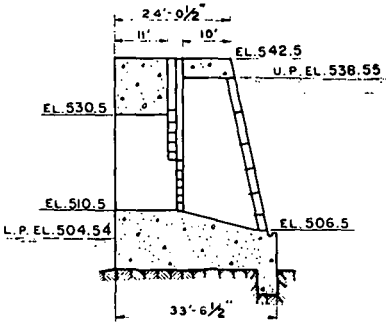
FIGURE N-4.2a Brandon Road Lock and Dam



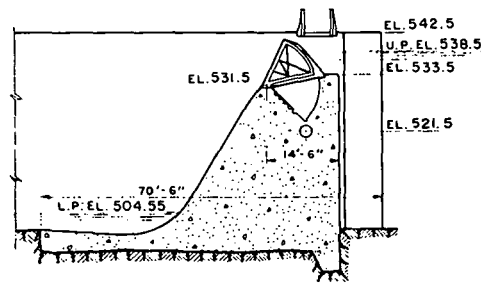
CROSS SECTION OF GUIDE WALL
AT C-C



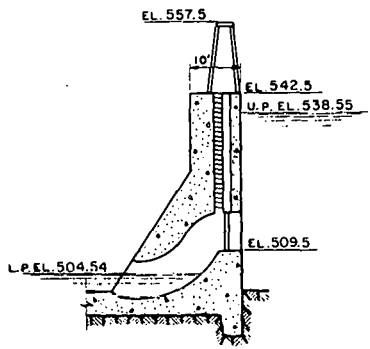
CROSS SECTION OF
ICE PROTECTION WALL
AT D-D



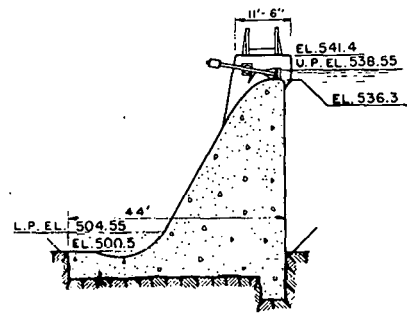
CROSS SECTION OF HEADGATES
AT E-E



CROSS SECTION OF ICE CHUTE
AT F-F



CROSS SECTION OF SLUICE GATE
AT G-G

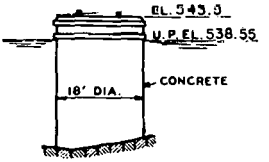


CROSS SECTION OF TAINTER GATE
AT H-H

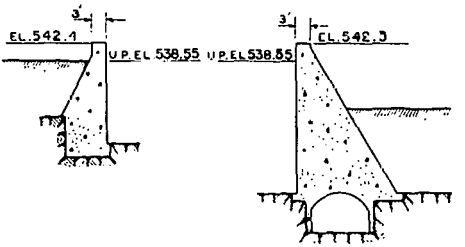
FIGURE N-4.2b Brandon Road Lock and Dam



CROSS SECTIONS OF LOWER APPROACH WALLS
AT S-S AT J J



ELEVATION OF MOORING PIER
AT K



CROSS SECTIONS OF RIVER WALLS
AT M-M AT N-N

FIGURE N-4.2c Brandon Road Lock and Dam

At the time of construction in the early 1930's, hydropower was considered, but because of authorization and funding problems, was not installed. However, the dam was provided with 16 headgates so that a future powerplant could be built immediately below the dam. The proposed powerplant would use only 4 of the existing 16 gates of the head gate structure.

Hydrology and Hydraulics

Provisions are available at the dam for pool regulation but flood flows must be passed as rapidly as possible, as existing freeboard is only three to seven feet. The pool level at Brandon Road remains fairly constant throughout the year. An adjusted flow-duration curve was developed and used in selecting the size of plant installation. Mean flow at Brandon Road is about 4000 cfs while the majority of flows is about 3000 cfs; the maximum flow of record was about 38,000 cfs in May 1974.

Mechanical and Electrical

The design of the Brandon Road powerhouse and selection of the turbine is intimately affected by the existing intake structure. Also affecting the powerhouse layout and turbine selection is the relatively high rock elevation in the tailrace and a high intake invert elevation which is approximately six feet above tailwater. Because of this, a turbine which could be set above tailwater was desired.

Several alternative turbine designs are suitable for the head and power capability planned. These are: vertical Kaplan, tubular turbines, Bulb turbines, and the Rim Turbine-Generator. A number of manufacturers offer these types of machines in packaged units complete with control valve or gate, turbine, generator control equipment, and speed increaser if required. Also, all of these styles are available with fixed or adjustable blades.

The sole purpose of this study was to determine the technical and economic feasibility of the proposed powerhouse. Actual engineering and design for construction will produce plans and specifications leading to competitive bids by several manufacturers. No inferences should be made that the selection of a particular manufacturer's equipment for the study will establish a single source bid situation.

Two different powerhouse configurations have been examined; one using Allis-Chalmers TUBE turbines and one using Escher-Wyss STRAFLO rim turbine-generators. The A-C units were selected for the study due to the availability of information. These Allis-Chalmers turbines have a runner diameter of three meters and 4 of these units can deliver the 15 megawatt plant capacity at a rated head of 9.1 meters (34 feet). The units will have five adjustable pitch blades and will be connected to a parallel shaft gearbox to increase the generator shaft speed. The generators selected for the feasibility study would be a synchronous type without a disconnect clutch as the generator can be rated for 100% of runaway speed.

Another turbine which appears suitable for this site is the STRAFLO rim turbine-generator as manufactured by Escher-Wyss of Switzerland. Preliminary data indicate 4 of these turbines also can develop the 15MW plant capacity at rated head with a runner diameter of 9.3 feet or less. The STRAFLO turbine would appear to reduce both the depth of excavation and the upstream/downstream dimensions of the powerhouse. However, in this type of powerhouse where the intake works are existing, savings in civil costs will have less of an impact upon turbine selection than in larger conventional hydro projects. The design considerations for this type of powerhouse are slightly different than for larger manned projects. Handling of gates, bulkheads, generators, gearbox, as well as embedded parts can be accomplished with a mobile crane. The removable portion of the tube and runner could be handled by a hoist and trolley.

The selection of the turbine type will have considerable impact on the design of the powerhouse. For small low-head hydro projects the inclusion of powerhouse construction in the turbine-generator contract should be considerable. There are two reasons for this: First, the cost of the turbine-generator units is three quarters of the project costs, and second, the selected turbine-generator unit may dictate the powerhouse configuration. Having the equipment supplier as the prime contractor is not unique and would pose no insurmountable technical problems.

Project Cost and Construction Schedule

Based on January 1979 price levels, turbine-generator costs account for 75% of the total construction cost of $8,250,000.00. The estimated total project cost, including 15% contingency, engineering and design, and supervision and administration costs, is $11,000,000.00. Under ideal conditions, the total elapsed time for the project from initial engineering and field investigations to the end of construction is estimated at 51 months. Eighteen months is allowed for engineering, and a total of 24 months is allowed for powerplant construction.

Economic Analysis

Cost estimates were prepared for various size generating plants. It was determined that costs for plant sizes in this range (4 to 18 megawatts) would vary linearly with installed capacity. The period of analysis for the project is 50 years. Interest and amortization was computed at 6-7/8 percent. Operation and Maintenance costs were derived from curves prepared for the National Hydropower Study.

The project benefit will ultimately be determined by the amount for which the power can be sold to Commonwealth Edison Company. Discussions with the power company indicated its current cost of producing energy ranges from 10 to 70 mills per kWh. It was estimated that 20 mills per kWh would be a conservative estimate of the value of power from this project. A net benefit analysis was used to scope the project. Powerplant investment costs for a series of plant sizes, based on manufacturers' information were plotted against a series of annual benefits. Benefits were prepared based on 20, 25,

and 30 mill per kWh. The annual benefits for all plant sizes are above the cost, even at 20 mills/kWh.

The study also indicated that 9 to 11 megawatts of installed capacity would produce the maximum net benefit, depending on the unit energy value that is used. Further investigation of plant sizes and available units showed that by increasing the plant to 15 megawatts, additional energy could be developed using the same number of units. Since we are trying to maximize energy output rather than net benefits, a 15MW plant was proposed. Expressed in terms of average energy cost, the cost of power from the 15 megawatt Brandon Road Powerplant would be about 13.5 mills per kilowatt hour, which is an economical energy source, compared to other alternatives.

Conclusion

The Brandon Road hydroelectric project offers the opportunity to develop a clean, renewable energy source at a reasonable cost. By today's standards this power project may not be as large as many other generation sources, but clearly the project can make a significant contribution to meeting electric power demands. Considering the national energy picture, generation at the project could conserve the equivalent of about 117,000 barrels of oil annually. Expressed in different terms, the 70,000,000 kilowatt-hours of annual generation that the project could produce would furnish the equivalent electrical requirement for about 9,000 homes in the Chicago area.

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

Session Eighteen

PLANNING, INFORMATION AND METHODS

Topic: Planning for Development III

Chairman: Mr. Augustine Jay Fredrich
Professor of Civil Engineering Technology
Indiana State University, Evansville

STUDY OF FACTORS AFFECTING FEASIBILITY OF LOW-HEAD HYDROELECTRIC GENERATION

Edmond R. Bates

Effect of Feasibility

The feasibility of low-head hydroelectric generation depends upon technical and economical factors. In general, technical knowledge must first advance to the stage where equipment works dependably and safely. After that, technical advances can be directed towards improving the economics.

The technology of low-head hydroelectric generation is past the first stage and well into the second. Hydroelectric equipment manufacturers are prepared to design, build, and guarantee efficient and dependable low-head machinery for virtually any desired set of conditions. Most manufacturers have also made concentrated efforts towards the development of improved equipment. The result is a number of strikingly different arrangements which compete for the low-head market.

In spite of these efforts, the economic position of low-head hydropower has receded relative to other sources of energy available for the generation of electricity. Although the recent advances in low-head design represent important technical achievements, large reductions in the cost of these installations have not been achieved. This is not stated to discredit the hydroelectric industry. It simply represents the difficulty of improving upon machinery that is already 90 percent efficient.

While the price of electricity has dropped, the cost of hydroelectric construction has risen. The result is that low-head generation has become less attractive with time rather than more so. Nevertheless, low-head hydrogeneration is economically feasible in many goegraphical areas at the present time, as witnessed by the many plants that were built in the 1950s. These plants demonstrate the development of the state of the art.

Low-head hydroelectric generating units are divided into two main groups. The first group, representing earlier development, has a turbine arrangement that uses a spiral case with wicket gates to control the flow. This arrangement was specifically developed for, and was subsequently adopted in, the development of low-head propeller and Kaplan turbines.

Tubular turbines make up the second group of low-head plants. They were developed to reduce the cost of low-head plants by simplifying the flow passages and thereby reducing the size of the civil structure. There are several distinct arrangements for tubular turbines, but the feature they all have in common is the elimination of the spiral case.

Except for some small plants, all tubular turbines are oriented so that their axis is horizontal or nearly so. The flow approaches the turbines axially but is first given a whirling motion by guide vanes located upstream of the runner.

Mr. Bates is responsible for assessing water resources plans for energy resource development and other appropriate technology at the Department of Energy Region VIII Office, Belmar Branch, Lakewood, Colorado.

The whirling motion is converted to shaft torque by the turbine blades, and the flow leaves the turbine with essentially axial flow. The draft tube geometry, which is simplified by the horizontal alignment, closely approaches the ideal shape for energy recovery.

To make use of this hydroelectric energy in a competitive way, a very compact type of turbine generator—the bulb unit—has been developed. The compactness of this unit reduces the overall size of the powerplant and, consequently, its installed kW cost becomes very competitive. The range of capacities that have been equipped with bulb units is large. It extends from 100 kW to about 55,000 kW per unit.

The amount of capital that can be invested in a low-head hydroelectric plant depends upon the alternative sources of power available. On the average, the annual cost of a hydroplant is about 10 percent of the capital investment. A low-head hydroelectric plant that would supply electricity to a power grid at 100 percent load factor would be feasible if it could be constructed with a capital investment at $440 per kW of firm capacity. If a low-head plant serviced an isolated system having a load factor of 60 percent, which would otherwise be serviced by a diesel set, up to $650 per kW could be invested. On the other hand, if the isolated system required a load factor of 90 percent such as might occur with some industrial applications, the investment could economically reach $1,000 per kW.

Feasibility of a hydroelectric plant, therefore, depends upon the type of plant that would best serve as an alternative and upon the operational load factor of the plant. The values quoted are rather high and serve only to show that relatively expensive hydroelectric plants can be economically feasible under certain conditions.

The economic feasibility of a hydroelectric plant also depends upon how much of the total development must be charged to the production of electricity. Many sites are developed for their hydropower alone. The entire cost of the project, including the procurement of land for the reservoir and the site facilities, the construction of the access road, the camp, the impounding structure, the flood spillway, as well as the power facilities, is charged to power production. However, the very lowest-head plants can be justified only when they are incorporated into a development built primarily for some other purpose such as flood control, navigation or irrigation. Of course, all facilities directly related to power production should be charged to the hydroelectric part of the development.

Ordinarily, head is not an overriding factor in feasibility studies. Medium low-head plants may be just as attractive as high-head plants because costs and benefits vary with head to some degree. However, for very low-head plants, it does become important because benefits in the form of energy production do vary with head while costs do not. For instance, the size of the impounding structure becomes more a function of the depth of the river than the head, and power facilities are designed according to the discharge rather than the head. The result is that the lower the head, the less likely the plant will prove to be economically feasible.

As a rough rule, the cost per kW of capacity is inversely proportional to the head height, all other things being equal. Equally rough, cost per kW of these considerations is just an approximation of power conversion rules applied to power equipment cost estimates.

The one attractive feature of river turbines is that they would require a very minimum of peripheral construction. Even access roads would not be required if they were built and maintained by river transport.

One of the outstanding advantages of very low-head hydroelectric development is its compatibility with the natural environment. Aesthetically, low-head plants can be very attractive. Tubular turbines can be fitted into a powerhouse with a very compact, low, unobtrusive profile. There is virtually no pollution associated with hydroelectric plants either in the form of sound, heat or smoke. The level of activity around a hydroplant is also low. The trend is to automatic control with a minimum of maintenance personnel. As a result, low-head plants can be located in areas such as lakeside or riverside parks where aesthetics are important without introducing an obvious industrial atmosphere to the area. This is in sharp contrast to steam plants with prominent industrial-type buildings, high stacks, and cooling towers.

Many of our dams already constructed need repair. This cost can be paid for by electrical generation. Since these plants presumably would be built only at sites where impoundments are to be created anyway, there is no question of effects on river profile. The only apparent drawback to developing hydropower at an existing impoundment is that there would be somewhat less aeration of the water if it goes through turbines rather than over spillway. This may have a bearing on the ability of the river to absorb pollution.

Another consideration that affects the development of low-head sites is the natural tendency for planners of power organizations to look to sources of large blocks of power to meet the rapid load growth. They ignore places that would develop only small amounts of power because these small sites do not solve the problem of the moment. The growth of small-capacity sites would probably require a separate department or organization charged solely with locating and developing them as they prove feasible.

The Department of Energy is involved in trying to: (1) Put out some financial assistance to perform site-specific feasibility studies so that you know whether or not you have a viable project, and (2) Build small demonstration projects around the country. I participated in a procurement whereby we selected 56 site-specific feasibility study proposals for funding. I was on the panel that picked these winners out over 300 proposals submitted. I believe that funding these kinds of studies, which can cost anywhere from $15,000 to well over $100,000, is the best method we can use to motivate developers to successfully accomplish the energy goals.

Conclusions and Comments

1. Hydraulic turbine manufacturers in the past have been actively engaged in the development of special turbines for low-head application. This effort has culminated in bulb-type units common in Europe and tube turbines which are finding application in North America.

2. The countries of Europe have made extensive use of navigation control structures for the generation of electricity and have built many units with heads less than 25 feet, whereas there have been very few units built in North America with heads of 25 feet or less.

3. Flowing water in rivers can also be used to generate electricity; but interest in this source of energy has been minimal, chiefly because of the high cost of the required equipment relative to the benefits.

4. The generation of electricity from flowing water of rivers is not economically justifiable except possibly in small quantities at very remote locations.

5. The available head is the most important factor affecting the feasibility of low-head hydroelectric plants. Considering well designed low-head plants of equal discharge capacity but different heads, the lower-head plant will have:

a. Lower kW capacity.
b. Larger, slower turning turbines.
c. Heavier, slower turning generators (alternatively more expensive speed-increasing-gears).
d. Larger flow conduits.
e. Lower overall efficiency.
f. Higher total cost.
g. Higher cost per kW.
h. Lower benefit/cost ratio.

6. Low-head generating units can be located in low-profile structures with high aesthetic qualities and function without contributing to the pollution of the environment.

7. There appears to be a need for research in the design of draft tubes for tubular turbines to apply modern principles of boundary layer control to reduce the length of draft tube diffusers.

8. Legal-institutional policies appear to be more of a detriment to development than the straight economic and engineering questions.

In addition to the above direct conclusions, there are a few comments that should be made regarding low-head hydrogeneration. It is not easy to understand why there are so few low-head units in North America compared to Europe. In the beginning of this century, a great many small, low-head units were installed on this continent, mostly by small utility and industrial organizations. With the development of large improved thermal and hydroelectric plants, most of these small plants were shut down as they wore out. In Europe, however, low-head hydrogeneration has continued to develop. Some of these developments may have been due to unsettled political climates, whereby governments would look to hydropower as being insurance against a loss of fossil fuel supplies. Undoubtedly, some is due to economic reflecting differences in the value of resources, including manpower, in the two continents. However, the impression is that low-head development has been bypassed in North America by planners who are pressed to develop large blocks of power to meet rapidly growing load demand. This tendency is likely to continue, even as the pollution problem associated with thermal and nuclear plants increases, because the development of low-head hydropower will never make a sizable dent in the needs for thermal and nuclear power. The development of low-head power, where economically justifiable, will seem to depend on the action of persons conscious of the waste of an untapped nondepletable national resource rather than on persons looking to meet power demands. If a program to develop low-head sites is desirable, extensive research in many areas of powerhouse design would be certain to bring about savings in the cost of the development program.

The demand for hydro, and hence its value, is tied to the price of oil and coal used in the alternative generation. The value of hydropower rises when the price of oil rises. The Department of Energy has tried to help potential developers with the first decision as to whether it is worthwhile pursuing the subject any further. If it is worthwhile, they present a cookbook approach with guidelines for each step along the way. The bulletin is entitled "Micro-Hydro Power." This bulletin may give you a feel for feasibility, but my recommendation is that you go to a consulting engineer for more detailed study before you spend a large sum of money.

REFERENCES

Auroy, F., "Micro-Power Stations on the River Mayenne," LaHouille Blanch, No. 1, pp. 25-32, 1964.

Bowman, Waldo G., "Constructors Harness the Tides in France," *Engineering News Record,* pp. 32-36, September 10, 1964.

Braikevitch, M., Gwynn, J. D., and Wilson, E. M. "Tidal Power with Special Reference to Plant, Construction Techniques and the Integration of the Energy into Existing Electricity Systems," Paper 242, Section C2, Seventh World Power Conference, Moscow, 1968.

Casacci, S. X., and Chapus, E. E., "The Bulb Turbine," ASME Paper No. 64, WA/FE-27.

Golding, E. W., *The Generation of Electricity by Wind Power,* E. & F. N. Spoon Publishers, London, 1955.

Hilgendorf, J., "Development of the Voith Tubular Turbine Design Exemplified by Plants in Operation," Voith Research and Construction, Vol. 15e, Paper 11, May 1967.

Kline, J. J., Abbott, D. E., and Fox, R. W., "Optimum Design of Straight-Walled Diffusers," *Journal of Basic Engineering,* pp. 321-328, September 1959.

Kovalev, N. N., *Hydroturbines—Design and Construction* (translated from Russian), U.S. Department of the Interior and National Science Foundation, 1965.

Leopold, L. B., Wolman, G. M., and Miller, J. P., *Fluvial Processes in Geomorphology,* p. 167, W. H. Freeman and Company, San Francisco, 1963.

Mayo, H. A., "Tube Turbine Units and Their Application," ASME Publication No. 65-WA/FE-12, 1965.

Mayo, H. A., Jr., "Tube Turbine Units, Their Application, *Mechanical Engineering,* Vol. 88, No. 5, pp. 118-124, March 1966.

Moore, R. C., "Induction vs. Synchronous Generators," Reprint No. 05R2338-6 from *Allis-Chalmers Engineering Review.*

Mosonyi, Emil, "Low-Head Power Plants," *Water Power Development,* Vol. 1, Akademiai Kiado, Budapest, 1963.

Sutherland, Robert A., "Tubular Turbines," Bulletin 309, Washington State University, 1968.

Department of Energy, *Fundamental Economic Issues in the Development of Small Scale Hydro.*

Federal Power Commission, *Hydroelectric Power Evaluation,* Washington, D.C., 1968.

Federal Power Commission, *National Power Survey,* 1964.

Staff Article, "The Rance Tidal Power Scheme," *Water Power,* pp. 6-16, January 1967.

A River Basin Code and Mapping System for Hydropower Sites

Eugene A. Jarecki and Thomas F. Papsidero

Introduction

The Federal Energy Regulatory Commission (FERC, formerly FPC) has used a basin-wide planning approach in developing a river and site-coding system for maintaining pertinent information on the hydroelectric power resources of the United States. In this system, over 14,000 streams and 5,100 developed and potential hydropower sites have been coded and located on a series of maps of the United States.

The river basin and site-coding system has been used by the Commission for over 30 years. ADP support is now provided by the Energy Information Administration (EIA) and DOE's Office of Resource Applications has assisted in funding the expansion of the system. Efforts are now underway to include several thousand additional sites being identified by the Corps of Engineers during its National Hydropower Study and by other Federal and non-Federal groups. The FERC inventory will also include sites of over 2,000 retired hydropower plants. Until now, no maps have been available which contained nationwide information on developed and potential hydropower sites.

The Commission's involvement in water and hydropower resources planning stem from its responsibility for licensing non-Federal hydroelectric power projects which affect navigable waters, occupy Federal lands, use water or water power at a Government dam, or affect the interests of interstate commerce. The Act also requires that projects to be licensed are "best adapted to a comprehensive plan for improving or developing a waterway or waterways." Under authority of the Act, the Commission develops and maintains a comprehensive inventory of developed and undeveloped hydropower resources of the United States and conducts meaningful evaluations and studies in order to facilitate the planning of Federal and non-Federal projects.

River Basin Coding

The recent revision and expansion of the sytem will permit coding of a greater number of sites—up to 100,000. The FERC system divides the country numerically into Water Resources Regions, as used by the Water Resources Council and the Geological Survey. Numbers are assigned to major river systems or a combination of small streams, and then progressively in

Mr. Jarecki is responsible for the development of Hydropower Resources Assessment in the Division of River Basins, Federal Energy Regulatory Commission, Washington, D.C.

Mr. Papsidero is responsible for river basin development at the planning level, Federal Energy Regulatory Commission, Washington, D.C.

upstream order beginning with the mouths of major rivers and proceeding to the uppermost tributaries identified on 32" x 41" maps covering the United States.

The system is similar to that commonly used in major sanitary systems; i.e., from wastewater treatment plant to major collectors and to its many connectors. It can be compared generally to the USGS Hydrologic Unit Code system. The regional boundaries are identical, but the further breakdown into the subregional and accounting unit boundaries varies somewhat. The FERC system permits labeling of additional streams, river basins, and hydropower sites at any time without interrupting the code series. It is designed to be used in establishing and maintaining a computer file of developed and undeveloped hydropower sites. All sites upstream or downstream from a given stream location or sites between any two locations may be quickly identified or retrieved.

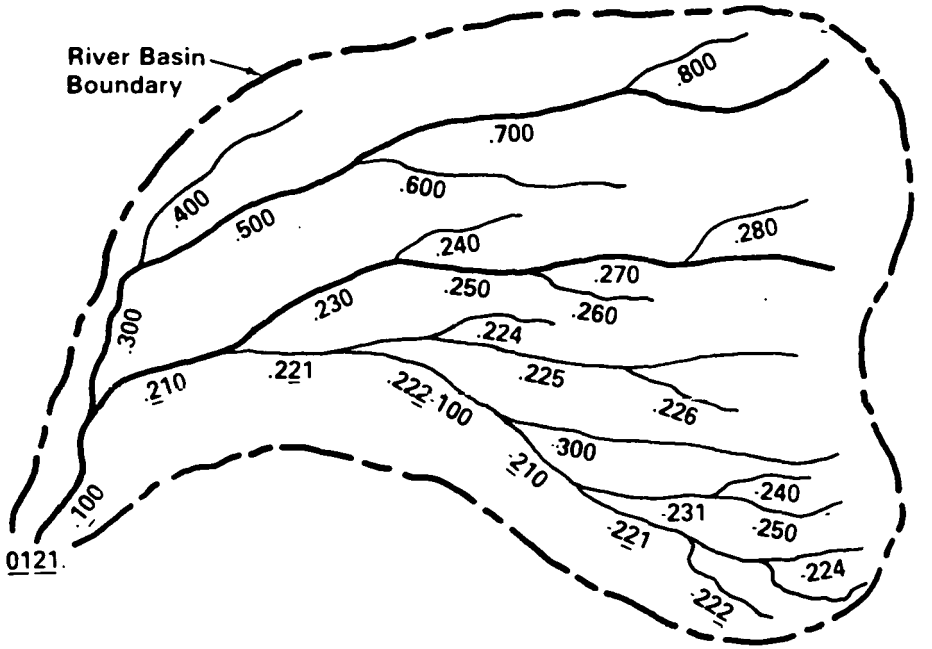
The river basin code numbers are composed of 10 digits. The first two digits are used to represent the 21 water resources regions. They are followed by two digits which represent major river systems within each region. All major river systems and tributaries within a region have been assigned numbers ending in an even digit, thereby reserving the odd digits for designating intervening areas between principal river basins and intervening stretches (main stem) of streams.

The next six digits of the code define each tributary in six orders, moving upstream with position in the code denoting the order of the tributary. For these six digits, even numbers are used to designate tributaries and odd digits designate main stems of tributaries. The assignment of the code permits computer processing of information on hydropower sites in sequences corresponding to the geographical locations of the 21 water resources regions in the United States, the relative locations of principal river basins within these regions, and the relative locations of tributary streams within each river basin.

In further describing the stream labeling, it may be likened to a "bookkeeping" process adapted to the order of streams and their tributaries. This labeling process covers all basins in the United States and Puerto Rico. Figure O-2.1 illustrates an example of labeling a principal river basin with the river basin code.

Site-Coding

The manner in which the rivers and tributaries are coded through 10 digits provides the basis for the method used in assigning a code letter, as the 11th digit, to existing and retired hydropower plants, undeveloped hydropower sites, reservoir sites, pumped-storage sites, or any other projects having a relative position on the stream. Each site in a given stream reach is identified by a letter from A to Z (O is omitted) starting with A at the mouth of a stream. One additional digit (letter) is being added to the site code to specifically identify alternatives to undeveloped potential sites. Table O-2.1 illustrates a specific example for establishing a site code for the Philpott hydroelectric plant in Virginia.



Breakdown	Region or Stream
01	Water Resources Region
21	Principal River Basin
.100	Main Stem (From Mouth)
.210	1st Order Tributary, Main Stem (from mouth)
.221	2nd Order Tributary, Main Stem (from mouth)
.222	3rd Order Tributary
-210	4th Order Tributary
-221	5th Order Tributary
-222	6th Order Tributary
0121.222-222	Complete Code for Entire Reach Where Labeled -222

FIGURE O-2.1 Coding A Major River System

TABLE O-2.1

Code Breakdown	Region or Stream	Name or Designation
03	Water Resources Region	South Atlantic-Gulf
16	Principal river system or river basin	Roanoke River Basin
.400	1st order tributary	Dan River (trib. to Roanoke)
.480	2nd order tributary	Smith River (trib. to Dan)
.485-100	Main stem of 2nd order tributary	Smith River
-M	Site alpha (developed or undeveloped plant location)	Philpott Hydro
0316.485-100-M	Site Code	Philpott Hydro

Mapping System

The skeletal boundaries of the map sets employ the use of the 21 water resources regions. The map sets for the system consist of 79 maps covering the conterminous United States, and six maps covering outlying areas; one each of Hawaii and Puerto Rico and four for the State of Alaska. Each map depicts a geographical unit which is based, with some modifications and exceptions, on the river basin base maps originally prepared in 1960 by the Subcommittee on Hydrology of the Inter-Agency Committee on Water Resources, which preceded the U.S. Water Resources Council. Within these geographical units, principal river basin drainage boundaries are delineated.

In preparing the final maps, blue and red overlays for each map of the 85-map set are being developed. Blue is used to depict all pertinent rivers and streams along with the river and stream names. The modifications made by FERC to the base maps include the addition of some rivers and streams to the extent that they are important in the assessment of hydropower resources. Red will depict the hydrologic boundaries of each geographical unit. The coding of water resources regions, river basins, and streams will be shown on this overlay. As indicated in map legend, conventional existing, conventional potential, pumped-storage existing, and retired-plant sites will also be shown in red.

The final maps, then will consist of the blue and red color-coded information superimposed on a map base presented in black. The base information includes international, state and county boundaries and names, and the locations of some principal cities to contribute clarification for the user.

The scale for the maps is 1:500,000 except for the map of Puerto Rico which is 1:250,000 and the map showing the entire State of Alaska, which is at a scale of 1:2,500,000. The three sectional maps of Alaska are from base maps prepared by the Defense Mapping Agency.

Using the River and Site-Code System

The inventory of hydropower sites, using this type of basin coding system has been used for years in connection with the Commission's analysis of license proposals, and for assessing the Nation's present and future hydropower resources. It has enabled the staff to identify headwater benefits situations in which assessments must be made for power benefits to owners of non-Federal hydropower plants which may have accrued from the operation of Federal or licensed reservoir projects located upstream. The inventory has been the springboard for many studies of other agencies such as the Corps of Engineers.

The expansion of the code system, the location of projects and sites on the basin maps, and the conversion of the entire inventory to the System 2000 data management process will facilitate its use for all purposes. There will be capability for making computer listings or analyses of any desired grouping or sequence of sites and obtaining direct computer output related to map locations of all hydropower sites.

Some examples of computer output are:

1. Listings of all undeveloped hydropower sites including alternatives in a given basin or portion thereof;
2. Tabulations of total hydropower resources of a geographic region, distinguishing between existing powerplants and undeveloped hydropower sites;
3. Tabulations of total existing or potential hydropower developments in a state aggregated by river basins within the state; and,
4. Listings by state of total existing and undeveloped sites having license or Federal planning status.

Each of these computer information outputs can be supplemented with dam, reservoir, or powerplant specifics, relationship to wild and scenic rivers, and other data compiled in the FERC hydropower resources inventory data file.

One limitation of the system is that refinements of the river codes and assignments of site codes must be done centrally, of course, to avoid duplication. It is expected that river basin code listings and maps will be updated periodically, although the timing is yet to be determined. The availability of the computerized hydropower resources inventory and supplementary atlas should provide a positive aid in serving the renewed interest in hydroelectric power development, as evidenced by recent Congressional and Executive initiatives, increased private requests for FERC licensing and permitting, sharp increases in fuel prices, and the possibility of major reduction in imports.

Summaries from the commission's hydropower resources inventory are now available as of January 1, 1979. Data for 5,131 existing and undeveloped hydropower projects, including both conventional and pumped-storage is included. A computer listing of pertinent data for 2,316 retired hydropower sites is also available. It is anticipated that the data management system 2000 will become operational early next year. Coding and plotting on the maps for the conterminous United States have been completed and preliminary black and white copies are available. Coding and plotting for the remainder of the maps,

including plotting of retired hydropower plants on all maps, should be completed by January 1980. The finished color map reproductions will be available sometime thereafter.

AN ENGINEERING/ECONOMIC MODEL FOR EVALUATION OF SMALL-SCALE HYDROPOWER FEASIBILITY

Dilip R. Limaye, Thomas C. Hough and William Meroney

Introduction

The recent increases in the costs of oil and gas, declining availability of these fuels, and environmental impacts of using coal and nuclear energy, have improved the relative attractiveness of small-scale hydro. A 1977 study by the Corps of Engineers indicated that a large number of small dams are potential candidates for hydroelectric power development. Synergic Resources Corporation has developed a comprehensive evaluation framework for feasibility studies of small-scale hydropower. This paper describes the development of an engineering-economic model to assist in the evaluation of the feasibility of specific sites.

This project was funded by the U.S. Department of Commerce, Office of Minority Business Enterprise, through the Philadelphia Urban Coalition.

Project Objectives

The objectives of this project were:

- To develop a standardized evaluation framework which can be used to evaluate the feasibility of small-scale hydropower development at existing dam sites.
- To demonstrate the application of this framework by performing a feasibility study of hydroelectric power development potential at the Flat Rock Dam on the Schuylkill River.
- To perform a preliminary feasibility assessment of several other sites to estimate their development potential.

Summary of Approach

The individuals, organizations and government agencies involved in development of small hydro require varied but accurate information for decision making. In this project the information needs of the various decision makers were identified, the strengths and weaknesses of previous feasibility studies were assessed and the major factors influencing the feasibility of small hydro were defined. A detailed evaluation framework was then developed as illustrated in Figure O-3.1.

Mr. Limaye is President, Synergic Resources Corporation, Bala—Cynwyd, Pennsylvania. Mr. Hough and Mr. Meroney are engineers with the firm.

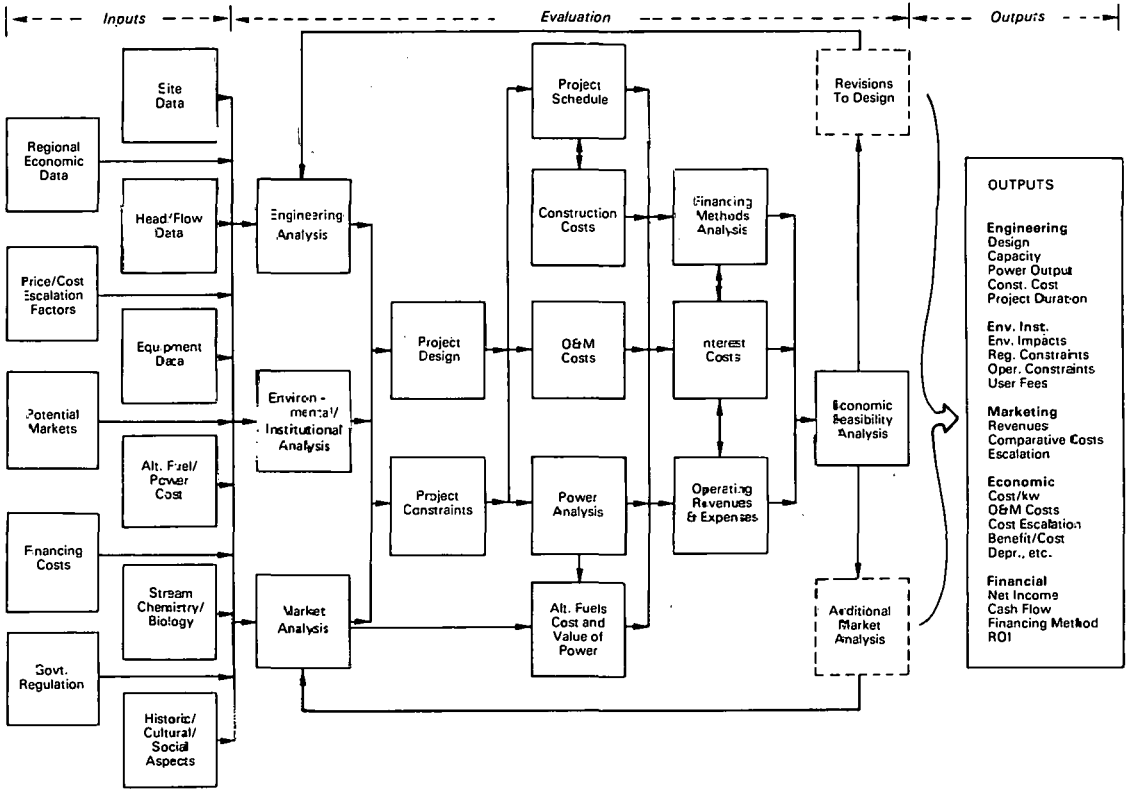


FIGURE O-3.1 Schematic Overview of Evaluation Framework for Hydropower Feasibility

The evaluation framework uses a step by step approach which focuses on the engineering, marketing and institutional/environmental issues to compare project design with project constraints. This comparison allows for revisions to the project design to develop an acceptable project design within critical site constraints. The refined project design is then analyzed for financial and economic feasibility. The approach is flexible in that input requirements and outputs are consistent with the information requirements of each project phase.

Model for the Evaluation of Small Hydro (MESH)

A group of interrelated computer submodels have been developed to support the evaluation framework described above. The submodels include: engineering; construction cost escalation; environmental/institutional; marketing; competitive fuel costs; financial; and economic. The relationship between these submodels is illustrated in Figure O-3.2.

The engineering submodel uses hydrologic data and equipment capabilities to calculate the installed capacity of the site, evaluate equipment alternatives to select the number and size of turbines, prepare an operating strategy for multiple turbines that maximizes power output and projects expected power generation under various flow conditions. This submodel can use up to 100 stream-flow data points to numerically generate a flow duration curve or a normalized flow duration curve based on the characteristics of streams in the Northeastern United States. The head and tail water-rating curve can also be approximated numerically at data points corresponding to the flows to allow for the calculation of power output.

Turbine characteristics and operating efficiency data are input to the model. Flow duration curves and corresponding head curves are multiplied by the turbine efficiencies to produce a power duration curve which in turn calculates annual power generation in kilowatt hours. The power duration curves and power generation for wet and dry years or months can be calculated by using the appropriate flow data. A Monte Carlo simulation can be used to estimate the power generation over the range of flow conditions at the site.

The engineering submodel can generate rough estimates of project cost using rule-of-thumb ranges of capital cost per kilowatt based on the head and flow characteristics at the site. As more accurate engineering cost estimates are prepared, these can be used in the model. Provisions are made to represent the cost data by FERC Cost Account.

The environmental/institutional submodel provides both a checklist of possible constraints and a mechanism to quantify their impacts on the project. The model lists 10 institutional and 10 environmental issues that may be encountered in small-hydro development. The model can accommodate up to 10 additional constraints that may arise at a particular site. This submodel classifies the impact of the constraints in 3 categories: capital cost, operating cost, and project delay. Incremental capital costs include items such as construction of a fish passage. Operating costs may include user fees, lost revenues from mandated flow requirements, or other operating constraints. Project delays include those expected from additional studies, intervention in licensing hearings, equipment delivery, etc.

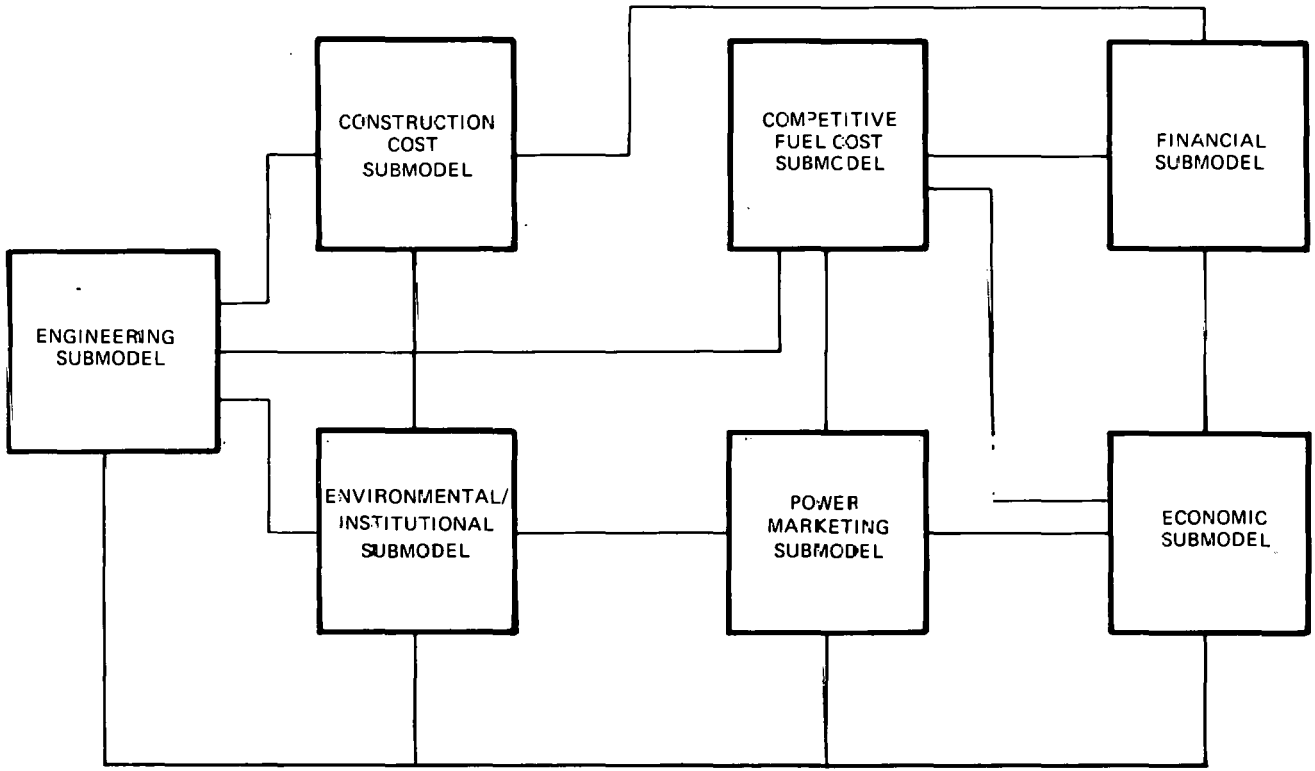


FIGURE O-3.2 Mesh Model Structure

The construction cost and cost escalation submodel uses the final project design costs by FERC Account and estimated project schedule to analyze project cost increases. Cost estimates are escalated by appropriate escalation factors for civil and equipment costs. Using the expected construction period the financing needs during construction and interest during construction are determined.

The competitive fuel cost submodel compares the cost of power produced by the hydro facility with conventional power generation alternatives. The projected cost of power generation from coal, oil, nuclear and natural gas-fired steam turbines and oil and gas combustion turbines are compared with the projected cost of hydro generation to calculate the value of hydropower and projected breakeven years. This submodel also calculates the potential fuel savings due to hydro generation.

The marketing submodel evaluates alternative markets for the power and the tradeoffs between alternative operating strategies. This submodel projects the stream of operating revenues based on power purchase prices or costs of alternative generation. The average incremental cost of the franchised utility serving the region is used in this calculation. Direct sales to other customers may be based on their current electric rates less standby and demand charges. The value of power under peaking, firm, and dump power operating strategies can be compared for each potential customer. Wheeling charges to distant customers' capacity, credits and other revenues can also be evaluated.

The financial submodel evaluates alternative mixes of financing using up to 20 different debt sources and 10 different sources of equity capital. The interest, principal and payments schedule for each capital source are calculated. The financial submodel also evaluates alternative depreciation and d amortization methods to maximize cash flow. This includes the analysis of investment tax credits.

The economic submodel evaluates the project costs and revenues, produces pro-forma financial statements and calculates several ratios which indicate project feasibility. The economic submodel uses revenue projections from the engineering and financial submodels. Projected annual income and cash flow statements are prepared for the life of the project. The net present value of the cash flow is calculated as are the benefit cost ratio, return on investment, return on equity, capital investment per installed kilowatt and production cost per kilowatt hour.

Applications of the Model

The MESH submodels were used for a detailed feasibility study of the Flat Rock Dam in Philadelphia. A summary of the Flat Rock Dam feasibility study results is shown in Table O-3.3. The feasibility study was used by the developer as the basis for an application for a DOE demonstration grant. The MESH model was also used for prefeasibility studies of 8 other sites on the Schuylkill and Lehigh Rivers in Pennsylvania.

While the MESH model was designed to support feasibility studies of individual sites, it is also ideally suited to the complex evaluation of multi-site or codependent river system operations. MESH goes beyond previous studies in its capability to test many alternative operating, marketing and financial

assumptions, and can provide significant assistance to developers, engineering firms, government agencies and others in rapidly evaluating hydro feasibility.

TABLE O-3.3

HIGHLIGHTS OF FLAT ROCK DAM FEASIBILITY STUDY

MAX. OUTPUT - 3.5 MW

TYPE OF TURBINES - TWO 3000 MM TUBE TURBINES

POWER OUTPUT - AVG. YEAR - 18 MILLION kWh

HEAD - 17 TO 20 FT.

MEAN STREAMFLOW = 2691 CFS.

CONSTRUCTION COSTS - $4.4 MILLION

ESCALATION AND AFDC, ETC. - $1.3 MILLION

TOTAL FUNDS REQUIRED - $5.7 MILLION

INITIAL OPERATION - JAN. 1982

BASELINE FINANCING PACKAGE

— $0.2 MILLION PMBDA AT 4% INTEREST

— $2.5 MILLION PIDC AT 8.5% INTEREST

— $3.0 MILLION EQUIP. MFG. AT 9.25% INTEREST

ANNUAL PAYMENT (30 YR. MTG.) - $542,000

POWER MARKETING -	Option 1 PECO	Option 2 CONT. CORP.
Current Rate (Mid '79)	26.0	32.5
Escalated Rate - 1/82	33.0	41.2
Power Sales (Million kWh)	18.0	18.0
Revenues (Thousand $)	603	739
FIRST YEAR EXPENSES (Thousand $)		
Interest	491	491
Depreciation, Amortization	453	453
O & M, etc.	136	136
Total	1080	1080
NET INCOME	(477)	(341)
CASH FLOW	(67)	69

SUPPORT SERVICES FOR SMALL HYDROELECTRIC PROJECTS IN NORTH CAROLINA

John L. Warren

In order to promote research and development of energy technologies and sources of particular interest to the State of North Carolina, the North Carolina State Legislature established the North Carolina Energy Institute. As part of its program, the Energy Institute has contracted with the Research Triangle Institute (RTI) of Research Triangle Park, North Carolina, to provide support services for public, semi-public, and private developers of small hydroelectric projects. These services have included (1) a survey of existing dams with small hydro potential, (2) an analysis of institutional and regulatory factors affecting small hydro development in North Carolina, (3) the provision of services to interested dam developers, and (4) the provision of a coordination center for groups interested in small hydro development within the state.

Survey of Dams

In order to determine the extent of the small hydro resource in North Carolina, a detailed list of sites with unused potential was developed from several sources. A primary source consists of lists, maintained by regional State offices, that specify dams covered by North Carolina's Dam Safety Law. This Law applies to all non-Federal dams with a height of less than 15 feet. Additional sites were identified with the dam files of the Hydrologic Information Storage and Retrieval System (HISARS), a computerized water resources data base for North Carolina. Also a preliminary inventory of dams prepared by the U.S. Army Corps of Engineers provided further information.

Sites that historically had generated hydroelectricity were inventoried using historical surveys prepared by the Archeology and Historic Preservation Section of the State Division of Archives and History and the list of retired plants prepared by the Federal Energy Regulatory Commission (FERC). We found the retired plant list to be an excellent source of small hydro sites not included in other dam inventories.

The dams contained in the preceding inventories were analyzed to determine:

1. Dam height (head, if known),
2. Type of construction,
3. Stream location,
4. Stream flow,
5. Gross power potential,

Mr. Warren is project leader for the (1) North Carolina Energy Institute's Small Hydro Support Project, being conducted by the Research Triangle Institute, and (2) a hydroelectric power feasibility study for the N.C. Department of Administration.

6. Ownership,
7. Utilization of any power generated.

From the original list of 3,000-4,000 dams, approximately 300 dams were identified as having development potential worthy of further analysis.

The primary criteria for selecting the 300 was the available power potential and the ownership of the dam. Emphasis was placed on those dams owned by municipalities, rural electric membership corporations, business firms, or other similar organizations because these dam owners are generally better able to finance the costs of a small hydro project. Even for these dams with apparent development potential, there are many gaps in pertinent information that we are currently trying to fill. Typical problems in developing a complete data base include imprecise location of the site, poor (or nonexistent) flow data, inaccurate information on dam height and available head, and unknown owners.

In order to increase interest in small hydro within North Carolina, this list has been made available to interested parties, such as Federal agencies, state agencies, and engineering firms. Its dissemination has encouraged those persons or organizations owning dams with hydro potential to consider developing their dams and has encouraged nonowners to consider the purchase or lease of available sites.

Detailed analyses of institutional and regulatory factors affecting small hydro development have been conducted by the Energy Law Institute. Consequently, we concentrated on those factors that were specific for developers in our state, including the following:

- Section 401 (Clean Water Act)
  Water Quality Certification
- Minimum flow requirements
- Protection of historic and archeological resources
- Requirements of the North Carolina Utilities Commission
- Protection and enhancement of wildlife resources, including threatened and endangered species
- Dam safety regulations.

For each of these factors, the coordinating or responsible agency was contacted and asked to detail its requirements for particular types of small hydro development. This information has been organized and is used to provide information on regulatory requirements and permits for potential developers of small hydro dams. In addition, key contacts were cultivated at each agency to facilitate the understanding by the agency and its employees of the needs of small hydro developers, both private and public. Requirements of Federal agencies, such as FERC, were also reviewed so that developers could be informed as to what aspects of the licensing process would apply to them.

Using the survey of existing dams in the state and the analysis of regulatory and institutional requirements as a basis, RTI is providing support services to small dam developers. These support services include:

1. A small hydro information center,
2. Production of small hydro information bulletins,
3. On-site reconnaissance surveys,

4. General assistance in applying to FERC for a license or to the Department of Energy for small hydro loan assistance.

A center of information on small hydro technology and related developments in maintained at RTI. Through this center requests for information on small hydro are answered. If answers are not available from the center, then the questioners are referred to specific individuals or agencies that may be able to respond. Information on very small hydro systems (less than 50 kW) is also disseminated due to the large number of individuals who are interested in small hydro for their homes or farms. Approximately half of all requests involve very small hydro installations.

A small hydro newsletter is periodically distributed to a mailing list of agencies, companies, organizations, and individuals. Information on DOE programs, available loan or grant monies, meetings, equipment suppliers, and sources of further data are included. In addition, a small hydro conference was held to provide developers and other interested persons with the opportunity to obtain relevant information directly from small hydro experts. Key participants included representatives of FERC, DOE, state agencies, Energy Law Institute, engineering firms, investor-owned utilities, and the public at large.

If an individual or company is interested in a site, we will conduct an in-office analysis of the site with data submitted by the developer and data available in RTI's files. If the site appears to have a power potential of at least 100 kW and the developer is interested, an on-site reconnaissance survey of the site will be conducted at no charge. This survey will be used to obtain additional information on the dam structure, water flows, ownership, and general site characteristics. The results of the reconnaissance are shared with the developer on either a verbal or written basis.

If a site has potential and the developer is willing to continue project development, RTI will provide assistance in filing the required applications with FERC and any state regulatory agency. Usually, this assistance will be in the form of information, contacts, and informal guidance. Should the developer wish to apply for funding from a Federal agency, assistance in preparing the application is also provided. Many different groups are involved in regulating, promoting, and developing small hydropower. As required, RTI serves as a coordinator or catalyst for instituting interagency or intergroup discussions for the review of policies affecting small hydro.

Future activities will emphasize assistance for those wanting to develop existing sites with significant potential, the completion of a history of hydroelectric power generation in North Carolina, and the finalization of the list of dams in North Carolina with unused hydroelectric potential.

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

Session Twenty-Two

PLANNING, INFORMATION AND METHODS

Topic: New Techniques and Projects

Chairman: Mr. James R. Hanchey
Acting Director
Institute for Water Resources
U.S. Army Corps of Engineers
Kingman Complex
Ft. Belvoir, Virginia 22060

POTENTIAL HYDROPOWER DEVELOPMENT FOR VERTICAL TURBINE-SPILLWAY COMBINE

W. Y. Chow and Alexander B. Rudavsky

Introduction

The advantages of small-scale hydroelectric power as an alternative energy technology are many. Significantly, low-head hydroelectric plants are relatively non-polluting and utilize renewable resources. In addition, the necessary facilities are small and can be made aesthetically acceptable in the natural environment.

This paper discusses the design, investigation, and development of the vertical low-head turbine-spillway combine structure located at Broadwater Dam in Montana. The project's overall goal was conversion of 4 to 6 of the 14 existing spillway bays into power bays. The project was initiated by the Montana Department of Natural Resources and Conservation, engineered by Tudor Engineering Company of San Francisco, with model investigations conducted by Hydro Research Science (HRS) of Santa Clara, California. The general layout of Broadwater Dam is shown in Figure P-1.1. It is located on the Missouri River seven miles southwest of Toston in Broadwater County, Montana.

Project Description

The spillway section of the Broadwater Dam is an ogee concrete structure rising 24 feet from its base to its crest (El. 3941.6 ft). The normal operating head water surface elevation will be a constant El. 3952.6 ft with a maximum of El. 3957.0 ft during a 10,000 year flood. The tailwater elevation varied from El. 3927.1 ft to 3953.0 ft.

The modifications to the dam structure consist of adding 4 to 6 power bays. Each bay would have a vertical shaft, low-head turbine and generator unit, a movable gate to facilitate spillway operation, and a draft tube to allow the water to exit at the power bay after passing the turbine vanes. Each power bay is 24 ft. wide with a 3 ft. thick wall separating each bay. The layout of one power bay includes two piers 3 ft. thick located along the centerline of the power bay, and one pier immediately upstream of the draft-tube entrance.

The draft-tube entrance diameter is 10.78 ft at elevation 3929.4 ft and narrows to a diameter of 9.2 ft in a vertical distance of 4.66 ft. The draft tube below the turbine vanes exits through a transition section from a single vertical circular shape to a double rectangular shape with a horizontal orientation before exiting the structure. Inside the horizontal section there is a gate used to block flow through the tube during operation as a spillway. Figure P-1.2 shows the configurations of the structures.

Dr. Chow is Chief Engineer, Hydro Research Science, Santa Clara, California.

Dr. Rudavsky is the Founder and President of Hydro Research Science, Santa Clara, California, and a Professor of Civil Engineering.

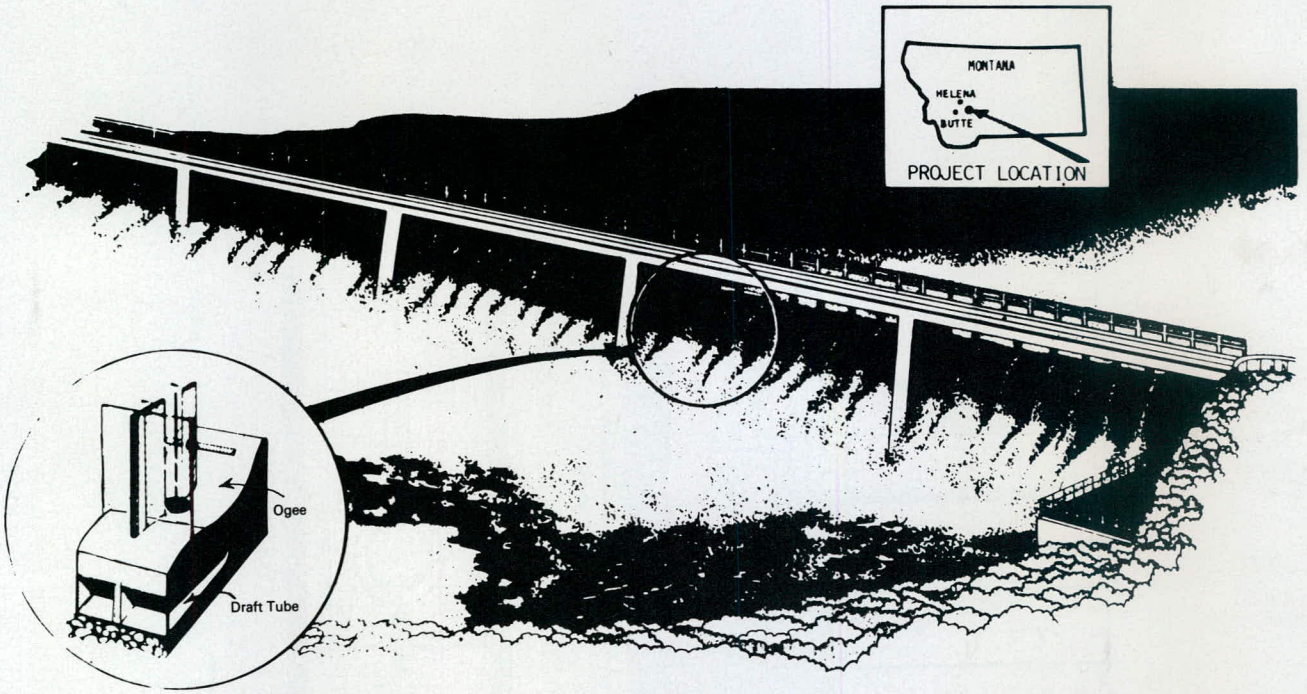


FIGURE P-1.1 Project Location and Extent of Model

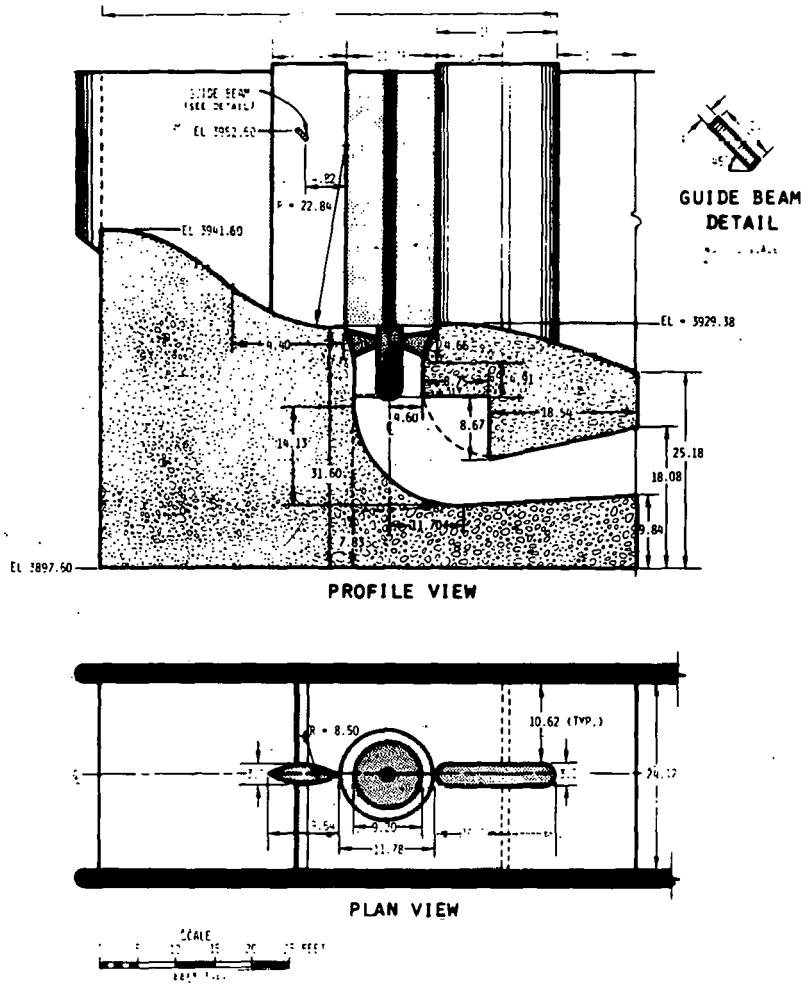


FIGURE P-1.2 Final Recommended Design

The Model

A sectional model was constructed to an undistorted linear scale ratio, model to prototype, of 1:24. The model proper of the structure only simulated one power bay. Since the power bay structure is symmetrical about the centerline, the model was constructed in basically a mirror image. The model consisted of the significant approach area to the structure (the experimental basin), the dam crest, the draft tube entrance, the diffuser for the draft tube, and the proposed piers and gates within the power bay.

Scope of the Experimental Program

The general purpose of the model study was to determine the soundness of the hydraulic aspects of the proposed design and, if necessary, modify the design to improve any undesirable flow conditions revealed by the model tests. Tests were conducted to analyze hydraulic conditions in the following areas of concern:

(a) discharge-head rating curve of the spillway;
(b) the area above the draft-tube entrance during the generation and combined operation and flood modes;
(c) the area immediately downstream of the model structure during the generation, combined operation and flood modes; and
(d) flow through the structure during the flood mode.

Close liaison was maintained with the client to ensure that the model investigations were practical in terms of design and construction, and representative of site and operating conditions.

The experimental program was divided into four different modes according to the operation:

1. Pure generation mode: This condition existed when the river flow, after irrigation diversion, was less than 5920 cfs. Depending on the magnitude of the available flow, one to four units would be generating power while all the spillway bays remained closed.
2. Combined operation mode: When the range of flow at the site was between 5930 and 31400 cfs, all four units would be generating power and depending on the flow magnitude, one to nine spillway bays could be opened to bypass excessive flow.
3. Controlled flood mode: When the flow was between 32,500 and 42,800 cfs, generating power would be terminated and the power bays could be converted to spillways as needed.
4. Uncontrolled flood mode (surcharge mode): In the event of rare floods (100 to 1,000-year floods) the surcharge space, from top of the embankment dam (El. 3957.6 ft) to the normal operating level (El. 3952.6 ft), would be utilized to facilitate flood bypass. All the gates would be fully open.

Table P-1.1 shows the experimental program.

TABLE P-1.1

Base #	Description	Discharge (cfs) 1 Turbine	1 Spillway Bays	Total	Frequency (years)	Elevation (ft) Headwater Surface	Tailwater Surface	Head (ft) Turbine	Spillway
I	Pure generation mode								
1	Shutdown	<460							
a.	Oper. 1 var. pitch turbine	515-1580	closed	515-1580	never	3952.6	3925.0-3927.1	27.6-25.5	closed
b.	Oper. 2 var. pitch turbine	510-1560		1020-3120	occurred		3926.2-3928.8	26.4-23.8	
c.	Oper. 3 var. pitch turbine	510-1520		1530-4560			3927.0-3930.0	25.6-22.6	
d.	Oper. 4 var. pitch turbine	510-1480		2040-5920			3927.6-3931.0	25.0-21.6	
II	Combined operation mode								
2a.	4 turbines + 1 spillway bay	1430	2630	8350	1	3952.6	3932.4	20.2	11.0
b.	4 turbines + 2 spillway bay	1370	2860	11200			3933.8	18.8	
c.	4 turbines + 3 spillway bay	1310	2936	14048			3935.2	17.4	
d.	4 turbines + 4 spillway bay	1250	2974	16897			3936.4	16.2	
e.	4 turbines + 5 spillway bay	1190	2997	19745			3937.5	15.1	
f.	4 turbines + 6 spillway bay	1140	3012	22634			3938.6	14.0	
g.	4 turbines + 7 spillway bay	1090	3023	25522			3939.6	13.0	
h.	4 turbines + 8 spillway bay	1050	3031	28451			3940.4	12.2	
i.	4 turbines + 9 spillway bay	1010	3038	31380	14		3941.2	11.4	
j.	0 turbines + 10 spillway bay	-	3043	30428	12		3941.0	11.6	
k.	1 turbines + 10 spillway bay	1010	3043	31438	14		3941.3	11.3	
l.	2 turbines + 10 spillway bay	990	3043	32408	17		3941.6	11.0	
III	Controlled flood mode								
3a.	10 spillway bays + 1 power bay		3047	33516	20		3941.8	shutdown	
b.	10 spillway bays + 2 power bay		3050	36605	33		3942.7		
c.	10 spillway bays + 3 power bay		3053	39694	53		3943.5		
d.	10 spillway bays + 4 power bay		3056	42782	91		3944.3		
IV	Uncontrolled flood mode								
	10 spillway bays + all	-	3534	49478	250	3953.6	3945.9	-	12.0
	power bays	-	5670	79380	10,000	3957.6	3952.0	-	16.0

Results and Discussion

1. The discharge-head rating curve was determined and plotted as a result of the model testing. Figure P-1.3 shows the results.
2. The model investigations indicated that the original designs had to be modified in order to improve the hydraulic performance of the structure. The modifications were:

   (a) The pier was streamlined upstream of the turbine entrance.
   (b) An anti-vortex beam was introduced into the structure to prevent a vortex formation that was inherent in the original design.
   (c) The shape of the spillway was optimized to offer the best hydraulic performance for the generation mode.

   (Figure P-1.2 shows the final recommended design of the structure.)
3. In general, the design of the structure was satisfactory with only minor modifications needed where the pure turbine generation and combined operation modes were concerned.
4. The flow patterns in the power bay during the pure generation mode and combined operation modes were satisfactory for the recommended design.
5. The bottom of the anti-vortex beams was at elevation 3951.2 ft. It was suggested that the turbine be operated only when the water surface was above 3950.0 ft. to keep the generation unit safe.
6. The streamlined pier, modified after the model studies, reduced the formation of eddies and vortices.
7. The tailgate position was important to the withdrawal pattern through the draft tube. There was a definite withdrawal area above the entrance of the draft tube which was defined by the model study.
8. The section of the spillway shape in front of the draft tube was important to the flow approaching the draft tube.
9. The following factors were important to the hydraulic performances of the structure:

   (a) The hydrological data regarding flood discharge and tailwater information, and the hydraulic condition of the approach to the dam were basic design information for the structure. The model tests were conducted based on this information. Therefore, sufficient and updated data will help properly design the structure;
   (b) The choice of the size and type of turbine was important to the hydraulic structural design; and
   (c) One important factor affecting the hydraulic performance of the structure was the head difference between upstream water surface and tailwater elevations, because the discharge through the draft tube was a partial function of the head difference.

10. Since this model only simulated one power bay, it reflected two-dimensional characteristics of the phenomena. Some limitations

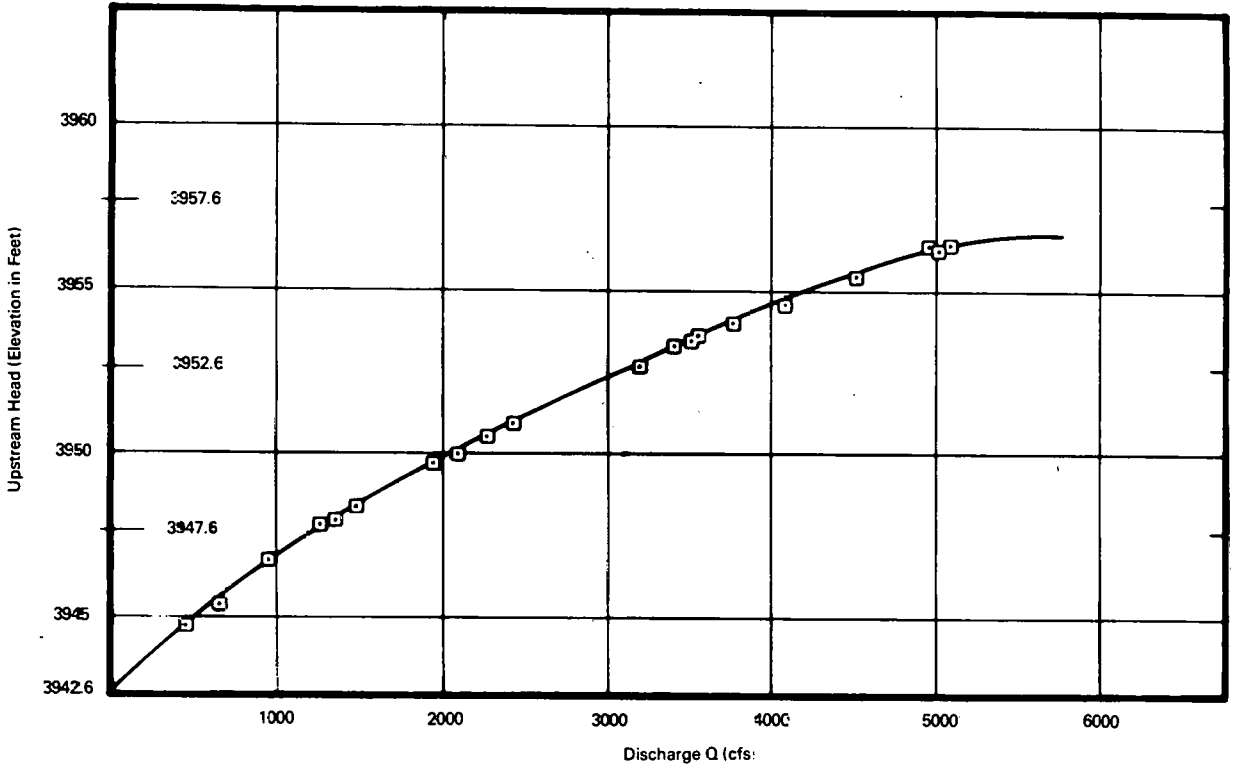


FIGURE F-1.3 Spillway H-Q Curve

had to be imposed on the model test results so that the results could be used for the prototype.

11. One important three-dimensional hydraulic phenomena in the model study was the hydraulic condition immediately downstream of the structure.

    (a) Conditions of pure generation and combined operation mode: The flow through the draft tube discharged downstream of the structure into a dead water area. Because of the dynamic behavior of the jet, it oscillated and had a tendency to cause scour on the river bottom. (The amount of scour occurring in the prototype will depend on the in situ bed material.)
    (b) Conditions of flood mode: During the flood condition, the power bay will serve as regular spillway bay. Flow will discharge over the spillway and a hydraulic jump will occur in the power bay and due to instability of the flow, the flow may cause scour at the toe of the dam.

Conclusions

1. The results of the model tests indicated that the conceptual design for changing the spillway into a power bay operating unit for Broadwater Dam was favorable and feasible from a hydraulic point of view and easily executed with minimal changes to the system. The preliminary studies coupled with suggested modifications, indicated satisfactory flow conditions under all modes of operation.
2. The scope of the experimental study involved the assessment and hydraulic solution to two key flow conditions: a) flow over the crest, withdrawal of water through the turbine, subsequent discharge downstream during power operation through the turbine, and subsequent discharge downstream during power operation mode; and b) flow over the modified spillway section under flood mode. Both flow conditions, after the introduction of modifications, were found satisfactory and did not pose any insurmountable hydraulic problems in the final design.
3. Flow conditions under the generating mode displayed uniform overflow over the ogee section and streamlined approach motion to the turbine throat. No vortexing or adverse eddying pattern was present. These excellent approach conditions were created by streamlining the auxiliary structures in the power bay, optimizing the location of the tailgate, and providing a cross beam which acted as a guide vane and assured prevention of vortexing at a considerable margin of safety. The flow-plume outflow pattern beyond the draft tube displayed typical effluent emergency under high tailwater conditions.
4. Flow conditions under the flood mode displayed a typical submerged hydraulic jump under high tailwater conditons at an abrupt drop. Such flow conditions were characterized by two large rollers above and below the drop. The velocity distribution under such

characteristics in the downstream region displayed higher velocities at the surface than at the bottom.

5. It was recommended that when the feasibility stage of this project progressed into the design stage, the following aspects be experimentally investigated and optimized for final design:

   (a) Under operation mode, the velocity in the draft tube exit area be evaluated to assess the erosional potential of geologic formation and bottom quality of the riverbed;
   (b) Optimize the location of the guide beam and its configuration from the structural, construction, and maintenance points of view;
   (c) Under flood mode, study further and analyze the submerged hydraulic jump behavior with respect to possible adverse pressure fluctuations, energy dissipation measures, and stabilization of the phenomena; and
   (d) Special shaping or protective cover arrangement for turbine intake should be investigated and seriously discussed with the turbine manufacturer.

   It is standard HRS practice that in any dynamic condition, pressure fluctuations are measured in the model. This technique is expedient and very valuable to the designer and structural engineers.

6. Also, for both operational and flood modes, the three-dimensional aspects of the merging flows should be investigated during design stage. For these studies a two-dimensional setup as used in present studies can be utilized, but two or three bay configurations should be modeled.

SMALL-SCALE HYDRO SIMULATION PROGRAM

J. J. Mankauskas, Jr. and E. S. Wright

Introduction

Traditionally, small-hydro projects have been evaluated by rule-of-thumb analysis. Stream-flow duration curves were established from actual or extrapolated U.S. Geological Survey Data, the working head established, and a plant capacity factor assumed. Average values of efficiency, value of power, etc., were used to establish estimated feasibility, and the evaluation of variations which might occur was limited to those which were easily calculable. Obviously, such procedures have little value in today's energy market where a high premium must be placed on the cost-effective generation of electricity from indigenous, renewable resources. Modern-day energy systems analysis incorporates many powerful tools to ensure system optimization in a wide variety of applications, and UTRC has conducted this type of systems analysis in a number of potential applications for many years. As a result, it was believed that a comprehensive computer program should be developed for accurate analysis of small-hydro sites. Consequently, a Corporate-sponsored effort was devoted to the development of the Small-Hydro System Optimization Program (SHOP). This paper presents the program's systems analysis capabilities and presents an overview of the program's structure and operation. In brief, SHOP attempts to match a customer's demand with the water resource available, and using real utility energy and demand rate schedules and energy generation equipment characteristics, determines the cost savings (if any) compared with the costs to meet that demand solely from utility power.

The development of a small-hydro site involves a substantial initial investment. The resulting high fixed cost is offset by "free fuel" (the water resource) which varies on an hourly, daily, seasonal, and yearly basis. The equipment specification, which determines the fixed cost, must, therefore, be highly optimized in order to maximize the value of investment. The SHOP program permits a site owner to investigate all scenarios of practical interest and measure their value, in dollars, in any year over the life of the small-head hydro system. Therefore, the site owner can make intelligent decisions regarding development based on his own future estimates of demand, inflation, utility rates, return on investment, breakeven point, etc. The program has proven to be a useful, concise tool for determining site feasibility and developing optimum design specifications in a rapid and economic manner.

Mr. Mankauskas is Associate System Engineer, United Technologies Research Center, East Hartford, Connecticut.

Mr. Wright is Program Manager for Low-Head Hydro Systems Evalutions at United Technologies Research Center, East Hartford, Connecticut.

Small-Head Hydro Systems Engineering Analysis

The small-head hydro system is shown schematically in Figure P-2.1. The system consists of a reservoir impoundment, hydroturbines, auxiliary heat engine (as an option), and a process controller. The hydroturbines and heat engine generate energy that is applied to the user's process and displaces energy that the user would have to purchase from the utility. The reservoir impoundment supplies water to the hydroturbines that drive generators through direct-coupled gearboxes. The riverflow into the reservoir is specified as a function of time of year through the reservoir's incoming river hydrograph. The hydroenergy, HYPOWR, generated by the hydroturbines is given by:

$$HYPOWR = 2.35 \times 10^{-5} * ETATUR * FTURB * HD * PLOSS$$

Where ETATUR is the hydroturbines' efficiency, FTURB is the hydroturbines' penstock flow, HD is the difference between the reservoir's surface elevation and the hydroturbines' tailwater surface elevation, and PLOSS is the hydroturbines' penstock loss. The numerical constant is the energy conversion factor that converts the penstock's flow potential energy to electrical energy.

The system controller effects the hydroturbines' and heat engine's operation and performance. The controller maintains the reservoir's surface elevation, HHWD, (Figure P-2.2) between the reservoir's maximum and minimum surface elevations, HMAX and HMIN, maintains the hydroturbines' tailwater flow, FTW, above the prescribed minimum tailwater flow, and also maintains the inventory on the hydroturbines' and the heat engine's operation and energy generation. The controller also determines when and how much energy is purchased from the utility.

The controller maintains the reservoir's surface elevation and the required tailwater flow by regulating the reservoir's leakage, bypass, and spillway flows, and the hydroturbines' penstock flow. The controller will allow the generation of hydroelectric energy whenever there is an energy demand and the reservoir's surface elevation is above the penstock's inlet elevation. SHOP's controller can specify the sale of hydroelectric energy when there is no process demand for it, or when the reservoir surface elevation is between the limits that permits hydroelectric energy to be generated. In regulating the time when excess hydroelectric energy can be generated and sold, a portion of the reservoir's volume is dedicated to generating hydroelectric energy that can only be applied to the user's future process energy requirements. This operation results in greater utilitation of the water resource, and lower process costs by always having reserve storage that can be used to generate hydroelectric energy, which can be directly applied to the user's process energy requirements. Lower process costs result because the lower-cost hydroelectric energy generated displaces an equivalent amount of the higher-cost utility energy that would have to be purchased if the hydroelectric energy were not available.

In SHOP, the user's process energy requirements are defined in kilowatt-hours usage and peak kilowatt demand on a monthly basis over a simulation time period. The controller develops energy in response to the user's process time-varying energy requirements through the following sequence:

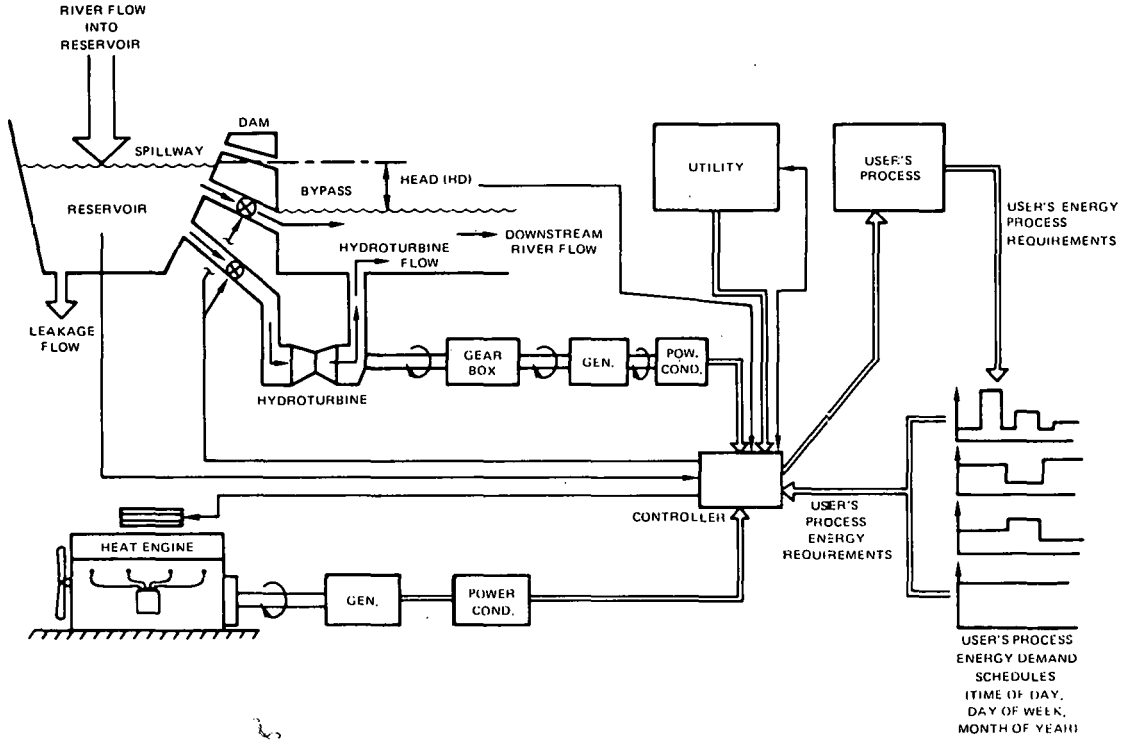
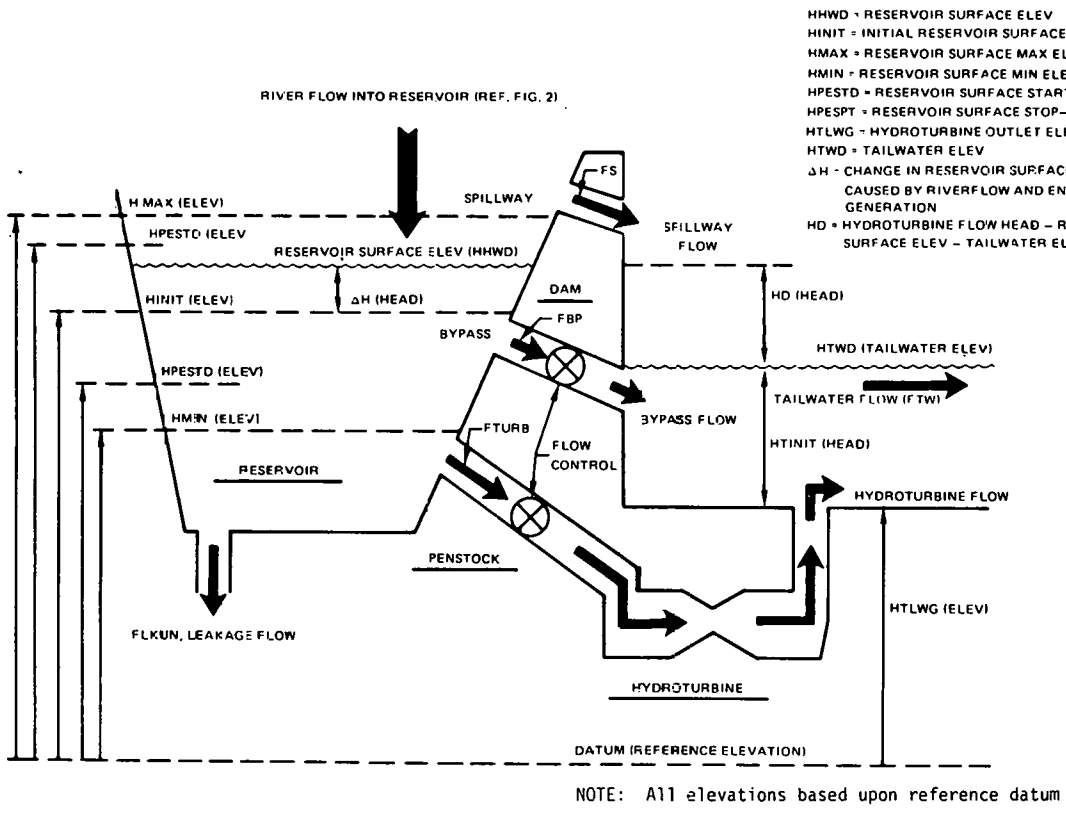


FIGURE P-2.1 Low-Head Hydroelectric Generation System



NOTE: All elevations based upon reference datum

FIGURE P-2.2 Reservoir Control Parameters

1. hydroturbines,
2. heat engine, and
3. purchased process shortfall energy from the utility.

The time-varying nature of the reservoir's river flow, and the hydroturbines' and heat engine's characteristics govern the amount of energy the hydroturbines and heat engine can generate and the amount of energy that has to be purchased from the utility.

In the program, the controller also functions as a killowatt-hour meter and accumulates the amount of energy and the costs of energy generated by the hydroturbines and the heat engine, and also the amount and cost of energy purchased from the utility. The hydroturbines' and heat engine's cost of energy are determined by

$$\text{Cost of Energy} = \sum_{i=1}^{N} \int_j E(t)\, dt * EC_{Nj}(i),$$

where $j\ E(t)^*_{dt}$ is the energy generated by the hydroturbines and the heat engine's direct maintenance and operational energy costs. The index variable, N, is the number of direct maintenance and operating cost groups for the hydroturbines and heat engine. The cost of the utility energy purchased is determined from process-shortfall energy purchased and the appropriate utility rate schedule. The utility energy cost is determined by the following algorithm.

$$\text{Utility Energy Cost} = \text{S.C.} + \Sigma CKW * KW + \Sigma CKK\text{-}WHR * KWHR \quad KW * KWadjhr + \Sigma CKWHA * (KWHRA * KW) \quad KWHR \quad \Sigma CKWHA * (KWHRA * KW) \quad KW * KWadjhr$$

In the utility cost algorithm, the first term represents the rate schedule's monthly service charge, while the second term represents a base-level cost related to peak power requirements. The third term is the kilowatt-hour energy cost up to the utility rate schedule's adjustment limit, KW*KWadjhr, while the last term represents the adjustment, which is the kilowatt-hour cost between the adjustment limit and the kilowatt-hours, KWHR, used by the process. In the above algorithm, CKW, CKKWHR, and CKWHA are the respective per-unit kilowatt, kilowatt-hour, and adjustment kilowatt-hour unit costs. KW and KWHR are the peak kilowatts and kilowatt-hours purchased from the utility.

Investment and First-Year of Operation Cost Summary

SHOP generates an investment and simulation time period (or first year of operation) cost summary. SHOP's investment summary includes the hydro-

site's equipment and construction capital costs (or replacement equipment cost if the system is being refurbished), startup cost, Federal and state investment tax credits, investment loan interest rate, and the investment loan amortization time period. SHOP combines these parameters to determine the user's after-tax-credits annual-loan payment, the loan's annual-principal payment, and the loan's annual-interest cost.

In SHOP, the hydroturbine and heat engine's capital costs are expressed in $/kW which are based on their installed capacity. The investment cost summary includes fixed and site-specific capital costs for the small-head hydro system. For example, the system's power line capital cost is based upon the physical length of the power lines connecting the system to the utility grid, while the electrical hookup cost is based on the system's installed capacity rating.

SHOP's first year of operation cost summary is based on the first year's investment loan interest payment, equipment depreciation cost, revenue from excess hydroelectric energy sold to the utility, shortfall utility energy cost, heat engine's fuel cost, and the site's property taxes and insurance costs. Also included are the hydroturbine's and heat engine's maintenance and repair costs, which are based on the kilowatt hours generated. These costs are generated over the simulation time period on a monthly basis with totals given for the first year of operation.

As part of the calculation of the monthly costs for the small-head hydro system, the equipment's depreciation costs are determined using one of three depreciation methods: the straight-line method, the double-declining balance method, or the sum-of-the-years digits method. The program-user selects the depreciation method to be utilized by setting the value of the depreciation variable IDEPR in the input data. The total investment in the system is a composite of the investments in the hydro equipment, the heat engine, and the site's civil works, where all three components are depreciated separately using the same depreciation method. This allows the program user to specify individual depreciation time periods and salvage values for the small-head hydro system's components and thus reflects real world operation.

Life-Cycle Cash Flow Summary

SHOP generates an optional economic summary that represents the system's life-cycle cash flow. This report, which is produced only when the user sets the computer input program variable CSFPO to 1.0, extends the economic analysis over the operating life of the system so that annual cash flow and long-term benefits may be estimated.

In SHOP, two economic comparisons are developed between small-head hydro system operation and the user of purchased utility energy. First, the annual operating costs of the small-head hydro system are compared to the cost of purchasing all energy from the utility. Secondly, the system's annual-cash flow, after taxes, and the after-tax cost of purchasing all energy from the utility are compared. The net present values of these costs are calculated, and the economic benefit of investment in the small-head hydro system is developed.

In the event that the system is generating excess energy for sale to the utility, SHOP generates two economic summaries. One includes the antici-

pated revenue; the second shows investment cash flow without the revenue. The basis for comparison in the cash flow summary routine is the costs developed during the simulation of the simulation-time period or the first year of operation. These costs are brought into the investment cash flow summary by escalating the first year of operation costs to obtain future-year costs. The cost escalation rates are based on historic rates experienced by the user, and are used throughout the economic analysis in the following way:

$$\text{Account Cost for Year (N)} = \text{Account Cost for Simulation Year}^{*}(1 + \text{Cost Escalation Rate})^{N-1}$$

Operational Saving

The annual saving for the investment in the small-head system is computed as the difference between the annual energy cost for the user operating his process by purchasing all energy from the utility and the total operating cost of the installed system. The operating cost of the system is defined as the total expense of the system less any revenue derived from its operation in the sale of excess hydroelectric energy to the utility. SHOP also calculates the net present value of the annual operational saving at the user's investment discount rate and accumulates this amount for the operating life of the system.

Economic Benefits

Another section of SHOP's cash-flow summary views the small-head hydro system's investment from the cash outflow perspective. The annual value of the energy cost, after taxes, of the user purchasing all energy from the utility is compared to the after-tax operating cost of the small-head hydro system. The difference between the two accounts is the annual economic benefit, on an after-taxes basis, of investments in the small-head hydro system. In this analysis, only operating costs are included in the economic benefit calculation; depreciation is not included as an operating cost. The principal payment is included in the total cash out-flow because this account represents a liability for the investment in the system, which must be reduced by annual payments.

Payback Period

The same routine which produces the above-described cash flow and investment analysis, also computes the payback time period of the system investment. SHOP determines the year in which the sum of annual-cash savings, after taxes, has accumulated to exceed the initial investment less any investment tax credits.

Internal Rate of Return

The internal rate of return, which is calculated as the interest rate that equates the present value of the expected future savings to the value of the system

investment, is computed by an iterative process in another subroutine in SHOP.

The internal rate of return, IRR, is the value which satisfies the following economic equation:

$$CTOTCP = \sum_{I=1}^{NOY} \frac{ASATS(I) + ALPR(I)}{(1 + IRR)^{**}I}$$

where: CTOTCP = total investment after tax investment credits,
ASATS = annual cash savings after taxes
ALPR = annual loan principal payment
NOY = number of operating years for the system

Program Structure

The Small-Hydro System Optimization Program structure, as shown in Figure P-2.3, consists of a main program (MAIN) and support subroutines, each of which performs a specific function. The MAIN program calls the support subroutines in sequence, and data are passed between the subroutines by COMMON blocks and arguments. Subroutine INPUT reads and prints the simulation data Subroutine ELCOMO computes the user's process simulation time period monthly, and calculates annual-energy costs as determined from the user's process energy requirements and the associated utility rate schedule. CAPITL computes the system's capital cost and computes its annual amortization payment schedule.

Subroutine YEAR compiles the system's monthly and annual performance parameters and statistics summary and log. Subroutine DAY regulates the simulation of each day, determines the appropriate control strategy to be applied to the system, and also selects and controls the algorithms for modeling and estimating the equipment performance and the flow into and out of the reservoir. Subroutine ALGO contains the algorithms for modeling and estimating the system's equipment performance and energy generation, flows into and out of the reservoir, and the reservoir's hydroturbines' tailwater surface elevations as a function of time; i.e., user's process energy requirements and overflow into the reservoir.

Subroutine ACOUNT compiles the system's maintenance, operational, depreciation, and purchased-energy costs for the simulation time period. Subroutine OUTPUT prints the system's simulation time period performance summary, statistics, and operating costs. Subroutine CASHFL generates the system's life-cycle economics summary which is based upon the simulation time-period performance, the investment structure, and the life-cycle economics.

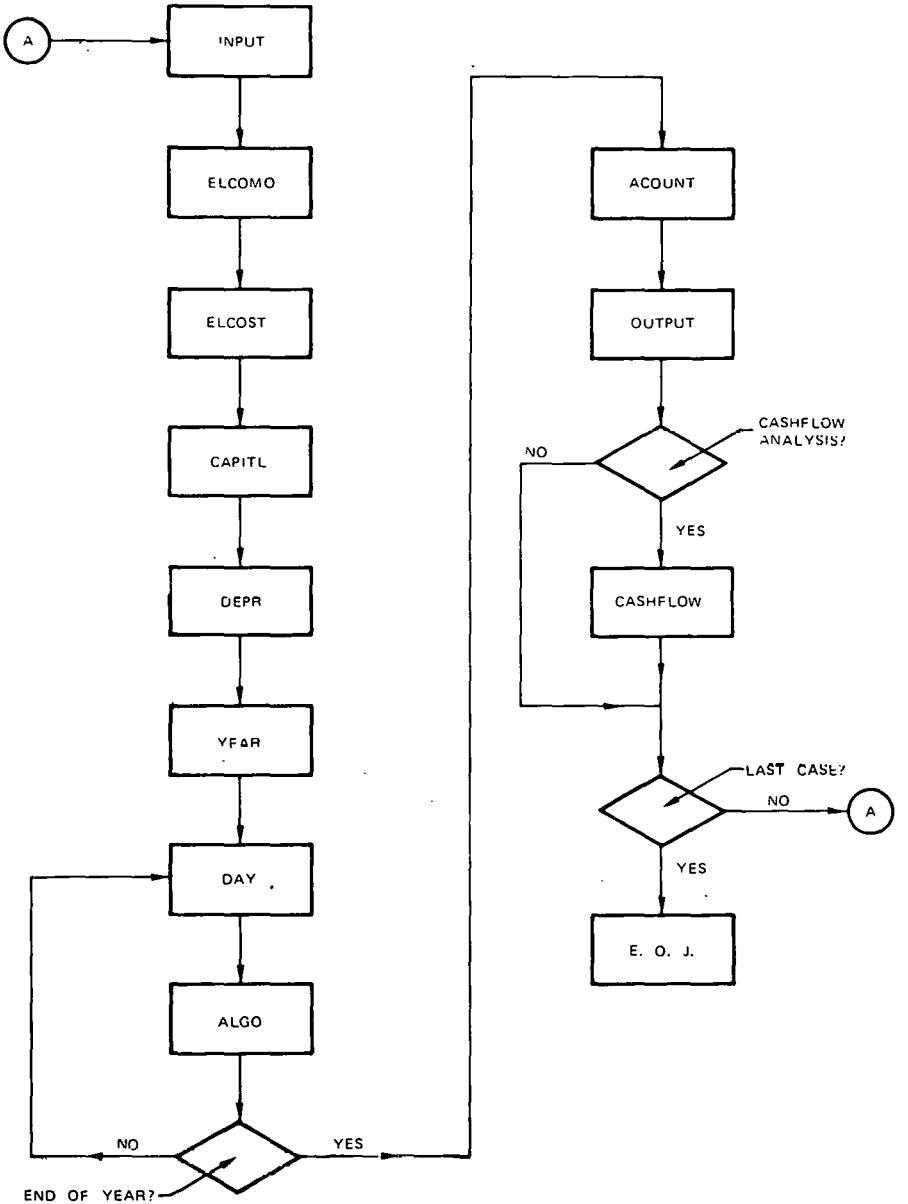


FIGURE P-2.3 Overview of Program Structure

SMALL-SCALE HYDROELECTRIC GENERATION AND THE SALT RIVER PROJECT

Eugene J. Lauerman

Introduction

The phrase "history repeats itself" is normally used to predict dire things. But sometimes history's repetition can have beneficial effects, as in the case of the Salt River Project and small-scale hydroelectric generation.

SRP began as a water reclamation and distribution project, using dams and canals to store and deliver water to a largely agricultural community. Hydroelectric generation, particularly low-head involving canal-power plants, was added as an afterthought. At one time, four small-scale facilities were in use, but as SRP's service area grew, so did the Project's generation commitment. In the era of cheap fossil fuel generation, the small-scale hydro stations gradually became less cost efficient and eventually all but one was phased out. Even the one which remained in use was used on an intermittent basis.

But the oil embargo of 1973 and the resulting crisis forced us to re-evaluate small-scale hydro and, after several studies, one of the original four sites was chosen to be proposed to the Department of Energy (DOE) for consideration in their Small-Scale Hydroelectric Power Demonstration Program.

The site, located on the South Consolidated Canal in Mesa, Arizona, has a 35 foot head and is slightly downstream from the original South Consolidated site. As recently as 1974, studies which had been carried out on a periodic basis indicated the benefit/cost ratio of the South Consolidated site was 0.95, the best of the three sites not in service. But the continued rise in fuel oil prices prompted a review in 1978 when DOE issued its first Program Opportunity Notice. By then, the benefit/cost ratio for the South Consolidated site had increased to 1.41. Because of that increase, the two remaining original sites are being reviewed to see if their benefit/cost ratios are now at unity or greater.

How does one go about analyzing any specific location for small-scale hydroelectric generation? A checklist is included in Figure P-3.1.

First, there must be adequate head, which is the difference in elevation between the upper impoundment and the lower-stream water levels. The kilowatts of generation vary directly with head. The second consideration is water flow. For SRP, this was relatively easy to determine with decades of records available from which to choose a representative period. Generally, there should be at least ten years of record, so wet and dry cycles can be observed. After flow has been established, plot a flow duration curve.

The physical setting is next. What presently exists: check structure, dike, dam, gateworks or nothing? Can it be modified or adapted to fit a small-scale hydroelectric unit installation?

Next, turbine applications should be explored. Which type units seem better for the conditions: propeller, Francis, Kaplan, etc.? At this point, if there is

---

Mr. Lauerman is Manager for Research and Future Projects Studies, Phoenix, Arizona.

no expertise in your company, turbine manufacturers can be of some help or a competent engineering firm can be retained. (Incidentally, DOE, Idaho Falls maintains a reference listing of manufacturers and engineering firms.) Next is the selection of either an induction or a synchronous generator. Manufacturers can supply cost estimates and typical operating curves for the package units. Then estimate the cost to install or modify an impoundment structure, estimate the equipment costs and installation, control and protective devices, hydraulic and electrical. After capital costs are estimated and annualized, taxes, insurance, operating and maintenance costs for the life of the project must be estimated and added.

Now consider the benefits - what is the energy and capacity worth on today's market, either to your system or if sold? The total benefit divided by the total cost determines benefit/cost ratio. If unity or greater, the site probably should be developed. If not, forget it.

Last, but not least, are the environmental effects. Depending upon location and what exists at the site, determination of impacts will require an environmental assessment. A competent environmental consultant should be retained once a decision is made to develop a site.

There are some "rules of thumb" to be considered in addition to the items mentioned previously.

A usual starting point for rough turbine sizing is to use the water-flow value from the duration curve at the point where flow equals or exceeds the value shown for 25 percent of the time. After an equipment selection is made, a flow range is available for use in determining the amount of energy that can be extracted from the falling water. The horsepower is roughly equal to the flow in cubic feet per second, times head in feet, divided by ten. To convert horsepower to kilowatts, multiply by 0.7. Most engineers would correct me, but these rules of thumb are assuming certain efficiencies and are adequate for approximate sizing.

Here are some specifics for our DOE Demonstration Project. The Eastern Canal will be modified by dismantling the existing check structure and installing the gates and control in a similar sized structure approximately 350 feet downstream. During generation, the South Consolidated Canal flow will be delivered to the head of the Eastern Canal. The water to be delivered to the South Consolidated Canal will drop through the hydro-unit and pass on into the South Consolidated Canal. The original South Consolidated Canal check structure and drop chute will be used to bypass flows above the design flow of the turbine and during nongenerating periods.

The turbine and generator will be of the standardized package type, currently being marketed by at least eight suppliers throughout the world, with specific operating ranges for flow, head and output. These packages consist of turbine, generator, speed increaser (where necessary), water passage liners and all necessary control equipment for the main unit and the auxiliaries. The principle advantage of the standardized turbine is the minimizing of design and manufacturing time and cost, which tend to be disproportionately high for custom designed equipment of small capacity.

Figure P-3.2 shows the flow at 25 percent of the time to be 530 CFS which converts to 1,300 kW. This preliminary capacity was used to obtain estimating prices for the turbine/generator equipment.

The flow range shown for the site of 0 to 1,100 CFS is unusually wide for a

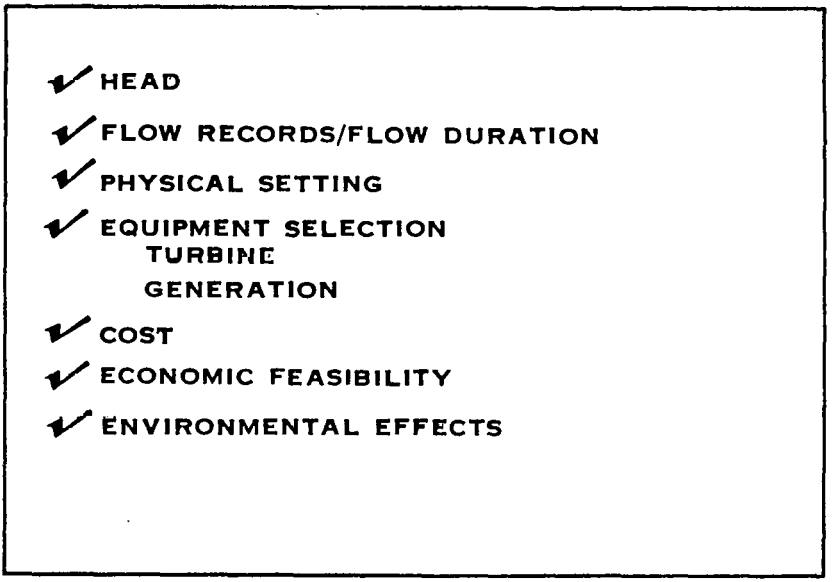


FIGURE P-3.1 Check List

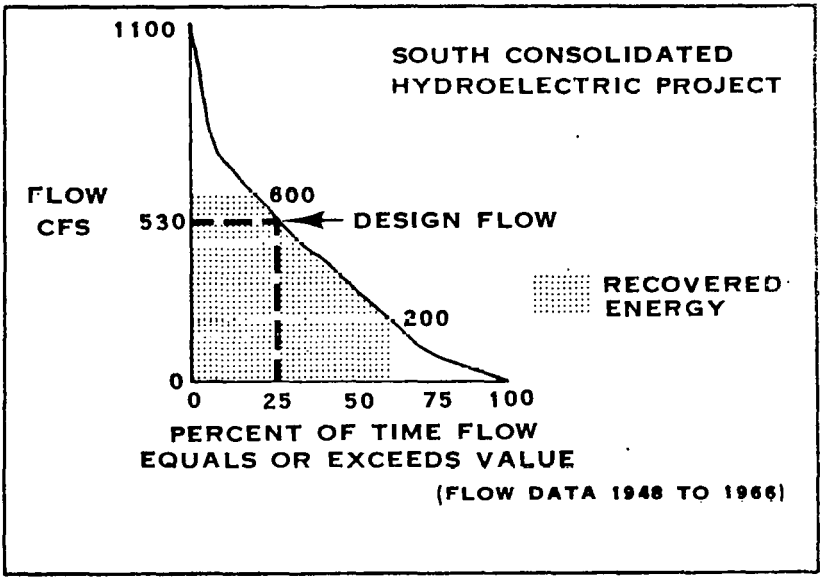


FIGURE P-3.2 Mean Annual Flow Duration

hydro plant and could not be efficiently accommodated by a single machine. The choice was between adopting a single turbine with a permissible range of flows somewhat narrower than those available, thereby sacrificing some energy output or going to a multiple unit installation. The adjustable blade-type propeller turbine has proven itself to be ideally suited to accommodating a wide range of head and flows, and was a natural choice here, particularly for a single-unit installation. The head is relatively fixed so the flexibility of the design will be utilized in controlling flows over the range required. Single machines of this type perform well for flows between 30 and 100 percent of maximum.

Requests for equipment application data and pricing were sent to several turbine/generator equipment manufacturers of package units. Suppliers were requested to make an appropriate selection from their standard turbines as to number of units, means of flow control and overall design for the given operating conditions. This information, along with price and performance data, was then subjected to a comparative evaluation in order to determine which design might be used for developing the cost estimate and structure layout. Performance data that was provided in response to the equipment inquiries permitted an upgrading of the turbine/generator capacity to 1,400 kW, the rating selected for bidding purposes.

In order to analyze each of the particular supplier's recommendations, the flow-data was broken into 50 CFS steps and the hours per year for each of these increments were determined from flow-data analysis. The appropriate values were substituted in the expression kW $=0.0085HQN$ (a refinement of the "rule-of-thumb") for each of the 50 CFS increments to determine the kW for each of these periods. That, multiplied by the number of hours, gave the energy for each period. As a result of the analysis, it was concluded that a single turbine/generator unit of the horizontal axis, adjustable blade type utilizing a flow-range between 200 and 600 CFS would generate the greatest amount of energy. The energy, estimated month-by-month, has an annual total of 5,987,960 kWh. Flow-data for the wet and dry years of 1966 and 1951, respectively, was also analyzed. This analysis indicated that the recovered energy in the wet year will be approximately 9.7 million kWh or 64 percent more than that of the average. In the dry year, recovered energy will be about 3.2 million kWh or 55 percent of that for the average year.

To determine the benefits of this project, the estimated monthly-average generation was multiplied by the monthly-average-system marginal cost. This was done for each of the months and an annual value of the energy obtained. This was calculated for the first ten years, utilizing the estimated average system marginal costs for each of the months of each of those first ten years. From that point on, the fuel cost savings were escalated at five percent per year and converted to 1978 dollars. This showed a total energy benefit of $3,481,000. (See Figure P-3.3.) From the prior work, the average capacity value in kW was utilized and multiplied by a current estimated cost associated with combustion turbine capacity of $2.85 per kW-month. For each of the months, this was calculated and totaled for the year, which gives an annual value of $22,970; this value was escalated at five percent per year for 50 years and present worthed back to 1978, giving a value of $667,000. The $3 million plus of energy benefit combined with the $667,000 of capacity benefit yields a total benefit of $4,148,000.

A capital cost estimate was also performed for the project. The construction costs were based on estimated material quantities taken from layout drawings. The estimating prices for the turbine/generator package were used. Miscellaneous equipment costs were obtained from cost records and published price data; engineering and project manager costs were developed from the scope of work correleated with the project schedule. The total capital cost, as shown on Figure P-3.4 is $1,353,000 ($966 per kW). Other costs were added to get the total cost in 1978 dollars for the 50 year estimated life. Operating costs were determined to be nil, because the plant will be remotely operated from SRP's dispatch center. The maintenance costs were derived from the Crosscut Canal Plant Unit for the most recent years at about $17,200 per year, including overhead. This was escalated at seven percent per year throughout the lifetime of the facility. Insurance costs were estimated at 0.1 of one percent of investment costs of $1,353 per year, which was escalated at seven percent over the project lifetime. Although SRP is a political subdivision of the state of Arizona, and exempt from property taxation, voluntary contributions in lieu of taxes are made to school districts, cities, counties and state, in accordance with legislation passed in 1963. Based upon the location of the proposed project, the annual in-lieu taxes were $44,650. Miscellaneous administrative costs of $20,000 were also included, bringing the total cost for the project for 50 years, in 1978 dollars, to $2,935,000.

The benefit/cost ratio is obtained by dividing the benefit of $4 million plus by the cost of $2,900,000 plus, yielding a benefit/cost ratio of 1.41. At today's oil prices, that benefit/cost ration has risen to 2.10.

In summary, SRP believes the advantages of this kind of installation are as follows:

- Economic use of existing water resources
- No water consumption
- Economic viability for run-of-river (canal)
- Fuel oil displacement of 4,000 Bbls/year
- No adverse environmental impact
- Use of commercial package unit
- Easily accessible location
- Provision for water-flow control
- Highest production matches need

Because of equipment and materials delivery schedules, we will not be starting construction this year. In October 1980, we will move the check structure in the Eastern Canal and install intake and outlet structures. In the interim, we might be able to install the penstock, powerhouse and place some of the machinery. If not, the remaining work will be done after the October 1980 dry-up so that the plant is complete in late '80 or early '81. One of the difficulties we face is that the completion of the plant, dictated by the canal dry-up periods, will coincide with low-flow months, so it might be late spring before we will have enough water-flow in the canal to adequately test the unit and get it ready for commercial operation. Test runs will be performed to obtain essential data on unit performance and for use in automatic control of the unit.

Now the rest remains to be experienced. With plant completion, we will tally the costs and compare them with estimates to see if we have done a good

ENERGY BENEFIT

PRESENT WORTH SAVINGS (1978 $)	
FIRST 10 YEARS	$1,000,000
NEXT 40 YEARS	$2,481,000
	$3,481,000

CAPACITY BENEFIT

AVERAGE MONTHLY KW AVAILABLE	
VALUE OF $2.85/KW-MONTH	$22,970
ESCALATED 5% /YEAR, 50 YEARS	
PRESENT WORTH AT 7 1/4% TO 1978	$667,000

BENEFITS

ENERGY	$3,481,000
CAPACITY	$ 667,000
TOTAL	$4,148,000

FIGURE P-3.3 Benefits

TOTAL COSTS 50 YEARS

	PW (1978 $)
CAPITAL	$1,353,000
OPERATING	NIL
MAINTENANCE	$ 905,000
INSURANCE	$ 60,000
IN-LIEU TAX	$ 597,000
MISC. AMN.	$ 20,000
	$2,935,000

BENEFIT/COST RATIO $\frac{\$4,148,000}{\$2,935,000} = 1.41$

FIGURE P-3.4 Costs and Benefit/Cost Ratio

job. In the end, however, we believe that the project is going to be cost effective and will yield annual savings. You are invited to visit the Project when it is finished; watch for the announcement in the DOE Small-Hydro Bulletin.

WEED HYDROELECTRIC DEVELOPMENT—A SMALL-HYDRO CASE STUDY

James D. Calvert, Jr.

Introduction

This paper describes a small-hydroelectric development of 630 kW successfully undertaken by the Village of Gresham, Wisconsin in the mid-1960's. Built at a time when many small-hydros were being routinely abandoned as uneconomical, the Weed-Hydro Development attests to the sound wisdom of developing our renewable energy resources and realization of the long term benefits therefrom.

Description of Development

The Weed-Hydro Development is located on the Red River in Shawano County, Wisconsin about a mile and a half east of the Village of Gresham. Its location is shown on Figure P-4.1, Location Map. The dam consists of a concrete-center section about 105 feet long flanked on either side by two earth dikes, each about 700 feet long. The concrete-center structure contains two intake gates for the powerhouse penstocks and a spillway section containing four 5 x 14 foot tainter gates. The reservoir provides a gross head for power of 25 feet and creates a reservoir covering about 230 acres, and extends up stream to the Village of Gresham encroaching slightly on the upper-hydro plant also operated by the village. Figure P-4.2, Vicinity Map, depicts these details of the development. Two penstocks, one 6.5 feet in diameter and other 4 feet in diameter lead to a powerhouse about 50 feet to the East across the road. Two units are installed, one having a capability of 150 kilowatts, and the other 480 kilowatts, for a total of 630 kilowatts.

The spillway will pass a design flood of 6200 CFS without endangering project structures. In addition to the gated spillway at the dam, additional protection is provided by a fuse-plug spillway having a capacity of 2000 CFS which is located about 520 feet west of the main dam.

The Weed-Hydro development has an average annual energy production in excess of 2,000,000 kWhs, and together with the upper-hydro development built in 1928 supplies 50% of the power needs of the Gresham Municipal Electric System. The remainder is purchased from the Wisconsin Power and Light Company or is generated at a small-diesel plant operated by the Village.

The following account of activities necessary to implement this project are illustrative of measures required to bring small-hydros into production:

1. Feasibility
   From the outset, it was recognized that feasibility of the project in the then prevailing energy economics would be difficult. At that time the principle alternatives were diesel-power generation and purchased power from the utility. Both of these sources were ex-

Mr. Calvert is Executive Consultant for Gilbert/Commonwealth, Jackson, Mississippi.

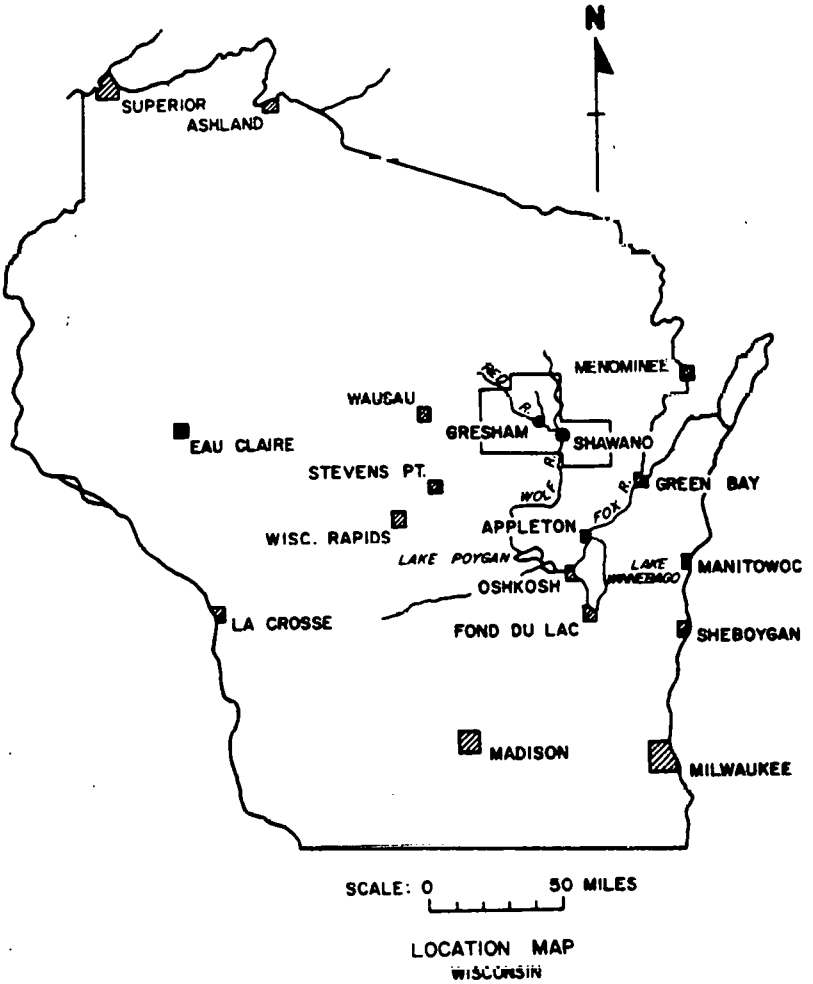


FIGURE P-4.1 Weed Hydro Development FPC No. 2464

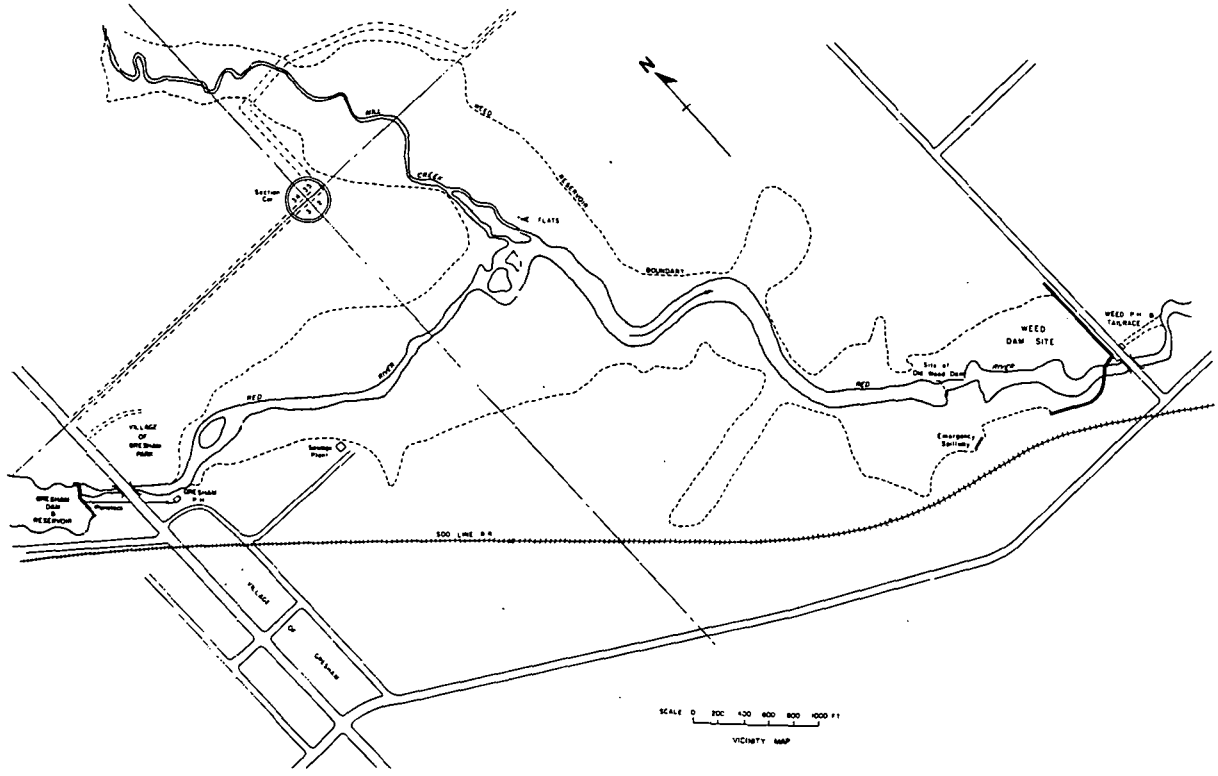


FIGURE P-4.2 Vicinity Map Weed Hydro Development FPC No. 2464

pensive and in the final analysis the Federal Power Commission chose to justify the new-hydro on the basis of the purchased power alternative. Extensive calculations indicated that the new-hydro would have a benefit-cost/ratio of 1.17 over the alternative of purchased power. Nonetheless, the 5 member commission was split over granting a license with three in favor and two opposed.

In retrospect it is interesting to note the general trend of energy economics of the Weed-Hydro over the past 15 years. Figure P-4.3, Predicted and Actual Power Costs, illustrates some interesting trends. The actual cost of alternative purchased power, while trending down at the time of licensing, has in recent years risen sharply, as a result of substantial cost escalation in thermal-plant construction and fossil fuels. In contrast, the hydro once built, maintains a relatively flat cost curve. It is also interesting to note the projected-cost curve for alternative power which was predicted by the two dissenting FPC commissioners, Swidler and Ross, at the time of licensing. At that time they believed that as a result of the then recently completed National Power Survey, energy costs would trend downward and Chairman Swidler predicted energy costs of 8.2 mills/kWh in 1980. However, events did not bear out this projection and actual energy costs today are 3 or 4 times the projected 8.2 mills/kWh. The Weed-Hydro Development today is operating well below this actual alternative cost and already has represented substantial savings to the village over costs they otherwise would have incurred.

2. Licensing

   The licensing process for the Weed-Hydroelectric Development involved the Wisconsin PSC and the Federal Power Commission, the latter becoming involved upon determination that the Red River was a navigable stream.

   Extensive hearings were held, particularly for a project of such small size. Several local landowners and the DNR of Wisconsin were intervenors to the project, and considerable testimony was received in opposition on conservation and fisheries aspects. However, it was finally concluded that the economic merits of the endeavor outweighed any adverse impact on fisheries and other conservation concerns. The project was pre-NEPA.

3. Financing

   Principle financing of the Weed-Hydro Development was obtained from a bond issue in the amount of $300,000 for a term of 20 years. Interest rates varied from 3 to 4 1/2 percent. The bond issue was secured by a lien on the Villages' existing utility plant. Additional funds as required were obtained from short-term financing and from internally generated funds of the municipal electric system of Gresham.

4. Environmental

   The primary environmental concern related to the protection of certain fisheries in the Red River, and to the preservation of natural and scenic qualities of the stream. It was demonstrated, however, that the fisheries resource of the 230 acre reservoir created would

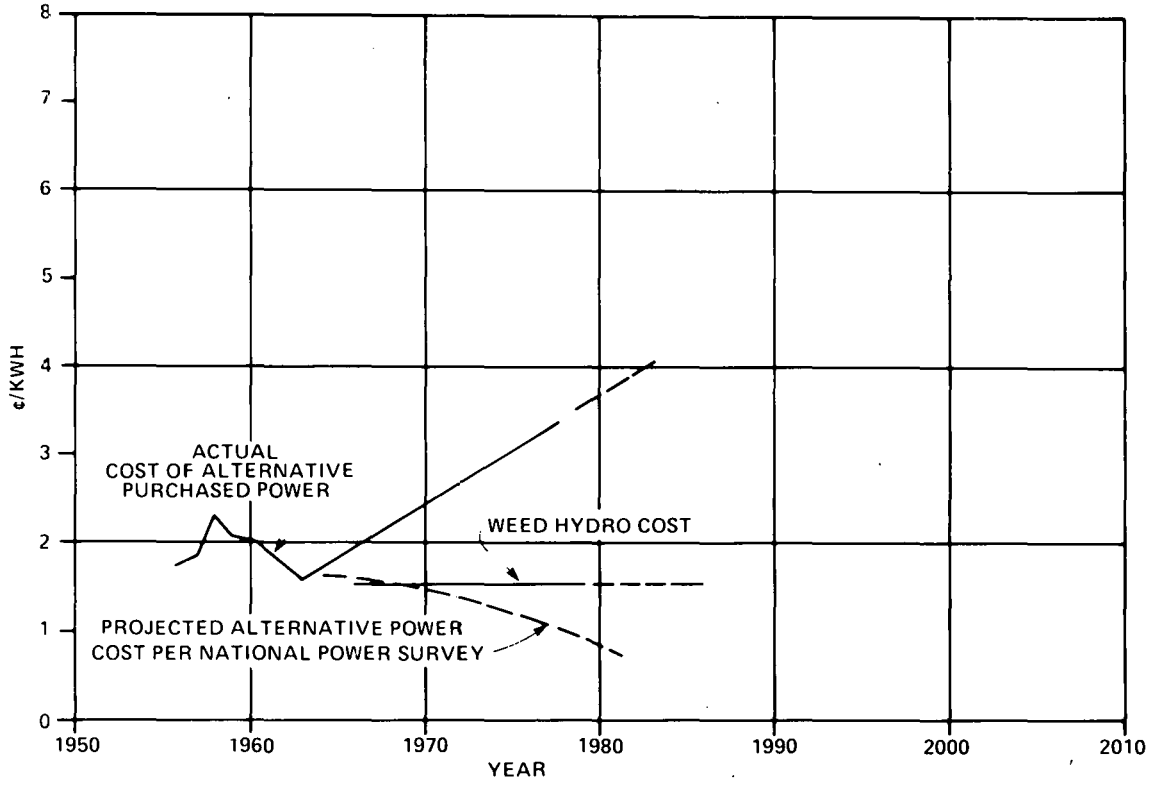


FIGURE P-4.3 Weed Hydroelectric Development - Predicted and Actual Power Costs

equal or exceed that existing in the natural river. It was also shown, that the new reservoir would provide greater recreational opportunities than the original stream which in its natural state was largely inaccessible due to private ownership of contiguous land. Other more direct measures were taken to protect aquatic life including provision of a small 10 kW hydroelectric unit at the spill way to release small-flows of water into a bypassed section of the river to prevent oxygen deficiencies.

5. Design
   Nearly every hydroelectric undertaking is extremely site-sensitive and requires a careful blending of accepted engineering practice with local resources and natural conditions. Innovation is often required to overcome significant cost barriers and for small hydros every avenue of potential cost economy must be explored.
   For the Weed-Hydro Development a number of cost-saving features were possible including the provision of used hydroelectric generating equipment, and reduction of concrete quantities through placement of spillway and intake structures on elevated-rock ledges of the dam abutment. Figure P-4.4, General Project Layout, and Figure P-4.5, Powerhouse-Intake, illustrate principal details of the development.

Hydraulic Machinery

For the Weed-Development it was recognized from the outset by the Village of Gresham, that new equipment would be extremely costly with less favorable overall economics. However, they were able to purchase two used hydroelectric units from locations in Michigan where existing plants were or had been taken out of service. These units were complete with turbines, governors, generators and some switchgear. However, the turbines were designed for operating heads different then available at the Weed site and consequently required certain modifications and/or runner replacement. These modifications were performed under contract with the James Leffel Company, who also provided supervision for erection of all the hydraulic machinery.

Civil/Hydraulic

As in all hydroelectric projects, the civil/hydraulic aspects of the Weed-Development represented the paramount engineering effort. However, much of this involved the dam, spillway and intake. Of major importance were the provisions for river diversion and care-of-water during construction.

Electrical

Electrical requirements for hydroelectric plants, particularly when retrofitting used equipment, are probably next in importance to civil engineering aspects. Modern-power systems impose strict requirements on reliability and

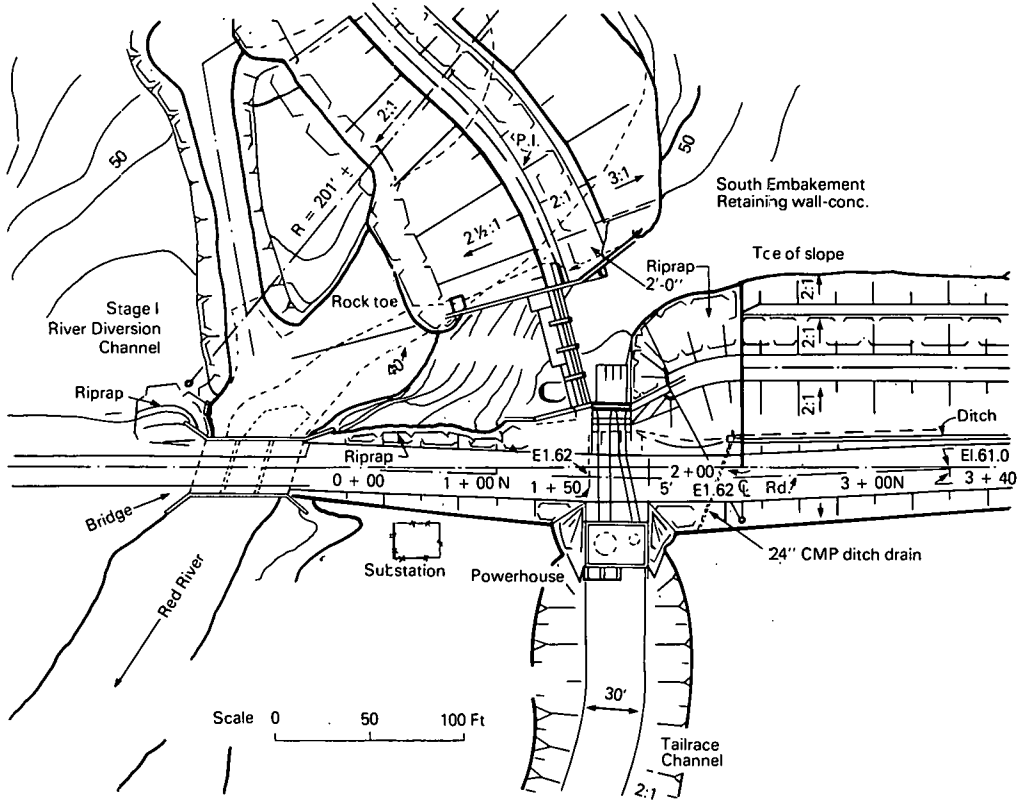


FIGURE P-4.4 Weed Hydroelectric Development - General Project Layout

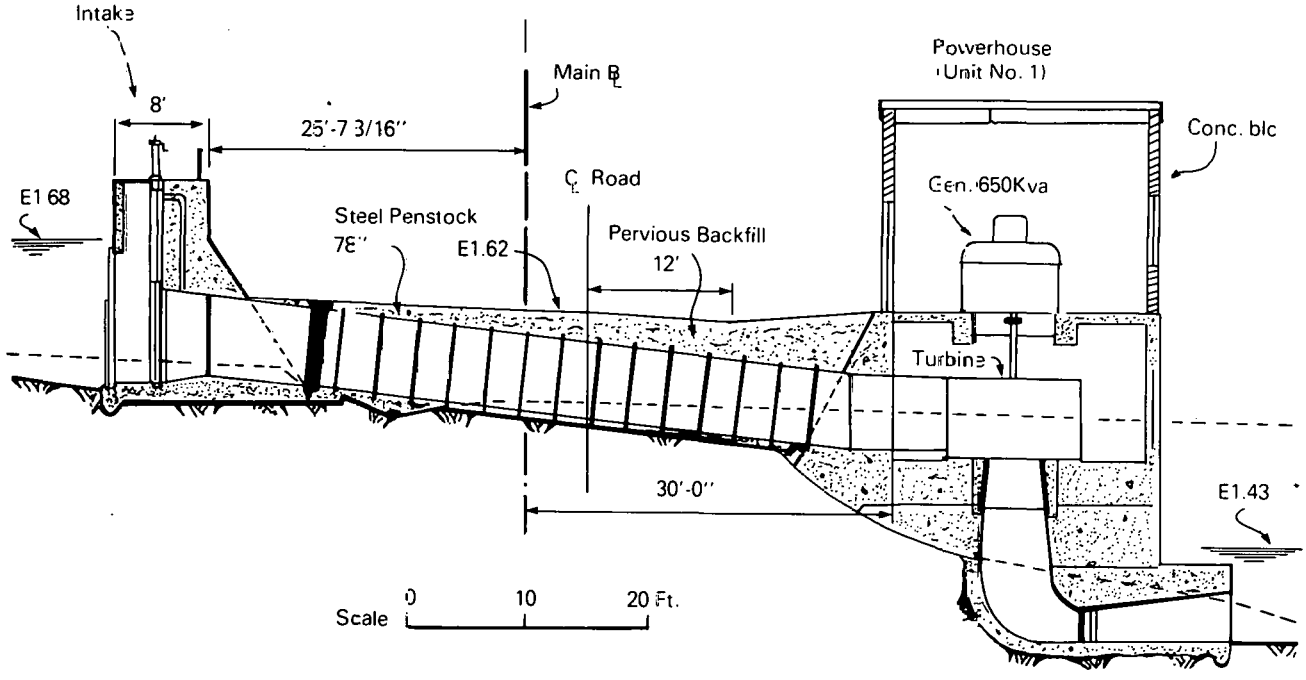


FIGURE P-4.E Powerhouse Intake - Typical Section Unit No. 1 Weed Hydroelectric Development FPC No. 2464

flexibility of operation and to a large degree electrical design and equipment influence these requirements. At the Weed-Development the difficulties experienced with retrofitting used electrical equipment were particularly troublesome and resulted in additional costs not anticipated, although, in total, the use of this equipment probably represented an economy over new machinery and apparatus.

Contracts and Procurement

Initially one main construction contract was set-up to cover construction of earth dam, spillway, intake and powerhouse and for installation of certain owner purchased equipment. In this contract it was also the responsibility of the successful bidder to assume full responsibility for diversion of river and care of water. However, bids received were considered excessive and the original-bid package was broken down into two separate contracts involving earthwork and, separately, construction of concrete and steel structures and erection of owner purchased equipment. The owner also took a greater degree of liability concerning river diversion and care of water. These bids resulted in a considerably reduced price for the work and awards were subsequently made.

Several procurement contracts were awarded for items to be purchased by the owner and installed by the contractor or others. Principle among these were:

Steel Penstocks
Tainter Gates and Hoists
Intake Gates and Hoists
Trashracks
Embedded turbine parts
Architectural Items
Electrical Conduit
Auxilliary pipeline

A separate contract was also let for installation and erection of electrical items.

Construction

Construction work on the project commenced in September, 1965 and the first power was produced in November, 1966, or about 15 months later. In order to complete certain clearing in the reservoir, a full head on the units was not achieved until early 1967. Thus, some 18 months was required to achieve full power output.

One of the critical construction activities involved the diversion of the river and closure of the main river channel. This was successfully performed in August, 1965 at time of low-stream flow through regulation at the upper dam in Gresham, and by the earthwork contractor working around the clock to achieve the necessary height of dam for the full diversion.

Project Costs

Total project costs as determined by a final audit of the Wisconsin PSC was $373,000 or $592/kW. This figure exceeded the earlier estimates of $276,000 by 35% . Fortunately, it developed that the used hydroelectric units were capable of greater output in kW than was originally estimated, so that costs per kW were nearly as originally estimated. Nonetheless, the overrun in cost emphasizes the difficulty one has in controlling costs on a small-hydro project, particularly where one is working with a completely new installation for dam, reservoir, and hydroplant.

Conclusions

It may be concluded from the experience with this small-hydro development that as size of installation decreases, the problems commonly associated therewith do not decrease in a proportional manner.

Furthermore, for small-hydros local leadership and sponsoring organization strength is very important. Often a single individual is the key leader responsible for achieving success on his own strengths, contacts, and perserverance. Where the sponsoring organization is an existing utility, this matter of local support is more easily attained.

Cost controls on small-hydros are vitally important and if not properly managed can seriously jeopardize economic viability.

Finally, it should be recognized that engineers and contractors often employed on small-hydros have limited experience, and capabilities and great care must be taken to assure that they are well organized, financed, and clearly understand their job.

In retrospect, the economic lesson to be learned from this experience is that what appears to be a marginal or near marginal hydro undertaking based on short-term energy costs, will nearly always turn out to show substantial savings over the long haul. This is particularly true today and for the foreseeable future where costs of alternative fossil fuels are escalating at a rapid rate.

POLICY SESSIONS

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

Session Five

POLICY

Topic: Public and Private Finance

Chairman: Mr. Robert M. Shepard
Sr. Vice President
Public Finance Department
Donaldson, Lufkin and Jenrette
140 Broadway
New York, New York 10003

POLICY RECOMMENDATIONS FOR FEDERAL AND STATE GOVERNMENTS TO EASE FINANCIAL CONSTRAINTS ON LIMITED RESOURCE HYDROPOWER DEVELOPERS

J. Keen Holland

The ability of the United States, or any country, to realize its potential for the development of small-scale hydroelectric projects is subject to a great many constraints. If we consider the present state of the art technology for small hydroelectric projects as a given, the remaining constraints to development may be grouped under three major headings -- Social/Environmental, Legal/Institutional, and Economic/Financial. While each of these headings has received some consideration in the development of policies to encourage small-scale hydro (SSH) projects, insufficient attention has been given to their impacts upon what we would call limited resource developers.

The term limited resource developer includes a great variety of potential SSH developers. Of course, farmers and other rural residents form a large part of this group. But a small town or city which is not presently in the electric generating business, even if it operates its own distribution system, may be considered a limited resource developer. Likewise, many rural electric cooperatives (RECs) have limited financial resources and staffs which may not have expertise in power plant design and operation. Certainly most small businesses would also fit this criterion. In general, we mean by limited resource developer any entity with limited funds or restricted access to capital, small technical staffs with little or no experience in electric generation, or in any other significant way is disadvantaged with respect to the regulatory and permitting agencies, consultants, equipment suppliers, power purchasers, or other organizations with which it must interact in the course of investigating, planning, and developing a small-hydro project.

While many of the recommendations in this paper will encourage SSH development in general, there are two important reasons why particular attention should be focused on the limited resource developer. First, the complexities of the development process (licenses and permits, finding and evaluating technical consultants and equipment suppliers, negotiating with a public utility or other power purchaser) are so intimidating that many such potential developers may throw up their hands in frustration, leaving many otherwise viable projects undeveloped. The second reason is more directly an economic issue. To the extent that many limited resource developers will be looking to provide power for their own use, the value of the power produced will be the retail price of the utility power which it replaces. This can substantially improve the cost-benefit analysis of a very small project.

The numbers of potential SSH developments is quite large which is why, in spite of their limited significance taken individually, they can have a substantial impact taken in the aggregate. We are all familiar with the early Corps of

Mr. Holland is a consultant with Berger Associates, Camp Hill, Pennsylvania.

Engineers estimate of a potential for 5,700 MW of capacity producing 17,000 GWH per year. Although some critics have suggested that the Corps estimates may be too high, we have not even begun to estimate the potential for very small hydro projects, often called mini-hydro or micro-hydro. Estimates of the number of farm impoundments created over many years through the actions of the Soil Conservation Service of the U.S. Department of Agriculture are on the order of one to two million. Development of even a tiny fraction of these small dams could add substantially to estimate of potential SSH capacity and energy.

In suggesting policies to ease Economic/Financial constraints on SSH development, we must keep in mind that these constraints are often the product of Legal/Institutional constraints imposed to mitigate Social/Environmental impacts of proposed projects. Therefore, some of the recommended policies contained here are not aimed specifically at project finance but will have an important indirect influence on the Economic/Financial viability of many proposed projects. A brief example may illustrate how closely intertwined these issues can be:

A typical SSH dam may have been in place for many years, preventing movement of a migratory fish species like the Atlantic Salmon. This environmental effect is tied to a social impact in that salmon fishing cannot take place above the dam. Congress creates a Legal/Institutional constraint by passing the Anadromous Fish Restoration Act which adds a new step to the review process, a new source of uncertainty, and a potential for a costly addition to the project (fish passage facilities) which will add nothing (and may detract somewhat) from the power production capability of the project, if implemented. Our potential developer is told that he must provide fish passage facilities (which may cost $30,000 per foot of dam height). The cost-benefit analysis of his project changes from slightly positive to slightly negative. Financing becomes impossible and the project is not undertaken. Result, no salmon pass the dam, the power it could have provided continues to be met from other sources (perhaps imported oil) with more serious economic and environmental costs for the community and the nation, and no progress has been made in meeting the goals of the Administration's energy program or the Anadromous Fish Restoration Act!

Lest the accusation be made that the anadromous fish law has been chosen as a convenient whipping boy, the same sort of scenario could be written around the case of a dam which has been designated a historic landmark or an impoundment whose level cannot be varied to provide peaking power because of objections from boating enthusiasts. This is not to say that such alternative considerations do not have their place, but the review procedures employed at state and Federal levels must not permit any one interest an outright veto over potential competing water uses. Even where such constraints are not imposed on a project, the uncertainty and delay occasioned by the imposition of additional steps in the review process increases the cost of the project and may have a chilling effect on other potential developers whose projects never reach this stage.

Principal Constraints on Limited Resource Developers are:

1. The inexperience and lack of technical resources at the disposal of the limited resource developer, often even a lack of sufficient

professional staff to provide proper coordination and follow through in dealing with the project review process.

2. The uncertainty and delays attendant upon the licensing and permitting process and the potential for incurring the added burden of regulation as a public utility with the extraordinary tax liability that often goes with such regulation.
3. The high cost and often total unavailability of financing for projects which are risky and, although small in the lender's eyes, may be quite large in relation to the developer's normal financial operations.

There are a large number of actions which could be taken at the state or Federal level to ameliorate these conditions. Some state actions will require changes in Federal laws or procedures. Other reforms may require Federal-state cooperation. The most important element is the commitment to encourage exploitation of this clean, renewable resource. In this respect, the outlook is quite hopeful. Attendance at conferences such as Waterpower '79, procedural reforms at the Federal Energy Regulatory Commission, innovative state-level actions in Massachusetts, New York, North Carolina and elsewhere, all point the way toward effective development strategies. Recommendations for dealing with each of the principal constraints identified above will be examined in turn.

Lack of Resources

The need here is for a coordinated SSH development advocacy program. The New York State Energy Research and Development Authority has begun to demonstrate what can be done in this regard on a multi-million dollar budget; at the other end of the scale, North Carolina's small-hydro program operated by Research Triangle Institute has demonstrated that great strides can be made even on a shoestring budget. Whether organized on a small or large budget, it is important that such a program be organized outside the chain of command of either the utility regulatory or environmental protection agencies of State government so that the program can function as an effective advocate for SSH developers both individually and collectively.

The potential developer, whether the owner of a promising site or a large electric user in the vicinity, must be aggressively sought out and confronted with facts about the opportunity to develop the small-hydro resource. Having been introduced to the subject, the potential developer should be given guidance in performing his own feasibility assessment or assistance in locating consultants who can assist him at a price he can afford and which the potential benefit of the project will justify. For very small projects, continuing advice and counsel through the permitting and licensing stages and project development may be required; larger projects will need and can justify the expense of outside professional assistance.

Because the conditions affecting the viability of SSH development vary considerable between different parts of the United States (topography, rainfall, legal situation, utility costs affecting marketing opportunities, etc.) it is advisable that this sort of technical assistance and advocacy program be organized at the State level, although Federal encouragement would be

helpful. Other actions which such a State program might take include familiarizing the agricultural extension service personnel with the opportunities for farmers and other individuals in rural areas to develop SSH. State universities might organize teams of science, engineering, and business students working under faculty supervision to perform feasibility and environmental analyses for limited resource developers.

Permits and Licenses

There is a need to reduce further the burden of the licensing and permitting process as it affects SSH developers in general and the limited resource developer in particular. The Federal Energy Regulatory Commission (FERC) has already accomplished a great deal with its short form licensing procedure and delegation of routine license granting authority to its technical staff. It is important that Congress reconsider its refusal thus far to give FERC authority to waive licensing altogether for very small projects.

At the state level, Massachusetts has accomplished a great deal by establishing a single State agency as the developer's point of contact with State government. Establishment of a lead agency or one-stop procedure for the issuance of all permits required by each State can help significantly to reduce delays and uncertainty for the developer, as well as his cost of compliance, without sacrificing the public's interest in a thorough review of all significant projects. Again, outright exemption from review for very small projects would encourage SSH development without harm to the public interest.

Perhaps the most serious barrier to SSH development in some of the States is the way in which public utilities are regulated and taxed. It has been too easy for many State legislatures to attempt to disguise a portion of the tax burden by levying a significant amount of what should legitimately be general revenue taxation in the form of special levies upon utility gross receipts, real property, and/or tangible personal property at rates substantially above those applicable to other corporations. While these costs may be bearable for a large investor-owned utility enjoying a monopoly on retail electric service in a substantial geographic area, the situation confronted by SSH developers is very different since they must compete with utility power to find a market for their output.

It is doubtful that the public interest in regulating monopoly utility companies is in any way served by extending such burdensome regulation to a small hydro developer who does not enjoy monopoly privileges. The added tax burden imposed in many states along with regulation will doom many otherwise viable projects. Each State must evaluate how its own laws and regulatory policies impact on small hydro and take steps to resolve this complex issue.

Financing

The Public Utility Regulatory Policies Act (PURPA) has accomplished a great deal in helping to assure a market for power from SSH developments. Perhaps more important however, is the provision of forgivable loans for feasibility and licensing studies for small-hydro developments. By making

loans for these purposes which need not be repaid in the event the proposed project is for any reason unfeasible, the PURPA § 402 loan program can make a substantial impact in reducing the risk associated with investigating the potential costs and benefits associated with SSH developments.

The § 402 program does not provide any substantial interest subsidy, however. For a small number of SSH developers (those borrowing only a portion of the project costs at commercial loan rates for periods of perhaps 20 years, likely to be true of only the smallest developers) the requirement that these loans be paid off in full out of the construction financing may work some hardship. In these cases, the loans might be allowed to run for the full ten year term. In the majority of cases, it is recognized that the cash flow position of the SSH development will be better if the § 402 loans are paid out of long term financing, even at higher interest rates.

Considerable concern has been expressed regarding the availability of construction loans under § 403 of PURPA. Although the Act included an authorization of $100,000,000 per year for each of the three fiscal years ending September 30, 1980, in view of other pressures on the Federal budget, it is unlikely that more than a small fraction of this amount will ever be appropriated, and even the full amount would only scratch the surface of the need for development funds. President Carter's Rural Energy Initiative may answer a part of this need, but more can be done.

Congress and the Administration should give serious consideration to a thorough restructuring of the PURPA § 403 program to provide leverage for the limited Federal funds that may be made available. A program of guaranteed loans from commercial lending sources combined with interest subsidies for some projects (perhaps including direct Federal loans on a last resort basis similar to the SBA program) would magnify the impact of the Federal program. It may even be advantageous to utilize the existing Small Business Administration loan mechanism for this purpose. The benefit to the government from such an approach would include reduced costs of program administration. To the SSH developer, the advantages would include dealing with a familiar program which is well understood by the financial community. One further refinement to PURPA which might be considered would be to allow limited use of the § 402 loans for studies of refurbishment or enlargement of generating plants at SSH dams which presently produce a limited amount of power.

In order to give homeowners developing small hydro projects for residential use the same tax advantages as apply to wind energy, the Energy Tax Act of 1978 should be amended to permit tax credits for renewable energy sources other than wind which are used for purposes other than residential heating or cooling.

The need for substantial reform of Federal tax laws relating to small hydro has recently been addressed in the U.S. Senate by the introduction of S. 1762 by Senators Nelson and Durenberger. The bill was introduced on September 18 and contains the following major provisions:

1. SSH eligible for the investment tax credit.
2. SSH eligible for the energy tax credit.
3. Effective period extended to December 31, 1985.
4. "Energy percentage" increased from 10% to 20%.

5. Optional exemption of SSH from Public Utility Property depreciation.
6. Creating a Class Life Asset Depreciation Range for SSH property.
7. Remove limits on maximum credit allowable.
8. Changes in the recapture rules as they relate to SSH.
9. Remove restrictions on use of tax-free bonds for SSH projects.

Although there has not been time to complete a thorough review of the aspects of the bill relating to changes in the treatment of utility property, S. 1762 does contain several elements which are undoubtedly valuable for encouraging small hydro development. In particular, coverage for SSH property under the investment and energy tax credits and the increase in the energy tax credit will make many heretofore marginal projects viable. Perhaps equally important would be the ability of State and local governments to issue bonds to finance SSH projects which will sell their output to investor-owned utilities.

The value of this last provision can be greatly increased if the states will act to create bonding authorities which will pool the financing for several small projects at a time. This would allow the substantial costs of preparing and marketing the bonds to be shared over a number of projects with reduced costs for all parties.

Conclusion

The prospects for development of small-scale hydroelectric projects are quite good. Although substantial financial constraints exist, particularly for limited resource developers, state and Federal authorities are demonstrating a deepening commitment to effecting changes in laws and regulations which will stimulate development in this field.

MUNICIPAL FINANCING OF SMALL-SCALE HYDROPOWER

Larry Hobart

Development of small-scale hydroelectric facilities at new or existing dams is increasingly attractive to local publicly-owned electric utilities which supply power to some 2,200 communities throughout the United States. One reason is that high fuel prices have become the driving force in utility economics—and the basis for customer complaints about high bills.

For the early years of the last decade, retail electric rate increases lagged behind the rising cost of living, as measured by the Bureau of Labor Statistics Consumer Price Index. However, during the past five years, electric rates—spurred by soaring fuel costs—have overtaken and passed the cost of living.

Obviously, the "inflation-proof fuel"—falling water—looks very good to many public agencies now in the power generation business. Systems which do not now generate are also finding it prudent to examine hydropower because the same high fuel costs are showing up in their wholesale purchase rates. As recently as the end of 1968, no wholesale rate increases were pending at the Federal Power Commission. In 1969, applications to the FPC for wholesale rate *reductions* were 10 times as many dollars as requests for rate increases, and less than $2 million in proposed wholesale rate increases were pending before the Commission at the end of that year. Ten years later, however, there were $570 million in wholesale rate increases pending at the Federal Energy Regulatory Commission.

While "fuel" costs and O & M may be comparatively low for hydro plants, construction and installation costs are heavy; but use of tax-exempt municipal bonds by public agencies offers an advantage over private corporate financing, with its higher-fixed costs, and results in lower total power supply costs on the same investment.

Over the last 12 months, the interest rate on an A-rated, 30-year public power system revenue bond has ranged between 6 percent and 7 percent. Financing firms figure that the difference between the annual fixed cost factor associated with local publicly-owned power systems and the annual fixed cost factor associated with ownership by a private power company can range from 3 percent to 5 percent of plant value in service. In other words, annual savings in power supply costs could be as much as 3 percent to 5 percent of the total cost of the generating plant.

When determining whether a small-scale hydroelectric plant is economically feasible, developers look at the anticipated costs of power from the project compared with the expected cost of comparable energy or capacity output at alternative fuel prices. Project costs include capital, equipment, engineering, licensing, and construction. Even with today's receptive economic conditions, the payout from many potential small-scale hydropower

---

Mr. Hobart is the Assistant Executive Director of the American Public Power Association, Washington, D.C.

projects will not be enough to make development advantageous. At those times, you should not, as one financial advisor said, "drag a dead horse across the finish line."

Conventional types of financing available to publicly-owned electric utilities, which seek to construct economic small-scale hydroelectric generating facilities, include general obligation bonds — where the debt is secured by the full faith and credit of the municipality — and revenue bonds — where the debt is secured by the revenue of the public-power system or by a power sales contract which guarantees payment of the debt.

The financing ability of local public-power systems is strong. In 1978 there were 4,984 municipal bond issues for a total of $45.9 billion, quadruple the dollar value of a decade earlier. Publicly-owned electric utilities accounted for just over four percent of the total municipal market in 1970, with thirty-seven issues for $750 million. Public power's share has grown very rapidly since that time: in 1976 there were 121 public power issues for a total of $4.5 billion, or 13.4 percent of the municipal market; in 1977 there were 87 public-power issues for $5.8 billion, or 12.8 percent of the market; and last year there were 62 issues for $5.8 billion, or 11.5 percent of the total municipal bond market.

A public-power system may join with other systems to form a "joint action agency" for the purpose of supplying power to each public system. Financing would be secured by long-term power sales contracts with a number of power purchasers who guarantee payment of a certain percentage of debt service on revenue bonds as well as operating expenses.

There are two basic types of joint action financing: project financing and system financing. Project financing relies on the credit of the purchasers of the project's output. Under a system financing arrangement, a joint action agency is obligated to furnish power from whatever sources are available, and purchasers are obligated to pay for power received at a rate sufficient to cover all of the agency's costs.

Substitutes for conventional types of municipal financing are retained earnings, leasing, short term notes, commercial loans, and government loans and grants. An example of a public system which is using a combination of methods to finance its small-scale hydroelectric project is the Turlock, California, Irrigation District.

Turlock, one of the oldest public-power systems in the country, has annual retail sales of 700 million kilowatt hours. It has 42,000 meters. Its system peak is 220 megawatts, contrasted with the 115 megawatt capacity of its generating plant (which is supplemented by power purchases). To help meet some of this peak demand, Turlock decided to build a series of 13 small hydropower plants along its irrigation canals. The first project, which will be on line this month, has a one megawatt capacity. It will provide electricity for about 992 average homes, and its output represents an annual savings of about 8,000 barrels of oil. It will produce power only during the irrigation season, which runs from March 15 to October 15. The cost of this project is $2.3 million.

This first project was paid for entirely out of general operating funds. Costs were kept down by using employees of the system to study the feasibility of the project and to construct the plant. The district's staff is large enough so that there is the expertise needed for such a project; the system has 326 full-time employees and 69 temporary workers. The directors of the system believed

that by constructing the project in-house they would have more control over costs and would gain additional expertise for future projects.

The second Turlock small-scale hydropower project will be on line next spring. It will have a 3.3 megawatt capacity, serve 2,380 average customers, and represent an annual savings of 19,000 barrels of oil. The project will cost $3.2 million. Of that amount, $719,000 comes from a grant furnished through the Department of Energy, and the remainder out of general funds of the district. This project will also be constructed by employees of the system. Feasibility studies for both projects totaled $1,800, and engineering cost $76,000 for the first project and $150,000 for the second project.

The district did not seek to standardize the hydro equipment. However, it placed its order for both projects at the same time, and utilized the same type of generators and turbines for both projects. Although the district cut costs by financing through general funds and by using its own personnel, maintenance and other functions had to be sacrificed and extra money may have to be put into areas which have been allowed to "coast." Secondly, although not the case in Turlock, rate payers may object to paying for a project through general revenues and would prefer lower rates instead of a large fund of accumulated revenues.

Turlock has also signed an agreement with two other small irrigation districts which do not produce power but own a hydro site to pay for the cost of developing that site. In return, Turlock will secure power from the project at a cost less than any other alternative fuel under a lease arrangement. As seen from this example, Turlock has combined methods to finance three small hydro projects, including use of general operating revenues, a government grant, and leasing. The remainder of the projects will be funded with bond issues.

The cities of Seattle and Tacoma provide another example of public-power systems which plan leasing arrangements with an irrigation district to develop small-scale hydropower facilities. The irrigation district in eastern Washington will finance the development through sale of revenue bonds secured by a long-term 40-year contract for purchase of power. Funds for the investigation and study were supplied by the cities, and expense will be rolled into the revenue bond when it is arranged. The first project is for five megawatts of capacity, and will cost $3 million.

Small-scale hydropower development is taking place in towns as well as in the country. The city-owned power system in St. Charles, Illinois, is working on one such plan. The proposal involves a 50-year old hydroelectric plant owned by the Hotel Baker, a non-profit unit of the Luthern Welfare Service of Illinois, Until the early sixties, the plant provided all the power at the Hotel Baker. The city proposed to enlarge and rehabilitate the plant to increase its capacity to 600 kilowatts. The city would maintain the plant and buy the power, allowing the city to lower its peak cost. The hotel would still own the project. The city has received a $36,000 study grant from the Department of Energy for the project.

Carlyle, Illinois, Municipal Utility intends to develop an eight megawatt hydroplant on the Kaskaskia River at a cost of $8 million, using a combination of Federal grants, loans, and electric revenue bonds. As the plant manager told APPA, "The river runs right past the plant, and we can see the power flow by." Once begun, the project is expected to take about 42 months

to complete. Carlyle is a town of 3,100 people. It has a nine megawatt plant, which will almost be doubled by the hydro project, and currently serves 1,490 meters.

Carlyle received a $52,000 grant from the Department of Energy for a feasibility study which the city supplemented by an additional $5,000 from its funds. Carlyle has applied for a $50,000 Federal loan to pay for FERC licensing procedures. It has also applied for a $1.2 million grant from DOE under the Department's small-scale hydro demonstration project program. Carlyle will also apply for State funds through the Illinois Institute of Natural Resources, which will allocate State bond proceeds to communities for alternative energy technology. The city will attempt to finance the remainder of the $8 million through revenue bonds at an estimated interest rate of 6 1/2 percent.

Because the cost of the project is large for a small town, the city is pursuing every government financing program, although such applications add to the schedule of the project. Examples of two "joint action" power agencies which have handled financing of small-scale hydropower in different ways are the Municipal Electric Authority of Georgia (MEAG), and the Massachusetts Municipal Wholesale Electric Company (MMWEC).

The borrowing limits of joint agencies are established by their state charter. Although most joint agencies cannot back up their borrowing by the full faith and credit of the cities they represent, MEAG can do so. MEAG has paid for feasibility studies of three peaking projects from general revenues. If development of the sites is feasible, then MEAG will sell bonds and capitalize the cost of the feasibility studies.

On the other hand, MMWEC secures its revenue bonds solely by revenues of the light departments of its membership. The agency contracts with member systems for a share of a project. MMWEC is considering a plan to raise $5 million to fund renewable resources, particularly hydroelectric potential. This sum would be incorporated in a revenue bond issue, proceeds from which would be used primarily to finance participation in a nuclear power project.

Another method of municipal financing available for small-scale hydropower development is leverage leasing. Leverage leasing has not yet been used by public power systems to finance small-scale hydro plants. However, leverage leasing has been used by a group of coops and municipalities, all members of the Intermountain Consumer Power Association, to finance part of a coal-fired plant costing over $400 million. Utah Power and Light Company financed 51 percent of the project. Forty-nine percent of the project financed by other equity participants leased their interest to a nonprofit cooperative, which in turn will sell the power from the leased interest under a power sales contract to members of the Intermountain Consumer Power Association. This group will take 85 percent of the power from the leased interest, and Utah Power and Light will take 15 percent of the power from the leased interest, in addition to its 51 percent.

The interest of the investor in such a project depends on the tax advantage available through deductions and credits. The bigger the tax cut, the more investors will be willing to pursue such financing. In the first year alone, the investment tax credit is worth 10 percent of the capital cost of the project to the owner. Legislation has been tentatively approved by the Senate Finance Com-

mittee which could make this method of financing even more attractive to investors by increasing the investment tax credit available for small hydroelectric projects from 10 percent to 30 percent. It would also allow a small dam developer to depreciate a significant percentage of his capital investment in his earlier years of operation — five to ten years instead of the current 40 to 60 years depreciation life.

In summary, there is a keen interest today among local public power systems in the economic potential of small-scale hydroelectric projects. Municipal bond financing is the conventional way to finance such facilities, but retained earnings, Federal funds, and leverage leasing may also play a role.

THE FINANCING OF SMALL-SCALE HYDROPOWER

George L. Tuttle

The City of Paterson, New Jersey (population 155,000) is the site of the "Great Falls" on the Passaic River—the second largest falls in the eastern United States after Niagara. This site was, in fact, the location of early industrial development which utilized hydropower through an elaborate raceway, or canal, system. The natural beauty and economic potential of the Great Falls area attracted the interest and support of Alexander Hamilton as early as 1791. It was only in this decade, however, that renewed interest in the importance and potential of the Great Falls has re-emerged. In 1976, President Ford designated the Great Falls area as a National Historic Landmark. And today, we are prepared to undertake a new hydroelectric project as an environmentally sound method of meeting our energy needs. In the case of Paterson, hydropower is also an integral part of our efforts to stimulate the local economy.

Therefore, my perspective is that of a municipal official seeking to find answers to the financial questions associated with hydropower development. I shall describe the key financial questions which a unit of local government must successfully answer if it proposes to develop hydropower.

As an economic enterprise, perhaps the first thing to realize about hydropower is that it is capital intensive: labor costs are likely to be relatively unimportant, while interest and return to capital costs are likely to be quite high, perhaps 85% or more of annual expenses. Hence, the question of how the project will be financed, and at what price, is of prime importance to the economic feasibility of the project.

Three sources of capital should be considered: state or Federal grant monies, equity, and debt. Unfortunately, state and Federal grants are presently not available at levels adequate to provide a significant contribution to the required capital costs. For example, we have been informed that the current Federal appropriation nationally for small hydropower is only $18 million, and that individual capital grants are limited to 15% of development costs. In contrast, the estimated development cost of the Paterson project alone exceeds $9 million.

For a municipal government, equity financing could consist of either a contribution of the site (if owned) at no cost or with an interest subordinate to holders to debt instruments, or by means of an initial tax appropriation. While a contribution of the site might be considered if required to make the project economically feasible, the passing of local tax monies to offset initial capital costs is unattractive for two reasons. First, geographically there may be taxpayers within the taxing district who do not benefit from the project. Second, in view of the long useful life of a hydroelectric plant, it is inherently unfair for current taxpayers to bear the full burden of financing a facility whose benefits will be realized over a period of many years. In my opinion,

---

.Mr. Tuttle is Director of Finance, City of Paterson, New Jersey.

this approach should be considered only if the project is vital to the local economy, the cost is modest, and feasibility cannot otherwise be achieved.

Most jurisdictions will find, then, that the bulk of the hydroelectric project's capital costs will be financed through the issuance of debt. This option will be particularly attractive if the debt can be issued with an exclusion of interest income from Federal (and state/local) individual income taxes. The balance of my remarks will briefly address the various aspects of issuing bonds—tax exempt bonds—for the purpose of providing capital for hydropower.

An obvious, but important, question is whether the unit of local government has legal authority under the statutes to construct the project and sell the electricity. If it does not, authorizing legislation must be obtained, or the unit may seek to sell or lease it's ownership to a governmental jurisdiction or a utility which possesses such power.

A second legal concern is the strength of the local unit's claim to the water which is to provide hydropower. Since revenues from sale of electricity may be diminished by any diversion of water for other purposes, it is crucial to establish the unit's legal rights to a flow of water sufficient to render the project feasible.

The local unit should retain recognized bond counsel to determine its ability to issue tax exempt bonds. All other factors being equal, the interest cost for taxable bonds will be approximately 50% higher than for tax-exempt bonds. Therefore, tax exempt status should be sought even if the project would be feasible when financed by taxable bonds. For most small hydropower projects, it should be possible to demonstrate eligibility for exclusion of the bond purchaser's interest income from taxation by virtue of the "local furnishing of energy" test. This test is met if it can be demonstrated that the project's electricity is consumed within a continuous two-county area. Because of the grid system used for distributing electricity, it cannot be taken for granted that the test is met even if analysis shows that area consumption exceeds the hydroelectric plant's output. Rather, engineers must be able to certify that the energy can, in some way, be traced to consumption within the two-county area.

Exemptions are also available under provisions for small issues and for exempt users. Where the small issue provision is to be used, the capital expenditures for the project *and* capital expenditures of any major user of the electricity within a five-year period cannot exceed $10 million. This test is difficult to meet, especially if electricity is to be sold to a utility for distribution. The exempt user test is met if it can be demonstrated that 75% or more of the plant's output will be consumed by organizations exempt from taxation (governmental units and non-profit organizations). Again, tracing is a problem in attempting to meet this test, especially if the local unit must rely on another company for power distribution.

Once the local unit is satisfied that it has authority to undertake the project, has sufficient rights to the water, and can issue tax-exempt debt instruments, it should seek to maximize the credit-worthinesss of the debt so as to keep interest costs as low as possible. It should also seek to minimize actual use of it's own credit so that it's ability to finance other needed public improvements in the community will not be impaired. These two objectives, lowest interest cost and minimum pledge of the unit's credit are frequently, but not always, in

conflict. However, both objectives must be kept in mind. The degree to which either must be sacrificed in the financing package depends on local circumstances.

Use of the local unit's credit may be minimized by the issuance of revenue bonds by the local unit or by a special purpose public authority created pursuant to applicable state statutes. Revenue bond financing is particularly attractive, and may be the only available method of financing the project, when the local unit confronts legal limits to its ability to issue general obligation debt. A revenue bond is typically secured only by the revenues and assets earned and held by the unit or authority in connection with the project. These are limited liability or special obligations which contrast from general obligation bonds, which are secured by the full faith and credit of the local unit, including it's power to levy ad valorem taxes. It should be noted that while revenue bond financing is generally more desirable than general obligation financing from the local unit's point of view, issuance of this type of debt can still have significant implications for the local unit's overall credit and debt structure. After all, the project is located within the jurisdiction and the local unit's name will appear on the bond. A default on the revenue bond is likely, therefore, to reflect on the general credit of the local unit, even though bondholders have no legal claim against it.

Assuming there are no legal impediments, the ability of a local unit to finance a hydropower project by issuing revenue bonds is dependent on it's ability to assure prospective purchasers of the bonds that the net revenues (gross revenues less operating expenses) will be adequate to meet all debt service requirements.

Simplistically, the higher the indicated coverage ratio—that is, the ratio of net revenues to debt service on an annual basis—the stronger the credit and therefore, all other things being equal, the lower the interest rate will be. In order to bolster the level of and confidence in the coverage ratio, the local unit should explore the possibility of obtaining base-load payment rates as opposed to dump rates. (Can a reservoir be created? Can the local unit's power source compliment another source creating a higher energy value?) Consideration should also be given to possible use of hydroelectric power to produce higher value energy mediums—hydrogen, for example. Finally, environmental and aesthetic requirements should be carefully analyzed so that maximum power output may be achieved consistent with the community's perception of a site's natural beauty.

As important as the level of the coverage ratio is it's reliability. We tend to think that energy values will escalate into the indefinite future, but that is merely an assumption. If the assumption is valid, the bondholder may have a sound investment, but he will not receive higher return, since he holds a fixed-income security. If, on the other hand, the assumption proves invalid—if, for example, energy prices plummet in ten years—the project's ability to repay debt may be impaired. Even given the assumption of increasing energy values, the bondholder must also consider the possibility of failure of production and/or failure of sales. Production failures might occur as a result of poor plant design or maintenance, seasonal or cyclical flow of water, or diversion of water. Sales failure can occur as a result of competition, market decline during recession or depression, bankruptcy of major customers, etc.

In view of these uncertainties, and in the absence of a pledge of taxing

power, the bondholder will typically look for a lease or a take-or-pay contract between the project and a credit-worthy public utility. Such a contract obligates the utility to pay an amount at least sufficient to pay operating expenses and debt service even if the power is not produced and even if it is not needed by the utility. Since a take-or-pay contract may require the utility to accept considerable risk, it needs to be compensated for that risk. An obvious way of doing this is some form of profit-sharing in the event that the project is successful. The important point is that where there is a take-or-pay contract, bonds are sold primarily on the credit of the utility, although the local unit's credit standing and the indicated coverage ratio will still have some influence on the interest rate obtained.

If the local unit cannot obtain a take-or-pay contract on terms which it considers acceptable, it may consider: a straight general obligation issue, a guarantee of the revenue bond debt, or provision of a deficiency contract. A general obligation issue should be utilized only if no other option is available and the local unit is convinced of the project's profit potential and/or favorable impact on the local economy. A guarantee by the local unit of the revenue bonds is, in a sense, the best of both worlds from the bondholders point of view. The bond becomes "double-barrelled" in that the holder has a claim on both the project revenues and the taxing power of the local unit. This option might be appealing to the local unit if it wishes to obtain a favorable interest rate, but is not overly concerned with overburdening it's credit, or if there are some special advantages to use of an authority such as flexibility of bond maturity schedules or management considerations. A deficiency contract is a compromise approach which pledges the local unit's support in the event a default would otherwise occur, but with conditions short of a full guarantee.

In summary, tax-exempt bond financing is likely to provide a large part or all of the capital financing required to develop most small hydropower sites. Thorough review of the available tax-exempt options in conjunction with local needs and revenue potential can make the difference between a feasible and unfeasible project, and can minimize the risk ultimately accepted by the local unit. Moreover, selection of the most appropriate option may enhance the potential profitability of an already feasible project.

Session Six

POLICY

Topic: Water: Management and Use

Chairman: Dr. Lewis H. Blakey
Chief, Office of Policy
Civil Works Directorate
U.S. Army Corps of Engineers
Washington, D.C. 20314

DEVELOPMENT OF A SMALL-SCALE HYDROELECTRIC PROJECT: POLICY AND POLITICAL CONSIDERATIONS BROADWATER DAM, MONTANA

Richard L. Bondy

The possibility that the Pacific Northwest — an area once known for its plentiful, cheap electricity—may have to turn to more expensive ways of generating electricity has made attractive the development of hydropower at previously uneconomical sites. The possibility that electricity could be generated at one such site on the Missouri River in Montana, the Broadwater-Missouri Project which is owned by the State of Montana, has already generated an interesting question: Should the state take advantage of electricity's high market value to gain useful revenue or should the state take steps to supply cheap electricity?

The State of Montana owns some forty water conservation projects, including twenty-three active reservoirs, all of which are managed by the Department of Natural Resources and Conservation (DNRC). These projects, most of which were financed through the sale of revenue bonds and by Federal agencies such as the Public Works Administration, provided badly needed employment at the end of the 1930's and continue to help stabilize Montana's agricultural economy by ensuring a reliable supply of water.

Many of these projects have fallen into poor condition because of age, and some projects have deteriorated so seriously that their users face extreme, even impossible, financial burdens to keep the projects operating. Many dams associated with these projects need modifications to meet modern safety requirements. Developing hydropower at the Broadwater Dam and at two other state owned projects could be a source of funding for the repair of all state owned projects.

On the other hand, the Vigilante Electric Cooperative, which supplies electricity to rural customers in the headwaters of the Missouri River, has been served with a notice of insufficiency by the Bonneville Power Administration (BPA). This means that after 1983, BPA will not guarantee that it can provide Vigilante any more electricity than it uses now. BPA supplies all of Vigilante's power now, but the cooperative must look for other supplies. The Vigilante Electric Cooperative sees development of hydropower at the Broadwater Project as a source of relatively inexpensive electricity for its customers.

Mr. Bondy is Chief, Engineering Bureau, Water Resources Division, Montana Department of Natural Resources and Conservation, Helena, Montana.

After identifying hydropower revenues as a possible source of funding and making an initial determination of feasibility, DNRC developed an overall plan for the rehabilitation of state owned projects. This plan, titled "Conceptual Plan for Montana Water Resources Projects," has as its key element the development of hydropower at three state-owned projects. Revenues gained from this development would be used to establish and operate an earmarked revolving fund to finance the rehabilitation of existing projects. This would be followed in a few years by additional hydroelectric generation facilities and the construction of new water development projects.

The first step in carrying out the plan was a preliminary feasibility study which found that the addition of generating facilities to three state-owned projects is feasible and that the Broadwater Dam has outstanding potential. A Department of Energy grant was then utilized for a complete feasibility study of hydropower at the Broadwater Dam. This study provides information needed for negotiations with utilities, such as a description of the power output from the project and cost estimates.

The recommended installation includes four generators with a total capacity of 9.76 megawatts. The initial cost is estimated to be $13,250,000, which results in an electricity production cost of 2.0¢ per kilowatt hour. The project will produce an average of 56 million kilowatt hours per year—the equivalent of 87,000 barrels of oil per year. The value of energy from this project is estimated to be 3.4¢ per kilowatt hour. This was determined by making comparisons with least cost alternatives for developing new power with similar characteristics in the area.

While the engineering work was progressing, activity concerning this project developed in the political and policy arena. Two utilities, the Montana Power Company and the Vigilante Electric Cooperative, expressed an interest in obtaining power from this project. Vigilante even applied for a preliminary Federal Energy Regulatory Commission (FERC) permit for this project prior to our application. We now have competing FERC applications. However, since the state owns the site and clearly indicates its desire and intent to develop the site, DNRC, under the FERC rules, would have the right for power development.

The Broadwater Dam will produce about three quarters of Vigilante's current annual power needs, but power from the Broadwater Dam will be much more expensive than the power the cooperative now purchases from BPA. Vigilante is having difficulty deciding how to proceed with negotiations on this project. The cooperative is hesitant to pay enough to recover the cost of the generating facilities and operating expenses for the project, much less anything that approaches the true valuc of the power from the project.

DNRC and Vigilante have held several preliminary negotiations, but it has become obvious to Vigilante that our proposed charge for electricity is more than they wish to pay. Therefore, Vigilante organized a powerful effort to enact a law which would have prohibited DNRC from building and operating hydroelectric dams. The bill also provided that the maximum price for leasing the project to power developers would be one mill per kilowatt hour and that half of all money received by the state from the lease would be reserved exclusively for maintenance and repair of the dam and associated irrigation facilities.

The bill was intensively lobbied. Its supporters cited the need for low power prices for Vigilante's agriculture customers and successfully characterized opposition to the bill as anti-agriculture and pro big government. The opponents of the bill cited the environmental benefits of power production at an existing dam and the need for financing project repairs.

Although the bill passed both houses of Montana's Legislature, it was vetoed by Governor Thomas L. Judge. In his veto message, the Governor called the bill ill-conceived because it would have severely restricted the state's ability to address energy supply problems and the fixed percentage requirement for repair and maintenance of the dam was arbitrary. The Governor pointed out that the state would be able to do the job more cheaply than private utilities or power cooperatives because the state can borrow money at a better interest rate than the utilities are able to obtain. With this background, we can now examine pricing policies in terms of expected impacts of DNRC and on the power purchaser.

If the power is priced near its full market value, the revenues from power sales, along with affordable increases in water use fees, would pay for correcting nearly all of the serious deficiencies in the state owned projects. This will also provide the means to DNRC to fully develop and utilize the assets created by its projects. This alternative would benefit all beneficiaries of all of DNRC's projects, especially the agricultural users who pay most of the costs incurred by each project.

A high power price, however, would require power users to pay a higher price for electricity. At Broadwater Dam, for example, the difference in power price between full market value and power production cost is substantial, approximately equal to the total price Vigilante's customers now pay for electricity. This would have an obvious severe impact on the power users, especially the utility's agricultural customers who must pump irrigation water to their fields. If power is priced near the cost of production, no revenues would be available from this source to implement the project rehabilitation plan. But the low power price would help keep electricity prices to users low.

Either party has a few alternatives. DNRC could use other sources of funding for project repairs in some cases. Water use fees could be raised substantially. This would create a severe hardship on project users, and in many cases, they simply could not afford to pay the increased use fees that would be required.

A second alternative would be state funding of the needed repairs. This would require taxpayers at large in Montana to provide additional subsidies to the projects. This has occurred in the past occasionally, but it is certainly not a reliable source of funds.

Another alternative would be to obtain federal funds for project repairs. This source of revenue is already used by DNRC to rehabilitate projects. DNRC would continue to use this source even with revenue from hydropower development since Federal subsidation of agricultural projects is expected to continue. A last alternative is to abandon and remove the projects that cannot finance the needed repairs. This would eliminate all the benefits they provide.

Vigilante also has options to paying the full value of electricity from this project. One option is to obtain power from other sources. However, no other

new power producing project is as likely to be constructed in the area as are the new facilities at Broadwater Dam. Other projects that could provide power for Vigilante include the Kootenai Falls Hydroelectric Project as well as steam-fired generating plants. These options are expected to raise several environmental concerns, experience some delays, and provide power that is likely to be more costly than the full value price from the Broadwater Dam.

Another option for Vigilante is a conservation program which could delay the need for additional power. A conservation program started a few years ago has slowed the increase in demand for electricity, but the major increases in power use are occurring because of increasing demands for pumped irrigation water. As a result of these conflicts and issues DNRC has developed several policies concerning the installation of hydroelectric power at its facilities:

(1) DNRC is willing to share in the benefits from its hydroelectric development with the power purchaser. A power price somewhere between the full value of the power and the cost of producing the power would be established. A formula for calculating the price of the power in such a way that both DNRC and the power purchaser would benefit from such things as low interest rates, Federal subsidies, and any cost savings that can be achieved for the project would be established. As the value of power increases over the years, the price of power under the formula would also increase, but at a slower rate.

(2) DNRC would allow the purchaser to participate in decisions on expenditures for operation, maintenance and improvements to the hydroelectric facilities. This will ensure that power costs will be at a minimum while ensuring adequate project performance.

(3) The power purchaser will operate and maintain the power plant. The power purchaser is likely to be more experienced in power plant operation and he will have the equipment necessary for this work. This should help reduce the price of the power.

(4) The entire cost of maintaining and repairing the dam used for power production will be included when calculating the cost of producing power. This policy recognizes that the value of the dam will be much greater to the power users than to the irrigation users. The effect of this policy will be a very small increase in the cost of power and lower water use fees for irrigation users.

(5) Operation of the hydroelectric facilities will not be allowed to interfere with the original purpose of the project, which was to provide irrigation water. Since the project would not be there if it were not for the irrigation users, their use of the project must be protected.

(6) DNRC will contract with a utility already in business for all of the power supplied from a project. DNRC does not intend to go into the power distribution business.

(7) DNRC will fully consider environmental concerns in the design of hydropower facilities. The minimal environmental effects of the hydroelectric facilities at DNRC's existing dams makes this development most attractive. For example, no modification of the existing flow pattern is anticipated at Broadwater Dam.

(8) DNRC wishes to pursue the development of hydroelectric power actively and rapidly. Rapid development is likely to result in lower power costs. (DNRC had authority since 1935 to install hydroelectric generators at state-owned water projects, but it has never been economically feasible.)

DNRC believes that these policies will ensure that maximum public benefits will result from development of the projects' hydroelectric potential. However, some institutional problems stand in the way of implementing these policies. These include a lack of man power available to pursue this development as well as an expected delay in obtaining a FERC permit. These problems must be overcome before hydropower can be developed at Broadwater Dam.

A source of funding must be found for the necessary project management effort. The legislature turned down DNRC's request for funding for this, and DNRC must now seek funding from other sources such as Federal funds. This lack of management time has made DNRC unable to press for a resolution to differences with Vigilante, and to apply for a recent Department of Energy construction grant program. They would not have accepted an application for a project for which there are competing FERC license applications.

Development of policies concerning the addition of hydroelectric power to state owned water projects has been a major, two-year effort by DNRC. Implementing these policies is another matter, given the political and institutional problems that have been encountered. DNRC, however, remains optimistic and believes in the necessity of these policies. If the institutional problems and differences with power users can be resolved, the State of Montana can make a small but rapid and important contribution to lessening our energy problems, and a vital and safe water conservation project program can be retained.

FEDERAL RESERVED WATER RIGHTS: IMPACT ON SMALL-SCALE HYDROPOWER DEVELOPMENT

Gary J. Fisher

Federal reserved water rights were first recognized by the United States Supreme Court in 1908 as being created at the time the United States set aside land for the purpose of establishing an Indian reservation.[1] It was not, however, until 1963 that the Supreme Court expressly held that water was also reserved at the time other Federal reservations, such as national parks, forests, wildlife refuges, monuments and recreation areas, were withdrawn and reserved from the public lands for specific national purposes.[2]

The Federal reserved water right doctrine is a judicial creation which the courts have described as "when the federal government withdraws its land from the public domain and reserves appurtenant water then unappropriated to the extent needed to accomplish the purpose(s) of the reservation."[3] The reserved water right has been held to be (1) created by implication as well as by express language in the reservation of public land for particular purposes,[4] (2) it arises from federal law and is not dependent on state law for its existence or perfection,[5] (3) it does not require that water be put to actual use,[6] and (4) it has a priority date as of the date of the establishment of the Federal reservation regardless of whether the water is ever actually put to use and whether future appropriators under state law have actual knowledge of its existence.[7] Because of these features—which are generally not recognized under the Western water law doctrine of appropriation[8]—and the fact that the scope and extent of some reserved water rights remain unclear and substantially uncoordinated with state water rights systems, the Federal reserved water right has created substantial uncertainty over the right to use water in areas with Federal reservations.

Mr. Fisher is Special Assistant to the Associate Solicitor for Energy and Resources, U.S. Department of the Interior, Washington, D.C.

[1] *Winters v. United States*, 207 U.S. 564 (1908).

[2] *Arizona v. California*, 373 U.S. 546 (1963).

[3] *Cappaert v. United States*, 426 U.S. 128, 138 (1976).

[4] *Cappaert, supra* at 139.

[5] *United States v. District Court for Eagle County*, 401 U.S. 520, 526 (1971).

[6] *Arizona v. California, supra* at 600-01.

[7] *Cappaert, supra.*

[8] There are also unresolved questions as to whether federal reserved water rights may exist for fulfilling the purposes for which areas have been acquired by the United States through purchase, donation and exchanges from private individuals and non-federal entities for inclusion as components of the National Park System, National Forest System, etc., in both the public domain states and the non-public domain states of the East. It is the opinion of this author that reserved water rights do not attach (1) to land areas that have left federal ownership and then are reacquired by the Federal Government, or (2) on land that had never been in Federal ownership prior to acquisition by the United States.

The impact of the Federal reserved water right on non-Federal water users discussed in this paper is directed solely to the 17 public land states west of the 100th meridian.

There is little hard information about the effect of reserved water rights on existing and future hydropower developments. On the one hand, actual consumptive uses by the Federal Government, particularly for use on Indian reservations, could have adverse consequences on downstream hydropower development.[9] On the other hand, non-consumptive uses of Federally-reserved water; i.e., maintenance of instream flows for fish and wildlife, scenic, aesthetic and environmental values, may very well have the practical effect of keeping downstream turbines running in many waterscarce areas and provide the water necessary for an expanded hydropower industry.

The assertion of a right to instream flows under the reservation doctrine has provoked the greatest amount of controversy between the Federal and private water users. Maintenance of instream flows on those Federal reservations that are located at or near the top of a watershed generally do not and will not interefere with vested state water rights because there are usually few, if any, upstream water users whose rights would be curtailed by the assertion of a reserved water right. A reserved water right for maintenance of instream flows on a Federal reservation that is not high on the watershed can, and may very well, however, have the effect of curtailing current consumptive uses and preventing the initiation of future consumptive water uses. The hydropower industry, however, being generally a non-consumptive user of water, should be an indirect beneficiary of any reserved water rights that the Federal Government may have for the maintenance of instream flows regardless of the location of the reservation on the watershed.

A further question arises as to whether a reserved water right may be asserted for the specific purpose of hydropower development. Under the authority of the Pickett Act[10], the President was authorized to "temporarily withdraw... public lands... and reserve the same for water-power sites." Furthermore, the Secretary of the Interior through the Geological Survey was authorized, pursuant to the Act of March 3, 1879[11], to classify land as valuable for power sites, and any lands so classified are automatically reserved and withdrawn from the public domain for power purposes when an application is filed under section 24 of the Federal Power Act for development as a proposed power project.[12] Pursuant to these statutes, literally hundreds of tracts of land were determined to be valuable for development as power sites and were reserved from the public domain.

---

[9] Unlike possible consumptive uses of reserved water rights on Indian reservations for large-scale agricultural and possibly industrial development, reserved water rights claims for consumptive uses on non-Indian Federal reservations are generally for such purposes as maintenance of drinking fountains and sanitary facilities at rest areas, campgrounds, park headquarters, the watering of pack animals, and maintaining vegetation at visitor facilities and for forage for wild and domestic animals. The quantity of water actually consumed for these uses is extremely small or *de minimus* and assertion of a reserved right for these uses should have little, if any, impact on either current or future water users. *See* Trelease, "Federal Reserved Water Rights Since PLLRC," 54 Denver L.J. 473, 487-92 (1977).

[10] 43 U.S.C. Sec. 141.

[11] 43 U.S.C. Sec. 31.

[12] 16 U.S.C. Sec. 818.

The development of these reserved lands for power purposes is under the administration of the Federal Power Commission (now the Federal Energy Regulatory Commission). The Department of Energy may wish to claim—although it has not to this author's knowledge ever done so—a reserved water right specifically for hydropower development on the numerous power site withdrawals throughout the West. The courts have not yet been faced with (and thus not decided) the issue as to whether the Federal Government may assert its reserved water right on behalf of non-Federal entities to assist private development.[13]

Until the numerous legal uncertainties concerning the scope of the reserved right are eliminated,[14] and those rights are systematically identified and quantified,[15] the actual impact on hydropower development in general, as well as in specific cases, is impossible to predict.

[13] In an analogous situation the Department of the Interior, for example, has never asserted a water right (reserved or non-reserved) for the use of mining claimants or mineral lessees who go upon and use the public lands and extract the resources thereof. It is the opinion of this author that assertion of a reserved water right claim on behalf of a private energy developer could not be legally sustained absent a clear intent from Congress that the water was being reserved for the use of a non-Federal entity. The reserved water right is, in other words, created for the use of the Federal Government to fulfill the Federal purposes of the reservation.

[14] The Solicitor of the Department of the Interior issued Solicitor's Opinion #M-36914, *Federal Water Rights of the National Park Service, Fish and Wildlife Service, Bureau of Reclamation and the Bureau of Land Management*, on June 25, 1979, which is the first comprehensive legal opinion issued by that Department setting forth in detail the legal basis of the water rights for the non-Indian land management agencies of that Department. That opinion goes far toward eliminating many of the uncertainties surrounding many of the legal issues involving reserved water rights.

[15] The President's Water Policy Implementation Task Force 5a on Federal Non-Indian Reserved Water Rights issued its draft report in June 1979. That report, which is now out for public review and comment, sets forth a series of recommendations designed to facilitate the expeditious identification and quantification of Federal water rights.

PROCEDURES FOR EVALUATING NATIONAL ECONOMIC DEVELOPMENT (NED) BENEFITS FROM FEDERAL SMALL-SCALE HYDROPOWER PROJECTS

James F. Johnson

Introduction

This paper will discuss the proposed procedures for evaluation of national economic development benefits from Federal hydropower projects now being developed by the U.S. Water Resources Council, with specific reference to small-scale hydropower projects. These procedures constitute the last and most detailed elements of the three-part Federal guidelines, the more general elements of which are known as the Principles and Standards for planning water and related land resources.

Principles and Standards

The principles, standards, and procedures as set forth by the Water Resources Council provide the basis for planning water resources projects. The *Principles and Standards* were published in the *Federal Register* on September 10, 1973 (U.S. Water Resources Council, 1973). The Principles provide the broad policy framework and conceptual basis for planning; the Standards provide for uniformity and consistency in comparing, measuring, and judging beneficial and adverse effects of alternative plans.

Procedures provide more detailed methods for carrying out the various levels of planning activities, including measurement of beneficial effects. Procedures were not published with the *Principles and Standards*. In their place, agency guidelines were to be prepared in conformance with the *Principles and Standards*.

President's Water Policy

The current effort to revise the *Principles and Standards* and to develop an evaluation procedure manual is a result of the President's Water Policy Reform Message of June 6, 1978 (U.S. President, 1978). In that message to Congress, President Carter stated that reforms in agency planning were essential in order to achieve economic efficiency and environmental quality in water resources management.

On July 12, 1978, the President directed the Water Resources Council to revise the *Principles and Standards* in order to (1) integrate water conservation into planning, and (2) require preparation of a primarily nonstructural plan

Dr. Johnson is the Principles and Standards Task Force Leader, U.S. Water Resources Council, Washington, D.C.

whenever structural project or program alternatives are considered.

In addition, the President directed the Council to review and evaluate current agency procedures and to publish a planning manual to ensure that benefits and costs are estimated using the best current techniques, and calculated accurately, consistently, and in compliance with the *Principles and Standards* and other applicable economic evaluation requirements.

Water Resources Council Schedule

In response to this directive, the Water Resources Council established a task force to revise the *Principles and Standards* and to develop new economic evaluation procedures. The task force was staffed by personnel provided by the Departments of Army, Interior, and Agriculture. This effort was initiated in August, 1978 with completion now expected in November, 1979. The proposed procedures were published in the *Federal Register* on May 24 (U.S. Water Resources Council, 1979) for 60-day public review and comment. The draft final procedures were sent to Agency Members of the Water Resources Council on September 28. Member approval to publish the procedures in their present form would permit publication of the procedures in the *Federal Register* as final rules, with adoption by agency administrators required within 30 days of the publication date.

Public Involvement

The importance of these procedures and the significance of their legal status as final rules underscore the need for a strong public involvement program. Public workshops were held in Washington, D.C. and Salt Lake City in September, 1978, as a basis for determining the issues to be considered in preparing the evaluation procedures. Additional public meetings were held in San Diego in January, and Washington, D.C. in February, 1979 to get public feedback on the initial draft changes. The most recent meetings were held in Los Angeles, St. Louis, and Washington, D.C. in July to obtain public views during the 60-day formal comment period.

In addition, there was a continuous effort to interact with certain concerned sectors of the public through "review" contracts with the National Wildlife Federation, National Governors' Association, and the Water Resources Congress. These organizations solicited the review and comments of experts in environmental, economic, technical, and policy matters, and provided valuable input throughout the formative stages of this effort.

Federal agencies also provided considerable input to these procedures. The major affected Federal agencies participated in a hydropower workshop in October 1978, to lay the groundwork for the new procedure. After that meeting, the hydropower procedure was developed by the Water Resources Council task force with phased inputs from Federal agency experts. And recently, a separate Federal water and energy task force reviewed the May 24 proposed hydropower evaluation procedures and provided useful input to the final draft procedures.

Significance of the Procedures to Small-Scale Hydropower

The hydropower evaluation procedure is significant, primarily because it will be published as a Federal rule that must be followed by each agency involved in Federal hydropower development. This procedure represents the first consolidated, consistently applied approach at the Federal level to evaluating benefits from hydropower; taking the analyst step-by-step through the evaluation process. The following items represent significant aspects of the procedure that are favorable to treatment of small-scale hydropower.

(1) *Simplified procedures for evaluating small-scale hydropower at existing dams.* Simplified procedures are permitted for small-scale hydropower projects of 25 MW or less at existing dams and other facilities (e.g., irrigation canals) where no significant adverse environmental impacts result from the installation and operation of power generating facilities, as long as these lead to adequate approximations of national economic development benefits and costs. Such procedures are permitted, but they have not been developed by the Water Resources Council. This simplification of procedures was permitted so as not to impede the evaluation of this resource, while the conditions that are provided should prevent abuse of this special permission.

(2) *Exemption from nonstructural plan requirement when evaluating small-scale hydropower at existing dams.* Development of a nonstructural plan, which involves energy reduction measures, is not required for small-scale hydropower projects of 25 MW or less as described above. This exemption was based on a consideration of the value of developing hydropower at existing small-scale sites with the relatively heavy burden that formulation of nonstructural alternatives would involve.

(3) *Measurement of Alternative Energy Costs.* The problem of measuring rapidly increasing costs is one that we have sought to address in this evaluation procedure. Although relative price relationships and the general level of prices prevailing during the planning study will be assumed to hold generally for the future, exceptions may be taken where specific studies and considerations indicate otherwise (e.g., relative fuel cost escalation due to increasing scarcity, or increasing capital costs to accommodate expected increased environmental or safety criteria). Fuel costs used in the analysis should reflect real economic prices rather than regulated prices.

Criticism of the Procedures

The hydropower evaluation procedure was criticized for certain perceived deficiencies that were considered to understate the value of hydropower. Although these concerns relate to hydropower evaluation in general, small-scale hydropower evaluation is directly affected.

(1) *Comparability.* The comparability issue is based on the Water Resources Council decision to evaluate both Federal and non-Federal alternatives in a comparable manner; that is, both the Federal hydropower alterna-

tive and the most likely alternative will be evaluated using the same (Federal) discount rate, and with comparable handling of taxation and insurance. This is currently done in the comparability test applied to determine the feasibility of hydropower objects.

Proponents of this change argue that the benefit procedure should measure comparative resource costs, and that the use of private sector interest, taxation, and insurance costs does not reflect differences in resource costs, nor does it reflect true national economic development benefits. Opponents of this change argue that the higher costs used for non-Federal alternatives reflect what the public is actually willing to pay, whereas the lower Federal-based costs would underestimate this value.

Comparability is the most significant issue related to the proposed procedures. The difference in "benefits" measured under the current and proposed procedures may be substantial, although all projects that previously "passed" the comparability test would still have benefits in excess of costs. The problem arises from a basic misunderstanding of the economic methods used to evaluate hydropower benefits. Where energy from electric power plants is priced at its marginal cost, that price could be used to calculate willingness to pay. In the absence of such direct measures of marginal willingness to pay, the hydropower benefit is measured by a different method—the resource cost of the most likely alternative. A basic premise of this approach is that the costs of each alternative be evaluated in a comparable manner.

(2) *Inflation-proof benefits.* Critics of the proposed procedures suggested that hydropower plants provide a hedge against inflation compared to thermal electric plants, because of their lower operating and maintenance costs. Consequently, they recommend that a cost adjustment be made to reflect the much higher impact that inflation would have on certain thermal plants relative to hydropower. This is a reasonable concern. However, it is inappropriate to consider such cost adjustments only with regard to hydropower plants and their alternatives. Consideration of costs adjustments to reflect variable inflation impacts would have to be made for all project purposes and related facilities, not just hydropower. Any proposal to provide such inflation-proof cost adjustments must first address the practical and political implications of making long-term forecasts of inflation.

(3) *Renewable resource credit.* Critics of the proposed procedures state that a credit should be given to hydropower to account for its positive contribution to foreign trade balance, military independence, and conservation of depletable resources. Although such contributions are noteworthy, a separate credit adjustment could result in double counting of benefits. For instance, the real cost of fuel should already reflect the cost associated with its increased scarcity as a depletable resource.

Conclusion

The new procedures should not be seen as a burden to project evaluation, but rather as an opportunity. Benefits obtained previously from the incomparable evaluation of alternatives lead critics to view hydropower evaluation as a gimmick, and detract from the true value of this resource. Instead, we

should look to the challenge of measuring the real economic costs of hydropower and its alternatives. The hydropower evaluation procedures provide the opportunity to utilize more progressive approaches to measure economic benefits, without the constraints of previous guidelines. The benefits are there, although they may not be easily measured. Don't expect simple credits and adjustments. Instead, additional effort in sound economic analysis and research should lead to identifying the real economic value of hydropower.

REFERENCES

U.S. President Jimmy Carter, "Water Resources Policy Reform," Message to the Congress of the United States, June 6, 1978.

U.S. Water Resources Council, "Water and Related Land Resources: Establishment of Principles and Standards for Planning," *Federal Register*, 38(174), Part III, 1973.

U.S. Water Resources Council, "Procedures for Evaluation of National Economic Development (NED) Benefits and Costs in Water Resources Planning (Level C)," *Federal Register*, 44(102), 1979.

OVERVIEW OF THE NATIONAL HYDROPOWER STUDY: THE VALUE, POTENTIAL, AND ROLE OF HYDROPOWER AS A FUTURE ENERGY SOURCE

James R. Hanchey

In the midst of all the renewed interest and activity surrounding hydroelectric power the Corps of Engineers has been conducting the most comprehensive assessment of the nation's hydropower resources. The National Hydropower Study (NHS), at the halfway point in a 3-year schedule, was authorized by Congress to determine the most effective means of utilizing the hydropower resources in the United States. The charter for this study encompasses both large and small-scale, high and low-head hydropower potential and includes a mandate to assess the economic, institutional and environmental factors that will enhance or impede hydro development.

In this paper, I will describe the National Hydropower Study, the purpose and goals and discuss the importance of hydroelectric power to an energy short nation. Based on preliminary information in the NHS computerized data base on both existing and potential hydropower sites, I will venture an estimate of the amount of power we can expect from hydropower resources. My estimate will broaden to a more precise assessment at the end of the study. Finally, I will describe the process we are using to accomplish the study, review our activities to date and our plans for the future.

Purpose and Description of the National Hydropower Study

The purpose of the NHS as described in the Water and Resources Development Act of 1976 (PL 94-587, Section 167) is "to conduct a study of the most efficient methods of utilizing the hydroelectric power resources at water resource development projects under the jurisdiction of the Secretary of the Army and to prepare a plan based on the findings of such study." Specific items which will be examined:

- Physical potential for hydro and attendant economic, environmental and institutional constraints.
- Magnitude and regional distribution of needs.
- Integration of hydropower generation with other electrical sources.
- Hydropower generation to meet national energy needs.
- Timing of hydropower development.
- Potential for conventional as well as run-of-river, pumped storage, advances in mechanical technology, and high-head and low-head projects.
- Reallocation of storage and operation modification.
- Measures to facilitate contribution of hydropower.

Mr. Hanchey is Acting Director, Institute for Water Resources, U.S. Army Corps of Engineers, Fort Belvoir, Virginia.

The scope of the National Hydropower Study includes examination of undeveloped sites, existing dams with no hydropower facilities, and existing dams that are already producing hydropower. In terms of complexity, those that are already producing hydropower can be added to the easiest. Existing dams for new installation would be the next most difficult and, finally, new dams would represent the most serious challenge.

The study is divided into a resource assessment and a series of special studies. The resource assessment consists of the development of an inventory and the determination, on a regional basis, of electrical power needs. The special studies, include both a policy assessment and a technical assessment. They involve environmental considerations, economic considerations, legislative, institutional, marketing and transmission issues. In the technical area the opportunity is being examined for modifying existing projects, and for construction of pumped storage.

An offshoot of the National Hydropower Study, resulting from procedures developed to do the analysis, is the capability to do special site analysis. The capability exists now to review specific sites which have opportunities for near-term development and projects that provide fossil fuel offset possibilities. Some of these special site analyses are being conducted as a part of the President's Rural Hydropower Development Program.

Importance of Hydropower

The Corps has identified over 1,100 sites — that are now generating electricity. These projects produce 221 billion kWh of energy every year with an installed capacity in excess of 68,000 MW. This is about 11 percent of the nation's electrical energy production and represents 3 percent of the nation's total energy. The Corps is one of the major producers of hydropower in this country. We currently operate 63 projects — with 18,000 MW of capacity. Other major actors, of course, include the Water and Power Resources Service (formerly Bureau of Reclamation), TVA, private utilities and municipalities.

Why do we think it is necessary to consider hydropower — why are we doing the hydropower study? First of all is the possibility of the offset of scarce fuel. The latest figures that I have seen indicate that petroleum products are used in the production of about 17 percent of the nation's electricity and natural gas is used to produce another 14 percent. Hydropower provides a fast startup capability, low-standby costs and has a particularly high value in use of peaking. It is cost competitive. Hydropower, particularly at existing dams — can be constructed within a cost range of $500 to $2,000 per kilowatt. This compares very favorably with coal and nuclear alternatives. In terms of operating costs, we now have some projects that are operating at 3 and 4 mills per kilowatt hour. That was fairly common for projects that were constructed back in the 30's and 40's. Projects constructed today will involve operating costs slightly higher than this, but still by comparison to the current alternative coal and nuclear operating and generating costs, are quite competitive and we see no reason why they won't be even more favorable in the future.

Another element that favors hydro development is that environmental costs are well understood, predictable and fixed, particularly with regard to existing dams. In large measure the environmental consequences have already occurred. We are not talking about making a substantial additional environmental investment. We understand the environmental cost associated with hydro development to a much greater extent than with coal and nuclear technologies. Certainly we expect fish and wildlife costs to be incurred. There are water quality problems for some hydropower projects. Water level fluctuation is difficult to manage when we are operating at peaking capacities. Finally, any hydropower project involving a large impoundment innundates considerable amounts of land with attendent environmental costs. On the other side of the ledger though, there are no significant air pollution costs associated with hydropower development and no thermal pollution costs. Another major benefit is due to the multipurpose potential of hydropower developments — recreation, flood control, and irrigation. Another important consideration is that we have had a strong industrial base. Hydropower is a mature technology with known costs, construction cycles, and available expertise. We have, not only in this country, but in other countries in the world, substantial industrial technology available. We are not pushing the state-of-the-art as we are in some of the other alternatives now being considered, such as synthetic fuel, nuclear, and solar. We know how to build hydropower projects. The Corps and the Water and Power Resources Service are two of the largest hydropower construction agencies in the country. We have a substantial experience in this country in the private consulting field. Coal and nuclear capacity is expensive. Petroleum and natural gas are depleting. All of these factors indicate that we need to take another look at the nation's hydropower potential that has been overlooked for the past 15 to 20 years.

Preliminary Estimate of Potential

There are many projects that are currently in the planning cycle. Many projects are authorized for construction by the Corps of Engineers and other development agencies in the country. Many existing dams can be retrofitted. Many projects already producing hydropower have empty turbine bays where we could add turbines and generators and begin to produce additional power. The NHS is considering projects that range from 50kW in the New England Area, to several in excess of 1,000 MW. The National Hydropower Study is not simply a small-scale study. It will produce a comprehensive estimate of the national hydropower potential.

To give you some kind of distribution of the number of sites that are in our current inventory and that we expect to survive future screening, the predominant number of sites are at existing dams. In the small-scale range — 15kW to 15 MW — we expect, after the next cycle of our evaluation, that we will have about 2,400 sites that demonstrate preliminary economic feasibilities. The larger sites are more limited, but when you begin to add up the potential in terms of capacity and energy they become a little bit more significant. New dam sites are limited. We expect that less than 250 new dams will survive economic and environmental screening.

Two examples may help to put the site assessment into perspective. The Bonneville Second Powerhouse is a project that is currently producing 554 MW base load capacity. The second powerhouse would add another 530 MW of power, increasing the energy from about 4,600 GWh to about 15,000 GWh per year. This amounts to a 33 percent increase in energy for a roughly 100 percent increase in capacity. The project cost is currently estimated at about $570 million. Thus, although we are talking about favorable economics, we are still talking about a fairly substantial public investment. Another type of project that is in the inventory is a pump storage project in our North Pacific Division. Tumble Lake Project, with a 200 foot of head, and 4,000 megawatts of peaking power is an example of one of the new sites that we're examining.

Brandon Lock and Dam is an example of a small-scale site on the old Illinois River at an existing dam. We recently completed a reconnaissance study that indicates we can produce power at this project for about 13 mills. The environmental impacts are negligible. This project has been nominated to the Department of Energy and is now a candidate for funding through the DOE Small-Scale Hydropower Development Program.

Where does hydro fit into the national energy program? At this point in the study, one has to speculate. We have completed only a preliminary inventory. We started out with about 55,000 sites and have screened them to approximately 11,000 sites. At this point, we expect the final inventory to be in the range of 7000-3000 sites.

There is approximately 68,000 MW of installed capacity existing and we expect that our study will demonstrate a capability to produce about another 70,000 MW, or doubling of installed capacities. The total national electric capacity is roughly 500,000 MW. In terms of the annual output we will again be able to double the electrical energy production. The national energy budget is about 80 quads, new hydro would provide about 2.5 quads. It's certainly not the answer to our energy problem, as Jack Watson indicated this morning, but we think it is significant. We are now using 13 million barrels of oil per day and we feel that the new hydro has the potential to offset about .85 million barrels per day.

The NHS Process

To determine the physical potential for hydroelectric power the NHS is developing a comprehensive nationwide data base that contains physical, economic, environmental, and social data on existing dam sites that already have hydropower facilities, existing sites that do not have hydropower, and potential undeveloped sites where hydropower facilities could be part of a new multi purpose dam. The information contained in the data base will be used to screen sites according to economic, environmental, and social criteria. The screening process will be carried out in stages using more stringent criteria at each stage. Sites passing the screening process will be incorporated into regional plans for future hydropower development.

The initial data base contained site information on approximately 50,000 existing dams from the Corps' National Dam Safety inventory. Corps of Engineers field offices also developed the same information on undeveloped dam sites. Information on other undeveloped and developed site potential was obtained from the Water and Power Resources Service, the United States Geological Survey, Soil Conservation Service, the Federal Energy Regulatory Commission, the Tennessee Valley Authority, and other water resource development entities, both Federal and non-Federal. Approximately 20,000 undeveloped hydropower sites were added to the initial inventory.

Corps of Engineers field offices screened the sites in the initial inventory to delete those sites which did not possess sufficient storage, head, or flow to generate a significant amount of electrical energy. Those sites failing to meet the screening standards were placed in an inactive category within the inventory. Approximately 17,000 sites were retained as a data base for further investigation as a result of this screening.

Additional data were obtained on these sites in order to calculate an estimate of their potential for hydroelectric power development. This information consisted of streamflow data, physical and hydraulic characteristics of each site, the capacity of existing and proposed hydroelectric facilities, and other information from the Federal Energy Regulatory Commission regional reports.

A computer program was developed to use this data in the computation of the hydropower potential at each site and to develop a generalized estimate of financial feasibility. Previously developed hydrologic models were adapted to use the information in the data base to determine the potential hydrodelectric capacity and the average annual energy available at each site for a range of power factors. The Federal Energy Regulatory Commission developed regional capacity and energy values for use in determining the economic value of hydropower at each site.

The large number of sites in the data base made it necessary to use generalized cost data that would be applicable to all sites for preliminary economic screening. Cost data were developed for a range of electric generating capacities and heads for a simple powerhouse and switchyard configuration. This cost data are only appropriate for use in screening the hydropower sites at this stage of the National Hydropower Study. Their use with the generalized power values from the Federal Energy Regulatory Commission, both based on optimistic estimates of capacity and energy, served very well for screening the 17,000 sites so that approximately 5,000 sites will be retained for analysis in the next stage of the hydropower study.

Eight studies have been outlined to address the range of socio-environmental, technical and institutional factors and issues that affect the development, operation, and management of the nation's hydroelectric power resources. The studies are:

1. An Assessment of Environmental Impacts and Issues Associated with Hydroelectric Power Development and Operation.
2. Modification of Physical Facilities and Operational Procedures for More Effective Use of Existing Hydroelectric Power Projects.
3. A Study of Economic Evaluation Procedures Applied to Hydroelectric Power.
4. Legislative, Institutional and Social Aspects of Hydroelectric Power Development and Operation.
5. A Study of Marketing and Transmission of Hydroelectric Power.
6. An Assessment of Alternative Hydropower Systems.
7. Pumped Storage: Present Practice and Future Assessment.
8. An Integrative Technology Assessment of Increased Hydroelectric Power Development.

The Corps has received requests for assistance in local areas and states as part of the President's Rural Hydropower Development Program. The above-mentioned Brandon Lock and Dam is an example.

The Corps is doing about 250 of these studies for the DOE. They are all scheduled to be completed by the 1st of October and are currently about 90 percent complete. The computer analysis capability developed from this study has enabled us to respond to these short-term needs in a timely fashion.

Summary

The National Hydropower Study is conducting a national resource assessment of the physical potential for hydropower and is addressing the major socio-economic, environmental, institutional and other policy aspects of hydropower development and operation. The studies associated with identification and assessment of potential will result in a comprehensive national and regional resource assessment, regional plans for development of the most attractive projects and an assessment of regional impacts of development. The policy studies will compare and evaluate alternative policies and will depict in a general way the consequences of future hydropower development. Recommendations will be made to Congress concerning the proper role of hydropower and a plan will be developed to incorporate hydropower into an overall strategy to help meet national energy needs.

Session Thirteen

POLICY

Topic: Environmental Issues and Impacts

Chairman: Dr. Peter Henault
Director, Department of Environmental Affairs
Seattle City Light
1015 Third Avenue
Seattle, Washington 98104

THE DEPARTMENT OF ENERGY ENVIRONMENTAL SUBPROGRAM PLAN FOR SMALL HYDROELECTRIC DEVELOPMENT

Stephen G. Hildebrand and George B. Grimes, Jr.

Introduction

The primary objective of the Department of Energy's (DOE) Small Hydropower Development Program is to stimulate re-development of existing dams amenable to hydropower generation which have a potential capacity of 15 MW or less. This objective will be achieved by providing financial and technical assistance to both the public and private sector. National legislation (National Environmental Policy Act, Fish and Wildlife Coordination Act, Endangered Species Act, Water Pollution Control Act, Wild and Scenic Rivers Act) clearly mandates that environmental concerns should be an integral part of technology planning and development. As part of the overall Small Hydropower Development Program, DOE has instituted an Environmental Subprogram Plan that is intended to provide necessary technical investigations to ensure that small hydroelectric technology is developed in an environmentally acceptable manner. These investigations should identify potential environmental constraints and benefits that must be factored in, along with engineering and economic concerns, for overall technology assessment. We discuss here the background and approach, and specific tasks implemented and planned in support of the DOE Environmental Subprogram Plan. A brief summary of the analysis of several environmental issues is presented.

Background and Approach

During the early phases of the DOE Hydropower Development Program (1977-78) two DOE activities assisted in the formulation of an environmental research plan. First, workshops were held in New Hampshire, Michigan, and Idaho concerning small hydro development, and environmental issues were discussed. Second, DOE prepared an environmental assessment of the overall program (Environmental Assessment Hydropower Development Program, DOE/EA-0040, June, 1979). Several potential environmental issues that may be constraints to the wide-scale implementation of small-scale hydropower were identified. These include:

Dr. Hildebrand is a research staff member, Environmental Sciences Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Mr. Grimes is Staff Engineer, U.S. Department of Energy, Washington, D.C.

1. Interference with both upstream and downstream movement of fish species due to physical blockage of streams by a dam, and turbine-induced mortality of aquatic biota.
2. Potential water quality modification downstream from small-scale hydropower facilities.
3. Water level fluctuations and associated effects on physical, chemical, and biological systems both upstream and downstream of small dams from the addition of electrical generating capabilities to dams that currently are not producing power.
4. Resuspension of sediments and associated deleterious materials, resulting from dredging and other operations, that may be necessary in the retrofit of existing dam-impoundment systems for electricity generation.

The development of a coordinated effort to address these and other environmental issues yet to be identified was deemed necessary, and in September 1978, DOE requested the Oak Ridge National Laboratory to assist them in developing and implementing an environmental plan.

A major consideration in developing the environmental plan was that investigations should have wide applicability to potential development efforts throughout the United States. In addition, however, the environmental plan should be flexible enough to allow for investigations that could identify and provide specific information on environmental issues that have not been raised to date. Since considerable research has been conducted on the environmental effects of large dam systems, the environmental plan should capitalize on this data base, where appropriate, to identify potential environmental constraints for small-hydro development. Finally, it was determined that a lead environmental organization was necessary to coordinate the implementation of the environmental plan. Such coordination would reduce possible duplication of effort that might arise from a more fragmented approach. Oak Ridge National Laboratory has been established as the lead organization to coordinate and implement the environmental plan. The specific tasks of this effort are phased in time to provide maximum utilization of extant information and to couple environmental analyses with the demonstration activities of the overall DOE Small Hydro Development Plan.

Specific Tasks of the Environmental Subprogram Plan

Task 1. Literature Review and Analysis of Specific Environmental Issues

Early in the DOE planning process four environmental issues were identified that may be constraints to the development of small-hydro technology on a site-specific basis. These issues include:

1. Environmental effects of dredging.
2. Fish passage around dams.
3. Water level fluctuation, and
4. Instream flow needs.

The first step in addressing these issues will be an analysis of available literature to clearly define the nature and potential significance of these issues for small hydro development. The results of these efforts will be published in four separate DOE reports that should be useful to developers in determining whether or not these issues may require analysis at a given site.

Task 2. Analysis of Existing National Data Bases

The literature analyses performed in Task 1 above will, of necessity, be generic. Task 2, however, will focus on determining the potential environmental constraints to small hydroelectric development on a more site-specific basis. The U.S. Army Corps of Engineers and the Federal Energy Regulatory Commission maintain computerized national data bases on hydroelectric sites. The U.S. Geological Survey and the U.S. Environmental Protection Agency maintain similar data bases on water quality and quantity. Two environmental issues (water quality and fish passage) are amenable to analysis by merging information from the above sources.

Water quality problems (low dissolved oxygen, altered thermal regimes, high levels of metals) are well documented below some large dam/impoundment systems. Whether or not such problems occur at small hydroelectric sites in the United States will be examined using this data base analysis approach. Determining the national extent of water quality degradation below small hydro sites is very critical in light of pending litigation in South Carolina and the District of Columbia regarding the intent to regulate dams as point sources under the National Pollution Discharge Elimination System.

The possible requirement of passage facilities to move migratory fish upstream and downstream around dams may be a significant issue at a small hydro site. The cost of such facilities (if incurred by the developer) could significantly affect the economic feasibility of retrofitting existing small dams for hydropower generation. It is not clear at this time what percentage of existing small dams in the United States, suitable for retrofit, may be affected by fish passage requirements. Two studies addressing this issue will be implemented. Both studies will utilize the latest inventory of small hydro sites available in the Corps of Engineers National Hydropower Study. The first study will compare the known distribution of migratory fish species potentially requiring passage facilities with the distribution of small hydro sites in the United States. The degree of overlap in these distributions will be a first approximation of the national significance of this issue. The second study will consist of a detailed survey of state and Federal agencies where more specific information concerning fish passage requirements for the sites identified during the first study will be solicited. When the extent of possible fish passage requirements is known on a national scale, DOE can then provide additional research and development concerning this issue as required.

Task 3. Environmental Research at DOE Small Hydroelectric Demonstration Sites

The Department of Energy has selected seven small hydroelectric projects

that will receive funds, on a cost sharing basis, to demonstrate the feasibility of developing small dam sites. In addition, a Program Opportunity Notice has been issued to select several additional demonstration sites. As an integral part of evaluating these demonstration efforts, environmental research will be conducted at select sites. This phase of the DOE environmental research plan is intended to collect site-specific data on issues that may be applicable to a wide variety of potential sites. The environmental research conducted at demonstration sites will be independent of environmental analyses that may be required as part of the Federal Energy Commission licensing process.

At this time, a team of environmental scientists has visited all DOE demonstration sites and assembled available environmental information. Environmental research plans for select sites are being prepared for implementation in calendar year 1980.

Preliminary Results of Analyses of Environmental Issues

Preliminary results of research in support of the Environmental Subprogram Plan indicate that most, if not all, environmental issues must be addressed on a site-specific basis to determine their significance. A brief analysis of several potential issues is given below. Two of these issues (water level fluctuation and fish passage) are treated in more depth by Szluha et al. and Bell and Hildebrand (these proceedings).

Fish Passage

For those fish species with a life history that includes migrations for successful spawning, blocking migration by a dam can have significant consequences. The technology that has evolved to bypass upstream migrating adult fish around dams is extensive. If a transfer facility is installed to minimize (1) delays in migration and (2) energy expended by fish in negotiating the facility, the loss in spawning potential due to blockage by a dam can be reduced.

If adults migrating upstream are passed around dams and spawn successfully, the eggs, larvae, and/or juveniles of those species that eventually move downstream are faced with negotiating the same dams. This downstream migration may be the time when significant mortality could occur that may adversely affect fish stocks. Losses of the early life history stages of fish that are migrating downstream may result from predation in a reservoir and/or mortality from passage through turbines or over spillways. In addition, migrants may remain in a reservoir and thus constitute a loss to a downstream fishery. The combined loss from both upstream and downstream sources of mortality may be sufficient to deplete fish stocks.

The primary determinants of the significance of the fish passage issue at a given small hydropower site are:

1. The species of fish currently utilizing the river or planned for introduction,

2. Habitat conditions upstream from the dam, and
3. Regulatory requirements.

If migratory fish species are present at a given site and appropriate spawning habitat is available upstream from the dam, fish passage facilities may be desirable. Whether or not such facilities may be required is difficult to predict. One might speculate that fish passage should not be an issue for retrofitting existing dams, if such facilities were not part of the original design and the dams have been in existence for years. However, if existing fisheries could be enhanced through fish passage, the licensing procedure required for retrofitting small hydroelectric facilities may provide a vehicle for state and/or Federal agencies to require such facilities.

Water Level Fluctuation

Water level fluctuation due to hydropower releases can adversely affect both reservoir and tailwater ecosystems. From a recreational or aesthetic standpoint, exposure of large expanses of reservoir bottom as a result of hydropower releases is an obvious concern to shoreline property owners. Fluctuating water levels, however, can also have indirect effects on biological productivity in the reservoir. Since many reservoir basins have a less extensive shallow water (littoral) zone than natural lakes, fluctuating levels can potentially restrict biological production in these areas. Water level fluctuation can also erode shorelines and transport nutrients from shallow zones to deeper regions of a reservoir.

Fluctuations in discharge and water level, if extreme, can significantly modify the aquatic habitat in the river below a hydropower facility. Water fluctuation due to peaking operations may be of differing amplitude or frequency than normal seasonal fluctuations. Fauna and flora adapted to seasonal cycles may be adversely affected by peaking fluctuations.

The mode of operation of a small hydroelectric facility is the major determinant of whether water level fluctuation will be a significant environmental issue. If a given facility will be retrofitted to operate in a peaking model with significant pondage, water levels may fluctuate, and the types of effects mentioned earlier must be analyzed to determine their significance.

Water Quality

Potential water quality considerations in tailwaters below dams include:

1. Alteration of temperature regimes,
2. Reduced turbidity,
3. Changes in dissolved oxygen,
4. Increases in the dissolved form of some metals, and
5. Altered nutrient and organic matter regimes.

The changes in water quality that occur in the reservoir and the significance

to downstream ecosystems depend, to a large extent, on thermal and chemical stratification in the reservoir and the depth of water withdrawal.

Hypolimnetic (bottom) water discharged during periods of thermal stratification can cause colder tailwater temperatures in the summer. Discharge from reservoirs can cause warmer tailwater temperatures in the winter. Such altered thermal regimes can reduce aquatic plant and benthic invertebrate diversity and modify the spawning activity of fish.

Reservoirs act as settling basins for suspended sediments. Reduced turbidity in the tailwater may increase primary production due to increased available light. Hypolimnetic releases of water from stratified impoundments can be low in dissolved oxygen and can have altered levels of dissolved metals (Fe, Mn), ammonia, and hydrogen sulfide due to transformation of these substances in anoxic water in a reservoir.

If a reservoir stratifies and water is withdrawn from near the bottom, water quality issues should certainly be examined in sufficient depth to predict potential adverse impacts.

Dredging

Physical effects of dredging may include resuspension of sediments, changes in water circulation patterns, changes in particle size and porosity of bottom sediments, and mobilization into the water column of nutrients and contaminants present in resuspended sediments. Several potential adverse impacts to biological systems as a result of dredging operations include:

1. Loss of primary production and stress to fish due to increased turbidity,
2. Destruction of benthic habitat, and
3. Secondary effects on aquatic biota from resuspension of nutrients, heavy metals, or toxic contaminants. Ultimate disposal of dredged material presents another environmental issue beyond the scope of this paper.

The potential significance of dredging impacts at a particular small hydroelectric site will be influenced primarily by the physical and chemical characteristics of the sediments and the amount of dredging required in the retrofit of an existing dam for power production. If it is necessary to increase the storage capacity of a reservoir by dredging, any or all of the above impacts may adversely affect the aquatic environment, and a thorough analysis should be performed to determine their significance and mitigation required.

This research was funded by the U.S. Department of Energy, Assistant Secretary for Resource Applications, Division of Hydroelectric Resources Development under Contract W-7405-ENG-26 with the Union Carbide Corporation. This manuscript is publication 1433 of the Environmental Sciences Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

LAND USE AND SMALL-SCALE HYDROPOWER: AN OVERVIEW OF ENVIRONMENTAL IMPACTS AND INSTITUTIONAL RESPONSES

Reuben C. Plantico

Introduction

Studies conducted by a variety of agencies and organizations indicate that small-scale hydropower (SSH) has the potential of making significant contributions to the nation's energy base (Clapp and Garner). Project development—whether it involves the rehabilitation of old dam sites or the construction of new sites—can be constrained by several factors. Technological and economic feasibility, the availability of suitable dam sites, environmental considerations and institutional matters will all play a role in determining the fate of SSH development in the coming years. Whether SSH projects are technologically and economically feasible are issues currently receiving a good deal of attention (NERBC *Regional Report*). Yet, unless we begin to assess other factors such as environmental impacts and institutional issues, the matter of SSH "feasibility" will have been only partially addressed.

This paper looks briefly at one aspect of environmental planning for hydroelectric projects—land use impacts. The definition of land use employed here is broad. The term "land" encompasses areas which are not exclusively terrestrial in nature. It includes those areas at the land/water interface such as riverine floodplains and wetlands. The term "use" is also defined broadly to include natural as well as other uses of land such as development for recreation, agriculture, or various commercial activities. Given this definition, the paper provides an overview of some of the land use impacts to which SSH development might lead. Also, some institutional mechanisms through which these impacts might be addressed will be reviewed.

Land Impacts of Small-Scale Hydropower

The nature and extent of the land impacts of hydroelectric facility development will be a function of several variables including the project's size, design, location and the environmental characteristics of that location. Absent this kind of information, predictions about specific land impacts of SSH development will be difficult to make. Obviously, the impacts, in many situations, will be more subtle than those of large scale projects where substantial construction, flooding, and multiuse development take place. Also, it is difficult to say whether the land impacts of SSH will be all that significant

Mr. Plantico is a Legal and Institutional Affairs Specialist, U.S. Fish and Wildlife Service (OBS), National Water Resources Analysis Group/Eastern Energy and Land Use Team, Kearneysville, West Virginia.

relative to other kinds of impacts such as those affecting the instream or aquatic environment. Nevertheless, while this uncertainty exists, there are some common impacts which ought to be kept in mind during project planning and decision making.

Small-scale hydropower projects generally fall into two categories: "run-of-river" and "store and release." Run-of-river facilities rely on the natural flow of the river to produce a base load of electricity. Many dams already in place and proposed for renovation are of the run-of-river variety. Store and release facilities impound water behind a dam. The water can then be released to produce varying amounts of electricity to satisfy either base or peak load demands. The following is a list of impacts which can result from these types of facilities:

A. Construction. Obviously, regardless of the type of facility, any construction activity will have some land or land/water impact. For example, construction of dams, power houses, penstocks and the like can alter the general scenery along a river, displace streamside vegetation, and present obstacles to terrestrial wildlife species.

B. Impacts Associated with Store and Release Impoundments. When water is held behind a dam to build sufficient head for hydroelectric generation, upstream riparian lands will be inundated. If these impoundments have been in place for some time, it is likely that environmental modifications and adaptions have already taken place. Fish and wildlife habitat has probably been modified (e.g. from ground nesting waterfowl habitat to "stub forest" habitat for woodpeckers, songbirds and the like). Owners of private riparian lands have since built homes adjacent to the new high water mark.[1]

However, new impoundment facilities present issues of immediate significance. Impoundment can cause the flooding of lands supporting agriculture, residential property, floodplains and wetlands. These wetlands and floodplains may support significant fish and wildlife habitat and flood storage to say nothing of other complex biological processes commonly associated with such environments (Odum).

C. Flow Regulation and Riparian Zones. Store and release facilities require that streamflows be altered to accommodate varying demands for electricity. However, there is concern that land/water areas such as floodplains and wetlands cannot sustain themselves when subject to frequent fluctuations in water levels. For example, when water is released to satisfy peak demands, "drawdown zones" are created upstream where floodplains and wetlands become essentially dried out.[2] Downstream, similar impacts may occur when flows are limited to store water behind the impoundment thereby depriving wetlands and floodplains of necessary water. Again, fish and wildlife habitat, water quality, and natural flood storage are dependent upon these land/water systems.

D. Dredge and Fill Activities. Sediment accumulation behind dams can seriously affect water flows critical to the generation of electricity. To ameliorate this condition, sediment can be dredged from the site. However, the dredged spoil must be dumped somewhere and that can have an impact on land resources. Filling of wetlands is a recognized problem. Dumping the spoil on the river's bank might result in sediment run-off and possibly toxic pollution where chemicals are found in the dredged spoil. On the other hand,

dredged spoil might well be used in nearby landfill projects which pose no threat to either the terrestrial or acquatic environments.

E. Transmission Lines. The impacts associated with transmission line construction can be significant especially in the west where great distances may separate hydro facilities, towns, and/or utility grids. Right of way corridors must be purchased—frequently in natural areas. In some cases herbicides are necessary to clear areas where poles and lines must be placed. In addition, line paths may impede the migration of many wildlife species.

F. Indirect Impacts of Small-Scale Hydropower. Where new facilities arise or impacts such as inundation create potential sites for recreation, new land use issues arise. Small-scale hydropower may well lead to new opportunities and responsibilities for supporting recreational, commercial, agricultural or residential activity. Such issues will require a careful evaluation of the land use trade-offs involved.

Institutional Responses to Land Use Impacts

Traditionally, land use policy has been a matter left to local jurisdictions. However, in the riparian area and, of course, on public lands, state and Federal agencies have jurisdiction over a number of activities which can affect land resources. Whether the land impacts resulting from future SSH development are significant enough to be addressed under relevant laws and decision making processes at the Federal, state, or local levels is a matter yet to be determined. In any event, it is appropriate to summarize some of the legal and institutional opportunities available to affect land use issues at all jurisdictional levels.

A. Federal Laws and Decision Making Processes. The Federal Energy Regulatory Commission (FERC), under the authority of the Federal Power Act, licenses all hydroelectric projects located on or affecting navigable waterways, affecting interstate commerce, located on Federal Lands (on which private activities are allowed under the public land laws) or which utilize water supplied by a Government dam. The Federal Power Act stipulates that the FERC must consider the overall public interest in the development of the waterway in its licensing decisions. Under the regular and short form application procedures for both major and minor projects, FERC requires applicants to assess the environmental impacts of their proposed developments (see procedures under 18 CFR §§ 4.40-.86 and § 131.6 (Supp. 1979). In addition, Executive Orders 11988 (Floodplain Management) and 11990 (Protection of Wetlands) requires all Federal agencies to review their procedures, rules and regulations as to their potential impact on floodplains and wetlands.

The Fish and Wildlife Coordination Act requires that the Department of Interior through the Fish and Wildlife Service (FWS) as well as state fish

[1] A significant land use issue involves the maintenance of old dam structures to preserve existing water levels and property values (Waite).

[2] The most common problem will probably result when wetlands created by virtue of old impoundments are subject to "drawdown" when old dam sites are rehabilitated.

and wildlife agencies be consulted on the licensing of dams which impound water over an area of 10 acres. The FWS may comment and make recommendations on a wide variety of aspects of the project to ensure that fish and wildlife and their habitat receive "equal consideration" in the project planning process. The FWS also plays a special role in indicating whether fish and wildlife protected under the Endangered Species Act will be affected.

The National Environmental Policy Act requires environmental impact statements for projects which will significantly affect the environment. Although it seems that SSH developers can avoid this exercise in many instances, there may be projects where the anticipated impact will require analysis, review, and comment under the NEPA process.

The Wild and Scenic Rivers Act may restrain the supply of suitable dam sites for future SSH development. Under the Act, Congress may limit development along specially designated stretches of rivers. The rivers must exhibit certain wild and scenic values in order to be incorporated within the National system.

Sections 404 and 208 of the Clean Water Act of 1977 and the Federal Water Pollution Control Act of 1972 regulate the dredging and dumping of dredged spoil along navigable waterways through a permit process and area management planning. This provides one method of addressing the dredging problem associated with some dam sites.

The National Flood Insurance Program provides a basis for the planning and regulation of activities along floodplains. To qualify for flood insurance, localities must develop appropriate regulations to control activities along flood prone areas (NRDC Handbook).

Finally, on public lands, a diverse number of agencies and public land laws address activities related to water resource development. These include but are not limited to the Federal Power Act, the Wilderness Act, The Federal Land Policy Management Acts and those laws and regulations controlling activities within the National Parks and Forests and on Indian Reservations.

B. State and Local Laws and Decision Making Processes. The legal and institutional opportunities to affect land use impacts of SSH are diverse and can be mentioned in only summary fashion. Of course, Mill Acts were and, in many cases, still are the most significant legal instruments favoring SSH development. Such Acts empower dam owners to flood upstream riparian lands so long as the injured property owners are compensated. Today, however, numerous laws in addition to the Mill Acts address these and related activities.

Public Utility Commissions and Water Resource Development Boards often possess licensing and permit powers for the construction of hydropower facilities and the use of water resources within a State. In some States these processes are influenced by State Environmental Protection Acts designed to stimulate review and analysis of environmental impacts of state authorized projects in much the same way NEPA does for Federal action.

In addition, the growth of statewide land use planning (see, e.g. Oregon LCDC) and regulations affecting activities in and adjacent to wetlands and floodplains (Kusler) has contributed to the list of forums through which the impacts of SSH might be addressed. And, of course, local planning and zoning boards retain control over numerous land use activities within their jurisdictions.

Conclusion

This paper has only touched on the environmental and institutional issues related to land use and SSH development. As it was mentioned earlier, the extent to which land impacts become significant issues for environmental planning remain to be seen. Certainly, decision makers ought to be aware of such impacts, the relative values of the land uses which SSH will encourage and/or preclude, and the institutional mechanisms for evaluating policy decisions related to these activities. Given this information and the great amount of interest and concern over SSH development, decision makers have opportunities to make possible the development of a valuable energy resource while being sensitive to important environmental factors.

REFERENCES

Clapp and Garner, "Look Back At the Future," *Water Spectrum*, Vol. 11, No. 3 (1979), p. 20.

Kusler, *Strengthening State Wetland Regulations* (1978).

Kusler, *Floodplain Regulations for Floodplain Management* (1976).

Odum, "Ecological Importance of the Riparian Zone," in *Strategies For Protection of Floodplain Wetlands and Other Riparian Ecosystems: Proceedings of the Symposium*, p. 2 (1978).

Waite, "Nineteenth Century Dams and Twentieth Century Problems: Commentary On A Statutory Solution," *28 Maine Law Review* 419 (1976).

Natural Resources Defense Council (NRDC), *Land Use Controls In The United States: A Handbook On The Legal Rights of Citizens* (1977).

New England River Basins Commission (NERBC) *Regional Report*, Vol. 7, No. 3 (August, 1979), p. 4.

Oregon Land Conservation and Development Commission, *Oregon Land Use Handbook*, Chapter 2 (1978).

U. S. Fish and Wildlife Service, *Review of Hydroelectric Power Projects Licensed by the Federal Power Commission* (1977).

RECENT CONGRESSIONAL ACTION AFFECTING SMALL-SCALE HYDROPOWER

Sarah J. Glazer

As someone who follows Congress' energy activities on a daily basis, I would like to review the congressional climate that gave rise to legislation in the past two years to encourage the development of small-scale hydropower facilities.

The legislation, founded in an atmosphere of concern for the environment, is taking on a new personality. Environmental groups fear that if the legislation is subjected to the major changes now being proposed, small hydropower will become the new pork barrel for Congress and could wreak the same kind of environmental damage—albeit on a smaller scale—that has been the legacy of giant hydro projects in the West.

The legislation Congress passed in 1978 to encourage small hydro development limited Federal aid strictly to rehabilitating existing dams. The sponsors of the legislation—who are both from northeastern states—were thinking of the New England industrial mill sites abandoned during the era of cheap fossil fuels when they drafted their bill. The construction of new dams was specifically excluded from the legislation because of the sponsors' concern for the environment.

This year, there will be several efforts in Congress to expand the legislation to encourage new dam construction and to increase the maximum size that defines a small hydropower project. A few environmental groups are gearing up to lobby against such expansions, fearing that small-scale hydropower may become the new pork among water projects in Congress.

Although some members of Congress can be expected to fight these revisions in existing law, they will face a Congress whose mood has turned anti-environmental and pro-energy development over the past year. The recent enthusiasm for synthetic fuels development in Congress—a major controversy in 1976—is one sign of the changing mood. Another sign is the proposal endorsed by President Carter to establish an Energy Mobilization Board that would have the power to waive requirements of environmental laws standing in the way of major energy projects. The debate over small hydro development—particularly at new sites—represents in microcosm the controversies that have developed over big hydro and other energy development plants funded by the Federal government.

In 1978, Congress approved Federal loans to encourage local governments, electric cooperatives and others to study the feasibility of installing small hydropower facilities at existing dams. The legislation also included $300 million worth of loans over three years for constructing small hydro facilities at existing dams in cases where the project proved feasible.

The provision containing the loans was attached to the 1978 National

---

Ms. Glazer is the Senior Staff Writer, Environmental Study Conference, U.S. Congress, Washington, D.C.

Energy Act[1] by a Senator and a House member from the Northeast. Both are committed environmentalists who saw the abandoned dams in their states as an untapped source of energy. Retrofitting existing dams was particularly appealing to these two members as a clean, environmentally sound way of supplying energy and thus avoiding the use of coal and nuclear energy.

Further, the use of small hydropower has the appeal of being decentralized in contrast to large conventional power plants controlled by utilities. As such, small hydropower offers the prospect of self-sufficiency for communities blessed with a powerful river. The two members who sponsored this legislation are Senator Durkin, Democrat from New Hampshire, and Representative Ottinger, Democrat from New York.

At the time that the National Energy Act was being debated, the section on small hydro attracted comparatively little attention from environmental lobbyists. They were preoccupied with more controversial issues, such as electric rate reform and residential energy conservation incentives. But environmental groups that lobby on energy generally look favorably on reviving these abandoned dams. Most of these groups trusted Ottinger and Durkin—because of their strong pro-environmental voting records—to draft the bill with an eye toward environmental protection.

In that trust, the environmentalists were not disappointed. The 1978 legislation strictly limits the loans to projects at existing dams. Impoundment structures may not be enlarged. The power project must use the water power potential of the existing dam and may have no more than 15 megawatts of installed capacity. The Secretary of Energy, who issues the loans, must first find that the project will have "no significant adverse environmental effects, including significant adverse effects on fish and wildlife, on recreational use of water. . . on stream flow. . . (or) on any other use of the water."

Finally, the legislation ignores the Army Corps of Engineers, whose presence normally raises a red flag to environmentalists as a matter for concern. Over the past year, however, there have been several efforts in Congress to expand the existing loans in ways that alarm environmentalists: One change would make new as well as existing dams eligible for the Federal loans. The

---

[1] This provision is Title IV of the Public Utility Regulatory Policies Act (HR 4018, Rpt. 95-1750) (Public Law 95-617). The law authorizes $10 million annually for fiscal years 1978-1980 for loans to pay up to 90 percent of the costs of conducting feasibility studies and preparing applications for a license. DOE will forgive the unpaid balance of the loan if the study shows the project would not be technically or economically feasible.

The title provides $100 million annually over the same three-year period for loans of up to 75 percent of the project costs of installing small hydro equipment. The costs of constructing fish and wildlife facilities are to be included in the costs. The Federal Energy Regulatory Commission is directed to issue simple licensing procedures for small hydropower projects in connection with existing dams.

Appropriations: So far the Carter administration has requested no funds for construction loans and Congress has appropriated none. Loans for feasibility studies have been appropriated by Congress at the authorized level of $10 million for FY 1980 in the Energy and Water appropriations bill (HR 4388) signed into law Sept. 24. This would be the third year in which $10 million has been appropriated for feasibility studies.

The appropriations bill also contains $8 million for an industrial development program started last year with $18 million in funding to encourage the development of turbines for small-scale hydro and to reduce the cost of such systems.

other proposal would expand the definition of a small hydropower project from 15 megawatts to 25 megawatts. The Senate has already passed a bill to accomplish those two changes in the law. But the measure (S 948) is likely to face such hostility in the House that it may die in committee. The Senate amendment (S 948) was cosponsored by Senators Durkin and Jackson, who is chairman of the Senate Energy Committee.

With no lobbying from environmentalists and little discussion of the bill before floor action, the Senate passed the measure June 14 by voice vote. There was no floor debate aside from the introductory statements of the two sponsors.[2] At the time, staff for the Senate Energy Committee explained that Jackson was pushing the bill so that several larger new hydro projects in his home state of Washington would be eligible for the Federal loans in existing law.

So far, the House Commerce Subcommittee on Energy and Power, which has jurisdiction over the subject, has taken no action on the measure. Nor has it considered the similar House bill (HR 4488) introduced by Representative Foley, also of Washington state. Although the House subcommittee may hold a hearing on the Jackson-Durkin proposal, it is not likely to send it to the floor, largely because of opposition from Ottinger, who sits on the panel. Representative Dingell (D-Mich.), who chairs the House panel, is likely to concur with Ottinger in opposing the expansion of the Federal loans to existing dams. As one staffer for the House committee put it, "We've already seen what large projects can do to the Columbia River; we don't need to see what they can do to the Schuylkill."

Environmental groups like the National Wildlife Federation share the concern that new small hydropower development could wreak the same kind of damage—although on a small scale—on wildlife and stream flows accomplished by large hydro projects in the West. Most of the potential for new hydro development is in the West, which is already highly developed. In the case of existing dams, however, it is generally believed that many of the ecological changes have already taken place and have reached a state of equilibrium.

Another concern for environmentalists is the question of whether small hydropower will be permitted to displace construction of new power plants using the more environmentally destructive technologies, such as coal or nuclear power. There is a good possibility that utilities will place a higher reliability standard on hydro than on conventional thermal plants. If a utility cannot claim reliable capacity from a small hydro facility, it will have no reason to cut back on power plant construction.

One environmental lobbyist told me, "There is relatively little interest among environmentalists in boosting the reactivation of these existing sites if it doesn't add up to the diminishing of building coal, nuclear or large hydro plants." Lately, environmental concern has focused on a proposal by Senator Gravel (D-Alaska) that would put the Corps of Engineers into the act. Gravel wants to attach his proposal (S 1641) to the biennial water projects bill (S 703). Gravel should be able to attach his small hydro proposal with ease, since he chairs the subcommittee with jurisdiction over the omnibus water projects

[2] See Congressional Record, June 14, 1979, pp. S 7658-S 7659.

bill: the Water Resources Subcommittee in Senate Environment and Public Works.

Under the Gravel proposal, the Corps of Engineers would be authorized to spend available water resources development appropriations as it deemed necessary for planning, designing and constructing small hydroelectric projects. Specific project-by-project authorization from Congress would not be necessary. The Carter administration has endorsed in principle the concept in the Gravel bill of providing the Corps with general authority to construct power plants at existing Federal facilities. The administration plans to submit to Congress shortly its own bill carrying out this objective.[3] The only restrictions in Gravel's bill are that each project have a maximum capacity of 25 megawatts, that it cost a maximum of $15 million in Federal funds and that the total annual Federal spending for all small hydro projects be not more than $75 million. For a district that wanted to contract with the Corps to build such a project, the same generous loan and repayment provisions would apply as for large Corps-built water projects.

One environmentalist described Gravel's approach as one based on the Corps' reputation for "getting things done." The fear of environmentalists is that the Corps would be less likely than the Department of Energy, which is the administering agency in the existing legislation, to refrain from building a project in the face of environmental problems. Gravel's proposal should not meet any opposition on the Senate floor. Once it reaches the House, however, Dingell's Energy and Power Subcommittee is apt to seek referral, even though traditional water projects jurisdiction lies with the House Public Works Committee. The counterpart House water projects bill (HR 4788), which the House Public Works Committee will send to the floor shortly, has no provision comparable to Gravel's. The House bill does include funds for the Corps to study and recommend existing sites that would be suitable for small hydro development.

[3] Testimony of Guy R. Martin, Alternate to the Chairman, Water Resources Council, before the Senate Committee on Environment and Public Works Subcommittee on Water Resources, Sept. 6, 1979.

[4] See Congressional Record, Sept. 18, 1979, pp. S 12883-S 12886.

In another arena, small hydropower construction (up to 25 megawatts) would be eligible for generous new tax breaks under a proposal (S 1762)[4] introduced by Senator Nelson (D-Wis.). The Senate Finance Committee has tentatively approved Nelson's proposal by including it as one of the tax credits to be funded through the windfall profits tax on oil (HR 3919). Nelson's proposal, however, could be the victim of fiscal responsibility when the Finance Committee starts trimming back the tax breaks it has approved to insure that it does not give away more revenues to taxpayers than the windfall tax would raise.[5]

As the legislation I have described to you indicates, there is clearly enormous enthusiasm for small hydropower in a Congress that is concerned with finding new sources of domestic energy and as well as reviving old sources. The question that now remains is whether Congress will move ahead at full speed to build small hydro plants at new sites or whether it will explore existing dams first to their full potential, as environmental groups are advocating.

---

[5] As approved by Senate Finance, the Nelson proposal would:

- Increase the existing 10 percent investment credit to 30 percent for small-hydro facilities installed at an existing dam and for fish passageways installed in connection with a small hydro facility.
- Allow small hydro dam owners to write off the cost of depreciated facilities four to five times faster than under current law as a way of alleviating cash flow problems for small developers with limited financing abilities.
- Increase the current 1.5 percent allowance for repairs to 4 percent, permitting owners to take a higher annual deduction for repairs on small-hydro facilities.
- Provide a special federal tax exemption for state and municipal bonds used to finance hydro facilities.

The House has not started to consider the tax credits yet.

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

Session Fourteen

POLICY

Topic: Energy

Chairman: Mr. Eugene O'Brien
Partner
Tippetts-Abbett-McCarthy-Stratton
655 Third Avenue
New York, New York 10017

AN ANALYSIS OF INSTITUTIONAL, ECONOMIC, AND ENVIRONMENTAL RESTRAINTS ON HYDROELECTRIC DEVELOPMENT AT EXISTING DAMS

Robert J. Taylor

The Johns Hopkins University Applied Physics Laboratory has developed for the Department of Energy a methodology which helps quantify the impact of the institutional, economic, and environmental (IEE) restraints on the hydroelectric development of existing dams. The methodology involves determination of the incremental costs of hydroelectric development versus the potential hydroelectric energy output within a designated area. The resulting hydroelectric energy supply curve (kWh versus ¢/kWh) is a valuable tool for assisting in determining what governmental policies will encourage greatest development of the resource. The following are some of the questions this tool should help answer: What are the types of hydroelectric developers that should be encouraged and how should this be done? What is the effect of taxes and insurance on the supply? What effects do the present licensing costs have upon the supply? What is the effect of low-cost, turbine-generators on the supply? What are the impacts of the present environmental and recreational requirements? What would be the effect of governmental subsidies, loans, and assistance (e.g., as a Federally-assisted liability insurance program) on the hydroelectric supply?

The methodology for obtaining the hydroelectric energy supply curves was divided into several tasks:

(a) Estimating the existing dam hydroelectric potential,
(b) Categorization of the dams,
(c) Selecting and visiting a random sample of the dams to determine the expected values for site specific functions such as the average expected costs of dam repairs, and required transmission line and road construction costs,
(d) Evaluating the environmental constraints at each site,
(e) Estimating the cost of development of hydroelectric power at existing dams,
(f) Determining the individual dam supply curves, and
(g) Estimating the regional supply curves.

A detailed discussion of the methodology and a sensitivity analysis for the potential sources of errors in the supply model using this methodology is given in Reference 1.

Mr. Taylor is Senior Staff Physicist - The Johns Hopkins University Applied Physics Laboratory, Laurel, Maryland.

The methodology has been applied to the area of Pennsylvania, Maryland, and New Jersey. Three hundred and ninety three non-hydroelectric dams were identified with individual potential capacities greater than 50 kW. An estimate of the potential hydroelectric annual energy supply curves for these three states is shown in Figure T-1.1.

One of the most important findings from Figure T-1.1 is the almost vertical shape of the supply curves above 4¢/kWh. This indicates that very little additional energy is available for prices above 4¢/kWh. If 2.5/kWh is a fair price for run-of-river hydroelectric, government subsidies above 1.5¢/kWh will be very ineffective in bringing additional hydroelectric energy on-line for developers with an annual fixed charge rate (AFCR) of 10.4%.

Impact of Type of Developer

The type of hydroelectric developer impacts the potential hydroelectric development through the cost of money available to each. The expected AFCR for private and public developers is given in Table T-1.1 (Ref. 2). Using these two different AFCR's, the hydroelectric supply curve for Pennsylvania can be derived. Figure 2 shows the supply curve for these two different rates.

TABLE T-1.1

AFCR Expected For Private and Public Developers

	Private Developer (%)	Public Developer (%)
Cost of Capital	12	8
Income Taxes	1.5	0
Other Taxes	2.56	0.5
Insurance Rate	0.2	0.5
Depreciation	1.67	1.67
Total AFCR	17.93	10.37

Figure T-1.2 shows some interesting results in the neighborhood of the 2¢/kWh through 3¢/kWh energy price range. At 2.5¢/kWh (the 1978 average running rate for the Pennsylvania, New Jersey, and Maryland power pool), the amount of hydroelectric energy annually available from developers with AFCR of 10.4% is 3.7 times the energy annually available from developers with an AFCR of 17.9% (note that 17.93 divided by 10.37 is only 1.73). At 3¢/kWh, the amount of hydroelectric energy available from developers with an AFCR of 10.4% is 4.5 times the energy annually available from developers with an AFCR of 17.9%. Thus AFCR is a very sensitive parameter in the development of hydroelectric power from existing dams within Pennsylvania.

If private developers were relied upon for hydroelectric development, a government subsidy of 1.5¢/kWh over a 2.5¢/kWh price would be required for an equivalent development by public developers. This would mean an an-

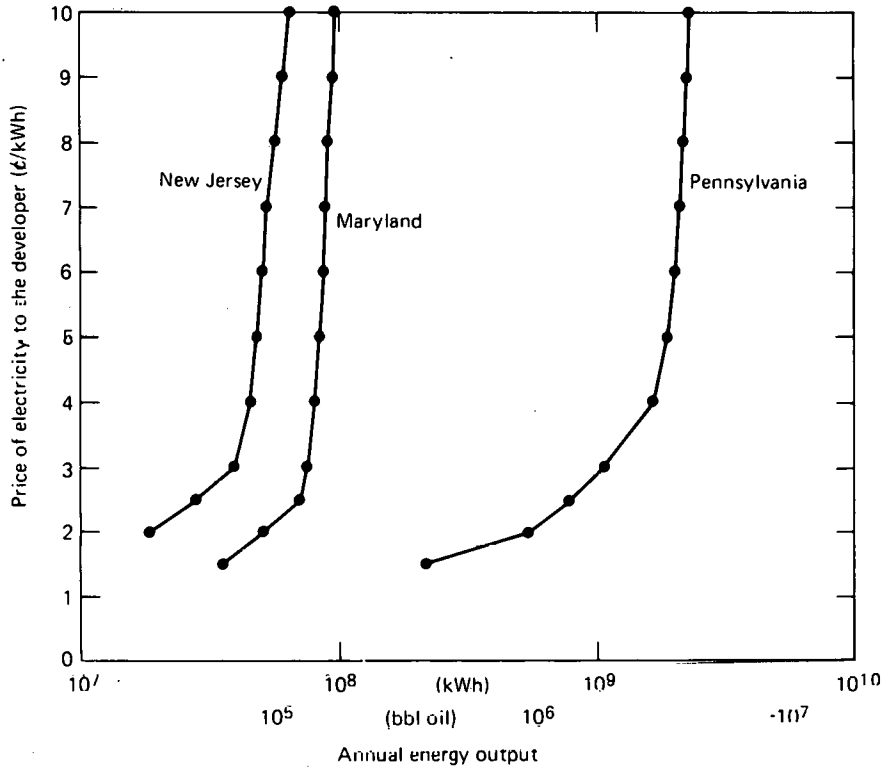


FIGURE T-1.1 The potential hydroelectric energy supply curve for nonhydroelectric dams (Potential capacity greater than 50 kW each) in Pennsylvania, Maryland, and New Jersey, using public developers.

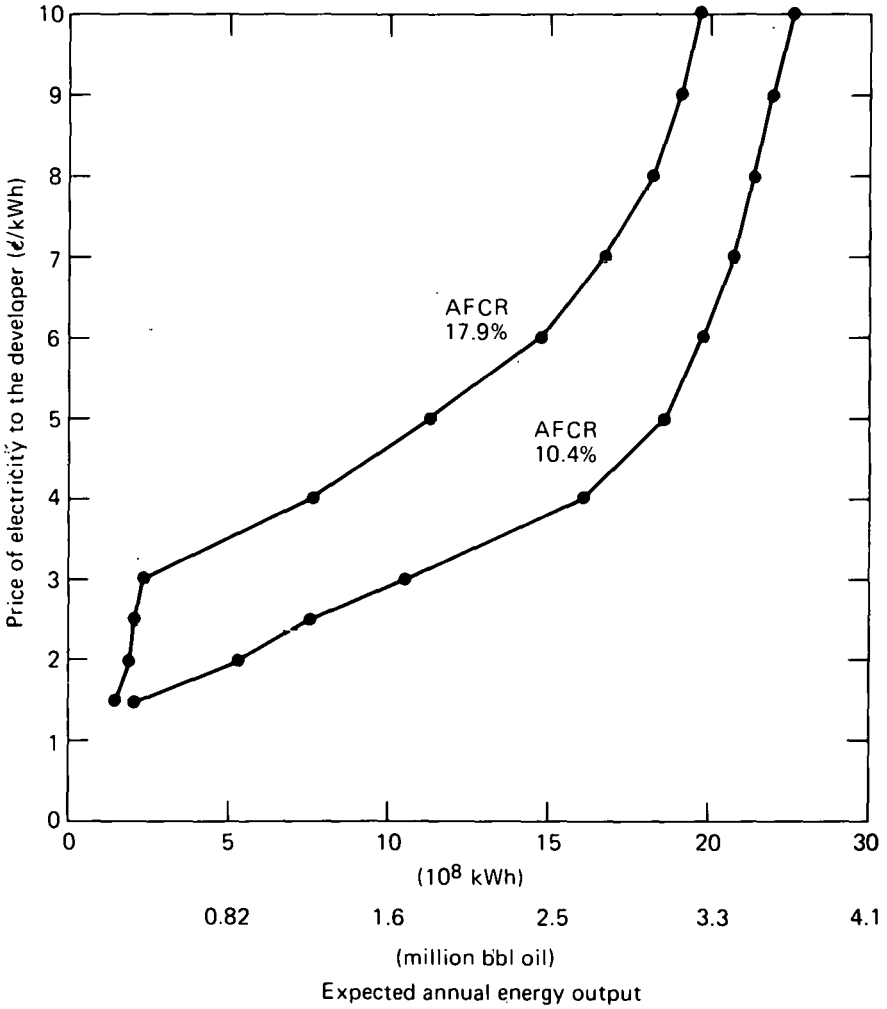


FIGURE T-1.2 The potential hydroelectric energy supply curve for 347 nonhydroelectric dams in Pennsylvania; two levels of AFCR

nual public expenditure of about 11.4 million dollars within Pennsylvania. Another method in addition to subsidies would be to offer low-cost loans. If 6.875% Federal loans were made available for 90% of the financing, the cost of capital to a private developer would be 7.69% (assuming a 15% rate of return on equity). Using the other components, the AFCR would be 13.6% for private developers. It appears that this approach would provide 70% of the energy potentially available from public developers at 2.5¢/kWh to the developers. Reducing other parts of the ADCR, such as taxes for private developers would similarly increase the supply.

Impact of Taxes and Insurance

Taxes and insurance are components of the AFCR. Increases and/or decreases in these components of the AFCR can have a significant impact on the hydroelectric supply. Decreases in the tax rates can be justified on the basis that development of this renewable resource can decrease our dependence on foreign oil. However, decreases in local tax rates for hydroelectric sites may require increased revenue-sharing by the Federal government. Decreases in the tax rates by 50% in addition to low-cost loans could bring the previous AFCR for private developers down to 11.6%. This would provide 85% of the energy potentially available from public developers at 2.5¢/kWh to the developer.

However, these gains for private development could be eliminated by potential increases in the insurance rate. The insurance rate assumed in the model was 0.2% (Ref. 2). Dam liability insurance rates may be in flux due to recent dam failures. Also, acts of vandalism have increased insurance costs at some sites. Insurance rates as high as 2% or higher have been estimated for a few projects. The potential impact on the supply by high insurance rates is very complex. It depends on the developer's present AFCR and the price he is receiving for the energy. For a better understanding of the potential impact of higher insurance rates and lower tax rates, a plot of the Pennsylvania supply versus the AFCR and price to the developer is shown in Figure T-1.3.

For a given AFCR and price, one can use Figure 3 to determine the actual impact for changes in the AFCR. For example, if the price of actual electricity is 2.5¢/kWh and the AFCR is 12.2%, a decrease of 1.8% in the AFCR will result in a 30% increase in the supply. However, if the AFCR is 15.4% and the AFCR decreases by 1.8%, the supply increases by 130%. Figure 3 indicates that government policy makers should seek not only the highest price possible for developers but also the lowest AFCR if the greatest potential for hydroelectric power is to be developed.

Impact of Cost of Licensing

The cost of licensing is assumed to be $40,000 per site for the computer model of the supply curve. This cost was set to zero for the supply model of Pennsylvania (AFCR equals 10.4%) and the changes in supply were determined. The maximum observed increase in energy output was +2.7%. The

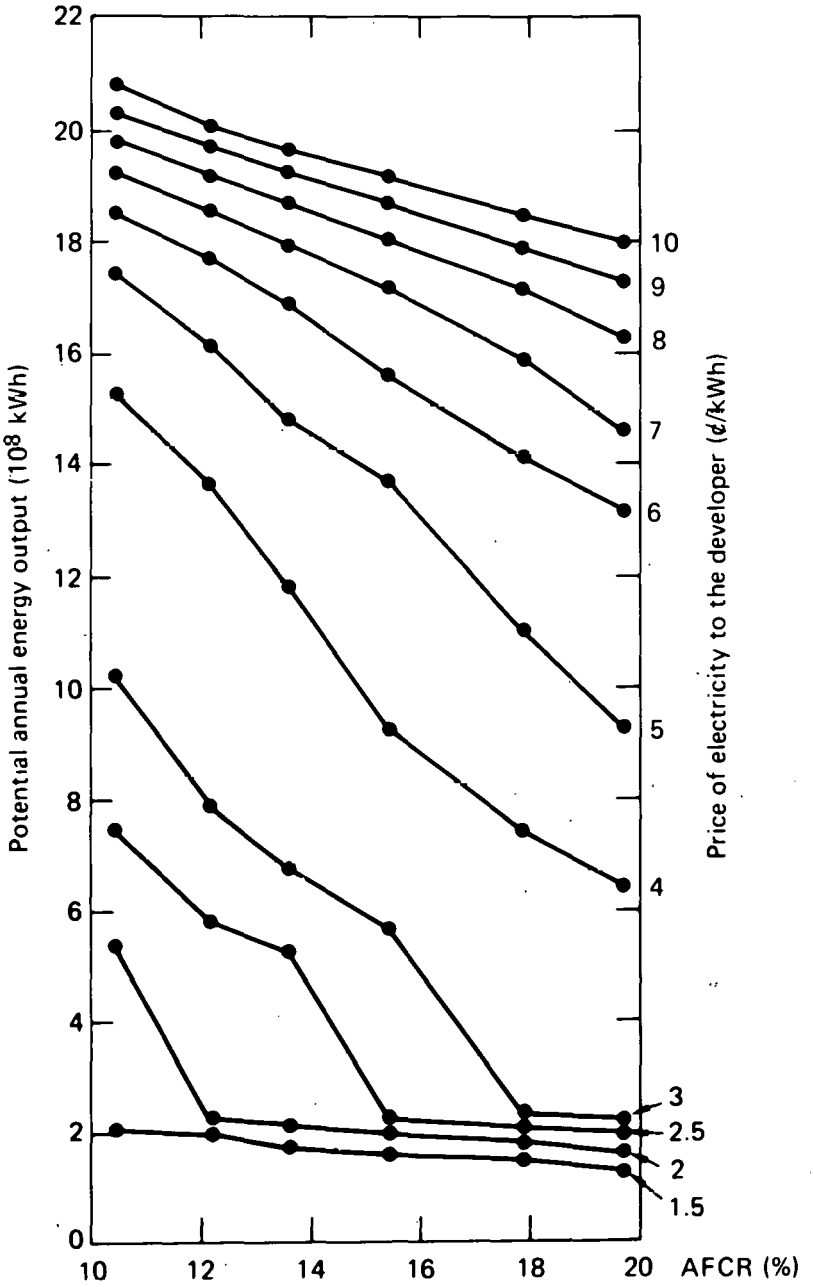


FIGURE T-1.3 The potential hydroelectric energy supply for 347 nonhydroelectric dams in Pennsylvania versus the AFCR at constant price levels to the developers.

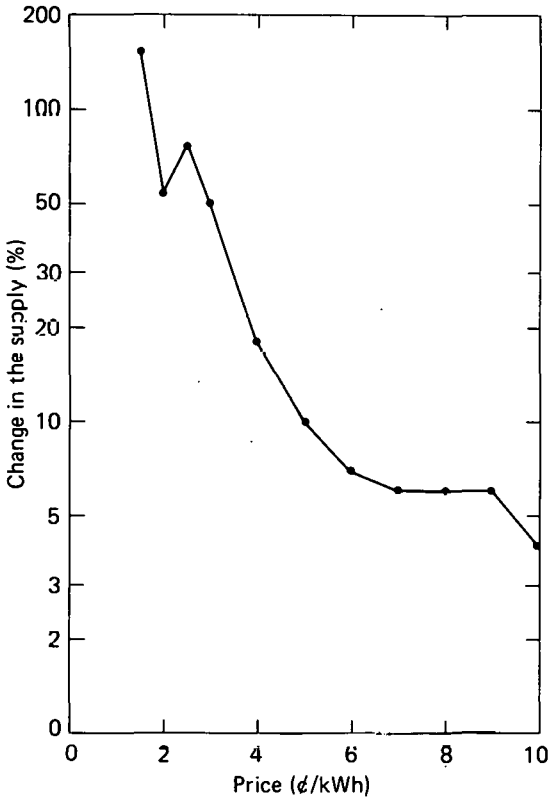


FIGURE T-1.4 Change in potential hydroelectric energy supply curve for the 52 largest non-hydroelectric dams in Pennsylvania when the powerhouse costs are decreased 30%.

reason this $40,000 per site cost decrease has so small an impact on the supply curve is the high cost of developing those sites that make the greatest contribution to the supply. For example, the average cost of development for the navigation dams is estimated to be $18,000,000 each. Obviously, for such sites a $40,000 decrease in cost is insignificant.

Impact of Low-Cost Turbine-Generators

The government has been encouraging standardized turbine-generators for small-scale sites. Lower costs should stimulate greater production, which traditionally has lowered costs also. If the costs of the powerhouse and equipment could be decreased by 30%, the impact upon the supply is shown in Figure T-1.4. The impact is significant for prices of electricity to the developer of 3¢/kWh or less. If the reasonable price for the power is 2.5¢/kWh, lowering the cost of the powerhouse and equipment by 30% increases the supply by 77%.

PRIVATE FINANCING OF SMALL-SCALE HYDRO PROJECTS

Hugh W. McLeod

Introduction

The sharp acceleration in the cost of oil and coal since the Arab oil embargo combined with a desire on the part of government and utilities to promote small-scale hydroelectric projects, has generated a great deal of interest in hydropower. Many projects which were not economical or practical several years ago can now be undertaken on a profitable basis for both the developer and power purchaser. The result is that small-scale hydroelectric projects are becoming a very exciting and dynamic area. The outlook is for continued rapid growth in this emerging industry. In Europe, a traditionally high-cost energy area, the small-scale hydro technology itself is well-known. This is transferable to the U.S. but the domestic technology of financing these projects is in the process of being developed and is not well understood or standardized.

I. Two Basic Types of Projects Are Financed

A. Projects where the credit decision is based primarily on the credit or other activities of the developer. Examples of this would include projects developed by a utility itself, a municipality, or a small project developed by an individual with enough net worth to justify the loan. Another way to say this is that the primary basis for the credit decision is *not* the cash flow or assets of the project, but the strength of the developer.

B. The other type is a project where the credit decision is based primarily on the cash flow and assets of the project, i.e., a true *project financing.* Most projects developed by individuals will fall into this category. This outline will concentrate on the private financing of the second category (project financing).

II. The Key Components of a Successful Small-Scale Hydroelectric Project Financing

A. A good power *purchase contract* that will provide sufficient revenue to service the principal and interest of the loans with an adequate safety margin *and* provide the developer with an adequate return.

B. The necessary *licenses* and *permits.*

C. A good *construction contract* (preferably turnkey) that will insure the project be completed on time and within budget or provide appropriate penalty payments to keep the project whole.

Mr. McLeod is Vice President, New England Merchants National Bank, Boston, Massachusetts.

D. A qualified *management - development and operating team* (probably most important).
E. *Appropriate financing.*

If any one of these key components is not available or sufficiently strong, the project's chance for success is lessened.

III. Project Financing Small-Scale Hydro Projects - How It Differs From Regular Loans

A. There is little fall back position outside of the project.
B. The dollars needed for the project are usually large in relation to the developer's assets. You cannot rely primarily on developer's net worth.
C. Unlike a real estate loan the project itself has little collateral value.
D. For all of these reasons the emphasis is on the project's *cash flow.*

IV. What Types of Financing May be Required?

A. Front-End Money to:

(1) Secure the site.
(2) Fund feasibility studies, environmental impact studies, and other site-specific issues.
(3) Apply for FERC licenses.
(4) Pay Legal & Accounting fees.

B. Construction loan - to finance the building of the project.
C. Long-term debt - to provide financing after construction is completed.
D. Junior money or equity to complete long-term financing.

All of these are usually interrelated and interdependent.

V. Possible Financing Sources Could Include

A. Government grants for front-end money and feasibility studies.
B. Private groups for front-end money and feasibility studies.
C. Commercial banks for front-end money, construction loans, 5-10 year junior money loans.
D. Leasing companies for medium-term financing.
E. Financial subsidiary of turbine manufacturer for medium-term financing.
F. Insurance companies for long-term debt financing.
G. Savings banks for long-term debt financing.
H. State agencies or authorities - tax-free, long-term financing.

VI. Project Financing - Can It Be Done? Yes! Is It Easy? No!

A. Requires a lot of work by all parties involved.
B. Lenders should have experience and expertise in the utility industry (including understanding the regulation process), the hydroelectric industry, and in project financing because there is little outside collateral and because they must mesh with the other par-

ties. If any one fails, the project and a lot of time and money may be lost.

C. However, it can be done! Let's look at one recent example.

VII. The Lawrence Hydroelectric Associates Project - A Case Study

A. The project - a $23.5 million, 15 megawatt, low-head, hydroelectric project utilizing an existing dam on the Merrimac River in Lawrence, Massachusetts - developed by the Essex Company, a group of six talented individuals. The financing was as follows:

B. Front money loan - New England Merchants National Bank.
C. Construction loan - a New York bank.
D. Long-term debt - an insurance company.
E. Junior money loan to complete long-term financing - New England Merchants.
F. Equity investment - Essex Company and a limited partner (EG&G, Inc.)

VIII. How To Improve Chances Of Getting Good Financing

Do your homework before you approach the lenders and prepare the following:

A. Cash flow projections for the project - does not have to be fancy.
B. Feasibility study.
C. Know what permits and licenses will be required.
D. Document your own background and expertise.

We believe there is a promising and exciting future for small-scale hydroelectric projects!

ELECTRICITY GENERATION IN RURAL AREAS: A FUTURE FOR SMALL-SCALE HYDRO PROJECTS

William B. Telaar

Good afternoon. I'm Bill Telaar, and I am a Fuels and Energy Engineer with REA. I have been asked to speak to you on the subject of "Electricity Generation in Rural Areas - A Future for Small-Scale Hydro." I have given this topic some thought, and I have decided to direct my comments primarily to that portion of the industry I know best; that financed by REA. I would like to describe our program to you, but first let me say that this method of generation is not new to rural areas and is certainly not futuristic in nature. Small-scale hydro has been providing electrical power to rural residents for some time. Construction of these small installations was curtailed by unfavorable economics during the recently ended era of cheap and plentiful oil and gas, but there are still a number of small-scale hydro plants operating in rural America. I checked our records, and as of this year there are 47 small hydro units in commission in 21 REA-financed generating plants, with a total installed capacity of 59,370 kW. The plant sizes vary from a single unit 175 kW station in North Carolina to a two unit 15,000 kW plant in Alaska. Other proposed installations are presently being considered. My point, of course, is that small-scale hydro is one of the oldest methods of supplying mechanical and electrical energy to replace the still older methods of supplying energy from the muscles of men and animals. The sudden rediscovery is a result of a change in economics, not technology. However, the change in economics makes small-scale hydro development appear feasible again. This old method of generation does have a future in rural areas, as well as a past. We in REA and the Rural Electrification Program are already working to increase our use of renewable sources of energy.

By now, some of you must be asking yourselves "Who and what is REA?" So, as I said earlier, I would like to briefly describe REA and the Rural Electrification Program. The Rural Electrification Administration (REA), which is an agency of the Department of Agriculture, was created by the Rural Electrification Act of 1936. This Act authorizes REA to make loans for rural electrification to nonprofit and cooperative associations, municipalities, public bodies, and electric utilities for the purpose of financing the construction and operation of generating plants, and transmission and distribution lines or systems for the furnishing of electric energy to persons in "rural areas" who are not receiving central station service. The Act defines a "rural area" as any area of the United States not included within the boundaries of any city, village, or borough having a population in excess of 1500 people. REA does not design, build, own, or operate any of the generation, transmission or distribution facilities. We do furnish technical and management assistance to our borrowers through office and field personnel to help further the

Mr. Telaar is an Energy Resources Engineer with Rural Electrification Administration, U.S. Department of Agriculture.

objectives of the Rural Electrification Act and protect the security of the Government's loan. To achieve program objectives, we help develop the resources and ability of borrowers to handle its own affairs effectively, and to achieve as soon as possible the internal strength and soundness needed to assure its success as independent enterprises.

We finance about 1,000 small rural electric utilities, most of which are cooperatives, in 46 states, serving nearly 30 million consumers over approximately two million miles of electric lines. We have also financed almost 11,000,000 kW of generating capacity of various kinds which supplies about one-third of the requirements of the program. The other two-thirds is purchased from investor-owned utilities and from Federal and state power agencies.

From these statistics, patterns emerge. Rural electric cooperatives supply the electrical needs of large portions of rural America, where a significant number of small-scale hydro sites are located. Cooperatives are nonprofit, consumer-owned and controlled, and therefore, are especially motivated to consider the wants and needs of individual members and to promote good consumer relationships by providing service of highest quality at minimum cost. The electric lines necessary to collect the power from small dams and distribute it to consumers are largely in place. The backup power necessary to assure continuous service to consumers is already available, some of it from small plants using gas and oil for fuel. Financing is available. By proper application and utilization of these conditions, we believe small-scale hydro will be economically feasible again and can contribute a significant amount of energy to supplement the existing conventional sources. In addition to the economic benefits, this will forward our national goal of reducing the consumption of fossil fuels.

We in REA and personnel from our borrowers' staffs are considering the impact of small hydro on rural electric systems and what preparation will be required. For any loan application, a substantial amount of preplanning is essential. When a loan request is received for a small-scale hydro installation, REA will require investigation of the technical aspects of the dam site, as well as such items as the need for the new installation, how the energy will be used, the electric lines available, any new lines required to gather and transmit the energy, and the environmental impact. The type of power and energy would also influence the decision. This consideration includes the availability of the power, both by time of day and time of year, the amount of water storage, the amount of energy produced, and similar factors. The most important evaluation, of course, is economics. An economic feasibility study considers all applicable factors, including the cost of installation, the comparative cost of alternative sources of power and energy, plant capacity and the projected amount of use. Cost of backup power when there is no water or maintenance is necessary, among others. All planning must be done in cooperation with the integrated power supply system in the area. As I previously mentioned, most of our borrowers purchase power and energy from other utilities, which are in turn interconnected with surrounding utilities. Close coordination between all parties is essential.

All these items can be evaluated for an installation proposed by a utility. The other type of installation whereby a private developer wishes to interconnect a hydro plant with a utility requires consideration of the items mentioned above, plus some others. Private developments include farm-size units installed to supply portions of the farm and domestic needs of the owner and possibly to sell some surplus energy to the local utility. There may also be some private plants installed for profit making purposes. All these installations must be encouraged in order to increase the amount of our national energy requirements obtained from renewable sources. Interconnections with such sources are particularly appropriate for nonprofit, consumer-owned utilities, where the emphasis is on quality of service, low cost, and member satisfaction. It is important, however, to begin with fair relationships with all parties and to proceed on a sound technical and financial basis. There have been several recent interconnections between electric utilities and consumer-owned generators, resulting in the identification of several factors for which early resolution is essential. Both utilities and those persons considering the installation of small generators should be fully aware of these factors in order that future disputes may be kept to a minimum.

To those of us in the electric utility industry, the primary consideration for any installation is safety. For example, it must be made impossible for a small locally-owned generator to feed into a section of line that has been disconnected from the system for repair or maintenance. This can be done by instrumentation that physically disconnects the two. Also some generators and inverters are line-commutated, which is to say that frequency is controlled by the interconnected system, and will cease to function when there is no voltage on the line. This appears workable, but some questions have been raised concerning the possibility of each of several small generators on the same section of line sensing the production from the others and continuing to feed voltage into a disconnected feeder line. This possibility is still being investigated.

Another item to consider is the wave form of the power that would be fed into the cooperative systems from the small power generators. The generators can be either of the a.c. induction type or d.c. generators that require inverters to produce the a.c. required. Some existing and proposed installations are of the d.c. generator type, using synchronous inverters from one particular manufacturer. The REA staff has been giving a lot of consideration to that inverter. The major areas of concern are the harmonic distortion of the wave form produced and the reactive power requirements. The information available shows 30 percent of this power production is in the form of harmonics and that the power factor is 0.5. We have not yet completely decided on the best course of action.

The harmonic distortion of the wave form can cause interference in television and radio signals, as well as telephone interference. So far this has been dealt with on a case-by-case basis, which is permissible for a few isolated installations. When small generators become more common, however, the problem will assume much larger proportions. We would like to derive a procedure to control or limit these harmonics and thus prevent the occurrence of a major problem. Several ideas are being discussed and considered, but as yet no definite conclusions have been reached.

If the line-commutated inverters with low power factors are employed in energy conversion systems, there will be a constant reactive power drain from the utility system. Also, rural electric systems are voltage constrained, which is to say we worry more about voltage than about energy losses, and any concentrated proliferation of such inverters in an area could cause an increased voltage drop on feeder lines, requiring the cooperative to install capacitors to relieve the problem. This could aggravate any telephone interference problem, as well as add to the cost of service. To those of you with non technical backgrounds who may not completely understand the terminology, just let me say that it is an undesirable set of conditions.

We have not been completely successful in educating the owners of small generators in the matter of rates. It is important that all consumers be charged fairly, including those who have no small power production. As you know, a kilowatt delivered during hours when electrical use is low has much less value than one that can be relied upon to be available during periods of peak demand. Without storage, small-scale hydro may have little or no generation during peak hours and, conversely, may have excess generation when utility system demands and marginal costs are low. Fair pricing should be sought and encouragement, *but not subsidy,* should be given to small power production. The metering for these installations must be carefully selected for full evaluation of all relevant factors.

There are other more minor considerations. We are trying to evaluate the liability, if any, of both the rural utility and the owner of the small generator. We caution both to check the status of liability and insurance coverage for both property damage and personal injury or loss of life.

When I was preparing this paper, I stopped at this point and considered the discussion so far. It sounds a little like a list of reasons why small-scale hydro should be discouraged. If so, it is unintentional. As I said earlier, REA is encouraging small-scale hydro installations as a source of supplemental energy. We believe such installations can result in a reduced cost of service and a reduction in the use of scarce and expensive fossil fuels. We are giving our full support to the small-scale hydro portion of the Rural Energy Initiative, and our borrowers are responding enthusiastically. We do believe that all installations should be done on a sound technical, financial, and organizational basis in order to encourage full development of the resource and to insure continued long-term use and acceptance. Costs must be kept to a minimum, commensurate with satisfactory construction and operation. Careful planning will be essential. Because of the organizational structure and the location of REA-financed rural electric utilities, these utilities are particularly suited for the application of small-scale hydro. Both REA and its borrowers are committed to the development of such new sources of energy.

I think I will close on that note and ask for any questions you may have at this time. Also, members of the REA staff are scheduled to be in several panel discussions at different times in this conference and will be available for informal discussions during the course of the conference.

THE SOCIAL IMPLICATIONS OF HYDROELECTRIC ENERGY

John A. Waring

This continent's destiny from time immemorial, even before man was here, it seems, has always been to develop its natural resources by means of water control. Dams as long as 1,500 feet and as high as 10 to 12 feet have been built by our native North American four-footed engineers - the beavers![1]

In the spring of the year 1607, when Champlain and his party had already been in New France (now Nova Scotia) for three years, the first English were arriving at Jamestown, Virginia. During the same time period, Sieur de Poutrincourt, one of Champlain's compatriots, built a water-powered mill on the Lequille River near Annapolis and Port Royal, across from the Bay of Fundy. Its purpose was to grind the wheat they were growing into meal and flour, relieving the Frenchmen and Indians of hand labor at which they had balked. No specifications were recorded, but engineers of the Nova Scotia Power Corp. (which built a 15,000 horsepower, automatic, hydroelectric station at the site) inform me that the one Poutrincourt built in 1607 was probably under 100 horsepower.

In 1646, on the 6th of March, the General Court of the Massachusetts Bay Colony issued to Joseph Jenkes what we would call a patent — their first for a mechanical device — only the word they used was "monopoly." And what was the invention for this first machine patent issued on the North American continent? Here is the transliteration of the court clerk's quaint handwriting:

> The Court considering ye necessity of raising such manifactures of engins of mils to go by water for speedy dispatch of much worke with few hands. . . .

Two years after that, at Saugus, Massachusetts, our first iron mill was erected and put into operation with a capacity of 7 to 8 tons a week (which was in 1648, the end of the Thirty Years' War).

The Saugus Iron Works has been restored — to near operational condition, by the U.S. National Park Service — including, as you have now guessed, the three water wheels which powered the blower and other machinery in the mill. The power of those combined three waterwheels was somewhere around 20 or 30 horsepower. (Incidentally, the first atmospheric steam engine in North America, erected in New Jersey in 1755, had a capacity of about 12 horsepower).

You think Saugus is far off — three centuries ago and 300 miles up the coast — there is a water-power mill right here in the city of Washington, in Rock Creek. The mill has a wooden water wheel and gears and it is actually operating — starting Wednesday for 5 days every week. Originally built over a

---

Mr. Waring is a research writer, lecturer, and consultant on the social, industrial, and historical impact and implications of science, technology, energy and natural resources.

[1] *New Larouse Encyclopedia of the Earth,* Crown Publ, N.Y., 1972. p. 289.

century and a half ago, it is now operated by the U.S. National Park Service and open to the public. It is called Pierce's Mill, with power capacity of around 25 horsepower. The water wheel is not just for show — it turns massive millstones that grind corn and wheat.

I'm bringing you up to date on these aspects of our North American technological heritage for a purpose. The future of hydropower on this continent is greater than its past. Yet there are some men who ridicule and scorn it, unbelievably, and I don't mean just the counter-culture environmentalists. The Chairman of the Board of one of the nation's largest electric utilities, chosen to give a speech on "Hydroelectric Power" before the National Industrial Conference Board, denigrated hydropower in every aspect - efficiency, capacity, potential, environment, cost, even spiritually. "The only good thing about it," he admitted, "was that there is no forseeable scarcity of its basic fuel supply."

In one environmental magazine I get, the Oregon writer stated that "hydropower is cheap and clean, but demand has grown and the rivers were tamed long ago. There is not enough hydropower to go around." Another such journal featured an article about anti-hydro activists with this headline: "TORPEDO THE DAMS! FULL STREAM AHEAD!" But the ultimate was reached by none other than the Chairman of the Board of TVA, recently retired Aubrey Wagner, who wrote an effusive, definitive, historical article for the *Tennessee Valley Perspective,* titled: "Energy - Its Vital Role in Society." Throughout its three pages never once did he mention the words waterpower, hydropower, or hydroelectric energy! What else can you expect! The current September 1979 issue of *Fortune* magazine has a special 28-page feature titled "The Energy System of the Future." Sure enough, hydropower —not even small-scale—is completely omitted.

Hydropower — both large and small — has characteristics so advantageous that no other form of energy can provide them so uniquely. An admittedly incomplete list would include:

Advantages:

1. Has a source of energy which is renewable and free of any price or labor.
2. Has the highest efficiency of any prime mover (about 85 to 90% , compared with less than half that for coal/oil, and only 2% thermodynamically for nuclear plants).
3. Has the least pollution of water or air (virtually none) - minimum of manpower (and so, lowest operating costs).
4. Has the most reliable and least outages—quickest starting—longest life (some hydro dams operating well after 50 years of service).
5. Can be planned for new fish and wildlife habitat and conservation - if on waterway, can be built with locks and other shipping facilities.
6. Can be designed to provide agricultural irrigation, raise water table on lands formerly arid.
7. Can be designated for flood control—provides for boating and other water recreation.
8. In some cases can be built to serve as a highway bridge.
9. In some cases can provide a community's water supply with a lake or reservoir.

Disadvantages:

1. Subject to drought—takes longer to construct.
2. Sometimes displacement of farmland, wildlife, fish.
3. Sometimes a silting problem.

The latter two can usually be solved or minimized. With all the multipurpose advantages that hydropower offers, where there is a choice between hydro and fossil-fuel or nuclear construction, the decision should be obvious. Local or regional—national electrical energy is the critical need.

Basically, energy is more essential to industrial North America than anywhere else on earth, since we have more powered technology here than there is in the rest of the entire world put together. The last such tabulation of total prime mover power capacity showed the U.S.—Canada with close to 70% of the world's aggregate.

Just how much technological power do we have in the engines and turbines powering our automotive vehicles, railroad locomotives, ships, planes, farm tractors, factories, mines, and electric utility stations. In absolute figures, the 1978 figure (which I just compiled for publication) is 27 1/2 billion mechanical and electrical horsepower installed and in use in the U.S.A., plus nearly 2 billion horsepower in Canada. The balance, making up the continent's total 30 billion, is in the lands of North America south of the Rio Grande.

The coal, oil, gas and waterpower powering those prime movers is what enables us to produce everything we have and do, amounting to 360 mechanical-electrical horsepower-hours for every man, woman, and child in the country, on the average, every 24 hours. (If you think you could duplicate any of that, keep in mind that a good strong workman is capable of just 1/20th of 1 horsepower of work.)

The 360 horsepower-hours per capita per day is a measure of our contemporary North American technological way of life and standard of living, even though the social, technical, and resource instabilities and oscillations resulting from politico-financial policy incompetence are becoming more and more serious.

The money and price syndrome so permeates our national viewpoints that we have failed to see our way of life in terms of physical reality until we turn on the light switch and the lights do not come on, the water does not flow from the pipes. Suddenly it dawns on us that financial tokens (regardless of whether called 'dollars' or 'rubles' or 'francs,' under whichever monetary-political ideology) are utterly immaterial and meaningless, except as interferences, in the real world in which we eat, live, and have our human being. Money turns no turbines, heats no steam, fires no engines, operates no machine tools, lights no homes, cooks no meals, lifts no elevators, powers no automobiles.

For example, to refine 1 pound of copper takes 7.2 kWh of electrical energy in one of our copper refineries.[2] To operate a standard 14 cu.ft. refrigerator steadily for 24 hours requires 14.8 kWh.(Edison Electrical Institute.) The pound of potatoes you may cook for dinner took 800 BTU in fuel to operate the tractors and other farm implements (USDA). To conduct an average long-distance telephone call uses the very small amount 0.032 of kWh. (AT&T).

[2]*Engineering & Mining Journal*, April, 1977.

In other words, everything in our North American way of life can be considered, planned, and measured in the unvarying metrical units of the mechanical and electrical energy required to mass-produce it per unit of materials. Only in industrial North America is human labor and work so immaterial and insignificant in production that it is meaningless. They are just as useless, from a production stand point, as are fancily printed little rectangles of green paper. In fact, in North American industry 99.99973 of the work is performed by technological energy—manhours are a microscopic trivia. In our agriculture the amount of toil is likewise barely detectable, only 0.00005 of 1% —in transportation and communications, it is even closer to 100% technological.

This is exactly the reverse of the 6,000 years of toil and scarcity without technological energy. Economics and politics were in their prime to manipulate the millions of people who did virtually all the work producing what little was made, buying and selling the scarcity values with tokens of price and barter.

In diametric contrast, a continental continuous accounting of energy will be the first step toward a dynamic balance between technology and our metallurgic and agrobiologic resources, between our industrial capacity to produce an optimum abundance and human needs - material and cultural. When this is done, on a functional, interdisciplinary basis as is now being researched and designed, an entirely unprecedeted energy society will come to scientific and artistic fruition.

The energy implications are intriguing—not utopian philosophy or ideology, remember, but technically feasible reality. For example, the basic concept for a continental hydrology has been completed by Technocracy Inc. planning the coordination-construction-operation of major rivers, lakes, and canals (new and existing) from coast to coast, Arctic to Tropics, chiefly for marine train waterway transportation (lowest energy per ton-mile), hydropower large and small (transmission 1,000,000 volts d.c. underground) — main project of a continental systems engineering social design for technological-ecological governance in dynamic balance. Additional energy-based continental concepts include railroad system, housing, urbanite cities, education, health care, and so on. The entire concept is derived from and primarily based on energy determinants as well as statistical mechanics, mathematical thermodynamics. It unifies the dynamics of engineering, agrobiology, and technology, discovered in the laws of nature by J. Willard Gibbs, America's greatest scientist (ACS), Nicola Tesla, Charles Proteus Steinmetz, and others earlier and since.

Howard Scott (1890-1970), the engineering scientist who discovered and developed the energy determinant laws, was the American who conceived the concept of applying science in order to build a functional civilization worthy of the scientific and artistic intelligence of mankind—in place of its avidity, cupidity, and stupidity.

To give you an idea of his engineering vision, he began an energy survey of North America in the 1920s. In an article in *Harper's* magazine, Jan. 1933, he wrote: "If we are to understand the problem at all, we have got to grapple with this question of energy; upon it everything else rests."

Session Twenty-Three

POLICY

Topic: Problems, Economics, and Ideas

Chairman: Mr. George B. Grimes, Jr.
Hydroelectric Resources
Development Staff
U.S. Department of Energy
Washington, D.C. 20461

SMALL-SCALE HYDROPOWER DEVELOPMENT IN THE WEST

Alfred C. Ingersoll, Fred K. Manasse, J. Morley English, and David Master

Introduction

While the conventional view of hydrology of the West is that of dry-stream beds during all but a few days of the year — and the Northeast has untold waterpower resources that were once developed for textile mills but now lie fallow — a closer look reveals a great many opportunities for small-scale (less than 15 MW) hydropower development in the West, frequently utilizing existing dams and reservoirs.

Western Workshop on Small-Scale Hydroelectric Power Generation

To take this closer look, the Department of Energy sponsored a Western Workshop on Small-Scale Hydroelectric Power Generation, held July 30 - August 1, 1979 in Pomona, California under the auspices of UCLA Extension. Scheduled for special focus on California, Nevada, Arizona, and Hawaii, the workshop was attended by representatives of a widely varying hydropower constituency, ranging from the Federal government (e.g., DOE, Army Corps of Engineers, Water and Power Resources Service, Bureau of Indian Affairs), to state government (Public Utilities Commission, Energy Commission, Department of Water Resources, Metropolitan Water District of Southern California) to the county and city governments (e.g., Los Angeles Department of Water and Power) and small-water districts; to major manufacturers of hydroelectric equipment and universities, and of course to architect-engineer firms who deal with hydropower design and construction. The workshop even attracted one international personality from behind what was once the bamboo curtain, Mr. Tu Zhaoxiang of the Peoples Republic of China.

Dr. Ellis Armstrong in his keynote address in the workshop eloquently developed arguments for exploiting hydropower in general, and in the western United States in particular. Furthermore, he emphasized a sense of urgency in "getting on" with a sensible program.

The U.S. has until recently not recognized that world oil resources are running out. On the basis of cheap and plentiful oil, we have built a dependency on oil for furnishing half of our energy needs. With the prevailing prices we were encouraged neither to conserve nor to exploit alternative energy sources.

Dr. Ingersoll is Director of Engineering Extension, University of California, Los Angeles.

Dr. Manasse is Professor of Electrical Engineering, University of New Hampshire, Durham, and Vice President, AETA Corp., Dover, New Hampshire.

Dr. English is Emeritus Professor of Engineering and Applied Science, University of California, Los Angeles.

Mr. Master is Research Associate, University of New Hampshire and a Principal of New Perspectives, Concord, New Hampshire.

Recent studies such as the one made by an MIT group and published as 'World Alternative Energy Strategies' (WAES) predict the peaking of world oil production sometime before 2000 and a subsequent steady decline thereafter. If these projections turn out to be true, or even if there is a reasonable probability of such predictions being true, we will be hard pressed as a society to make-up the energy deficit in time to avoid serious economic disturbance. Therefore, it is a simple matter of prudence to move ahead vigorously on all feasible energy alternatives, even those which in themselves are not sufficient to meet total needs. Certainly hydropower development utilizing existing dams is one such alternative. SSH has the added attractiveness of:

- Relatively low-cost.
- Utilization of a renewable resource.
- Benign environmental impact.
- An already established technology.
- Short lead times needed for construction.
- Readily accomplished by the private sector with little help from government, other than providing legislation of appropriate incentives.

Workshop participants were divided into eight workshop panels, with assigned chairperson and rapporteur for each. The subjects addressed by these panels were:

1. Engineering and retrofit design,
2. Financing,
3. Regulation and licensing,
4. Environmental impact,
5. Marketing and utility interface,
6. Technology and information transfer,
7. Economic and feasibility analysis, and
8. Hybrid systems (e.g., Solar-hydro or wind-hydro, etc.).

Overview and Conclusions

One scarcely needs to reiterate the main advantages of hydropower: high efficiency (characteristically above 90 percent), the ultimate in loading flexibility (ideal for peaking since it can be brought on line from cold start in two or three minutes), and almost ideally benign as to environmental impact. Several conclusions were reached in the two-day workshop, which may be summarized somewhat as follows: The technology of hydroelectric power generation has been with us for a long time, well into the last century. There has been little development in the last three or four decades, however, because of the ready availability of cheap energy from oil, and especially from imported oil since World War II. The hydro field had been so quiet, in fact, that many recent proposals to DOE for revitalizing hydro sites have been rejected mainly because of the lack of competence in this field on the part of the consultants to be used. Now, with increasing prices for oil, we must consider

developing energy from all sources thought heretofore to be only marginally economical.

Nationwide it is estimated that perhaps 5400 megawatts (MW) of hydropower could be developed at existing dams, from units of less than 15 MW capacity. In California alone this figure would be on the order of 450 MW. The great advantage of such development, of course, is the opportunity for rather quick completion (in many cases two to three years), with only minimal consideration required for environmental impact statements and the like, owing to the fact that the major hydraulic structures are already in place.

Some Considerations of Workshop Panels

Technological problems were seen to be of little consequence in this kind of development. Due attention must be paid, of course, to matters of safety in rehabilitating old equipment. A penstock built and installed a half-century ago may still be in good condition, but its serviceability must be ascertained carefully, with special consideration given to the hazard of flooding the environs in the case of a major failure. Similarly, hydraulic structures of concrete may appear to be in good condition, but when subjected to the forces of rapidly flowing water—particularly under conditions producing cavitation—they may deteriorate very quickly.

Relatively small-scale hydraulic turbines have been under development continuously, if not in the United States, then in other countries—notably in China in recent years—and there are no barriers to progress seen on this count. Induction generators, well developed in concept, appear to allow some room for improvement in application to small-scale hydro. One technical concern of utilities is the matter of protection from under- and over-voltage levels when they tie small-scale hydro into a line serving a variety of customers.

Problems of environmental impact were generally thought to be minimal, but one must never discount such concerns. It was brought out that a hydraulic reservoir is considered by the EPA to be a "point source of pollution" and it must be proven environmentally acceptable before development plans can be approved. Most aggravating to some small-scale developers has been the requirement for recreational planning in conjunction with hydro development. While the appropriateness of recreational facilities as adjunct to the hydro development is evident, the project should not be held up pending approval of recreational planning. The protection of fish and wildlife is of course well familiar to westerners. Although fish ladders are sometimes questioned as to their effectiveness there is no real question as to their necessity.

Matters of financing small-scale hydro were seen to be of really prime importance. For all of its apparent advantages, there is no question but that incentives and subsidies will be required to get small-scale hydro moving in the near future. There is a limitation, for example, on the use of tax-free bonds which are so important in the development of municipal utilities. To qualify for tax-free bonds, the power generating unit must sell at least 75 percent of the energy produced to publicly-owned utilities or districts at the state and

local level. Questions of DOE grants for demonstration and development were not really a subject of discussion at this workshop.

Regulation and licensing questions were considered to be of real substance. Since the "golden age of hydro" a half-century ago, the nation has moved inexorably toward more government regulation of everything. It is well known that the regulation and licensing permits for a thermal power plant—to say nothing of a nuclear plant—can take years. For hydroelectric development, the procedure is presumably somewhat less involved, but still incentives are needed to promote early development. The best example, perhaps, lies in considerations of "renewable resource," which currently includes such energy sources as solar and biomass, etc., but not hydroelectric power.

There are efforts currently under way to include small-scale hydropower development under the "renewable resource" blanket. Clearly, hydroelectric energy is a renewable resource, so why should it not be included categorically? The reason, evidently, is that the rationale behind the "renewable resource" provisions—granting considerable licensing and regulation advantages—is tied to encouraging new kinds of development. Hydropower is not only well established as an energy source, particularly in the West, but it comprises the main source of system energy for any number of western utilities. Clearly, the "renewable resource" benefits need some limitation of scale, and it seems possible that the 15 MW breakpoint might be argued successfully.

Marketing and Utility Interface Problems

Perhaps the main thrust of the workshop came from the marketing panel. The problems of utilities in handling small quantities of hydropower produced by independent site owners are many. It has been noted earlier that the utility needs protection from aberrations in voltage and the utility must certainly protect itself in the matter of reliability of small-site sources, both from the standpoint of short-run outages from breakdown and longer run shortages from dry seasons, such as the western drought years of 1976 and 1977.

In only a few cases is it possible for a hydro-site owner to develop and use all of his energy output on his own property, without connecting to the local utility. Even in this event the owner must realize that he needs the utility as a standby for the time when his own unit breaks down or when he has a dry winter. There must be some accommodation, therefore between owner and utility as to suitable standby charges. For its part, the utility must plan carefully for standby capacity as an increasing percentage of its customers develop their own energy. One simple answer, of course, is for the utility to build its system on the assumption that it must be able to supply all of the "displaced oil" load from thermal generation when necessary, thus equating small-scale generation only to equivalent savings in purchase of oil.

When the small-scale hydro unit is actually connected to the utility, the "meter runs backward" and there may be new problems. Can the owner simply be credited with energy fed back into the line, at the same rate he pays for energy used? Not likely, for in this case the utility serves as a kind of electrical energy reservoir, receiving the excesses and supplying the deficiencies, but

without charging for the use of the reservoir. But consider the other side of the coin. Suppose the owner acts as a reservoir for the utility, supplying energy at periods of peak demand? Now the utility is the gainer, but how reliable is the small-site producer?

These considerations are enormously complicated when the owner generates energy at one site and uses it at another, requiring that he negotiate with the utility for "wheeling" his energy from one point to another. Conceivably the utility could establish a wheeling charge based on the amount of energy wheeled and the distance it is carried. The situation is not that simple, however, when any substantial amount of energy is to be wheeled, for the utility must allow for line capacity to carry the wheeled energy in addition to its regular requirements, and that means added capital investment. On the other hand there could occur the situation where the utility finds the hydro supplier to be in a load region, and his point of use to be in an area of excess supply. This means that the owner would actually be doing the utility a favor by decreasing the need for power transmission from supply to load. But, again, how reliable could such an arrangement be considered to be?

The sum of these considerations is that as long as the hydrosupplier represents but a tiny fraction of the utility's business, the questions of standby, reliability etc. are not too difficult to handle. As the percentage of such activity grows, however, the utility must make more and more plans for alternative supply in the event of mishaps. Further, when the small-scale hydro is but a tiny fraction of their business, either in or out, it becomes a burden on utilities to accommodate these "nuisance factors." This is definitely the current circumstance in much of California, the evidence being that it is quite commonly difficult to get the utility return telephone calls from small-scale hydropower suppliers.

New Hampshire—the first state in the union to act on such matters—passed a law that simply requires any utility in the state to purchase any and all hydropower generated energy available, whenever and wherever produced, at a flat rate of 40 mills per kilowatt-hour. Whether western states should follow suit is a matter of much conjecture.

Some Economic Issues Relating to Small-Scale Hydro

The economic issues may be subdivided into: overall methodology for societal economic justification; evaluation of projects from the viewpoint of a private firm on the one hand, or a public or quasi-public enterprise (i.e., utility) on the other; and financial feasibility.

The justification for the government, representing society as a whole, to encourage SSH depends on its relative attractiveness in comparison with other energy alternatives. The government, by providing incentives in the form of loan guarantees, tax credits, price subsidies, R & D support, cost sharing, etc., can influence the private sector to make favorable decisions. In effect, the funds which government makes available either directly or indirectly to encourage private decisionmaking must be viewed as a societal investment. This is justified only to the extent that the private sector must be reimbursed for its externalities (societal costs less benefits). In this context the shadow price of

energy based on the true societal cost of imported oil is the relevant price criterion for the government to use in determining the scale of its support. Aside from this it is also necessary for the government to allocate its support capital among all competing energy alternatives in such a way that reducing dependence upon imported oil is optimized. How this is accomplished requires a great deal of subjective analysis involving the political process and accordingly can only be approximated. Nevertheless, the principle can be stated quite explicitly.

In a sense the government holds an investment portfolio of all energy projects and societal funds should be allocated in such a way as to maximize the expected net benefit to society compatible with risk. From this viewpoint, it would appear that SSH offers considerable promise in that the required capital is small compared with oil shale, coal synfuels, tertiary oil recovery, or for technologies such as wind, biomass, and solar. Secondly, SSH has little technical risk. Thirdly, the expected return may be much higher than these other energy forms. In fact conceivably SSH may dominate and should be utilized to its maximum practicable level before considering allocation of funds to any other approach.

Within the framework of government constraints and incentives, a number of methodological questions relating to private utility evaluations need to be resolved. One problem in particular relates to the treatment of inflation. Inflation is usually considered in relation to the price index. It is common practice to evaluate projects in terms of constant dollars. Sometimes added escalation costs are estimated for cost components which are inflating more rapidly than the price index. However, when constant dollar prices are used the inflation rate should be taken out of the discount rate (i.e., interest rate% for both debt and equity capital. While this would improve the approach, it in no way captures the transfer payment effect of inflation nor the interaction inflation has on relative prices.

One other problem arises in establishing comparability for evaluations undertaken by privately-owned public utilities and public-power agencies. While in fact, a particular project should be expected to yield the same net benefit to society irrespective of its ownership, different decisions may be reached depending on utility structure. In the case of the privately owned utility, income is taxable but is not for one publicly owned. In the first, risk is assumed by the investor who accordingly requires a rate of return commensurate with risk. In the case of the publicly owned utility, the same degree of risk is assumed by the community which is the owner (i.e., an implicit stockholder). In the latter case, the real return is hidden in the reduced price paid by the rate payer. As a result, the discount rates used for evaluations have traditionally, albeit unjustifiably, been lower for the publicly-owned than for the privately-owned utility.

The third area of concern—finance—is perhaps more a question of a general misunderstanding of the role of finance in an economic analysis. The economic evaluation establishes the investment suitability of a project whereas the financial feasibility has to do with the management of the funding. The question is "How" rather than "What." Often studies are carried out and decisions made on the financial feasibility rather than economic

suitability without realizing that they are separate questions. It might be very worthwhile for these basic issues to be investigated and a handbook or set of guidelines published. This would provide a common standard for evaluating proposed SSH projects.

Conclusion

There are certain characteristics of the western United States which are unique and which possibly make the exploitation of small-scale hydro even more urgent than for the U.S. as a whole. Of the current electric generation in the U.S. about 15% is provided by hydro but almost double this percentage is applicable for the West. Furthermore the development of shale oil and coal in the western U.S. have very serious environmental problems. The environmental issues have engendered opposition of strong environmentalist groups. Small-scale hydro is not nearly as susceptible to the kinds of delays and obstructions which have been peculiar to the Western U.S.

Finally mountainous terrain with heavy rainfall in the Northwest and desert regions in the south have required unique forms of water resource development. About 90 percent of irrigation water in the United States is employed in Florida and the western U.S. The historically intense concern for water resource development, in general, is likely to grow even more intense in the future.

A case can be made for small-scale hydro everywhere even without considerations for its economics. Any energy source which has potential for replacing oil may be worth considering, regardless of price, simply because the opportunity cost to society of not having adequate energy to maintain our economic activity can be many times the current price of OPEC oil. However this is not to say that economics is unimportant. On the contrary, it is, and some of the economic as well as financial issues were key issues addressed in the workshop. The general consensus can be succinctly summarized and was stated by Ellis Armstrong in his keynote "Let's Get on with it!"

PROBLEMS IN EVALUATION OF FEDERAL SMALL-HYDRO PROJECTS

Richard L. Mittlestadt

With the resurgence of interest in adding powerplants at existing Federal hydro projects has come a renewed interest in estimating the value of hydropower. As most of you are aware, our Federal procedures are in a state of flux. The Water Resources Council's proposed Principles and Standards (P&S) evaluation manual, which Jim Johnson discussed on Monday, is intended to lead us out of the woods, and the short-cut procedure for small hydro projects is definitely a step in the right direction. However, there are still a number of key factors in the hydropower chapter for which no specific guidance has been provided.

In this paper, I would like to discuss some of these factors, specifically, system energy costs, fuel cost escalation, inflation, dependable capacity, intermittent capacity, and the alternative means of evaluating small projects with little or no dependable capacity. I should point out that some of the ideas discussed here were developed by the Water Resources Council's Water and Energy Task Force, which has been conducting an in-depth review of the manual's hydropower evaluation procedures. Also, by way of introduction, I should mention that Principles and Standards still holds to the cost of the most likely alternative as the means of measuring a hydro plant's benefits. And it is generally interpreted that the most likely *thermal* alternative will still be used as the yardstick against which the hydro and nonstructural alternatives would be measured.

System Energy Impacts

Historically, we have simply compared the cost of constructing and operating a hydro plant to the cost of constructing and operating a single thermal plant. This ignored system costs, but worked satisfactorily as long as systems were relatively small and the hydro plant and the thermal plant performed in about the same manner (i.e., base load hydro was compared to base load thermal). As power systems became more complex and more diverse, and as hydro plants were scoped at lower plant factors, it became necessary to account for system cost impacts. In other words, the existing plants in the system would operate a little differently and system costs would be somewhat different with the thermal alternative than with the hydro plant. This phenomenon was recognized in the Principles and Standards document of 1973, but it was slow in being applied.

Mr. Mittlestadt is Head, Long-Range Planning Unit, Power Section, North Pacific Division, Corps of Engineers, Portland, Oregon.

The Federal Energy Regulatory Commission (FERC) has developed several procedures for deriving these system costs, and they are customarily applied as adjustments to either the energy or annual capacity costs of the thermal alternative (the power values). The following figure shows the results of adjusting the costs of a nuclear alternative to account for its impact on system energy costs. It is through application of the system energy cost "adjustment" that FERC has developed some power values that have caused raised eyebrows among Corps of Engineers and Bureau of Reclamation planners. Strange as some of these power values may seem at first glance, careful analysis has shown that the values are usually correct conceptually, if not in magnitude also.

The greatest problems seem to occur in deriving the costs of thermal alternatives for hydro plants operating in the peaking and intermediate plant factor range. Limitations in the tools available for making the system costs analyses have caused some difficulties in this area, although FERC is making progress in implementing a better system analysis model. However, in the 50-70 percent plant factor, or base load range, the system energy cost impacts are small, and existing system impact models produce reasonably accurate results.

Real Fuel Cost Escalation

Because of increasing scarcity and/or the increasing difficulty of extraction and processing, the cost of powerplant fuels is increasing in real terms—that is, independent of inflation. Recent literature cites projected annual real fuel cost escalation rates ranging from less than one to more than three percent for the various fuels, and all fuel costs are escalating—coal and nuclear as well as oil. The P&S Manual permits accounting for this real cost escalation, and it is significant, particularly where the thermal alternative is fuel cost intensive. By failing to recognize real fuel cost escalation, we are understating the value of our small hydro plants. The more fuel-intensive the thermal alternative, the greater the understatement.

Once it has been decided to account for real fuel cost escalation, the question arises, what escalation rate and for how long? As stated earlier, a wide range of escalating rates can be found in the literature. Reviewing agencies tend to look very carefully at adjustments such as this, so credibility is important here. The WRC Water and Energy Task Force recommended that the Department of Energy provide official fuel cost escalation rates for use in hydro benefit evaluation. In the absence of such values, the Electric Power Research Institute (EPRI) periodically provides recommended escalation rates for use by their contractors in comparative analysis of alternative generating systems. However, some feel that because of the nature of EPRI's bias, their values are inclined to be on the low side. But whatever rate one uses, one should be prepared to defend it vigorously.

A wide range of opinion also exists on how long escalation should be applied. Some feel that because of uncertainty, escalation should be limited to a

Note:

Since most small hydroplants fall in the 50-70 percent plant factor range, we can do our benefit analyses with confidence using generalized regional power values from FERC if available, or ignore the system cost impact if generalized values are not available. But, if the small hydro plant is being scoped as in international range or peaking plant, system energy costs impacts are important, and it is usually desirable to ask FERC for specific power values for that particular hydro plant.

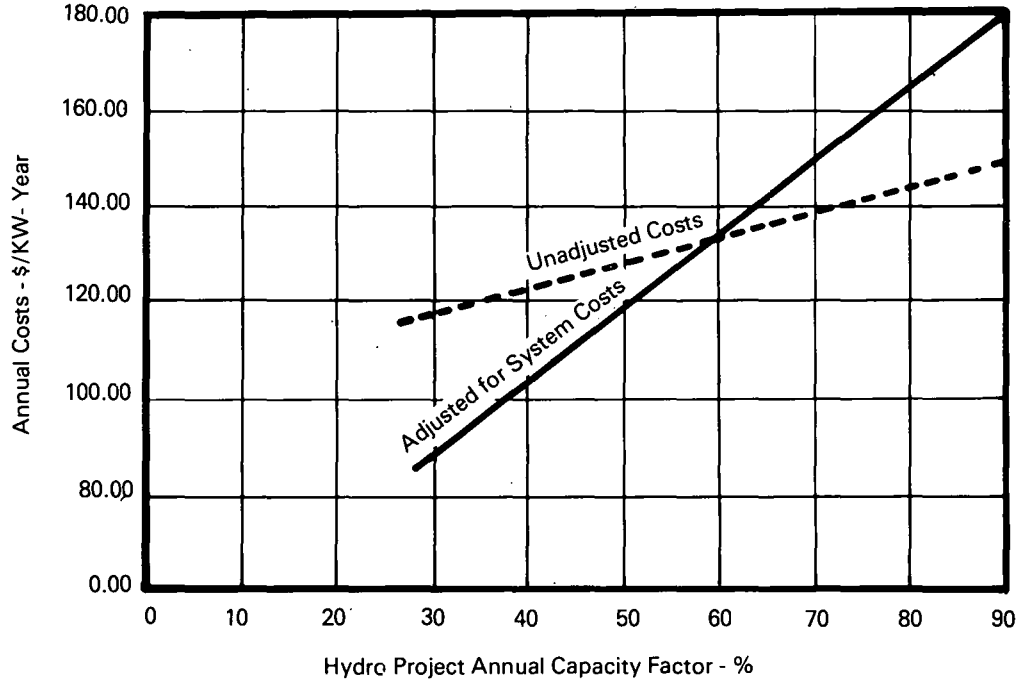


FIGURE U-2.1 Annual Costs of Nuclear Alternative

10 year period, while others hold that escalation should be applied over the entire life of the hydro plant. A case can be made for escalating fuel costs right up to the point of the first thermal plant replacement (30 years), but I tend to favor 20 years from project online date (which may be 5-10 years from the present).

Inflation

Treatment of inflation is a controversial subject, but unless it is properly accounted for, the analysis will be biased against hydropower. Although Principles and Standards prohibits use of inflation in computing future benefits, I contend that we are incorporating inflation in our analysis through the discount rate we are using. However, we are only reflecting inflation half-way—in the treatment of fixed costs. The variable costs are not adjusted for inflation and that biases the analysis against our capital-intensive hydro projects.

One approach to rectify this would be to remove inflation entirely from the analysis and use an inflation-free discount rate. This approach clearly illustrates the magnitude of the bias we are dealing with. Assume for a moment that our 7-1/8 percent Federal interest rate includes just over 3 percent inflation so that we would use an inflation-free discount rate of 4 percent. We will look at two different hydro plants, one with a base load plant factor, where coal would be the alternative, and one with a peaking plant factor, where combustion turbine would be the alternative. Assuming these hydro projects both have 1.5 to 1 benefit-to-cost ratios using an inflation-free analysis, we can see what happens to the B/C ratios when we use the half-way treatment of inflation through using our 7-1/8 percent discount rate, but not accounting for inflation in the variable costs. The impact is large enough when looking at base load hydro plants when nuclear is the alternative (the B/C ratio drops from 1.50 to 1.07), but really becomes substantial when we are looking at peaking plants (B/C ratio drops from 1.50 to 0.88).

Although removing inflation entirely makes a nice, clean analysis, it is not a practical solution. An alternative approach would be to adjust future variable costs to reflect the same amount of inflation that is in the discount rate. This approach is commonly used by the utilities and others in their analysis of generation alternatives. I am not certain whether or not Principles and Standards would permit this or not.

A third approach has been suggested by EPRI in their guidance to research contractors, and that is to use an inflation-free discount rate in present-worthing future variable costs. The net benefit analysis could then be done by comparing the total present-worthed costs of hydro to the present-worthed costs of the thermal alternative, or, if an annual cost analysis was required, the normal Federal interest rate could be used. This approach accounts for inflation on the variable costs but does not require an implicit statement of inflated costs. This approach perhaps has the greatest merit for use in evaluating Federal hydro projects.

Here again, there is the question of how to select an inflation-free discount rate for present-worthing and how far into the future should it be applied. Because of uncertainty, it would be appropriate to limit this analysis to the

same 20-30 year period used in accounting for real fuel cost escalation. As far as to how much inflation is included in the Federal interest rate and what should be used as an inflation-free discount rate, there is certain to be controversy. The question of what the Federal interest rate is supposed to represent becomes an issue, and socio-political biases enter the picture. However, it is more important to make an attempt to estimate a value than to ignore inflationary impact because of lack of agreement on an appropriate value. EPRI suggests an inflation-free discount rate of 3.8 percent, and this would appear to be a conservative value, suitable for use in our analyses until a more precise value can be developed.

Dependable Capacity

Traditionally, we have applied a very strict test to hydro capacity before we have permitted capacity benefits to be claimed. We have virtually asked that hydro capacity be available 100 percent of the time. When hydropower was a system's sole source of generation, this might have been an appropriate test, but when a hydro project is just one element in a large, diverse power system, it is no longer appropriate. We do not apply this test to thermal plants, which have high forced outage rates besides being out for a much as 2 months per year for scheduled maintenance, so why must it be applied to hydro?

Applying overly restrictive dependable capacity criteria has a particularly large impact on small hydro plants. Run-of-river projects typically have seasonal low flow periods, where dependable capacity is limited. Similarly, at storage projects, the requirements of flood control, irrigation, or other project purposes may result in seasonal periods of little or no dependable capacity. However, this does not mean that these types of projects cannot make a contribution to overall system reliability. Basically, that is the whole purpose of defining hydro dependable capacity. It is not to determine how much capacity can be provided 100 percent of the time, but to determine how much alternative thermal generating capacity would have to be constructed if the hydro plant were not built.

Tools are now available for evaluating dependable capacity on the basis of contribution to system reliability, but they are only starting to be applied. We looked at a 75 MW hydro project in southern Idaho—adding power at an existing flood control and irrigation project—when for all practical purposes, releases are zero for 5 months of the year. However, high releases were available during the irrigation season, which was also the high power demand season. Using conventional techniques, the project would probably get no dependable capacity credit. Using a loss-of-load-probability model, it was determined that the 75 MW hydro project made the same contribution to annual system reliability as 43 MW of combustion turbines and 45 MW of base load coal. These values, then, would be used as the basis of dependable capacity. The problem with this approach is that it requires considerable knowledge of system operating characteristics. It often is not practical to do an analysis of this type for a small hydro project.

Another approach is to base dependable capacity on the amount of generation (or streamflow) that is available some specified percentage of the time. If

the likely thermal alternative has a 90 percent availability, then dependable capacity would be based on the flow that is available 90% of the time. Caution should be used in this approach when looking at a run-of-river plant, to make sure that the streamflow availability is based on daily flow records. Use of monthly average flows will tend to overstate dependable capacity. Use of weekly data is better than monthly averages, but daily flow data is preferred.

Other techniques for estimating dependable capacity are also available, such as using firm energy divided by a base load plant factor or using the capacity that can be provided in a specified critical month, which is derived from system studies. However, whichever approach is used, care should be taken to insure that capacity credit is given to small hydro when credit is due.

The foregoing discussion of dependable capacity is based on the hydro plant operating in the base load mode, which is probably the usual case for a small-hydro project. However, if the project has daily storage available to permit load-factoring, additional capacity credit can be claimed and sometimes a larger plant can be installed to permit the project to shape flows to meet daily peak loads. However, in these cases one should be certain that the daily storage is both available and usable and that the peaking operation does not conflict with other project purposes or downstream river uses.

Intermittent Capacity

It can be shown that capacity above that which is dependable also has value - providing flexibility, permitting capture of energy that would otherwise be spilled, and contributing to system reliability. Corps of Engineers planning criteria permits this "intermittent capacity" to be evaluated on the basis of up to half the value of dependable capacity. However, for the capacity to have even partial value, it should be available a reasonable amount of the time. The level of availability that represents a "reasonable" amount of time has not yet been defined, but in the Pacific Northwest we are suggesting half credit for capacity that is available 75 percent of the time. If a loss-of-load-probability analysis is used to define dependable capacity, the value of all hydro capacity is accounted for, and hence it would not be appropriate to claim additional credit for intermittent capacity.

Market Value Analysis

An alternative method of analysis for small hydro projects - one which circumvents some of the complexities such as dependability of capacity and magnitude of system energy cost impacts - is to base the economic analysis strictly on the basis of the estimated market value of the energy. The P&S Manual does permit use of alternative—though unspecified—procedures for analyzing small hydro projects having little or no dependable capacity. It is suggested that the market value approach might be applicable in these cases.

Basically, this approach involves estimating the market value of the hydropower—in mills per kilowatt hours—and basing the economic analysis on this value. The market value could be developed in cooperation with the

Federal marketing agency, FERC and/or the potential buyer of the power. Real fuel cost escalation could be included in the value if appropriate. Then, annual costs for various hydro plant sizes could be computed and tested against benefits based on the average energy produced by the respective plant sizes and the market value of that energy.

At this point it should be pointed out that just because a hydro plant is small does not eliminate the need for attempting to size the project by maximizing net benefits. We have seen too many reports by inexperienced consultants and agency planners where an attempt has been made to justify a preselected plant size. Sometimes physical, environmental or marketing constraints preclude optimization, but the test should still be made.

The market value approach admittedly ignores some the fine points of power benefit analysis, but it is easy to apply and should produce a reasonable estimate of the hydro project's value. If it is impossible to agree on a single market value for the energy, sensitivity tests could be made to test alternative values, to see if they would have any impact on scoping the project.

Summary

There are some other very interesting issues which could also be treated, such as using Federally financed versus utility-financed thermal plant costs in developing benefits and whether or not it is appropriate to allow credit for hydropower's renewable resource qualities, but time does not permit. However, I hope I have been able to provide some insight into some of the real benefits that accrue to hydropower - some benefits that in the past have been either overlooked or not treated adequately. In addition, I hope that airing these issues will help to stimulate further thinking, and that we will be able in the future to come up with a more accurate value of hydro in comparison with our nonrenewable thermal alternatives.

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

INTERNATIONAL PERSPECTIVES SESSIONS

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

Session Ten

INTERNATIONAL PERSPECTIVES

Topic: Development Experiences

Chairman: Dr. Alan B. Jacobs
Chief, Energy Office
Agency for International Development
Washington, D.C. 20523

A TALE OF TWO FEDERAL SYSTEMS: CANADIAN - AMERICAN LAW ON HYDROELECTRIC DEVELOPMENT

Peter W. Brown

This paper, in the space permitted, will briefly examine the regulatory systems of two federal systems of government - Canada and the United States. The purposes of the paper will be to identify certain similarities and differences in approach by hydroelectric development in each country and attempt to assess the potential benefits of different forms of regulation in Canada to the United States experience. Apologies are due to my Canadian colleagues for what is certain to be a surface treatment of their sophisticated federal and provincial systems. However, from the standpoint of a careful student of the American system, much can be learned and much in the American system can be rationalized if we draw on the Canadian experience.

For purposes of simplifying the analysis and meeting space limitations, the Province of Ontario has been chosen as an example of a provincial regulatory system. Most certainly other provincial systems are equally helpful. In this regard it is assured that because of the large measure of exclusive jurisdiction of provincial legislatures in the Canadian Federal system, the various provincial systems will be especially rich in novel and rational approaches to hydroelectric development. These other systems bear careful study as well.

The first question posed in this paper is why, with the vast amount of statutes, cases and regulations concerning the regulation of hydroelectric development in the United States, should another system be examined? The question almost answers itself. The vast amount of regulation in the United States may, in fact, be one of the largest impediments to small-scale hydroelectric development (SSH). The regulatory system certainly increases the amount and cost of needed information and may impose costs on developers which are out of proportion to the external costs imposed by redevelopment of existing sites. The important result is to reform the American system so that transactions cost are kept to a minimum and proper account is taken of the external costs of SSH developments.

I. Similarities of the Two Systems

One of the attractive features of the Canadian system for purposes of comparison with the American system is that is is a Federal system which is based on a written document of long standing existence, i.e., The British North

Mr. Brown is Professor of Law at Franklin Pierce Law Center, Concord, New Hampshire, and Director of the Law Center's Energy Law Institute.

American Act of 1867, 29 and 30 Vict. 3 ("BNA"). The United States, of course, has a written constitution which establishes a federal system with individual states occupying positions similar to the provinces of Canada.

Secondly, water law in the eastern provinces of Canada engrafted English common law in much the same manner as the eastern states received English common law. The province of Ontario adheres to the doctrine of riparianism. See *Buchanan v. Ingersoll Waterworks Co.*, 30 O. R. 456 (1899), defining a riparian owner as one whose real estate is in contact with the bank of the waterway and whose rights to the water are not possessory but are in the nature of servitudes. Moreover, early in the history of the Province legislation was enacted concerning the construction of dams and other obstructions on waterways in the province; Lakes and Rivers Improvement Act, ONT. REV. STAT. 1960, c. 203 as amended, 1971 Ont. Stat., vol. 1, c. 50. Unlike the early American mill acts, e.g., N.H. Rev. Stat. Ann. ch. 482 (1955), the Lakes and Rivers Improvement Act does not provide a process whereby a mill dam developer may back flood an upstream riparian's property subject to the payment of damages. However, the Ontario statute does require a developer to obtain a permit to construct or improve a dam from the Minister of Lands and Forests, §§ 9 and 10.

Finally, as with the states and Federal government in the United States, the Province of Ontario has experienced a burst of environmental protection and energy related legislation in the last few years. Within the past decade the Ontario Parliament has enacted an Environmental Protection Act, 1971 Ont. Stat., Vol. 2, c. 86; the Environmental Assessment Act, 1975 Ont. Stat. c. 69; the Endangered Species Act, 1971 Ont. Stat., Vol. 2, c. 52; and the Power Corporation Act and amendments, Ont. Rev. Stat., 1970, c. 354 as amended 1973 Ont. Stat., c. 57. This legislation follows a pattern familiar to students of the American system. The Federal Clean Air and Clean Waters Acts (33 U.S.C. § 1344 et seq.) are similar to the Environmental Protection Act. The National Environmental Policy Act ("NEPA") (42 U.S.C. § 4321 et seq.) with its environmental impact statement process is similar to the Environmental Assessment Act and, of course, there is a Federal statute which bears the same name and function as the Ontario Endangered Species Act. See 16 U.S.C. § 1531 et seq. The legislation listed above[1] affects hydroelectric development and represents an attempt to apportion rationally and fairly the external costs of such projects.

II. Dissimilarities - Some Potentially Useful Highlights Of The Canadian System

While the Canadian system of government is a federal system, there has been a custom and usage premised on Sections 91 and 92 of BNA that gives

[1]For a detailed treatment of the American legislation, see *Federal Legal Obstacles and Incentives to the Development of Small Scale Hydroelectric Potential of the Nineteen Northeastern United States* (Draft Report) Energy Law Institute, Franklin Pierce Law Center, Concord, New Hampshire 03301 (1979) at pp. 61-81 ("Federal Report").

provincial governments plenary authority over matters of internal development. Accordingly the licensing system for hydroelectric development is not afflicted by a two tier system of licensing.[2] Under the American system there is considerable licensing redundancy in that the Federal Energy Regulatory Commission, in the course of issuing a license, defers to state permitting processes and must require an applicant to obtain a water quality certificate from the state water quality agency under § 401 of the Clean Water Act. See *Federal Report, supra,* and 16 U.S.C. § 791-824, (Part I of the Federal Power Act). This redundancy significantly increases transactions costs for developers and, in all probability, does not assist in dealing with environmental review and mitigating the external costs of a project. See *Executive Summary: Five Case Studies of Small-Scale Hydroelectric Development,* Energy Law Institute, Franklin Pierce Law Center, Concord, New Hampshire (1979).

The important lesson to be learned from the Canadian experience is that development has occurred in Canada, which development has undoubtedly had interprovincial impacts. Yet the Canadian Federal Government has evidently learned to live with provincial regulation of this development, with the exception, as noted, of developments on boundary waters under the 1909 treaty.

With respect to environmental regulation by the Province of Ontario, there appear to be two developments which provide guidance to the American system. The frst is an effort to avoid duplication or at least specify with some precision the object and scope of legislation. The second is a degree of flexibility and finality to the environmental review process not found in American law.

The Environmental Policy Act is clearly aimed at preventing, eliminating or reducing pollutants and contaminants in the environment. See *Canadian Encyclopedic Digest* (Ontario), 3rd Ed., Vol. 10 at p. 54-94-1. The Environmental Assessment Act, on the other hand is a statute designed to assure that the overall impact of projects which do not emit a pollutant are given a complete review. It is difficult to imagine under this description of Canadian law a dispute such as is presently pending in the United States as to whether dams are a "point source" pursuant to § 402 of the Clean Water Act. (See *Federal Report, supra.* at pp. 66-68; and *South Carolina Wildlife Federation v. Alexander,* Civ. Action No. 76-2167, (D.S.C. filed November 16, 1976). Under existing American law, an attempt is being made to apply § 402 to dams notwithstanding environmental review by the Federal Energy Regulatory Commission under NEPA, a § 401 permit requirement, clearance by the Army Corps of Engineers and review by Fish and Wildlife agencies at the state and Federal level.

The Environmental Assessment Act also permits the Minister of Environment to exempt projects from coverage of the act and the necessity to prepare

[2]One exception to this statement for hydroelectric development in Ontario is the jurisdiction of the International Joint Commission established pursuant to the Boundary Waters Treaty of 1909 between Canada and the United States. Under this Treaty the Joint Commission must approve, among other matters, the construction of any dam on "boundary water."

a full blown assessment. In addition, the Lieutenant Governor in Council may exempt classes of projects and developers from the requirements of the Act. (§§ 41 and 45.) To date, it appears that the exemption provisions have not been used to exempt broad catagories of projects (See e.g., Ontario Regulations, 836/76, Vol. II, (1976).) Moreover, under the Act there is an established process for review of the assessment with the right of public participation. There are no provisions for citizens suits after the administration process and review is completed (§§ 7[2]; 18[19]).

By contrast, the American system under NEPA is not as flexible nor does it have ordered finality. With respect to projects having minimal impacts, i.e., SSH at existing dams, the Federal Energy Regulatory Commission must issue a negative declaration. (42 U.S.C. 4321, and *Hanley v. Kleindienst,* 471 F. 2d 823 [2nd Cir. 1972] *cert.denied* 412 U.S. 908 [1973]). However a negative declaration may be challenged either in the Federal Energy Regulatory Commission licensing process or by the citizen suit. Citizens groups may also challenge the adequacy of the environmental review notwithstanding a full blown hearing before the Federal Energy Regulatory Commission. *Cf.* § 18(19) of the Environmental Assessment Act which bars judicial review of decisions of the Environmental Assessment Board.[3]

Conclusions

The Canadian System of regulation of hydroelectric development has roots common to American legal systems and is a useful guage of the rationality of the American licensing system. In the space permitted this paper has attempted to contrast the Canadian federal system with the American federal system and American environmental regulation with the environmental regulation of the Province of Ontario.

It is worth noting that Canadian law defers to provincial regulation even in those instances where there will doubtless be significant interprovincial impacts. Canada has selectively reserved for international control the sensitive developments in boundary waters. At this writing, despite highly laudable efforts of the Federal Energy Regulatory Commission to simplify licensing; there are two licensing systems, Federal and state, which inevitably will be involved even for SSH projects.

There is no question that SSH and most especially other larger hydroelectric projects must be examined from the standpoint of the environmental or social costs they will impose. To the extent possible these costs should be mitigated and avoided or borne by the project. However, the process of review must be effective; i.e., it must ask the right questions and develop appropriate data. To the extent the process is confusing and duplicative the chances are the review will miss the mark. Again the Ontario system offers useful insights.

[3]A significant constitutional issue would be raised if Congress foreclosed all judicial review. However, judicial review is now available on appeal to a U.S. Court of Appeals from a decision of FERC. The question remains as to whether another avenue of judicial review should be open, that of the suit by citizens groups in the Federal District Courts.

It has delineated carefully the role of environmental assessments, it has through its exemption provisions provided flexibility and through its administrative process provided ordered finality.

743 - 744

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

PAGES 743 to 744

WERE INTENTIONALLY

LEFT BLANK

strategies. Each option complements a particular development strategy. A clear understanding of the country's development strategy is vital to match the option with the strategy.

Development Strategies

Many developing nations follow the *Top-Down* strategy to national policy formulation and the generation of national development plans. As the strategy implies, the process begins at the highest levels of government. Infusion of funds and talents at the top are expected to generate national policies and programs; and the benefits from such programs are expected to filter down to the masses at lower levels. The top-down strategy is a highly centralized and coordinated approach to national development. Governments that subscribe to the top-down strategy of development, find it natural to support large-scale hydropower projects.

It would be difficult to fit a program of small-scale hydropower generation into the plans and organization developed under a top-down strategy. This is because a small-scale hydropower program represents a highly decentralized activity with centers of such activity dispersed across the nation.

The *Bubble-Up* strategy on the other hand, encourages citizen participation at all levels of the decision making process—from the formulation of a national policy to the implementation of such a policy. Since citizen participation is highlighted in this apporach, it offers a better opportunity to enlist the commitment of citizens that is essential for implementing policies and plans for national development.

A Case Study

The importance of understanding the national development strategy prior to promoting a particular hydropower generation program is illustrated by the following case in Afghanistan.

Under a USAID contract a consortium of U.S. Universities was assisting the College of Engineering, Kabul University reach international standards. As an advisor to the hydraulics department, I had the opportunity to visit several hydropower projects in the country. Most of these projects were completed with external financing.

The Hindukush mountain range from India and Pakistan extends into Afghanistan. The mountainous terrain with snow and rainfall in the central and northern regions provides attractive sites for hydropower generation. Unfortunately, the rugged terrain also makes it difficult to support a transportation network that links the many villages in the region to the metropolitan centers.

Yackolong is one such village in the heart of Afghanistan. With a rural population of about 700 it is almost isolated from the rest of the country. In 1970, when I visited this village there was no electricity, no industry, and no water supply system. The Medical Assistance Program operated a medical clinic at Yackolong and an American doctor visited the clinic once a week.

He brought a diesel generating set to operate the X-ray machine and the pump for the clinic.

Close to Yackolong, there is a natural site for small-scale hydropower generation. A nearby stream flows eleven months of the year. There is a natural pond in the stream that can provide a continuous head of about 500' without major hydraulic structures. Since flow records for the stream do not exist, measurements at site and observations of the high water marks on the sides of the stream and pond were made for preliminary determination on the flow and head for a small-scale hydropower-plant.

Citizens of Yackolong volunteered their services during the reconnaissance study and enthusiastically supported the project. It was estimated that the small-scale hydropower generated would provide electricity for the village, light the streets, run a flour grinding mill and dryer. Since small turbines were not popular[3] during 1970, it was possible to get only one quotation for the machinery.

A project proposal with rough cost estimates was prepared and submitted to the appropriate ministry for funding a detailed study. In spite of several meetings and discussions on the proposal, no action was taken. The following points were made by the minister during the discussions:

1. Small-scale hydropower generation was not in the five-year development plan. He was not sure it will be in the next five-year plan.
2. Since no stream flow records or reliable hydrological data for the region were available, it was premature to fund a hydropower study.
3. Government funding for a small-scale hydropower study in one village would inundate the ministry with requests from others. The government did not have the funds to study a national system of dispersed small-scale hydropower stations.
4. The national electric grid would be extended to include Yackolong in the near future.

The government in power at that time followed the top-down strategy for preparing the five-year development plan. It also supported large scale hydropower generation. Under the circumstances it would have been difficult for the government to promote a system of small-scale hydropower stations.

The real issue, however, is whether streams should be gaged and records kept over a long period of time before small-scale hydropower stations can be built. In Afghanistan, private citizens took the risk and installed water wheels. They are working satisfactorily. I am not sure whether governments will take a similar risk for micro hydropower projects.

[3]"Prospects for Traditional and Non-Conventional Energy Sources in Developing Countries." World Bank Staff Working Paper No. 346, July 1979, sections 57 to 61.

Conclusion

There are attractive features in the bubble-up approach to national development. This strategy encourages citizen participation in the identification of local needs and in the implementation of projects to meet the needs. Small-scale hydropower generation complements the bubble-up strategy. It assists in the creation of a group of discrete self-sufficient communities across the nation.

Unfortunately, rural communities may not possess the political clout necessary to bring about the decentralized form of development that promotes dispersed centers of economic activity across the country. The lack of political representation in government may be the reason why rural areas in developing nations remain depressed.

A modified strategy[4] for national development that captures the positive features of the top-down and bubble-up approaches to national development might be appropriate for promoting a judicious combination of large scale and small scale hydropower units in developing nations.

[4]"A Methodology for Formulating and Implementing Science and Technology Policy for a Small Developing Country (Costa Rica)." Report by Franklin J. Ahimaz, Program on Policies for Science and Technology in Developing Nations, Cornell University, June 1975.

SMALL DECENTRALIZED HYDROPOWER FOR DEVELOPING COUNTRIES

Kenneth Grover

Goal

The goal is to improve the way of life for rural and decentralized peoples in developing countries. For any effort to succeed, it must offer a usable solution to an existing problem. This would mean that identification of all problems associated with the satisfaction of energy demand be completed in great detail for each logical geographic, or other division of the developing country.

As a general rule, foreign aid donors must live with the matrix of climatic, geographical, cultural and political factors which already exist on day one of the Agency for International Development (AID) effort. A complete recognition of all pertinent factors, together with a reasonable assessment of the strength of each is essential to the development of a usable solution to the unsatisfied energy demand of the receiving country.

It is unwise to compare the energy demand of a developing country with that of the U.S., Europe, Japan or other developed countries. Consultants, leaning on backgrounds related to optimum systems they have known, have often made incorrect recommendations to receiving countries. Absence of network, minor concentrations of people, decentralized schools and hospitals, secondary use of water for irrigation, low GNP/capita (with attendant low debt-retirement capability) and incorrect assessment of future growing rural industrial demand have been the factors most often overlooked in power systems which were technically correct, but a poor working solution of the country's needs.

Approach

Even in the face of the variables listed above, the logic path for a usable system can be successfully developed with the following approach.

Define the Need

The local AID office is in close touch with the factors needed to make a correct assessment of the character of the need. The political and other factors are properly assessed and given to the hydroelectric expert as a part of the scope of assignment.

Mr. Grover is President, GSA International and GTA, Katonah, New York.

Consultant Effort

In most of the developing countries, the scope of effort of the hydro consultant will include the following:

1. Develop the hydro information package. This will include the information related to rainfall, run-off, gaging station data, and other factors which dictate the design of the hydro station. Generally, run-of-stream units have lower costs.
2. Develop the site selection criteria list which will include the needed data on year-around water supply, market or need for power, present network availability and future plans, non-dam low-cost water supply, possible secondary use of water, power cost lower than diesel, possible combination use in conjunction with bio-mass or other.
3. Using the data listed in the site selection criteria list given above, one or more sites are chosen for installation of the demonstration unit which the AID donors wish to see installed.
4. Cost the engineering and equipment supply "package" to be given by the donor group. This will mean that preliminary engineering must be completed for equipment selection and costing.
5. Estimate the receiving country's cost of installation of the equipment supplied by the donors.
6. Calculate the plant-site cost of power to be generated by the hydroelectric installation. (See Appendix)

Joint Effort With Consultant

1. Analyze the socio-economic impact to the receiving area as a result of this new power availability.
2. Assess the probable rate-structure for the area in ¢/kWh.
3. Project the increase in disposable income due to power.
4. Determine the probable social, cultural and economic impact on the area to be served by this installation.
5. In addition to the above, each site is written up for:

    a) economic feasibility
    b) social soundness
    c) technical feasibility
    d) administrative feasibility
    e) environmental concern

6. The site, or series of sites, may now be recommended for funding as a result of the above analysis. This funding may take many forms although in our experience the AID donors may fund the demonstration part of the development and the World Bank or other entity may elect to finance the total cost of the country's hydropower development.

The scope of this talk includes the approach taken by the speaker in two widely varying locations, working with AID. We speak first of Panama which is a somewhat "S"-shaped section of land about 800 miles long and 100 miles

wide. That section toward North America (about 450 miles in length), bounded by Costa Rica on the Northwest and the Panama Canal at the opposite end, is divided along the long axis by a mountain range about 6000 feet above sea level called the Cordillera (Kor-dee-a-lara). About 33 miles is the distance from the peaks to the Carribean and 67 miles from the peaks to the Pacific.

About two million people live in Panama; 50% of them (1,000,000) in Panama City itself. Only about 20,000 live north of the Cordillera. On the north side the annual rainfall is a little above 200 inches, of which about 190 inches runs off the steep terrain. Here is a rain forest with 20 rivers about the width of the Hudson but only 33 miles long. In the 33 mile race to the sea the water drops about 6000 feet.

On the south side of the Isthmus there is about 40 inches of rainfall (much the same as New England) and there is where the people live. The rainy season gives about 32 inches in 5 months and 8 inches in 7 months. Irrigation is necessary to practice adequate agriculture to feed the people.

Originally, (prior to 1975) 60 or more small diesel units furnished power to larger villages and about 40% of the people had no power; the remainder were served by fossil fuel stations. U.S. consultants recommended several large hydroelectric power stations to be built at a distance of 300 miles west of Panama City. The theory was that power would thus be available right down the center of the populated land. Two things happened.

(1) At about the time the first unit came online, the OPEC group struck with its second large jump in pricing. The greatest good for the greatest number was served by using the low-energy cost hydropower for the one million people in Panama City. The cutbacks in OPEC fuel left a relatively small amount of hydropower for the rural areas, and this only to larger cities.

(2) Cheap power at the dam-site does not mean cheap power 300 miles away. To lessen the wheeling losses 150 KV transmission levels were employed. Now the overhead lines passed over all of the smaller cities without serving them because of the expense of transforming sub-stations and distribution systems. Over 33% of the Panamanians were still without power. At the same time, and for the same reason, diesel fuel increases raised the actual cost of electricity to over 20¢/kWh, with no increase in area GNP or disposable income.

The AID assignment was to assist the Panamanians through their government-owned power system IRHE in developing a technology base and a demonstration project as a first step in developing a small decentralized hydro system. They elected to first replace all diesel systems wherever hydropower was possible. Second, they would transfer the used diesel units to villages where no hydro was possible and no power existed. In some cases the new diesel location would be in a small village within sight of the large overhead 150 KV transmission line.

In order to assist in the development of the technology base for SDH basic hydraulic turbine-generator application and engineering sections were reproduced from our GSA Engineering and data book. Pricing was given from updated quotes of U.S. and foreign manufacturers from water to wire.

We travelled to several mountainside sites and staked out diversion ditches, trash racks, head gates, penstocks and power-house sites. For mountain villages run-off is more uniform year-round as we approached the Cordillera. We established the following criteria for SDH units for the mountainous area of Panama:

1. Non-dam, run-of-stream.
2. 120% of summer minimum flow is design point.
3. 140% of actual area demand is design point if less than #2 above.
4. Wherever possible diversion ditch is at 90° to stream flow at take-off point.
5. Settling basin at each end of diversion ditch.
6. Trash rack 1/2" spacing.
7. Guillotine type of head gate and warm drive.
8. Steel penstock and stand pipe down to 20 kW.
9. Impulse turbine from 40 feet head upward.
10. Vee-belt drive up to 200 kW (gearing above).
11. DC generator and inverter up to 10 kW.
12. Woodward electronic governor and load diversion system above 20 kW.

Three sites are being built to these criteria and the first will be operational about January 1980. All are above 200 kW—Sante Fe, San Francisco and Coclesito.

This site selection system as well as the next Continent discussed, has certain social, economic and cultural facets that must be recognized.

> In all cases, lack of electrical energy must constitute a problem in the way-of-life desired by the area residents and;
> In all cases the logic path employed must yield a usable result or the plant will cease to function for some reason.

Moroccan Approach

The speaker was retained by AID to study the small decentralized hydro potential of the Atlas and Rif mountains of Morocco. Much work had been done in need definition by the local AID group in Rabat and by the headquarters AID office in Washington.

The logic path employed involved 5 distinct steps which were summarized in a 6th step, or final report. We would like to add that much of this work had already been started in preliminary form by AID/Rabat and we were saved a great deal of time in the analysis effort by inputs from AID in Washington and Rabat. We would like to name the 5 steps and expand a bit of detail later in this talk.

1. Information package development.
2. Development of site-selection criteria.
3. Locate demonstration units.

4. Develop engineering and equipment supply costs for hardware and local erection costs as borne by receivers.
5. Development of socio-economic impact of power availability at these remote sites.

The information package was developed as follows:

1. Precipitation for Haut Atlas, months in which it occurs.
2. Three River basin hydrology records. Rif and Haut Atlas
    a) Marrakech - Haut Atlas Copy of Climatologie
    b) Beni Melal - Haut Atlas 2.2.1
    c) Tetouan - Rif Mountains
    d) Dades East of Haut Atlas
3. Irrigation Patterns
    a) Present
    b) Forecast
4. Contour Maps
    a) Entire Haut Atlas
    b) Marrakech
    c) Beni Mellal
    d) Tetouan - Rif Mountains
5. Power Grid Map
    a) Existing Generation & Local Centers & KV Rating
    b) Projected Growth of Network & New Industries
6. Population Patterns
    a) Present
    b) Projected

Site selection criteria list was as follows:

1. Year around water
2. Market, use or need for power
3. No network power available to site area
4. Non-dam, low water supply costs
5. Possible secondary use of water (irrigation or other)
6. Power cost/kW equal to or less than diesel
7. Possible combination use:
    a) hydro plus diesel (diesel during low water)
    b) hydro plus biomass/steam (biomass during low water)

Note: In addition to the above, each site must be written up:

a) Economic Feasibility
b) Social Soundness
c) Technical Feasibility
d) Administrative Feasibility
e) Environmental Concern

The final selection of sites is to be made by a joint-committee of:

Department of Energy, Department of Interior and political representatives of area plus AID, ONE and Office of Nuclear Energy, DOE.

The location of the demonstration units was dictated by the rule of "the greatest good for the greatest number" (after all other criteria had been satisfied).

A band northeast of Alfoure on the north side of the Haut Atlas was selected for investigation at Tillougguit. This site was deemed to be technically feasible and under planning, the 2000 people there will not have electricity for another 15 years. (See Appendix A for cost estimates this site.)

Another area offering hydroelectric potential, but without any electricity planned in the foreseeable future, is on the south side of the Haut Atlas at Msemrir on the Dades River. A diesel generator supplies small amounts of power twice daily but this is expensive, too small, and requires frequent maintenance. We investigated the area and found a site where by using a canal and a hydro unit, we could produce up to 200 kW of power. (See Appendix A for cost estimates this site.)

A second area in the Dades Valley is Ait Arbi, where a large spring emerges from the mountainside about 35 meters above the Dades River surface. Two small villages are nearby and about 200 kW could be recovered for perhaps 6 months/year with lesser amounts available at other times. (See Appendix A for cost estimates this site.)

Social Soundness

The history of projects in other developing countries leads us to believe that here, too, some of the early advantages of rural power will include hospitals, irrigation systems, local small industries and improved communications. Certainly, in a country such as Morocco, great increases in yields per hectare will result from irrigation. It should also be recognized that use of irrigation water from wells will bring other hectares into production that are now too dry to support agriculture. These factors will absorb increasing numbers of rural workers, and with increased standards of living in rural areas, rural people will not flock to urban centers and form slums such as are already building up around Rabat and Casablanca.

The buildup in agricultural development due to small de-centralized hydropower, will increase Morocco's exports of food products and, at the same time, lessen Morocco's dependence on foreign oil.

Without an internal fossil-fuel energy base, we feel that Morocco should not attempt to become an industrial-based economy. When purchases of oil are no longer physically or economically possible, Morocco must fall back on its basic strength (agriculture), and exist on solar, bio-mass, shale oil, and total hydro development. All of these alternate energy sources are appropriate to de-centralized power philosophy. Thus, SDH is socially sound and in harmony with the future of Moroccan society.

APPENDIX

Calculations of Ait Arbi (High Head)

1. Flow @1M³/sec.	=34CFS.		
2. Head @35 Meters	=105 Ft. Net Head		
3. Penstock 6" PVC	=300 Ft. x $15/ft.	$ 4,500 or	18,000 dh.
4. Pelton Turbine	=High Speed unit	32,600 or	130,000 dh.
5. Linkage & Governor	=Woodward or equal	2,400	
6. A.C. Generator	=Enclosed, S.E.	20,400	
7. Governor Deflector	=Nozzle Control	3,600	
8. Fabricated Baseplate	=W/c Foundation Bits	2,800	
10. Electrical Equipment	=Brkrs, Gauges, etc.	8,400	
11. Engineering (GSA)	=Combining Package	11,375	
12. Engineered Package	=U.S. Funds	$89,475 or	357,900 dh.
13. Installation Materials	=600 M-days @$20	12,000 or	48,000 dh.
14. Installation Mtrls.	=22 Yrd.Concrete & re-bar	2,970 or	11,880 dh.
15. Supporting Steel	=2 tons @.75/#	3,000 or	12,000 dh.
16. Power House	=150 Ft²@$40/ft	6,000 or	24,000 dh.
17. TOTAL FUNDS U.S. PACKAGE		$89,475	
18. TOTAL FUNDS MOROCCAN PORTION			95,880 dh.

19. U.S. Package is $447/kW
20. Total installed package is $576/kW plus ONE in-house engineering.
21. ROI @ 10% & years = 1¢/kWh debt service.

THE ROLE OF SMALL HYDROELECTRIC POWER GENERATION IN THE ENERGY MIX DEVELOPMENT FOR THE PEOPLE'S REPUBLIC OF CHINA

Alexander Ansheng Tseng, Deng Binli, Mao Wenshen, and Tu Zhaoxiang

I. General Aspects

In the year 250 B.C. the Dujianguan Irrigation District was built in Sichuan Province where 200,000 hectares of farm land were irrigated. In 1977 the first stage of irrigation with small-medium hydropower projects was completed under stage 1 of the same district. Already benefitted are 660,000 hectares of farm land.

The First Century Roman engineer Vitruvius gave an account of water-mills, and by the end of the Roma era many were in operation. As civilization progressed, the higher energy consumption always led to resource supply problems which can best be illustrated in Figure V-4.1. As indicated in Figure V-4.1, hydro electricity only got started about 1844 with Boyden's reactive turbine installed at Lowell, Mass. In the year 1882 the first hydroelectric central station in the U.S. was installed at Appleton, Wisconsin to provide 250 lights. In an energy short society, all environmentally sound energy sources deserve the highest priority. Small and medium size hydroelectric plants with improved new performance can surely help meet the world's energy needs and conserve our nonrenewable fossil fuels.

In places where hydropower resources are available, small hydropower stations can best be established to help the realization of rural electrification without costly long distance transmission or subtransmission lines. From the very outset since liberation in 1949, the Chinese Government has attached great importance to the utilization of the hydropower resources. The development is characterized by its large-scale usage of the small and micro-hydropower resources.

As a result of the development of the machine tool industry, difficulties in manufacturing the equipment for hydropower generation have been overcome. Special research institutes equipped with test facilities were set up after 1958 to design medium and small hydropower equipment, such as water turbines, generators, speed governors and the auxiliary devices. The developing tempo testified to the correctness of the way we have taken for rural electrification. The long-term development of China's hydropower resources is one of the effective measures in the course of China's modernization.

Mr. Tseng is a consulting Engineer, Palo Alto, California; Mr. Binli is a working member of the Electric Power Department, Peking, China; Mr. Wenshen is a working member of the No. 1 Machinery Department, Peking, China; and Mr. Zhaoxiang is the Vice Director of China National Machinery and Equipment Export Corp., Peking, China.

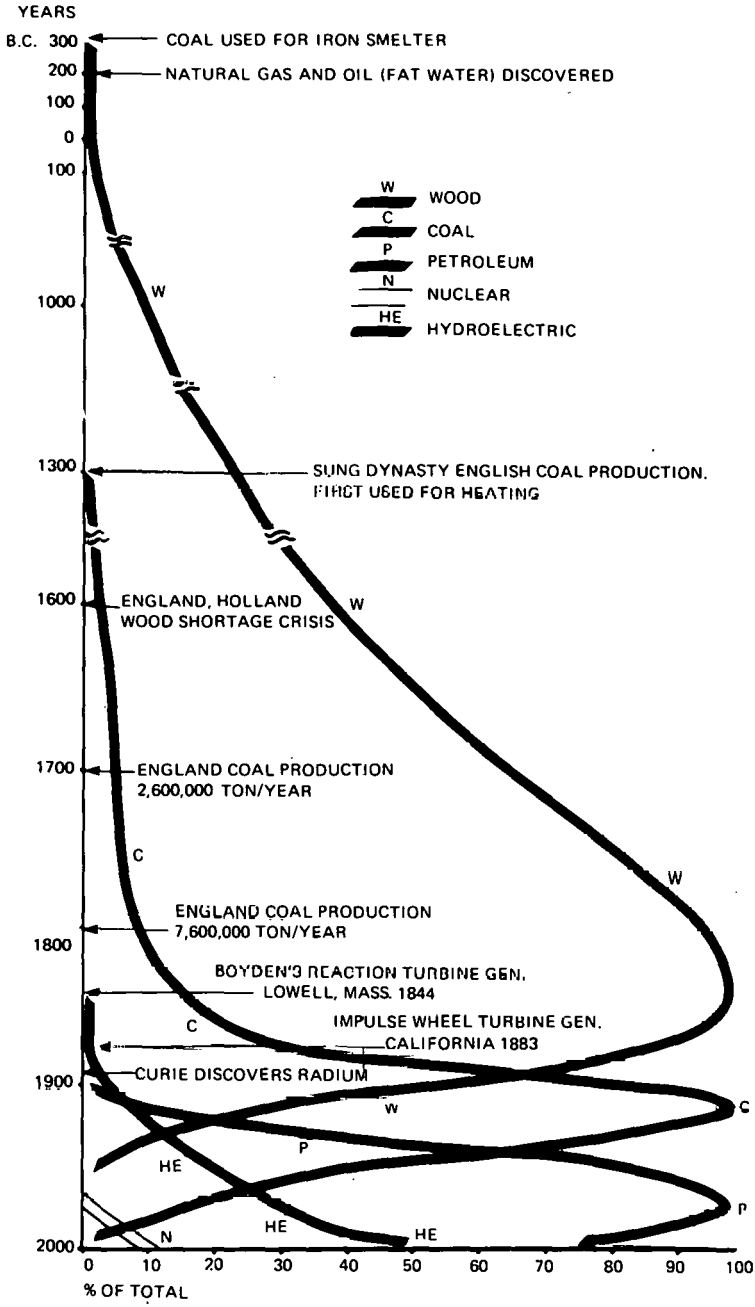


FIGURE V-4.1 Energy Consumption and Resource Supply.

China, rich in her waterpower resources, occupies 15% of the total world reserve. According to our survey, there are about 1600 rivers in China with a total capacity of generating about 580,000 MW, of which approximately 150,000 MW are generated by using the hydropower from medium and small rivers.

In accordance with the prospect for the development of China's hydropower resources, hydro-turbine sets rated 6000 kW and under are defined as small-sized units, and hydro-power stations with an installed capacity up to 12000 kW as small ones. Units below 500 kW capacity are regarded as generating sets "for agricultural purposes," and those with capacities from several kW to 200 kW are considered as micro units (or micro sets). They are small-sized and easy to transport.

Since 1958, China has constructed more than 80,000 small and micro-hydropower stations with a total capacity of 5400 MW. Most of them are built by the people's communes at the county level for the use of commune members. Hydro-power generating units with capacities below 500 kW account for more than 60% of the above-mentioned numbers. They supply the electric power for the local industries and small workshops, for the application of grain drying, wood-cutting, oil extraction, and lighting and film-showing. A number of people's communes have set up small hydroelectric power stations with capacities up to 1000 kW or more. Such people's communes have developed their own local industries, commune-run small factories or workshops and other side-occupation industries. This is one of the ways to reinforce the commune's economic strength. Most of the small hydropower stations run by countries or people's communes have already shaped their own network for power supply. Approximately 50% of the counties of China, i.e., about 1100 in number, are reported to have the hydropower resources with the potential capacity of 10,000 kW power supply or even higher. In these counties, efforts are being made to have the station with 10,000 kW capacity installed as soon as possible. With about 10,000 kW of electricity available in a county, the initial requirement of power supply for its industrial and agricultural application can be met with minimum system investment cost such as interrupting capacities for circuit breakers, heavy transmission lines and line losses.

The development of small and micro-hydropower stations has not only solved the power supply for the people's communes, but also has the advantage for multi-purpose application; for example, the simultaneous development of its forestry, agriculture, livestock farming, fishery and other commune-run industries.

Most counties have one or more main hydropower stations with the capacities of several thousand kW. Now, a great number of people's communes in the rural areas prefer to develop small hydropower generation stations instead of diesel generating sets because of its expensive fuel, difficult handling and complicated maintenance. At present, any county or people's communes where the hydropower resources are available will exert every effort to build small hydropower stations, in addition to the methane gas generated from animal farms.

Without electricity, it is impossible for a county or a people's commune to make any long-term planning and development. That's the reason why the small hydroelectric power is developed at an exceedingly fast tempo. China

has a staff specialized in its production and design work, as well as in research and development. The annual manufacturing capacity of the small hydropower generating equipment is more than 1000 MW. They have accumulated much experience in manufacting during the past 30 years of practical work, and further improvements are expected in this respect. For standard Hydro Electric Units, see Table V-4.1.

II. China's Present Status for the Development of Small Hydropower Equipment

In 1952, several 800 kW water turbine generator sets were produced, and in 1954 we began to manufacture the 10,000 kW hydroelectric sets with a head of over 30 M high. At the same time, specialized plants and research institutes with test facilities were set up. The staff of experts specialized in research, development, design, manufacture and installation, as well as operation. Liu Chia Shia Hydropower Station, with installed capacity of 300 MW/set, was put into operation in 1973.

Due to the abundant hydropower resources, and big differences in its hydrographical diversity, appropriate measures must be taken in order to meet various requirements, otherwise the result will be a great variety of different models and types which makes the mass production very difficult. This is most important for the production of small hydropower units. Beginning with 1972, work on standardization of the hydropower generating equipment was carried out. Since then, unified design work was practiced on a national scale, and strict quality requirements for the products have been defined. The head range for the water turbine generating sets is limited between 2.5-400 meters, and the output is between 12-12000 kW.

Recently we have been developing tubular turbine sets which are especially suitable for very low heads with very large flow rates. Compared with the conventional vertical shaft Kaplan sets, the tubular types have the advantage of higher efficiency in the district of large flows. The tubular turbine sets, especially the medium and small-sized ones, are still in the research and development stage. Many technical problems need to be explored further and improved.

A bulb-type tubular turbine set at 10,000 kW, with the runner diameter of $D_1 = 5.5$ meters, is just now under construction. Another small bulb-type and experimental tubular turbine set for a tidal power station will soon be put into operation. It has an output of 500 kW and the runner diameter is $D_1 = 2.5$m.

We are aware that the micro-hydro generating sets with the rating capacity from several up to 200 kW are worthy of development, especially for those countries where energy resources are limited and the hydropower resources are widely scattered.

In China, water turbines are divided into two categories: The "large-medium" and the "medium-small." For the latter type, the specific speed N_s between the different runners is somewhat wider than that of the large-medium type. For reactive turbines, N_s is ranged from about 100 up to 760 with 8 runners, while the impulse type has 4 runners.

Table V-4.1

Specification of Water Turbine Generator Sets 12～500KW

Item №	Turbine				Generator				
	Type	Model	Head (M)	Flow (m^3/sec)	Capacity of Generator (kW)	Speed (rpm)		Voltage (v)	
						50Hz	60Hz	50Hz	60Hz
1	Axial-flow reaction type	ZD760-LM-60	2～6	0.80～1.80	18, 30, 40, 55, 75	1000	1200	400	460
2		ZD760-LM-80	2～6	1.40～3.50	30, 40, 55	1000	1200	400	460
					75, 100, 125	750	900	100	460
3		GD560-WZ-60	8～14	0.90～2.20	40,55,75,100,125,160,200	750	720 (900)	400	460
4	Mixed-flow reaction type	HL210-WG-20	6～15	0.12～0.19	12, 18	1000	1200	400	460
5		HL310-WG-30	6～18	0.32～0.53	18, 30, 40, 55	1000	1200	400	460
6		HL260-WJ-35	10～25	0.50～0.80	55 ,75	750	900	400	460
					100, 125	1000	1200	400	460
7		HL260-WJ-42	8～25	0.65～1.15	75, 100, 125, 160	750	900	400	460
					200	1000	1200	400	460
8		HL110-WJ-42	30～80	0.36～0.59	100, 125	750	900	400	460
					160, 200, 250, 320	1000	1200	400	460
9		HL240-WJ-50	15～40	1.20～2.00	125, 160, 200	600	600	400	460
					250, 320, (400)	750	720	400 (6300)	460 (6300)
					500	1000	900	6300	6300
10		HL220-WJ-50	25～59	1.50～1.80	320, (400)	750	720	400 (6300)	460 (6300)
					500	1000	900	6300	6300
11		HL110-WJ-50	35～80	0.56～0.85	200, 250, 320	750	900	400	460
					400, (500)	1000	1200	400 (6300)	460 (6300)
12		HL110-WJ-60	30～70	0.70～1.10	160, 200	600	600	400	460
					250, 320, (400)	750	720	400 (6300)	460 (6300)
13		HL240-WJ-71	23～32	2.90	500	500	514	6300	6300
14	Impulse type	CJ-W-55/1×58	100～260	0.12～0.19	75, 100, 125, 160	750	720	400	460
					200, 250, 320, 400	1000	900	400	460
15		CJ-W-65/1×72	100～260	0.18～0.29	125, 160	600	600	400	460
					200, 250 320, (400)	750	720	400 (6300)	460 (6300)
					500	1000	900	6300	6300
16		CJ-W-92/1×11	138～145	0.50	500	500	514	6300	6300

For water turbine generator sets having capacities not over 500 kW, customers may make use of the above table for choosing the right specifications. Those not herein specified can also be supplied subject to individual negotiations.

The serial production of standard types contains 12 runners with the usable head range from 2.5-400 meters. Recently, a research institute in Tianjin has turned out several new types of mini-hydro electric generator sets with capacities from 1-20 kW, according to the heads and flowrates of the sites. Efforts have been devoted to developing installations of minimized output. Thousands of these units are produced annually. The abundant requirements coming in from all over the country lead to further improvement of the design work. Information received is that they are very welcome to those who live in the mountainous regions.

We are of the opinion that, both to conserve energy and reduce expenditure of fuel oil, there is a growing demand for micro-hydro generating equipment.

III. The Prospect and Long-term Development of China's Small Hydropower Generating Equipment

China's energy policy is the simultaneous development of hydropower generation and thermal-power generation, plus local fuel cell power generation; and of large, medium, and small types of units. Priority is given to those areas where medium and small hydropower resources are available, so as to relieve considerably the burden for the national grid, and to supply power needed to develop industry and agriculture on the county and people's commune level. If over 1000 counties in China could be equipped with hydropower stations with installed capacities of 10,000 kW each, one can imagine how important a role they are going to play in the realization of four modernizations of our country. Our main target now is to make our efforts for the rapid establishment of "10,000 kW hydroelectric power in the counties," which is also the prospect for the development of small hydropower resources.

For the construction of small and micro-hydropower stations by counties and people's communes, the Chinese Government's policies can be summarized as follows:

1. Wherever the water resources are promised, the government impels installation of small or micro-hydro power stations which not only step up the production of industry and agriculture, but also raise the income and living standards of the local populations.
2. Huge amounts of state loans with low interest are dedicated annually to people's communes that engage in constructing the aforesaid stations.
3. To the plants that produced hydroelectric power installations and equipment, the government would give timely and appropriate investments to increase production.
4. With the small and micro-hydro stations that are integrated into the national grid, the state would supply electricity with a privileged charge in order to promote rural electrification.

IV. The Objective of Future Small Hydro Project Developments

a. Automatic Stations. The automatic remote control generating station is especially suited to systems in which many small power stations are used. In such circumstances the operating staff expense at each station would be prohibitive, but making each station automatic and linking all into a common distributing system makes the operation more economical and reliable. Such an installation could eliminate governor control. The gates are preset at some opening corresponding to the desired output of the generator. Suitable control circuits shut down the station in case of overload, overspeed, or any other kind of trouble. Normally the starting and stopping of each generator set is accomplished automatically by the response of float switches actuated by the change in the level of water above the dam.

In small stations, induction generators should sometimes be used because of their simplicity. They require no exciter, no voltage regulator, and no synchronizing equipment. The disadvantage is that they take their excitation from the system in the form of reactive current, thus lowering the system power factor. They are usually small in number, however, and their advantages often outweigh this disadvantage.

b. Methods to sustain dispersed small hydro-generation without heavy transmission and subtransmission system. The traditional utility planning criteria and a probabilistic approach which is developed in Europe using a combined generation-transmission reliability program, will be evaluated at each region, depending on the local river water flow and hydrology conditions, plus the possible limited intertie with the large national grid system.

The dispersed power plants can, in principle, be sited in the transmission, subtransmission or distribution network; the total dispersion credit should consider all three network levels. This paper will not discuss the economics and technical determinants of regional small hydro units at this time. However, some of the recent studies conducted by Stephen T. Y. Lee indicate that the overhead transmission credit of dispersed power plants is in the range of $76 to $159 per kW (in USA) of installed capacity. In situations where underground cables could be deferred, the credit could be as high as $250/kW. This transmission credit compares with the national average capital cost of $110 of transmission investment per kW of generation addition derived from Electric World data (September 15, 1977).

c. Future electric power system development outlook. Historically, electric utilities began as isolated systems serving local communities. Over the last several decades, electric utilities in all industrialized countries have followed a common trend of increasing size of equipment and degree of interconnection.

For local small hydroelectric service to the farmers and agricultural production, a high load factor could be accomplished by proper load management, thus electricity produced by small generators with low degrees of interconnection may be more economical, in addition to being local service oriented. A true service-oriented small hydroelectric, wind power, geothermal regional generating unit could become less capital-intensive than production by centralized system.

China heartily welcomes hydroelectric experts from all nations to visit and exchange experiences in techniques. As one of the members of UNO, as well as the IEC, China would be much obliged to take an active part in various international activities.

The Chinese word for crisis can be literally translated as "danger" and "opportunities." Thus under the present energy crisis period, we see opportunities for research alternative energy sources together, such as solar, wind, anaerobic digesters, methane gas from animal and farm wastes, in addition to small hydroelectric projects.

Session Eleven

INTERNATIONAL PERSPECTIVES

Topic: Technology

Chairman: Mr. James Victory
Vice President
Kvaerner-Moss, Inc.
800 Third Avenue
New York, New York 10022

MODERN SMALL-SCALE HYDRO TURBINES

Nils H. Rømcke.

Sorumsand Verksted A/S, a member of the Norwegian Kvaerner Group, has manufactured hydro turbines since 1904. In the last decade we have devoted considerable attention to the development of small-scale turbines.

The purpose of our development program has been to achieve a major reduction in cost without reducing efficiency or quality. Our standardization has focused on Pelton and Francis turbines in the range 0.5 - 10 MW and tubular turbines up to approximately 3 MW, although we also manufacture much larger turbines. However, only the small-scale Francis and tubular turbines will be considered here.

Francis Turbines of Standard Design

A key word in cost reduction is standardization. In spite of this, a certain amount of tailor-made design is unavoidable, due to specifications of head, flow, suction head, and speed, which may vary from one installation to the other.

Our small-scale Francis turbines incorporate 12 different hydraulic configurations, each of which represents a specific speed. Each of these designs has been standardized, and their scale may be varied as required. Any specific speed in between these 12 variants can be achieved by minor alterations to the runner, thereby enabling coverage of the whole specific speed range from 60 to about 350. (Specific speed is calculated to turbine output in kW and head in m). This combination of severe standardization and one-off design has enabled us to reduce costs by as much as 30 to 50% and still deliver a turbine which is properly suited to the demands of flow, head and speed. A diagram showing the utilization range has been worked out for each of the 12 variants. This is supplemented by such information as output, runner diameter, and speed as well as demands for setting of the turbine for cavitation-free performance as a function of flow and net head. There are also indications of overall dimensions for any installation. The dimensions are expressed as rations of the runner outlet diameter.

Extensive Use of Stainless Steel.

With the exception of a few bronze parts, all major components employ welded steel, including guide vanes and runners. The use of stainless steel is

Mr. Rømcke is Manager of the Construction Department at Soerumsand Verksted A/S, Soerumsand, Norway.

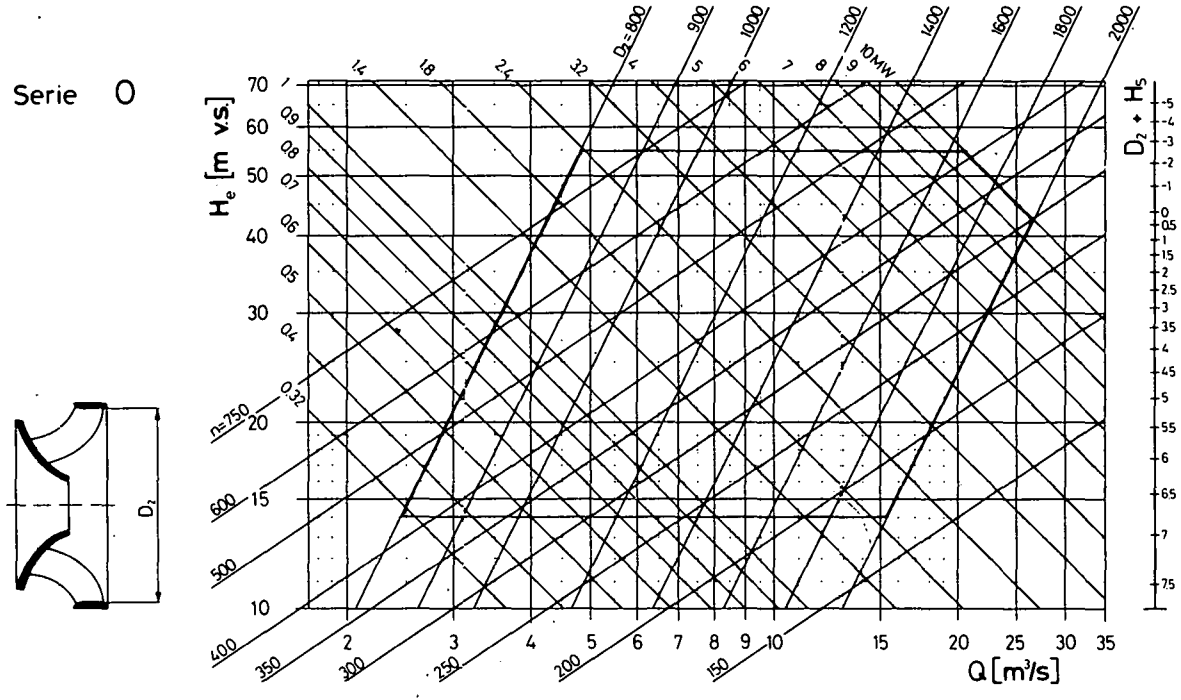


FIGURE W-1.1 Main Data for the Francis Turbines

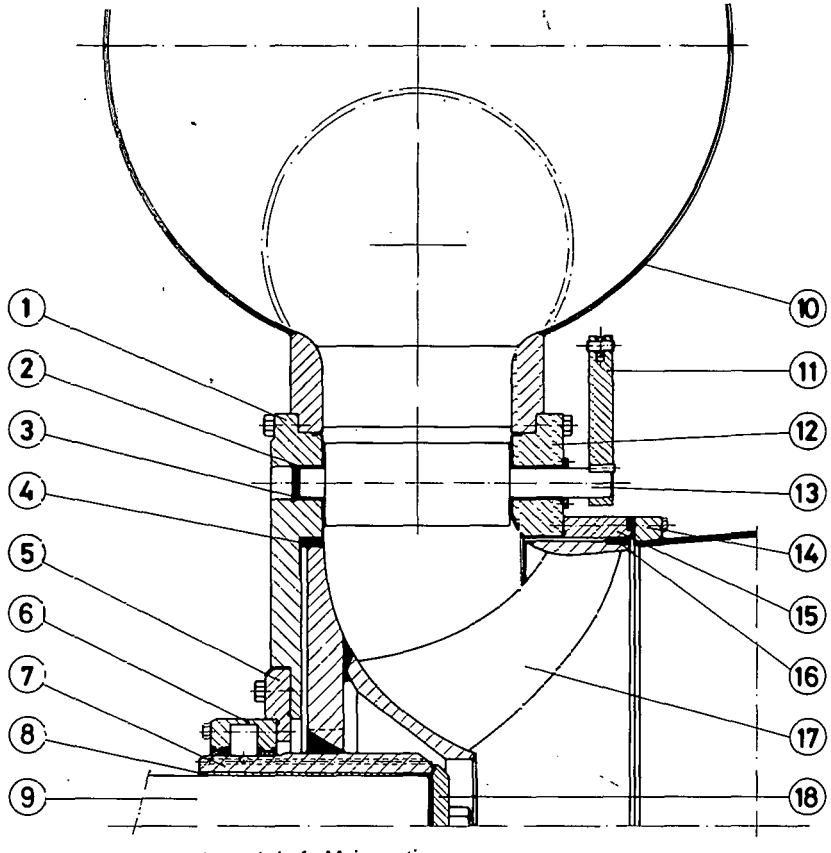


FIGURE W-1.2 Standardized Francis turbine with horizontal shaft. Main section.

becoming increasingly accepted, due to substantial maintenance advantages in the long run. Stainless steel is normally recommended for guide vanes, runner and draft tube inlet. Additionally, the turbine covers normally have a welded layer of stainless steel on the facing surfaces. Judicial application of materials and correct choice of turbine setting eliminate damaging cavitation effect on runner and draft tube even after long service.

No Lubrication Points

Lubrication-free bearings are used throughout on guide vane bearings and all link connections, because of 20 years of experience on Francis turbines. The use of correctly dimensioned bearings and well-suited materials offer at least as long a life as conventional, lubricated bearings. The abolition of lubrication points is especially significant where a power station is unmanned.

Non-Contact Shaft Seal

Shaft sealing is solved by employing 2 or more sealing stages drained off to the tailwater or the drainage sump in cases where the turbine setting is below the tailwater. The seal is working without contact between stationary or rotating parts, but design and choice of material permit temporarily a certain amount of such contact.

For a turbine setting above the tailwater, air will normally be drawn in through the seal, and water will not pass through the drain pipes during normal operation. This principle of sealing is employed in Norway on larger turbines, including those which are submerged. The provision of additional passages in the runner boss will allow more air to be drawn into the turbine. This is a simple and secure method of damping oscillations in the draft tube. Channelling the air to the center of the runner is a form of automatic air-intake applicable also to turbines which are deeply submerged.

Runner Mounting by the Oil Pressure Method

Most small-scale Francis turbines are horizontally arranged with the runner mounted directly to the free end of the generator shaft. A flywheel, if required, may be favorably mounted at the other end of the generator shaft. This configuration results in a very compact arrangement, and both turbine shaft and bearing are spared. Generator bearings must be dimensioned to absorb thrusts and weights from the turbine.

Normally, the runner is fixed to the shaft by using the oil pressure method. This is a shrinking operation whereby the boss is expanded and friction is partly overcome during the operation. Shaft and boss are conical with a very slight pitch. Where the shaft is cylindrical, a thin-walled sleeve externally coned, is mounted on the shaft to accommodate the runner. The use of such a

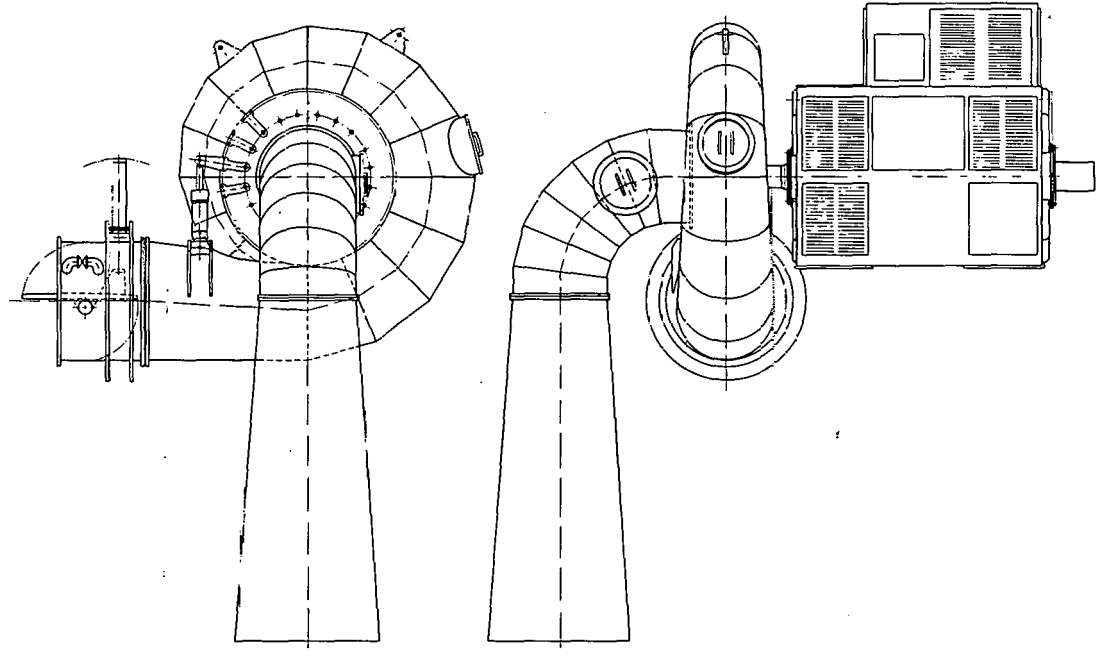


FIGURE W-1.3 Compact arrangement. The turbine runner is mounted directly to the free end of the generator shaft.

sleeve enables the use of standard shafts with normal tolerances for the generator. Larger torques may be converted by using this method than by keying the runner to the shaft. The shaft requires no splines or keys which could contribute to material fatigue. This is especially important in the case of the horizontal shaft and where the runner is attached directly to the generator shaft. Ease of dismantling, after many years of service, is vitally important in compact installations. By using a rubber seal at the one end and shaft seal located on the runner boss, the complete shaft is protected from contact with water.

The Tubular Turbine

The S-shaped tubular turbine with speed increaser and generator outside the flow is a comparatively new type at Soerumsand Verksted A/S. The first of these entered service n the autumn of 1978. This type of turbine is easier to standardize than the Francis turbine. Various specific speeds are achieved by regulating the angle and number of guide vanes and runner blades while the external arrangement is retained. By using a speed increaser between turbine and generator, the speed of the turbine may be selected as required. As with the Francis turbine, relevant data are shown in an application diagram. All significant dimensions relate to a given diameter of the runner. By selecting the runner diameter, the necessary dimensions of an installation are easily determined.

Generally, an arrangement of fixed guide vanes is employed, and the output is regulated by varying the pitch of the runner blades. This arrangement gives a shallower efficiency graph than fixed runner blades and adjustable guide vanes. Our development program has emphasized the importance of high efficiency. For this reason the runner chamber is spherical and the draft tube is very purposely designed, even though a marked increase in cost is thereby incurred. Efficiency tests on a model have confirmed the efficiency to be very high even at partial load.

The prototype, which entered service in 1978, performs noiselessly irrespective of load and is servicable way down to 20% of full load. The installation takes a 15% overload before the first signs of cavitation are noticeable. After one year's operation with various loads, including overload, no indication of cavitation damage has been found.

Bronze Runner Blades

All major components are executed in welded steel, except for the runner blades which are cast in nickel-aluminum bronze. This high-tensile bronze alloy is cavitation-pitting resistant, easily cast, and can be welded without the need for preheating and subsequent annealing. Welded stainless steel is used for the runner chamber, otherwise ordinary carbon steel is employed.

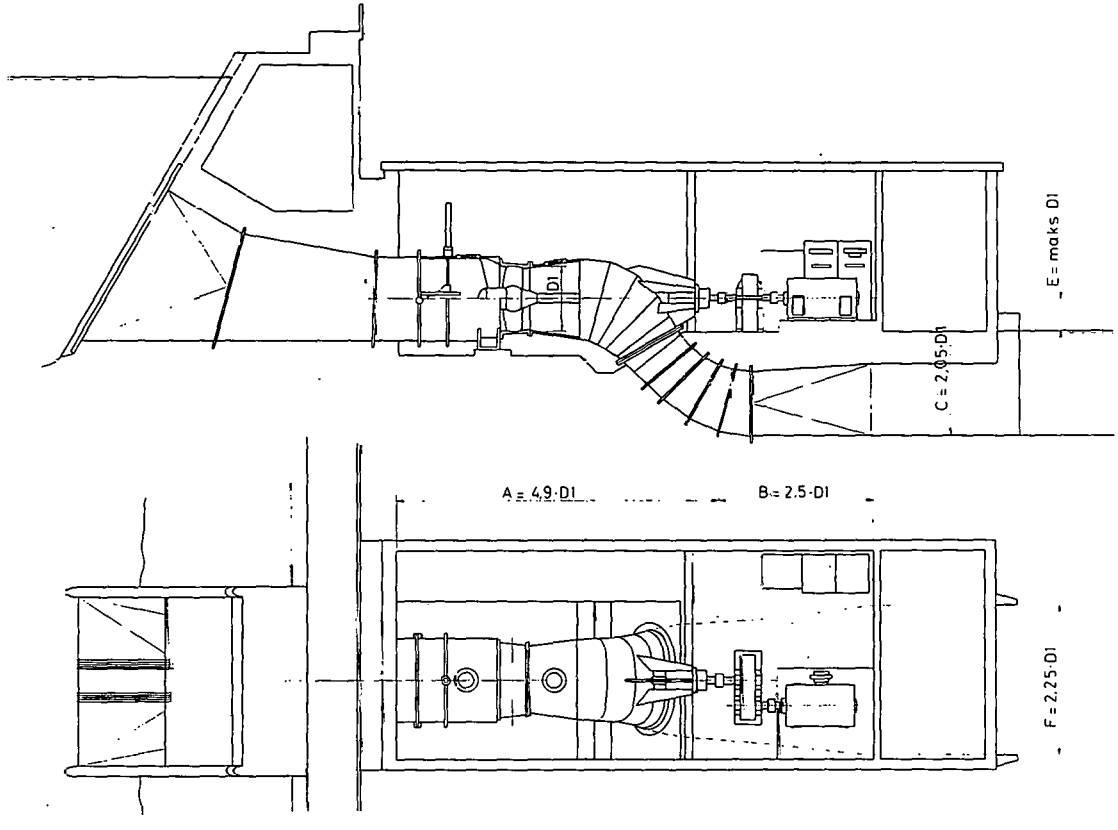


FIGURE W-1.4. Standardized tubular turbine. The dimensions are expressed as ratios of the runner diameter.

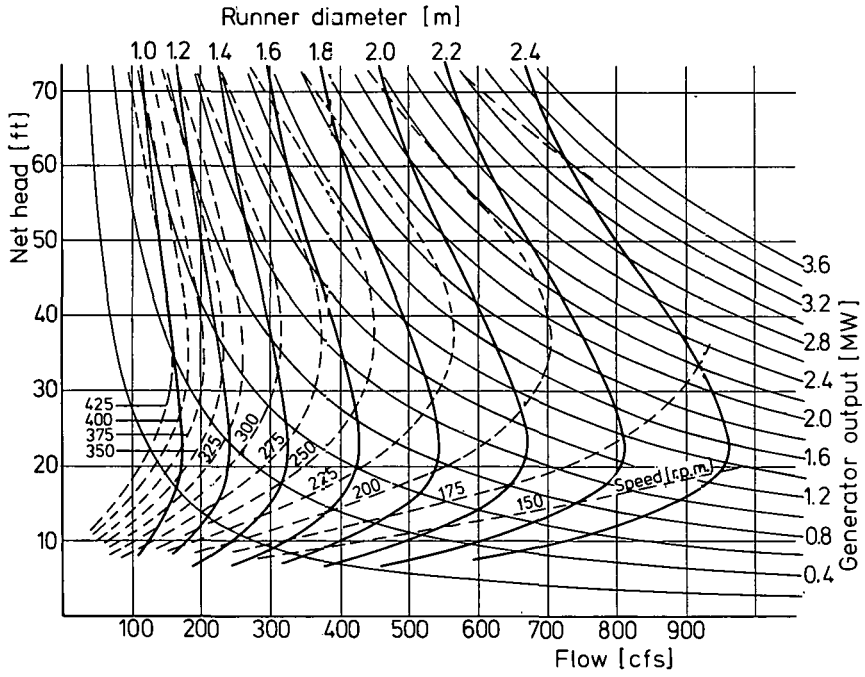


FIGURE W-1.5 Diagram showing output, runner diameter, and turbine speed for a tubular turbine with constant suction head

Water-Lubricated Rubber Bearings

The bearing in the bulb is of rubber and is water-lubricated. The shaft is of stainless steel. This bearing, which has proved very satisfactory, is of the type used in ship propeller installations. Up to date, there is no indication that this type of bearing is affected by pollutants in the water. The great advantage of the water-lubricated bearing is the total elimination of any of the doubtful sealing points to be encountered in the oil-lubricated bearing.

The Francis Turbine May be a Better Solution Than the Tubular Tubine

Francis turbines can be used where heads are low, whereas tubular turbines have their practical limit upwards at about 20 m. Comparing the two is therefore of interest. Taking as an example a power station under construction in Norway beside an existing dam, net head 8 m and rated power 1 MW.

Main data for the turbines concerned were:
Francis turbine with adjustable guide vanes: Speed: n = 140 r.p.m., runner'diam.: 1.9 m, max. suction head: 6 m.

Tubular turbine with fixed guide vanes and variable runner blades: Speed: n = 255 r.p.m., runner diam.: 1.6 m, max. suction head: 1.6 m.

In either case a speed increaser would be installed between turbine and generator rendering the lower r.p.m. of the Francis turbine insignificant.

The advantage was for the Francis turbine which permits a very great suction head. This will always be the case where heads are low.

The Francis Turbine is Pricewise Competitive

Using a Francis turbine with a steel spiral casing, the price would be about the same as for a tubular turbine. For this plant, however, it was considered a vertical Francis turbine in an open pit. Comparative prices for turbine and generator would then be approximately:

Case 1:	Tubular turbine	100%
Case 2:	Francis turbine with steel spiral casing	100%
Case 3:	Francis turbine in an open pit	80%
Case 3:	Francis turbine in an open pit, was 2/50 estimated to be most competitive when considering total costs.	

Tubular Turbine - High Efficiency With Low Load

In terms of efficiency the tubular turbine and the Francis turbine may be compared. The tubular turbine with fixed guide vanes and variable pitch runner blades will usually describe a flatter efficiency graph showing efficiency to

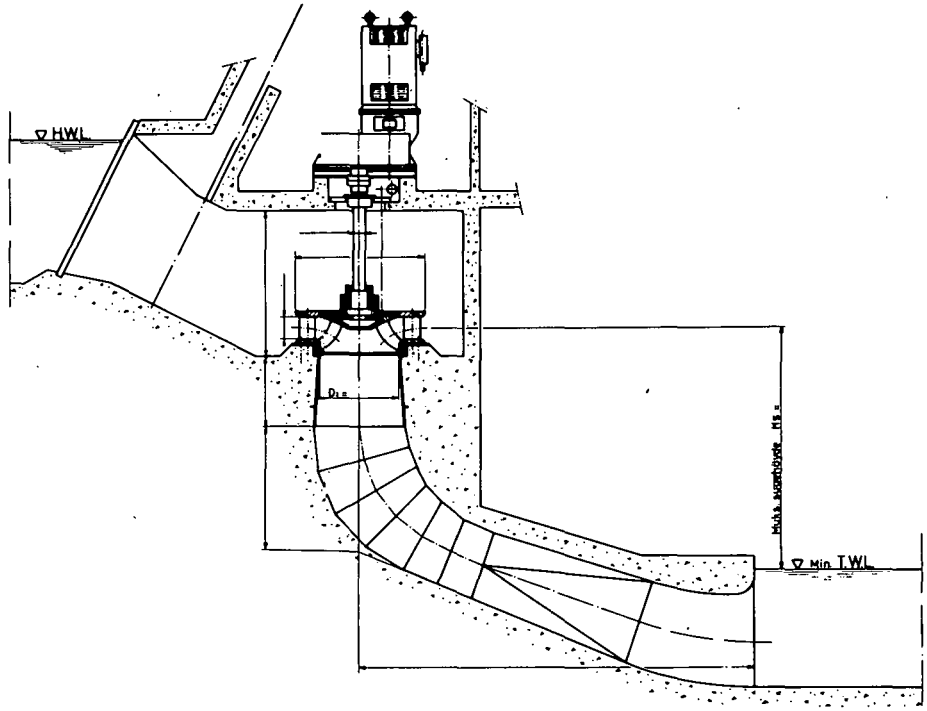


FIGURE W-1.6 Vertical Francis turbine without spiral casing

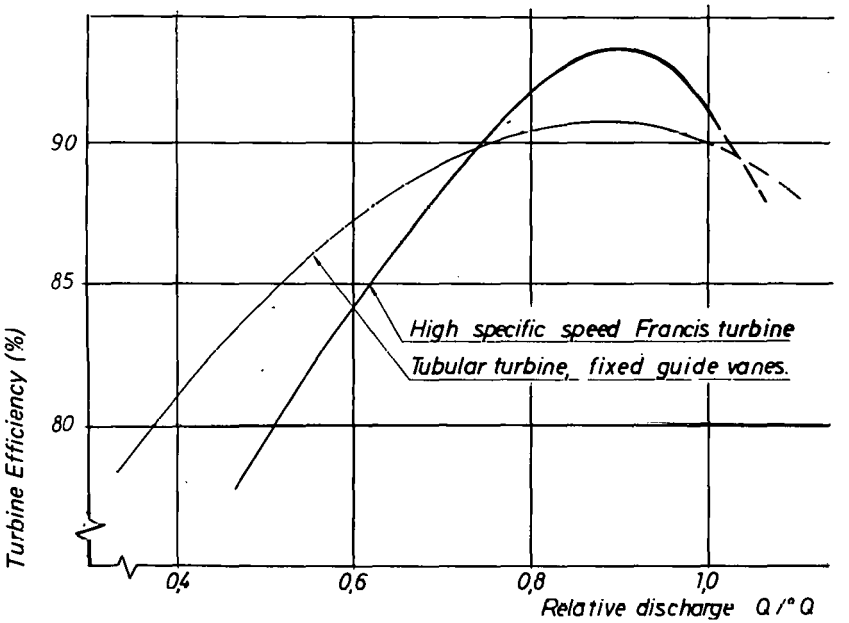


FIGURE W-1.7 Typical efficiency diagram

be higher at lower loads, compared to a Francis turbine with high specific speed. The Francis turbine on the other hand will normally show several percent better efficiency at the highest point of the efficiency graph at about 90% of full load. The Francis turbine is therefore well suited for "on off" regulation. In this case, the Francis turbine in an open pit was preferred due to the favorable vertical arrangement. It was also desirable to permit greater suction head since the tailwater level can vary considerably and a draft tube gate could then be dispensed with.

SMALL-SCALL HYDROPOWER: AN APPROPRIATE TECHNOLOGY FOR LESS-DEVELOPED COUNTRIES

Robert D. Kersten

Introduction

Hydropower technology is on the shelf, and available now, of proven feasibility both technically and economically, and presents a sound and rational energy solution from the environmental viewpoint. It is a technology which could be useful to the Less Developed Countries for the long term irrespective of the shift from abundant low-cost fossil fuel options or the development of more exotic alternate energy technologies.

The gap in standards of living between the developed and less developed countries (LDC's) continues to grow. Progress of the LDC's toward a better life has been slowed by the worldwide economic troubles that continue to result from the 1973-1974 increase in oil prices.(1). The task of meeting the requirements of an energy-hungry world has never been more demanding that it is today. Water power, with its continuing replenishment and non-depleting characteristics, remains one of the most attractive sources of energy (2).

However, insofar as LDC's are concerned, even small-scale hydropower (SSH) tends to be high technology. (See a suggested master plan for Guatemala, Reference 3.) That is, an indigenous infrastructure of personnel and hardware that does not exist is required; major load centers are envisioned (which help more developed areas but do little for distributed rural areas); and significant relatively large civil works will be needed. Thus, even SSH tends to become a capital intensive technology.

The phrase "appropriate technology" is coming into more common usage. Since technology traditionally has connoted technical "hardware," there is a tendency for people to stress this aspect of "appropriate technology" at the expense of a more all encompassing meaning of this concept (4).

One of the most important aspects of "appropriate technology" which must be emphasized, is its social and political dimensions. Relating this to LDC's, it is clear that attempts to improve the standard of living and the quality of life of the people in such countries require more than just technological hardware artifacts. Introduction of modern capital intensive technology into an LDC requires approval and/or cooperation of the political power structure in that country and it is this element which historically stands to gain the most benefits from such technology transfer (4,5).

Utilization of capital intensive technology tends to widen the gap between the rich and poor and tends to increase dependency rather than self-reliance

Dr. Kersten is Professor of Engineering and Dean, College of Engineering, University of Central Florida, Orlando.

on the part of the people (5, 6). Emphasis must be placed on many small steps—"on adopting what we already know is better"—not on buying the latest big machine (6).

The realities of village life do not always lend themselves to sophisticated 20th Century technology. Public, private and international agencies seem to be turning to a "from the bottom up" approach (7). Large-scale capital centered projects tend to bypass the poor, widen economic gaps, and intensify urban congestion.

The question then, is, what current technology would be most useful to many LDC's for the long term? It seems evident that SSH (or even mini- and micro-packaged hydro units) is that technology. The technologies most of the world needs are those based on indigenous energy and human resources of the respective countries. (1).

LDC's now have a total of about 2.8 billion people, or approximately 70 percent of the total world population. For social, humanistic and political reasons, it is essential that the present economic gap between the more advanced and the LDC's be narrowed or closed. Thus energy and resource requirements of the LDC's may well dominate worldwide demand in the next few decades (8). The revival of interest in SSH in the advanced countries could well redound to the benefit of the LDC's.

Distributed Needs

The nature of water resources includes a distributive element which makes it ideal for rural development. The apparent shift in development policy from the traditional "top-down" industrialization approach to the "bottoms-up" reach-the-village approach requires decentralized applications of energy resources attainable through development of hydropower in many regions of the world.

It is generally concluded, that the range of techniques based on renewable energy resources offer the best possibility in the long range, for developing societies throughout the world, for which basic needs can be satisfied, and goals beyond the satisfaction of basic needs are more quality-oriented than quantity-oriented (9). The motivation for any development effort should be either to satisfy *basic needs,* such as food, shelter and human life conditions, or in particular, when basic needs have been provided to *improve standards,* e.g., by providing more material goods or intellectual "goods", by improving working conditions, improving educational opportunities, by increasing public participation in decision making and discussions of long-range social planning.

Distributed SSH systems offer excellent opportunities to not only augment energy supplies to many rural areas, but to begin in a modest way the development of a community infrastructure, training of operating and maintenance personnel, initiation of small-scale agribusiness enterprises, and resulting in relatively major contributions to the improvement of quality of life. SSH is found in abundancy in most mountainous regions and offers sensible possibilities for decentralized applications in LDC's.

Quality of Life

This application of a relatively simple appropriate technology could result in a shift in emphasis from goods to people and thereby result in a general "quality of life" improvement in the LDC's. Certainly modest distributed hydropower developments could lead to increased food production, better utilization of indigenous natural and human resources, prevention of unemployment and urban sprawl through labor-intensive projects, off-setting of population growth by development, improved health care, and augment the role of education for better adaptation in overcoming the problems of LDC's through their own actions.

One cannot identify "quality of life" exclusively with economic factors such as per capita income, gross national product, etc., because many important non-economic factors are also involved. Nevertheless, it is clear that substantial economic growth is needed within the LDC group. Furthermore, it is obvious that in order to close the economic gap, the LDC's will have to sustain long-term real economic growth at annual rates higher than those prevailing in more developed countries. Such economic growth will clearly require increases in energy consumption (8).

What constitutes "desirable development" is a difficult question, and will vary from one country to another, depending upon their own internal aspirations and the way in which those aspirations are influenced by comparisons with more industrialized nations. It seems clear, however, that economic development in terms of real disposable income and the way in which this translates to the availability of goods and services is an essential part of any development plan (8). Thus SSH development could lead to development of dependable clean water supplies, improved health care, refrigeration for medicine, milk and other basics; all of which lead to a more competent work force. Further lighting of communities, provision of radio and television, etc. in the interests of enhanced educational opportunities coud lead to significant community development. Finally, modest energy resources could enable the basic processes (e.g. grinding, sawing, milling, pumping, etc.) to be undertaken that would contribute to economic enhancement of indigenous natural resources with a resultant real economic growth.

More importantly, this small step could contribute immeasurably toward freedom from hunger (5) and lead to many improvements in nutrition, health care, rural and urban development, etc. (10). It must be recognized, however, that the key is the ability to produce and use energy in even relatively small quantities.

Impact of Small-Scale Hydropower on Less-Developed Countries

Consideration of the implications of the development of a renewable energy resource (hydropower) on the general economic development, social and political framework or infrastructure, and enhanced potential of LDC's to provide for themselves is exciting to consider. The challenge of supplying food, housing, health service and education for some six billion people by the

year 2000 (70 percent or more in LDC's) is the main engineering problem for the rest of this century (11).

An approach which stresses rural development programs is ideally suited (from an energy standpoint) in many LDC areas to SSH. Modest energy production could enable implementation of rural development programs aimed at increasing food production, preventing unemployment and urban sprawl through labor-intensive projects, offsetting population growth by development, and augmenting the role of education for better adaptation (11). Recent evidence in China, Egypt, Costa Rica, and other countries indicates that population growth is best curbed by better economic conditions rather than politically tainted policies.

The choice of energy (and other) technology influences a given society in several ways, such as demanding certain skills and education, by introducing certain usage patterns, by placing emphasis on conservation or oppositely on wasteful habits, and determining the scale of certain infrastructures (9). Particularly, for LDC's, the choice of energy (and other technology) can have a very strong influence on the kind of society emerging. Some choices will well promote the development of large concentrations of economic activity, enhance the influx of people to the large cities, and preserve the power and profit in the hands of a minority.

Other choices are more likely to promote the development of rural areas, and by spreading the economical activity also make it easier to follow a policy of approaching a more equitable distribution of profits (9). It is likely that at least some of the renewable energy technologies are compatible with or directly stimulating for an equitable distribution policy. Emphasis on transfer of SSH technology would appear to be a near optimal choice to support this strategy. Clearly, it could lead to renewed emphasis on community health programs, rural and community development and enhanced agriculture (6, 7, 10, 12). Such activities would tend to be labor-intensive, spread over a large number of small projects, and involve technology transfer on a people-to-people basis.

Economics

A brief comparison of hydropower project economics versus scale of development and several pertinent technologies is presented in Tables W-2.1 and W-2.2.

The four sensible alternatives for small scale (including "mini" and "micro") are noted in Table II. Production expenses tend to eliminate "fossil engine" and capital costs eliminate photovoltaics. Wind machines of mini/micro scale may be feasible in some localities depending upon storage battery economics. SSH has the clear advantage. Further improvements in economics should be expected if equipment manufacturers can standardize and package units for rural/remote installations.

TABLE W-2.1

AVAILABLE TECHNOLOGY

TECHNOLOGY \ SCALE	LARGE ≥100MW	SMALL 10≤MW<100	MINI 1≤MW<10	MICRO MW<1
Nuclear	*			
Coal	*	*		
Oil	*	*		
Gas	*	*		
Fossil Engine		*	*	*
Solar Thermal		P		
Solar Photovoltaic				*
Solar Biomass		P		
Wind		P	P	*
Hydro	*	*	*	*

P = in pilot plant stage

TABLE W-2.2

TYPICAL COSTS

TECHNOLOGY	INSTALLED CAPACITY $/kW(1)	PRODUCTION EXPENSES Mills/kWh (1)
Nuclear	800 - 900	4 - 8
Coal, Oil, Gas	300 - 400	15 - 20
Fossil Engine (2)	300 - 400	300 - 450
Photovoltaic (2)	10 - 20,000 (3)	NIL
Wind (2)	1500 - 2200 (4)	NIL
Hydro (2)	200 - 3000 (5)	1 - 2

(1) Data from various sources including DOE Plant Construction Cost and Annual Production Expenses reports.
(2) Sensible alternatives considering scale.
(3) Estimates are in $5-6,000 range for 1985.
(4) Optimistic does not include storage batteries.
(5) $3000/kW average cost of President Carter's "Rural Energy Initiative."

REFERENCES

1. Abelson, Phillip H. and Irene Tinker., "Technology Transfer", *Science,* Vol. 195, No. 4276, 28 January 1977. P. 351.

2. Seoni, R. M., et. al., "Review of Trends of Large Hydroelectric Generating Equipment", *Proceedings IEE,* Vol. 123, No. 10R, October 1976. P. 1138.

3. Goertner, M. and S. Morarin., "Electricity Masterplan for Guatemala," *Water Power and Dam Construction,* June 1977. P. 50-52.

4. Slaby, Steve M., "Appropriate Technology, A Means Towards the Development of Self Reliance", *Working Document,* Segundo Simposio-de Ingenieria, El Salvador, Centro America. 19-23 Febrero 1979. P. 36.

5. Nicholson, Heather J. and Ralph L. Nicholson., *Distant Hunger, Purdue University Series in Science, Technology, and Human Values, Vol. 3, 1979. P. 167-8.*

6. Grubbs, W. Eugene., "Can We Really Help?" *The Commission,* Vol. 42, No. 7, July 1979. P. 7.

7. Skelton, Martha., "The Upper Volta, Relief is Spelled P·E·R·S·E·V·E·R·E", *The Commission,* Vol. 42, No. 7, July 1979. P. 9.

8. Thomas, Carl O. and Jawaharlall Baquont., "Resource Utilization in Emerging Nations: Technical, Economic, and Policy Relationships," *Proceedings, Appropriate Technology for Underdeveloped Countries,* San Salvador, El Salvador, February 19-23, 1979. P. 1-35.

9. Sorensen, Bent., "Energy Technology and Social Structure", *Proceedings, Appropriate Technology for Underdeveloped Countries,* San Salvador, El Salvador, February 19-23, 1979. P. 38-55.

10. Cheyne, John R., "Can This Dream Become a Vision?," *The Commission,* Vol. 42, No. 7, July 1979. P. 12-13.

11. Cortes-Comerer, Nhora., "Changing Concepts for a Developing World," *Civil Engineering,* American Society of Civil Engineers, January 1977. P. 66-69.

12. Crawley, Winston., "Pyramid of Possibilities", *The Commission,* Vol. 42, No. 7, July 1979. P. 13.

MICRO-HYDRO AS AN APPROPRIATE TECHNOLOGY IN DEVELOPING COUNTRIES

Rupert J. Armstrong-Evans

Background

Waterpower development in Britain was a long and slow process but at its peak there were tens of thousands of mills in operation. It was the Industrial Revolution which brought about its rapid development for mining, textiles and engineering power. Whereas the old water wheel was well suited to the slow running applications such as corn milling, it was soon replaced by turbines that were much more compact and also able to make use of a wider variety of sites. With the invention of electricity, dynamos were fitted in many corn mills, mines and other engineering establishments. Many of these early plants were not purposely built to produce electrical power but even a few kilowatts of electricity were very desirable for lighting purposes. The communities around these centers were often the first to have electric light and it was engineers from these centers that often built the next generation of installations, for farm and village projects. The turbines were either built by one of the specialized turbine manufacturers which by this time had been established or they were simple, locally-built machines, some of which are still running today. The only shortcomings of the simple machines were their governing, a matter which can now be overcome. The purpose-built machines reached their peak in the nineteen thirties and virtually no changes in the basic design have been introduced since; as would be expected the price of these units is not prohibitive for small schemes. It was with these factors in mind that we set out to rethink the whole system in which small plants are built.

Budgetary Control

When investigating the economics of micro-hydro it is important to look at the proportion of the budget that is spent on design, civil works, the plant and distribution; and to keep them in a carefully controlled ratio whatever the power output. It is easy to appreciate that the time it takes to design a small turbine could be as great as that required to design a large one, but the former may never be able to justify the marginal costs of a skilled designer. In my opinion it is essential to look at every feature of a machine, such as flow control, and determine the actual cost benefit of that feature. The principle that I am putting forward is simply that the smaller the plant, the simpler the system has

Mr. Armstrong-Evans is Director, Evans Engineering, Launceston, Cornwall, England and a consultant with Intermediate Technology Development Group, London.

to be to remain economic. This not only applies to the plant but also to the organization and system that is employed to install and run these plants. This is the reason that most international consultants cannot find an economic way of building plants of less than about 500 kW. At the other end of the micro-hydro scale a unit producing as little as 500 watts, which could be bought in the local bazaar, could be both economic and serviceable if it were installed by the purchaser.

It should not be overlooked that large schemes can result in considerable economic and political power being vested in the hands of a few people. Large schemes also involve large loans because the scheme cannot be built up over the years as demand increases, there being civil engineering structures which are required right from the outset of the project. On the other hand, small-scale hydro can be developed by local industry at a rate suitable to the area. Large schemes will tend to create jobs during the construction phase, and subsequently in large power, using industries which may not be the most desirable type of development. Finally, there is the tendency to supply the urban areas first for economic reasons—and this may only increase the problems of urban growth. In Appendix I, I have laid out some details of the type of system that I think is appropriate to the size of the powerplant and the type of development.

The Application of Load Control (see Appendix II)

After many years of building and running small hydro installations, my father and I have come to the conclusion that: (1) It is not worth building a mechanically complicated machine just for the purpose of governing, when this can be achieved by other methods such as load control; and (2) It is not usually worth designing a machine to operate under low-water conditions if the kilowatts that are produced under the circumstances are uneconomic. It is better, under such circumstances, to install several fixed-geometry machines or even run a diesel plant during the dry season.

Over the last few years we have developed the concept of electronic load control governing from a simple system built by my father 30 years ago, to one which can control many types of distribution network. We have found the system both cheap and reliable and although many people were skeptical in the early days we now find many engineers around the world adopting the system.

Some years ago I was fortunate enough to meet up with the Intermediate Technology Development Group, which was set up by the late Dr. Schumacher to promote self-help type projects in the developing world. Since that time we have together been looking closely at the problems and potential of some of these countries and trying to design equipment and systems that are both appropriate to the site and to the people who will build and operate them. Our key objectives have been:

1) To reduce the complexity of the mechanical work to whatever the builder is capable of carrying out.

2) To keep the quality of the materials as high as possible where it is critical to the operation of the machine.

3) To separate the functions of heavy mechanical engineering from that of electrical and control. This cuts out the area of precision engineering associated with governor manufacture.

4) To use locally available materials where practical.

With our village sized plant, i.e. 5kW to 100kW, we use this mixture of simple mechanics and electronic control, and I see the day coming when we can produce a machine which will require no maintenance at all between bearing changes, being a period of at least five years and typically ten. Some people may be surprised to find electronics as an appropriate technology, but if we look at what is involved in the construction of a hydraulic governor, in terms of machinery and trained personnel then it is easy to see that one moderately competent electronic engineer with only the most basic facilities can build and repair all the electronic governors that a country could use. Another advantage is that the unit is so cheap and small that a spare unit can be carried in your pocket and can be replaced by an unskilled operative if the need arose and the faulty unit returned to the service engineer. As many developing countries have a thriving trade in transistor radios it is not too difficult to find suitably skilled people to carry out this kind of work.

Implementation

Let us examine in more detail the various types of plant and system that can be used. We have already said that outside contractors and consultants would be hard pressed to make even a 500kW plant economic unless it was part of a larger development project. The first level which I am concerned with is the local or district-sized scheme and is the most common size being proposed at the present time for rural electrification, i.e. 50kW to 100kW. To build such schemes will almost certainly involve a government department, if it is not directly for an electricity department. Such projects involve tariff collection and may well form part of a future grid system. The feasibility study would typically involve two people who must collect all the physical data necessary to design the scheme. This includes survey data, geology, and hydrology. The other main area which should be covered concerns the economics, use and distribution of the power. It is necessary for there to be a considerable overlap in the functions of these people as no scheme of this size can justify the specialist engineers, hydrologists, and geologists necessary for larger schemes. At the design stage it is imperative that those who carried out the feasibility survey should also do the design work for the site and at least specify the equipment if they do not actually design it. Pilot projects usually involve more people than could be justified economically. If this size of project is to be adopted as a norm then it is probably advisable to form a company that is specifically concerned with micro-hydro work and can carry out everything from the survey to the management. The company should either have its own workshops or be a joint venture with an existing engineering works.

I am mainly concerned that the initial organization is pitched at the right level, rather than what happens once the projects are under way, because any split between survey and design, and between design and construction could

spell disaster for the project. It is not uncommon for friction to develop where one organization designs a site and another builds. It is absolutely imperative that the whole organization comes under the same management with small schemes.

The next level down, i.e., between EkW and 50kW, may be a lone engineer or a firm of agricultural engineers who have a hydro-engineer on their staff. The problem is getting the wide range of engineering skills without having to employ specialists on the smaller projects. An established agricultural engineering firm will already have the "in-house" skills to tackle this kind of work, but to set up a company from scratch with specialists will require a very rapid expansion to over 20 plants per year to become economic. The lower end of this power range which I have called "village" schemes, will have to be carried out by a "lone engineer" who must survey, design, and install the plant; though the plant itself can be brought in and he will obviously have site labor. The involvement of other specialists could kill the project economically. For those people who say that this scale of operation is not worth bothering with, I would like to point out that in Wales, which is a fairly mountainous region of the U.K., over 400 small-schemes were built, nearly all of which were less than 10kW. Most of these plants were built by lone engineers operating from very small workshops. One particular man installed over one hundred such plants in his lifetime and some bought components for their turbines from my grandfather's company. At this level it is the engineer himself that is the key to success and not the organization, so effort in promoting this level of electrification should go into training and support for the man in the field.

Finally, the lowest level of output is the units below 5kW. Many people will consider this a joke but it all comes under the heading of micro-hydro development. It is not economic for an engineer to survey and install such units unless the system is virtually a "door to door" operation. Once such units are established they should be available in the local Bazaar as would a small diesel plant and the installation must be very simple and be carried out by the purchaser or with some help from the salesman. The system must be low-voltage and as safe as possible as it must run with little or no technical backup. The smallest plant that has been suggested to date is only a few inches across and is suitable for charging radio batteries and should cost only a few dollars from a local shop.

Overall Planning

Decide what type of development or what mix of systems. If you build one large plant and it is a failure you lose everything, but with smaller units you can afford many more so you disseminate the technology faster and it is extremely unlikely that all of your plants will fail. Even those plants that have failed can be moved on to new sites or rebuilt by those people who have made a success of other schemes, so all may not be lost even with the initial failures. Large schemes, however, train few people and any mistake in the engineering tend to be very permanent and expensive to rectify.

Our basic philosophy is that you start small and introduce a plant which can be looked after locally and as people want more power they replace them with larger units and their old units go to new sites. And so the process continues, with the "old hands" having the most experience taking on the bigger and more sophisticated units. If however, you build from the top down, i.e. by installing a 100+ kW unit you do not disseminate the technology because you have a "technology gap" as exists in western countries with nuclear power when the staff are trained externally and not from within the system.

It is important that a general plan is made to cover later stages in development, for example:

1. The future development of larger sites of up to 1MW is an area and what effect this will have on existing plants, will they lose their consumers to the new project or will they be worked into the system?
2. Who will control abstraction and water rights?
3. What standards of voltage and frequency will be adopted?
4. Can diesel plants be used to develop load centers prior to a more major water power scheme being constructed?
5. What tariff structures can be used to stop the peak-load problems from developing?
6. What industries can be promoted to use surplus power during the wet season?

Conclusions:

(a) The use of electronic load control facilitates the use of very simple mechanics and thus reduces the cost of a turbine plant by up to 80% .

(b) There is a complete family of electronic control devices which can be used to economize on water, optimize plant output and the investment on power lines; and all can be built with minimal facilities in developing countries.

(c) It is important that a tariff structure is set so as to encourage the installation of equipment that does not cause high peak loadings. e.g., heat storage cookers.

(d) If power was purchased by capacity rather than by units consumed it dramatically reduces peak loadings. In Norway the system involved a watt-hour meter that only started to record when the rated supply current was exceeded and the cost of these extra units used over and above the rated supply was so high as to make it unattractive.

(e) Simplicity of design does not imply poor quality and reliability is a function of simplicity.

(f) The system adopted for the development programme must be 'Appropriate' to the actual size of the units being installed, in order to keep the correct ratio of costs.

APPENDIX I

A Micro-Hydro Development Program

Initiation of Project

Information gathering

(from external agents,
consultants & manufacturers)

Overall Planning

(determination of: policy, timing, industrial development, organization)

Financial Planning	System Design	Training Program
(type & terms)	(production, consumption & logistics)	(type & depth)

Capability Point.

Specific Project.

Budget	Specific Design	Manpower

(site, equipment, load management logistics: construction & maintenance)

Implementation

Operation

After the project has been initiated, there follows a period of information gathering, when the person or committee seeks information from consultants, manufacturers or technical publications. From this an outline plan must be formulated; covering the type of development, what effect it will have on industry and the community and also what type of organization should be encouraged or setup to best meet the type of development required.

More detailed plans are then evolved to cover the finance, system and training future staff. By the end of this phase we have a capability to tackle a specific project. Once the specific project has been selected then the final stage can be started, and this involves the budget, the specific design and the manpower. As you will appreciate all these factors are closely interlinked and impose restraints on each of the others. It is the failure to look at a project in this rather simplistic way that results in so many small projects being abandoned. Design and manpower must be tailored to fit the budget and budgets should be worked out from the return on capital and projected costs of alternative power systems.

Only too often a designer is working in a vacuum and he produces a design which is rejected because it is too expensive. It is in my opinion vital to work very closely with the financial planning side and maintain this balance between the various sections of the project.

APPENDIX II

Electronic Load Control

All hydroelectric systems require some form of governing system. Let us suppose a system of 20kW is operating at full-load, providing power at the desired voltage and frequency. If loads amounting to 10kW are then switched off, the rotational speed of turbine and generator will start to increase, giving a greater voltage output at a higher frequency, both undesirable effects, as well as being potentially dangerous to the generator through over-speeding. The conventional solution to this problem is to reduce the flow of water into the turbine until the electrical output of the generator is again appropriately matched to the load; this approach may be termed flow control. The mechanical or hydraulic governor needed for this purpose is a complicated and expensive device, which for small installations is typically more expensive than the turbine itself if it is to have a similar operating life and reliability.

The alternative approach, possible with the use of an electronic load controller, is not to vary the amount of water entering the turbine, but to ensure that the electrical load connected to the generator remains constant, and hence the system works at maximum power all the time (this may, of course, be done without any form of mechanical or electrical control device at all, but for a system of moderate size serving distributed loads the problem of ensuring that these loads remain constant is difficult without some form of control mechanism). A relatively simple electronic device is connected to the generator, the device senses the output and ensures that the voltage and frequency remains constant by diverting surplus power into a ballast load. Thus, in the case mentioned above, initially all output from the generator will be going directly to the primary load; when 10kW of primary load is removed, this is sensed rapidly by the controller (far more rapidly than the response that any mechanical system can achieve), and 10kW is switched to the ballast load.

It may be felt that the diversion of surplus electrical power to a ballast load represents a waste of power which would not occur with a mechanical governor. However, except in the relatively unusual case of the supply of water being limited (for example, if the turbine is fed from a reservoir), it is clear that a mechanical governor causes waste of power by shedding water whereas a ballast load can be usefully employed. It is also important to note that an electronic controller is no less appropriate for use in a developing environment than a necessarily complicated mechanical governor, whose manufacture will require precision engineering facilities. Electronic components will certainly need to be imported by many countries, but assembly of the controller demands very limited facilities, can be carried out in low volumes, and does not require high level skills.

The most significant advantages of electronic load controllers for use in micro-hydro-electric installations as compared to conventional mechanical governors are summarized below:

1. Cheapness: the U.K. cost can be between £100 and £500 depending on the rating and number of phases (the latter cost would apply to a 3-phase installation of 40kW); this will constitute at least an

80% reduction as compared with currently available conventional governors. The cost is sufficiently low, that, if desired, a spare controller may be kept on site.

2. Reliability: no maintenance is needed for the electronic system, and such devices have been in use for a total of over 250,000 hours in 25 installations in the U.K., with no significant failures having occurred.
3. Easy transportability.
4. The possibility of using surplus power in the ballast circuit for a variety of purposes, rather than deliberately shedding water power as in a conventional system. This is of considerable interest, since the possibility of making practical use of the surplus power developed in the ballast circuit has very desirable effects on the load factor, and hence on the economics of the system. Systems installed in the U.K. have provided hot water, cooking and space heating. Other possible uses include absorption refrigeration systems and various industrial processes.
5. The possibility of using simple, fixed geometry turbines, since no provision need be made for varying the flow by means of valves or gates.

Implications of Load Control on Turbine Design

The adoption of the load control system facilitates the design of very simple turbines suitable for local manufacture. The traditional Pelton wheel is controlled by a combination of a variable jet (spear valve) and a deflector, the latter being directly linked to the mechanical governor. Such plants are expensive and do not give the maximum output afforded by a turbine using several fixed jets which can be opened and closed to meet seasonal variations in river flows.

Load control was originally designed for use with low-head reaction turbines, because the components necessary to achieve variable flow in such turbines are much more expensive than those required in either medium or high-head impulse turbines (see Appendix IV for classification of sites).

The actual mechanical governor will cost about the same whatever the turbine type, but a mechanically-governed Pelton wheel would only require additionally the inclusion of a deflector, a mechanically governed low-head installation would require a Kaplan or Francis turbine, both of which have a large number of intricate and accurate machine components and are therefore complicated and expensive to build.

The load controller thus makes possible the economic development of low and very low-head sites, down to as little as 1 meter, which were formally excluded because of the high cost of the equipment. Seasonal variations in river flow are catered for by the provision of two or more smaller units of different capacity which can be run in various combinations and permutations. Added advantages of installing several smaller units instead of one large unit include portability of equipment for easy installation and the simplicity of the alternator drive, which results from the higher shaft speeds of the turbines. By

adopting a modular design for the installation, considerable savings can be obtained in time and cost.

APPENDIX III

Economic Analysis of Rural Electrification by Micro-Hydro

A study of the economics of micro-hydro electricity generation in Nepal has been carried out by ITDG in 1979 in connection with a Nepal micro-hydro project with which ITDG is working in close collaboration. Based on reported costs at six existing or planned sites, estimates of capital costs of a "model" installation of 40kW were made as follows:

	%
Civil Works	24.0
Generating Equipment	27.4
Transmission	36.5
Other	8.2
Transport	3.9
	100.0

Total costs for this hypothetical installation would be Rs. 829,800 (approximately £30,000) of which Rs. 275,900 would be accounted for by unskilled labor, largely in the civil works. The cost per installed kilowatt would therefore be about Rs. 21,000 (£750).

Annual costs for the "model" 40kW installation were estimated as follows:

	%
Depreciation	13.5
Maintenance	6.9
Loan repayment (10 years @ 10%)	79.6
	100.0

Annual cost for this installation would be Rs. 169,600 (£6,100) of which the repayment of the loan is much the most significant factor. Estimates of capital and operating costs of a similarly-sized diesel installation were also made based on a local study; the combined results are presented in Figure W-3.1.

Additional important assumptions are: fuel cost at site Rs. 4.7/litre; total capital cost of diesel installation Rs. 440,000 (£15,900). Significantly no allowance was made for increasing fuel costs (currently estimated by the World Bank to be increasing at approximately 8% per annum in real terms for developing countries) and it may be noted that after the ten-year loan repayment period, the sole cost of generating hydro-electric power will be the maintenance of the equipment whose life should extend for much longer periods.

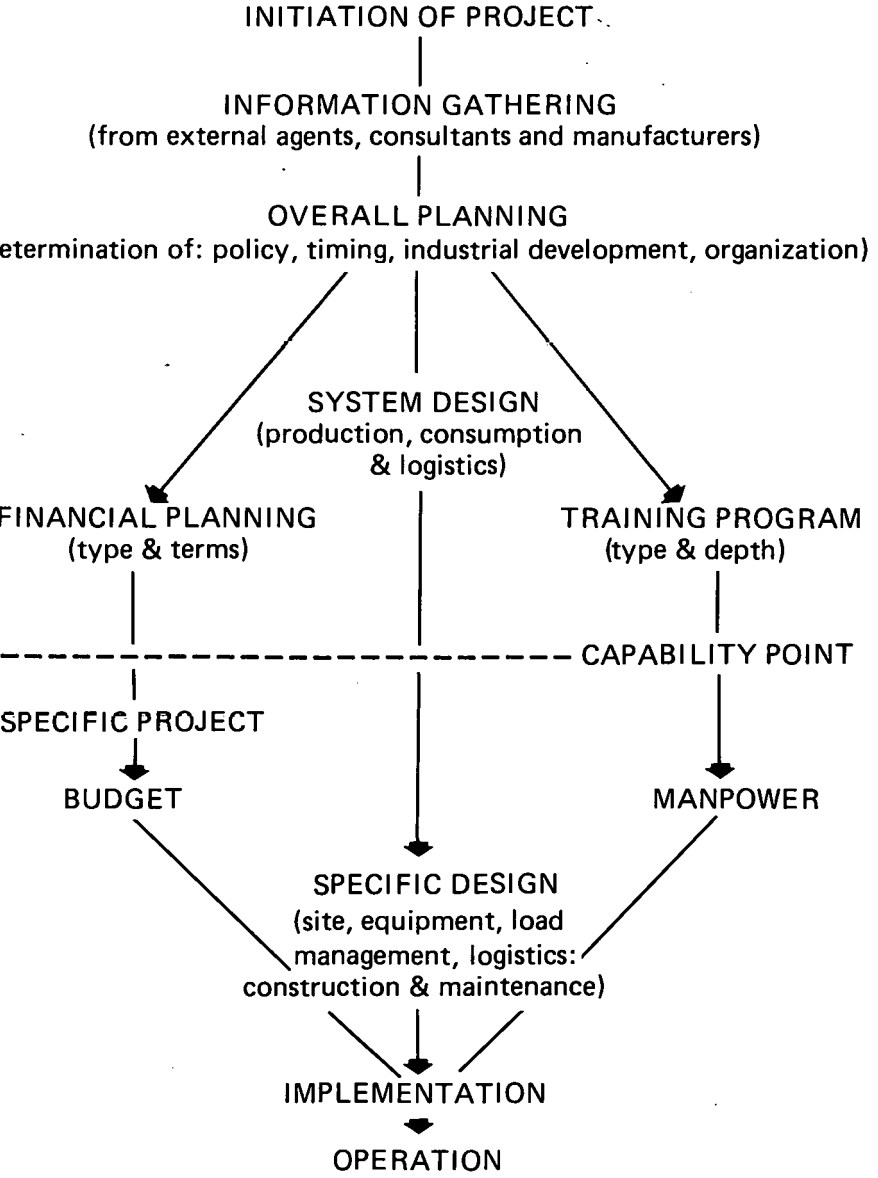


FIGURE W-3.1 A Micro-Hydro development program

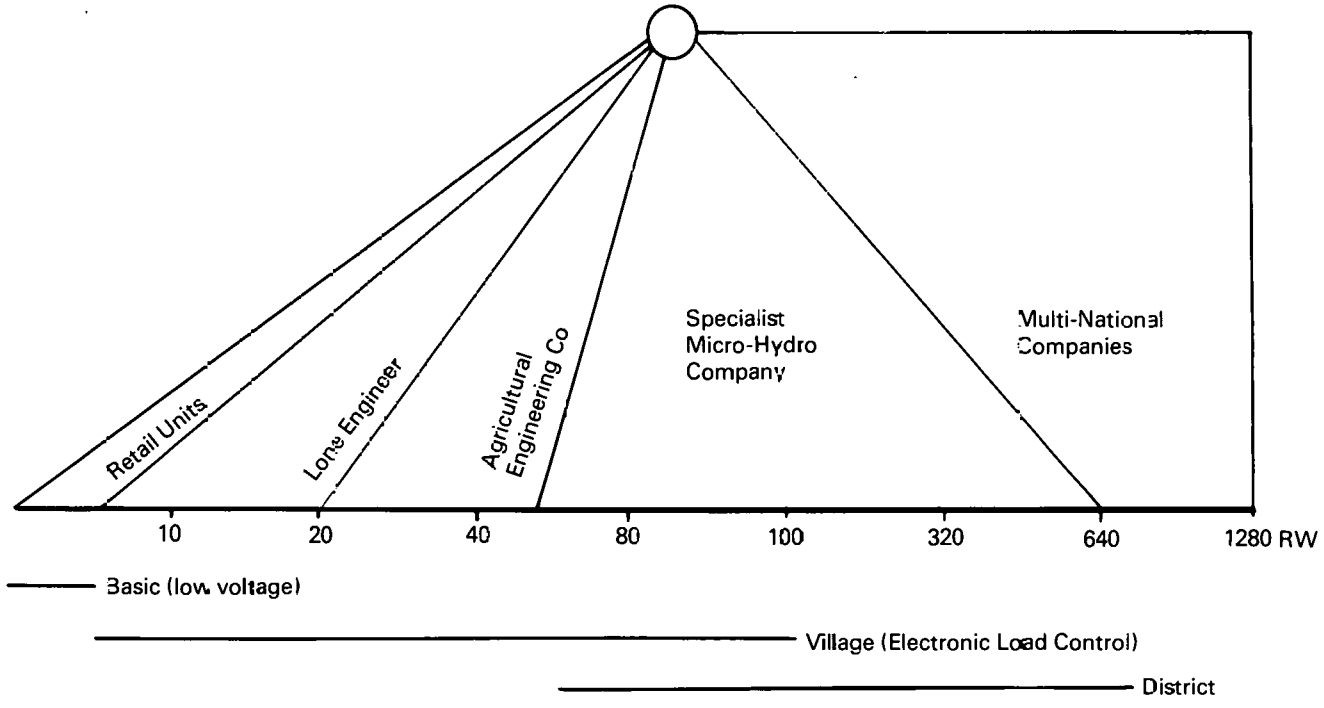


FIGURE W-3.2 Maintaining Balance Between Sections of a Project

The principal conclusions from this study of the two alternatives for rural electrification are:

- Total operating costs are equal for the systems at a load factor of about 0.1.
- At a load factor of 0.4, hydro approaches grid electricity (at about Rs. 0.35/kW hr) in cost.
- In either system, load factors (or capacity utilization) must be good if costs to consumers are to be acceptable.
- The very low (or zero) marginal cost of hydro means that off-peak or special category sales at very low prices can contribute to fixed costs.
- At a load factor of 0.3 average unit costs of hydro are equal to the minimum marginal cost, i.e. fuel only, of the diesel system. Hence micro-hydro installations should be able to undercut existing installed diesel electric costs at moderate capacity utilization.

Although the data used in this study are specific to Nepal, they are in some respects uncertain and use was not made of the low cost technology advocated earlier in this paper. It is reasonable to conclude that similar results will be found at any site where the choice of technology for rural electrification is to be made between a micro-hydroelectric installation and a diesel generator set. It therefore seems clear that where a load exists, i.e. where a diesel generator is in operation and needs replacement or where one can quickly be developed, a small-hydro scheme would be a good commercial option. It would also have desirable socio-economic effects in the form of local employment, import reduction and income distribution.

In practice, however, most cases are less simple. The installation would often be the first source of power available and capacity utilization could be low while people adjusted to the use of electricity and small industries developed on the basis of the newly available power (this is borne out by experience in Nepal). Early years of operation are likely to be unprofitable, and this will not be appealing to investors, either private or public. Financing which matches the expenditure/return pattern therefore seems desirable, in the form ideally of a loan with a (say) two-year grace period before the start of repayment.

APPENDIX IV

Outline of Evans/ITDG Experience and Advisory Capability in Micro-Hydro Electric Systems

(a) *ITDG:* The Group is a London-based non-profit organization established in 1965 with the following aims:

1. To identify gaps in the range of technologies available to developing countries;
2. To develop new technologies, when necessary, or to modify existing ones to make them more appropriate;

3. To test and demonstrate intermediate technologies and to publish and disseminate the results;
4. To assist developing countries both at a technical level and with policies to make the best use of their productive resources.

(b) *ITDG Power Activities:* These are managed by the ITDG Power Unit and include advisory work and joint collaborative hardware development projects in the fields of water, wind, biomass and solar power. Micro-hydro-electric power is one such field.

(c) *Evans/ITDG Experience in Micro-Hydro:* The Group has been collaborating over recent years with the small British company, Evans Engineering, in the development of small-scale hydro-electric systems in the power range 1kW-100kW for use in the U.K. and developing countries. More specifically this collaboration has concentrated on the following work in the U.K:

1. *Technology Development.* Development of three different electronic load control systems. Further development work being undertaken to prove the systems at capacities up to 100kW and over. Development of high and low-head turbines using load control.

2. *Installations.* Design and installation on a commercial basis in the U.K. of over 20 electronic load controlled micro-hydro systems of power outputs ranging from 1.2kW to 40kW and heads ranging from 2 meters to 60 meters.

The above work has been undertaken with a view to transferring the technology to developing countries and helping establish a local capability in manufacture and installation. Work undertaken with developing countries includes:

1. Manufacture of dispatch of a complete micro-hydro plant for a pilot installation in Lesotho and components to Fiji, Pakistan, and Nepal.
2. Introductory training in the U.K. of engineers from Sierra Leone, Belize, and Papua, New Guinea.
3. Advisory visits to Kenya and Nepal.
4. Technical assistance and funding to a Nepal pilot micro-hydro project of 30kW (with IT-Industrial Services, the industrial unit of the Group).

(d) *ITDG as a micro-hydro resource organization:* The Group provides advice on all aspects of micro-hydro systems from site identification through to plant design, manufacture and installation, the main objective being to establish a local manufacturing and installation capacity. More specifically the Group can respond to request for assistance through:

(a) advisory visits;
(b) collaborative projects (including provision of hardware where appropriate) and
(c) training.

APPENDIX VI

Classification of Sites

In order to specify the size of machines under consideration, and the types of use to which they may be put, it is useful to subdivide micro-hydro installations by power, into the following classifications. In general, the cost per kilowatt of installed capacity will drop with increasing size of system.

Scale	Power	Use
Very small - low	1 kW or less	lighting for up to 10 households, battery charging.
Village	5 - 100 kW	lighting for 10 - 100 households, water pumping, agricultural and light industrial uses.
Local electrification	100 - 500 kW	All purposes; a high voltage distribution system would probably be involved.

It is also important to make distinctions between the types of machines that are used at different sites, depending on the head:

Classification	Head	Type of turbine
Very low head	up to 3 meters	Open flume reaction turbines, possibly built into the dam.
Low head	3 - 6 meters	Cased reaction turbines.
Medium head	6 - 30 meters	Impulse turbines - Banki (Mitchell) or Turgo impulse types.
High head	30 meters upwards	Impulse turbines - Pelton Wheels

The above distinctions are for a nominal power of about 10kW; at different powers the dividing line between the different types of turbine to be used will occur at different heads. For example, it would not be appropriate to use a Pelton wheel at sites with less than 40 meters head if the power output is 25 kilowatts.

SMALL HYDRO — A VIABLE ALTERNATIVE NOW

John S. Gladwell and Calvin C. Warnick

Throughout this conference we have heard and will continue to hear why small hydro is already a feasible alternative. Then why is it necessary that we meet at all? Why do solar or wind enthusiasts find it equally necessary to meet and keep saying that they too have feasible alternatives?

Is it in part because we continue to use the wrong word? Are we stressing too highly (continuing a long treasured concept of abundant energy) the idea that we have all kinds of choices? It seems likely that if we continue our present attitudes toward energy we will be approaching the time when we will be beyond considering any energy source as an "alternative" to any other source. Some think we may be very close to that time. In most parts of the world—certainly in the United States—we need to consider all sources of energy. But still, hydro is not usually thought of, other than as an aside.

It is, unfortunately, all too common knowledge that hydro is passe. After all if it were really worth discussing we would be doing something about it. We all know that there won't be any more big dams—and those small ones don't do enough to worry about. In fact those small dams just complicate our systems unnecessarily. We've all heard these comments.

The authors disagree emphatically on all counts for several reasons. First, we believe we will see a shift away from our present all too emotionally-based environmental bias to a much more reasoned conservation approach. This will eventually open up many hydro opportunities. Second, we believe when we get serious about energy development we will see that the problems of integrating small hydro into large systems will be solvable without the predicted disasters. And, finally, we are extremely pleased to hear of utilities that are taking rational perspectives on small hydro—a radically different view many were taking not two or three years ago.

Hydro is *a* source of energy. It may not always be the source that needs to be developed first—but to arbitrarily cast it aside because it doesn't solve the problem is an incredibly naive view of this world's energy situation. Happily, more and more decision makers are beginning to realize this.

The one thing we all need to get out of our collective minds is that there is a single (or simple) energy fix to this increasing world problem—or that there should be. The great challenge for the world today is to develop a balanced energy future, taking into account the most appropriate and reasoned use of all our resources.

In some areas of the world the importance of small hydro may not be quantitatively or economically sufficient to warrant its serious consideration at this

Mr. Gladwell is Director, Idaho Water Resources Research Institute, and Professor of Civil Engineering, University of Idaho, Moscow.

Mr. Warnick is Professor of Civil Engineering, University of Idaho, Moscow.

time. But in many areas, even though the overall percentage of that guaranteed by small hydro may be small, its incremental value will be much greater. Furthermore, because hydro systems are capital intensive relative to operational costs they tend to have built-in inflationary protection.

An important fact that must be remembered is that something around 600-700 kWh production at a hydro plant almost anywhere will reduce the requirement for oil (or its fuel equivalent) by one barrel. If you are not an oil rich nation, that should be significant. If you have oil reserves, it means they will last longer.

Which makes us point out that there is an alternative that must be considered by nations, particularly developing countries—the alternative of being responsible for their own energy futures, or being forced to depend upon external owners, possibly unreasonably.

Economist friends tell us that there is nothing wrong with being dependent upon external sources (powers) for anything as long as it is advantageous to you. We agree. Free enterprise is a wonderful thing. The idea of trying to live on an economic island, independent of any other group—even if it were possible—would probably not be in a country's best interest.

Yet, countries do not want to become overly dependent upon others for their existence—certainly not on those key resources that could cause social and economic disaster should the supplying country make an unfortunate decision regarding the supply. Energy resources certainly fit that description, as the United States is beginning to realize. Whether or not the OPEC nations are justified in raising their prices is irrelevant. The fact is that it is causing important problems, which in a number of ways might have been avoided. As mentioned before, we need to consider balanced energy programs. This means that we should not be too quick to reject the renewable energy resources.

The more use a country can make of hydro or other renewable fuels the less it may have to depend upon external forces in its drive to modernize or maintain its independent existence. This is as true of the United States today as it is of the least developed country in the world. Yet for a number of practical reasons the concept of small hydro—really hydro in general—will probably find more wide reception in developing countries.

As Mercer (1978) puts it in discussing the difference between European and American attitudes on small hydro,

> . . .the impression that low-head development has been bypassed in North America by planners who are pressed to develop large blocks of power to meet rapidly growing load demand. The tendency is likely to continue, even as the pollution problem associated with thermal and nuclear power increases. The development of low-head power, where economically justifiable, will seem to depend on the action of persons conscious of the waste of an untapped non-depletable national resource rather than on persons looking to meet power demands.

But should this be true? Unquestionably the amounts of power produced by small hydro projects will never satisfy our present demands. Must we,

however, continue to wear blinders and look only for the big blocks of new energy to the exclusion of the smaller (and more numerous) sources? Can we so casually accept the risks of the big energy sources, then argue so vehemently about the minute losses (if any at all) that many hydro projects would cause? Can we so quietly accept economic analyses such as I recently heard that says we will have all the free energy we want from the fusion process if we only invest $30 billion dollars in research? A system that we are not even sure today will ever work? Attitudes like that point to the single fix mentality.

If for no other reason at all, the use of hydro in developing countries is a logically simple step. The last thing those countries need is to be thrust unwittingly into a nuclear technology age, and in most cases be needlessly dependent thereafter upon foreign expertise. Although the individual hydro outputs may be small, the system is one that can be comprehended and can be depended upon to produce with high and consistent efficiency. And, it uses the countries own resources. But some would claim that the amount of hydro potential remaining does not warrant a serious program of effort on our part.

Is there really that much hydro left to be developed in the world? Without a doubt the theoretically developable potential is extremely large. In the Pacific Northwest of the United States we have, in a recent study, found nearly 40,000 MW (Gladwell, et.al., 1979a). Obviously only a small portion will be developed—economic, social and environmental perspectives will take their toll. On reviewing specific sites, we found a potential of nearly 12,000 MW (Gladwell, et.al., 1979b). Again many will never be developed; but those were only the previously identified sites.

Nationally, as most of us here are aware, a Corps of Engineers study (U.S. Army, COE, 1977) revealed a potential of nearly 55,000 MW by retrofitting or expanding existing structures alone. Although the estimate may be practically overestimated, it nevertheless indicates a significant and presently undeveloped national renewable resource. (That sum alone represents an oil-fired capacity of 266 million barrels of oil annually.)

Internationally, the World Bank (Moore, 1979) has estimated that the installed hydro capacity will triple by 1990 in 97 developing countries. The estimate is for a total of 205.8 GW—up 135.4 GW from 1976. Armstrong (1977) estimates a 2.2 million MW world installed and installable capacity—which according to his calculations amounts to about 12 percent of the total hypothetical world gross potential.

The question is not whether there remains a potential for hydro. The real questions revolve around whether it can be economically developed—and if it can, whether or not it will be left unconsidered because individually the output from the sites appear to be too small. It is not a matter of pushing hydro as the complete solution to anyone's problems. It is a matter, however, of re-educating decision makers in the potential of such a system.

Clearly, that is what is going on in the United States—right here—now. But it is not enough. We must be sure that hydro, as a very real alternative, is given the full consideration it should receive. We believe, that this same educational process could be advantageously (to all countries concerned) transferred to developing countries. We come then to the real thrust of this paper—that the United States needs to consider exporting education as well

as know-how and technological capabilities as a very important part of the package. We suggest that foreign aid programs involving hydro should include training of the recipient countries' technologists. This would include:

1. Techniques of resource evaluation
2. Design of hydro plants
3. Construction practices
4. System operations
5. Unit maintenance
6. Unit replacement or upgrading

We do not believe for a moment that most developing countries will have the interest in or capability of replacing completely foreign expertise. Nevertheless, it is to their own benefit and interest that a corps of local expertise exist. We believe, furthermore, the nation that pursues such a course will benefit by the positive response it will engender. It need not be considered a purely altruistic action.

Our experience at the University of Idaho indicates that there is a demand for educational programs in hydro—programs that by-and large are now nonexistent. The real expertise in hydro, however, is now located in consulting firms and government agencies, not by-and-large in universities. For example, we reviewed catalogs of most of the nation's land grant colleges and found that in the civil engineering programs hydro power is almost exclusively dealt with as a very minor portion of courses in hydraulic design—a few lectures at most in an undergraduate civil engineering program. At the graduate level some universities have specific courses, but our brief survey revealed no "programs" by which a civil engineer could upon graduation consider himself, even remotely, a hydro-engineer.

And yet the demand is there, as the response to our short courses and conferences on small-hydro planning and design have shown. It has convinced us that a market exists for a broad program of educational experiences:

1. Concentrated short-courses for professionals, both domestic and foreign
   - live
   - video taped
   - slide/tape
   - english and foreign language

2. Carefully tailored conferences that will aprise decision makers of the opportunities yet remaining in hydro.

   - including a corps of experts and generalists who can be called upon to visit specific locations (foreign and domestic) and respond to problems.

3. Post-graduate programs of longer duration through which professionals could study hydro in greater detail both in the classroom and by practice.

Because of the existing inertial resistance to hydro that has developed over the past 40 to 50 years, it is also important that two other "educational" features be seriously considered:

1. We must review and codify the successes and failures of the more recent examples of small hydro implementation. We need a documentation of the objectives and results (successes and failures)—energy production; economics, social and environmental impacts. We need the "why's?" and the "why nots?" And we need to make such a document widely available. If it is as we say, such a document should be a tremendous asset in showing the world the true value of small hydro.
2. Particularly in developing countries, we need to carefully plan and document the impacts of a number of demonstration small hydro plants. Such demonstrations should include all of the technology transfer programs previously suggested.

It would also be of great value internationally to prepare an objective motion picture presentation of the advantages and disadvantages of small hydro. Such a film documentation could show those considering implementation much more easily than what we are talking about. Certainly, it would have great additional value to any in-person visits and presentations. Unquestionally, the documentation of the demonstration plants recommended above should include a full filming—from initial conceptialization through operation.

Conclusion

Small can be beautiful—to a point. We all should admit freely that small hydro is not the answer to our collective energy problems. Nor is any other source of energy. But hydro does offer the potential of adding a very important marginal increment. Small can be economically attractive. Many sites in many countries are already so. And because of the high up-front costs, the inflationary protection makes hydro even more appealing. Furthermore, the use of a renewable resource such as hydro lessens a country's dependence upon the whims of extreme pressures.

But small can be controversial. What needs to be done is to point out the facts about the potential. And this can advantageously be done by a positive and varied program of education. If what we have to say is correct, then we need a program to educate those to whom the advantages will accumulate.

REFERENCES

Armstrong, E.L., "The Impacts of the World's Energy Problems on Low-Head Hydroelectric Power." *Low-Head Hydro,* 1977, pp. 13-20.

Gladwell, J.S. and Warnick, C.C., *Low-Head Hydro,* Idaho Water Resources Research Institute, University of Idaho, 1977, 206 pp.

Gladwell, J.S. and Warnick, C.C., "Small Hydro—A Second Chance", *Water International,* March, 1979. pp 9-21, 24.

Gladwell, J.S., et.al. "A Resource Survey of Low-Head Hydroelectric Potential—Pacific Northwest Region, (Phase I)", *U.S. DOE Completion Report,* U.S. Dept. of Energy, Contract No. EG-77-S-07-1691, March, 1979.

Gladwell, J.S., et.al. "A Resource Survey of Low-Head Hydroelectric Potential At Existing Dams and Proposed Sites in the Pacific Northwest Region (Phase II)", *Completion Report,* U.S. Dept. of Energy, Contract No. EG-77-S-07-1691, Sept. 1979.

Mercer, A.G., "Very Low-Head Hydroelectric Generation", *Low-Head Hydro,* 1977, pp. 103-113.

Moore, E.A., *Electricity Supply and Demand Forecast for Developing Countries,* Energy, Water and Telecommunications Department, World Bank, 1979, 16 pp.

U.S. Army Corps of Engineers, *Estimate of National Hydroelectric Power Potential at Existing Dams,* Institute for Water Resources Ft. Belvoir, VA, July, 1977, 77 pp.

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

WORKSHOPS

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

WORKSHOP ONE

Finance and Marketing

Chairman: David C. Auslam, Jr.
President
Auslam & Associates, Inc.
Sacramento, California

Panelists: Ed Barbour
Chief
Resource Analysis Branch
Bureau of Reclamation
Denver, Colorado

David Donovan
Vice President
Chase Manhatten Bank
New York, New York

Gordon A. Marker
President
Essex Development Associates, Inc.
Boston, Massachusetts

Hugh McLeod
Vice President
New England Merchants National Bank
Boston, Massachusetts

Introduction

The Financing and Marketing Workshops were attended by over 100 persons during the two-day period. By rough count, approximately ten percent of those were developers, with the remainder representing consulting firms; local, state, and Federal governments; and utilities. The main objective was to have workshop participants interact with the panel to answer small-hydro development questions. The focus was on *private* small-hydro financing and marketing of project power. The method to accomplish the objective was to have each participant write a relevant question to the panel. The questions were then distributed to the panel members and each question was answered and discussed.

A summary of the key points developed during the worshops follows:

Finance

1. There are two basic types of projects as viewed from the financial perspective—those that can be financed according to the financial prowess of the developer (usually small projects or larger projects of utilities) and those that require project financing from outside sources based on the cash flow of the project.

2. Financing falls into four major categories: development, which includes feasibility analysis; construction; long-term; and junior money or equity. The categories are interrelated, and all phases of project financing must fit together. Development funds are subject to complete loss if the project is not feasible (e.g., inadequate cash flow or environmental hurdle). Sources of funds include equipment manufacturers, equity participation of developers, and commercial banks. The primary sources for long-term financing are insurance companies. It can be expected that the rates will be variable and tied closely to the prime rate (the rate should be around 125 percent of prime). This will vary depending on credit strength and credit conditions at the time. The long-term notes will be written for 20 to 30 years. Junior money or equity is used to complete the long-term financing and can be obtained through equity participation, commercial banks, and other sources according to the ingenuity of the developer. Commercial notes for the purpose of junior money usually will be five to ten years in duration.

3. The small-hydro developer should be prepared when entering the world of private financing. This will include a well-organized and complete feasibility study.

4. Commercial financial institutions will usually require a 4 to 1 debt to equity ratio depending on the requirements of the lender and FERC approval. The requirement can vary *greatly* between projects.

5. As a rule of thumb, commercial banks are not interested in projects with construction costs of less than $500,000 to $1 million. This will vary greatly among banks.

6. Limited partnerships are probably the best organizational structure with which to obtain equity participation. This is due mainly to the potential investment tax credits available to investors.

7. Private project financing is possible but it requires a lot of work by the developer and lenders. An example given in the workshop was the Lawrence Hydroelectric Project (15 MW plant capacity) on the Merrimack River in Massachusetts which will produce 100 million kWh of electricity by 1980 (total construction costs of $24.5 million).

Marketing

1. Until recently, utilities have appeared not to be interested in small-hydro projects because singularly, they had little to offer in terms of adding to a systems capacity, reducing cost of service, or increasing profits. This is particularly true of profit motivated investor owned utilities who obtain growth in earnings by increasing company-owned capacity.

The lack of incentive on behalf of the utilities was recognized in the Public Utility Regulatory Policies Act of 1978 (PURPA). In fact, Section 210 of PURPA lays the groundwork for requiring electric utilitie. to purchase small-hydro electric energy.

2. With the rapidly escalating cost of fossil fuels, the market for small-hydro output will grow stronger. The developers should be sure to investigate all possible purchasers. These will include utilities (including IOU's and public utilities) and private manufacturers.

3. The power purchase contract is the keystone of project financing.

4. Wheeling is defined as an electric utility providing transmission services for another utility, power producer, or power purchaser. If a small-hydro producer could wheel output to end users or other utilities, this wider market might allow the power to be marketed at a higher price.

Sections 202 and 203 of PUPA give the FERC authority to order interconnection and wheeling of power produced from a "small power production facility" if such an order is in the public interest and would:

a. Conserve a significant amount of energy,
b. Significantly promote the efficient use of facilities and resources, or
c. Improve the reliability of any electric utility system to which the order applies.

Wheeling charges could vary widely among projects.

5. During the first four to eight years of project operation, a negative cash flow might be experienced. This deficit period could be provided for in a number of ways such as: (1) Adequate equity participation; (2) A marketing contract where the power purchaser guarantees debt services; and (3) Financing which reduces payments during deficit years (such as interest only in early years).

6. During the feasibility (risk) period, a FERC license should be obtained. The license application requires engineering documents, and environmental impact report, water quality permits, and fish and wildlife permits.

7. The key to financing and the marketing agreement is the ability to service the debt over the life of the project.

Summary

Private project financing is possible, but not easy. Interest rates will typically be 125 percent of the prime interest rate charged by commercial banks. The lower limit for project size is probably around $500,000 in construction costs to consider a small-hydro site for commercial "project financing."

Utilities are becoming more interested in purchasing small hydro. This is probably due to public relations, PURPA, and increasing demand for electricity. Regardless of the reason, developers should shop carefully for the best price. Wheeling should not be a problem since PURPA requires utilities to wheel when in the public interest. The market agreement should require the purchaser to guarantee debt service when possible.

There was a substantial amount of interest in the financing and marketing workshops which indicates a serious attitude towards small-hydro development. The workshops were designed to briefly address problems and questions being experienced by the participants and it is realized that some of the questions need more in-depth answers. To this end, the members of the panel encourage questions and interchange from all interested parties involved in small hydro.

WORKSHOP TWO

Planning

Chairman: David C. Willer
Manager of Water Resources
Tudor Engineering Company
San Fransicso, California

Panelists: Gavin Wornock, Discussion Leader
Vice President and General Manager
Acres American, Inc.
Columbia, Maryland

Darryl Davis
Chief
Planning Analysis Branch
Hydrological Engineering Center
U.S. Army Corps of Engineers
Davis, California

Nelson Jacobs
Division of Planning Coordination
U.S.B.R. - Federal Center
Denver, Colorado

Antonio Ferreira
Project Mangager
Electric Power Research Institute
Palo Alto, California

Public Attendance

Four sessions were provided at the conference with the attendance varying from 30 to 65 in each session.

Introduction

The purpose of the workshops was to provide a forum for discussion between participants and resource members relative to the planning of small-hydro facilities. The format for the workshops consisted of first a compiling of

the subjects which the group would like to discuss pertaining to planning. The questions were ranked according to the interest of the group. Then, each question was read and referred to a resource panel member for a response. Thereafter, other resource members commented along with workshop participants. View graphs were prepared which outlined several of the more common questions, i.e., "How do we start developing a small-hydro facility?" and, "What should a feasibility study contain?"

Questions and Responses

The questions which were of most interest to the groups and responses are provided in the following:

a. *How does one start planning a small-hydro project in a community?*

Answer: The first step which can be taken is as follows: Form a community committee consisting of someone knowledgeable in finance, engineering, and law, and an elected official. This group should question and obtain as much data from whomever may have previously studied the project, such as, the local utility, the Corps of Engineers, Bureau of Reclamation, Geological Survey, River Basin Planning Commissions, etc. The committee should study the data to determine, in their opinion, if the information appears to warrant the hiring of a consulting engineering firm for further investigation.

b. *What are the necessary steps to develop a small-hydro project?*

Answer: The steps consist of initial investigations, reconnaissance study or appraisal study; engineering, financial and environmental feasibility studies; permits and licenses; final design; construction; and start up.

c. *What is the difference between a reconnaissance study and a feasibility study?*

Answer: A reconnaissance study is a relatively complete small-scale feasibility study in which the issues that are expected to be important at the feasibility stage are raised; the intent is to appraise the central issues, not formulate solutions, and to perform a first cut economic analysis. A favorable finding would indicate that the expenditure of more money for a feasibility study is warranted. A feasibility study is designed to formulate a project, design an implementation strategy, and provide a basis for an implementation commitment. The findings should be whether or not a commitment for construction of the project is warranted.

d. *What should a feasibility study contain?*

Answer: In answer to this question, an outline for a feasibility report was discussed. In general, the main topics suggested are as follows: Summary; Introduction: Description of Existing Facilities;

Hydraulics and Hydrology of Site; Recommended Project Development; Project Power Production; Project Costs; Financial Alternatives and Power Cost; Project Power Value and Marketing; Benefit/Cost and/or Financial Evaluation; Environmental, Safety and Social/Institutional Aspects; Project Implementation; and, Conclusions and Recommendations.

e. *How should transmission connection and utility interface be obtained?*

Answer: The discussion of this question took two forms: one, the need for further interpretation of the intent of Congress in passing the Public Utility Practice Act of 1978 as related to wheeling and interconnections; and secondly, the problems utilities have in handling the transmission of power from small-hydro plants. The utilities have physical problems with electrical stability of transmission lines and the problem of how to charge for this service in a fair and equitable manner to both their rate payers, investors and developers of the small-hydro facility.

f. *Where can assistance be obtained?*

Answer: The kind of assistance that is most helpful in locating sites is the Corps of Engineers National Hydropower Data Bank. This data bank contains information on 17,000 sites for powerplants at existing dams. For technical assistance, there are several manuals available or under preparation, such as, the Corps of Engineers Guide Manual "Feasibility Studies for Small Hydropower Additions," now in print, and "Lower Limits-Low-Head Hydroelectric Installations" by the U.S. Bureau of Reclamation, now under preparation, and the Electric Power Research Institute manual entitled, "A Simplified Methodology for Economic Selection for Low-Head, Small Capacity Hydroelectric Sites," now under preparation. As a part of the discussion of this question, the participants expressed a need for additional technical transfer of the expertise needed in planning and designing a small-hydro project.

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

WORKSHOP THREE

Developing Policy/Legal Context

Chairman: Peter Brown
Director, Energy Law Institute
Franklin Pierce Law Center
Concord, New Hampshire

Panelists: Robert H. Ballard
Manager, Capacity Planning and Capital Budget
Pennsylvania Power and Light Company
Allentown, Pennsylvania

Peter Burno
President, Wisconsin Edison Company
Edgerton, Wisconsin

Robert C. Coleman
Private Developer, Bethlehem Mink Farm
Franconia, New Hampshire

Roger Lamson
President, White Current Corporation
Weston, Massachusetts

Gary Mongeon
Economic Development Specialist
Strafford Regional Planning Commission
Dover, New Hampshire

William A. Rumberger
Manager, Electric Systems Projects
Niagara Mohawk Power Corporation
Syracuse, New York

Henry Uberto
Plant Engineer, Municipal Electric Authority of Georgia
Atlanta, Georgia

Individual panelists described briefly their involvement in SSH development and outlined problems they had confronted.

1. *In The Licensing Area*
   (a) Before licensing process, get the local people involved - notify the neighbors of the project; tell them what you are doing. (Burno, Lamson)
   (b) Dual system (state-Federal) is a problem; state systems do not seem to be expediting the licensing or *permitting* process; FERC has improved substantially. (Rumberger, Lamson)
   (c) FERC should consider impact of larger upstream developments on smaller downstream facilities in terms of compensating downstream facilities for energy losses occasioned by upstream regulation. (Lamson)
   (d) Relicensing Delays at FERC are a problem. (Ballard)
2. *Environmental Review*
   (a) Fish ladders a major problem: clear direction should be given to a developer *when* he/she is to build. Who pays - there should be some assistance to the developer.
   (b) Environmental Protection agencies should be compelled to examine costs *and benefits* (including energy benefits) of project and *weigh* the costs and benefits.
3. *Power Marketing*
   (a) Educate the State Public Utility Commissions on PURPA, Title II. (Lamson)
   (b) Clear directions to PUC's should be provided by FERC regulations on rates. (Lamson)
4. *Taxes and Subsidies*
   (a) Local property taxation - too quixotic - property valuation of SSH should be performed by assessing agency w/*expertise* in property valuation. (Burno)

Note: Participants wanted to know what panelists did to provide information to other persons interested in development and how long the licensing process really took.

WORKSHOP FOUR

Government Funding

Chairman: Ralph Burr
Hydroelectric Resources
Development Staff
U.S. Department of Energy
Washington, D.C.

Panelists: Fernando Allegria
Office of Youth Programs
Department of Labor
Washington, D.C.

Anthony Carey
Energy Advisor to
Assistant Secretary for
Community Planning and Development
Housing and Urban Development
Washington, D.C.

Richard A. Davis
Fuels Engineer Power Supply Div.
Rural Electrification Administration
Department of Agriculture
Washington, D.C.

Wayne Fernelius
Research Planning Staff
Water and Power Resources Service
(Formerly Bureau of Reclamation)
Washington, D.C.

Roger Hamlin
Youth and Energy Projects
Department of Labor
Washington, D.C.

David J. Howe
Senior Loan Officer
Community Facility
Farm and Home Administration
Washington, D.C.

Ralph F. Kessler
Project Manager
Economic Development Administration
Department of Commerce
Washington, D.C.

Christine McElligott
Assistant Development Director
Housing and Urban Development
Washington, D.C.

Richard Saul
Chief, Energy Programs
Community Services Administration
Washington, D.C.

William Telaar
Rural Electrification Administration
Department of Agriculture
Washington, D.C.

Each participant described his/her agency's programs that are applicable to small-hydro development, and how these programs might be utilized by hydro developers. A printed hand-out embodying the same material was available.

Introduction

With the establishment of hydroelectric power as a source of energy in the United States, the President has asked Department of Energy (DOE) to coordinate a multiagency effort to increase supplies of energy in the Nation's rural areas. This effort, called the Rural Energy Initiative (REI), seeks to maximize the effectiveness of on-going Federal programs that are, or can be, oriented toward small-hydro development, as well as certain other energy sources.

Promising existing hydro sites will be identified and assessed, and when appropriate, will be referred for full-scale feasibility studies. The REI target is to bring about 100 retrofitted sites on line by 1981 with approximately 300 MWe of additional capacity.

Current Activities

DOE has asked that each of the Federal agencies involved provide input concerning their hydro involvement in relation to the rural energy initiatives. DOE's coordination efforts have resulted in the following information.

The Bureau of Reclamation accomplished planning, estimating, design, contract administration, construction, supervision, and related activities in the development of water and land resources projects in the 17 Western states. Projects developed under the Reclamation Act of 1902 directly benefit local sponsoring entities as well as indirectly benefiting other entities. Such local entities are held legally responsible under contracts for repayment of all reimbursable portions of the project costs. Planning, design and construction activities and funds related to all activities require justification annually through the budget process. In addition to annual fund approval, individual project feasibility studies and construction initiatives require specific authorization by the Congress.

Under Public Law 84-984, the Small Reclamation Projects Act, loans and/or grants can be approved by the Secretary of the Interior for single-purpose irrigation or drainage projects and other multiple purpose functions of water supply projects. Hydropower development may be funded under this act if it can be accomplished as an addition to other water supply functions of the project. Single-purpose hydropower development under this act is not possible.

The Federal Reclamation program does not include provisions for direct assistance loans and grants.

Community Services Administration (CSA's) role in small-scale hydro development will be limited to providing assistance to low income communities in their planning, and in securing funding and financing for feasibility studies for dam retrofit, and also the development of activities for the use of the power generated. CSA has contracted with the International Science and Technology Institute (ISTI) for the preparation of audio-visual training materials to assist local communities in preliminary assessment and planning for small-scale hydro development, and for the providing of on-site technical assistance to selected low income communities involved in such development. ISTI has, under previous contracts with CSA, carried out a study of small-scale hydro potential, entitled "Potential Use of Small Dams to Produce Power for Low Income Communities," and prepared a pamphlet, "Developing Small Hydroelectric Potential", based on the study, which has been published by CSA.

The Economic Development Administration (EDA) is actively participating in the Administration's interagency initiative to promote the development of small-scale hydroelectric power. They will use the following program tools in this effort:

- Public Works (Title I) Grants - Under this authority grants are available to eligible applicants (states, local political subdivisions, Indian tribes and private or public non-profit organizations) for the development of public works projects which will stimulate economic development in designated redevelopment areas.
- Business Development (Title II) Loans - This program provides loans and loan guarantees to private industry for the purpose of creating or retaining permanent jobs in designated redevelopment areas.

- Technical Assistance- This program provides grants for activities such as feasibility studies and demonstration efforts which are designed to foster economic development.
- Institutional Support - EDA provides institutional support to states, multi-county economic development districts, cities and other local bodies through its economic development planning and research grant programs. Informational and technical support may be available from these grantees. For example, a number of the districts assisted the Corps of Engineers and DOE in identifying potential dam sites.

While small-scale projects are eligible under all these programs, it is anticipated that the majority of EDA dollars will come from the Title I program. EDA will be interested in those projects which result primarily in on-site use of the power produced and have income and job producing benefits. EDA, in most instances, will not consider projects as eligible which simply result in power being purchased by a large utility company and placed in a grid system for subsequent distribution. Power produced solely for residential consumption will not be eligible for EDA assistance. Projects that produce power for commercial/industrial activity will be appropriate for EDA funding. A business loan could be made to a private business to retrofit a dam for electric power, i.e., a paper or textile mill.

For more information on the potential eligibility of a project and EDA program procedures, applicants should contact the appropriate Economic Development representative.

Rural Electrification Administration (REA) makes loans and loan guarantees to nonprofit and cooperative associations, public bodies, and other electric utilities to finance the construction and operation of distribution lines of systems, generating plants, (including hydroelectric) and transmission lines to provide initial and continued adequate electric service to persons in rural areas. Rural areas are defined in the Rural Electrification Act of 1936, as amended, as any area of the United States not included within the boundaries of any city, village, or borough having a population in excess of 1500 inhabitants.

Most REA loans bear interest at the standard rate of five percent, with a two percent rate being available under special circumstances. For large-scale facilities, such as generating stations and transmission facilities, REA normally provides a loan guarantee. Guaranteed loans may be obtained from any qualified lender, and bear interest at a rate agreed upon by the borrower and the lender. REA has an agreement with the Federal Financing Bank whereby loans guaranteed by REA have an interest rate based upon the cost of money to the Federal Financing Bank and the rate for each advance of funds is determined at the time the advance is made. REA guarantees may be made concurrently with a direct loan from REA.

With regard to the financing of facilities for communities, REA activities are confined to financial assistance to those systems which qualify under the Rural Electrification Act. REA can provide assistance to eligible borrowers for joint projects with other systems not eligible for REA financing, or for the

purchase of a portion of a large project constructed and operated by non eligible borrowers. In each case, however, the net result of the financing must be the providing of, or the improvement of, service to rural areas in quantities commensurate with the amount of financing provided.

The Department of Housing & Urban Development (HUD) has an Urban Development Action Grant Program that is a highly flexible economic development tool which seeks to create partnerships among government, the community and private industry to overcome problems of development. Action Grants are designed to assist severely distressed cities and urban counties in revitalizing their stagnating economies and reclaiming deteriorated neighborhoods. The program searches for unique opportunities where qualifying communities can use Federal funds to stimulate new, or increased private investment.

Action Grant funds are available to carry out projects in support of a wide variety of economic revitalization or neighborhood reclamation activities that involve partnerships with the private sector.

These activities may include a broad range of development actions like land clearance; site improvements; providing infrastructure; rehabilitation, and building public, commercial, industrial and residential structures.

Other possibilities may involve Action Grant financing in the form of equity funding, loans, loan guarantees, lease guarantees or other appropriate mechanisms for joint public-private development.

Priority will be given to those proposals where the community will be in a position to recapture or recycle its Action Grant funds if the project is especially successful.

The program is designed to encourage innovation in joint public-private community development and can address a wide range of problems and opportunities such as converting under utilized land or structures to more productive use; such as the retrofitting of a hydroelectric dam by a private developer and the inability to finance the project without Federal assistance.

HUD will be looking for projects that generate substantially more private commitments than the Action Grant money requested. However, HUD will take into account the various types of projects considering the degree of private leverage. A community must request a determination of eligibility from the HUD Area Office before submitting an application. HUD will then supply the needed data. An applicant may also ask for a preliminary determination of the proposed project's eligibility at the same time.

The Farmers Home Administration (FMHA) has agreed to utilize its network of local offices to identify existing dams which may be candidates for the small-scale hydro program. Under this program, dam sites which are identified as having potential for electric generating purposes will be examined by a team of specialists and if found suitable will receive aid from the Department of Energy for engineering feasibility studies. Funds for rehabilitation of dams and generating equipment may be obtained from a number of sources including the FMHA farmer programs and business and industry loan guarantee program.

The FMHA guarantees loans to family farmers and ranchers for farm ownership, improvement and operation.

Guaranteed loans are made and serviced by legally organized private lending institutions, such as commercial banks, Federal Land Bank, Production Credit Associations, insurance companies, and savings and loan associations. FMHA provides the lender with a guarantee to reimburse up to 90 percent of any loss the lender takes on a loan.

The use of an FMHA guarantee may enable a private lender to serve, or continue to serve, a farmer who cannot be served on a wholly conventional basis. The maximum amount of loan FMHA can guarantee is higher than the limit on an FMHA insured loan made directly to the borrower by the agency.

All applications for FMHA guaranteed loans are treated with equal consideration, without regard to sex, age, race, color, religion, national origin or marital status.

WORKSHOP FIVE

Licensing

Chairman: Ronald Corso
Deputy Director, Division of
Licensed Projects
Federal Energy Regulatory Commission
Department of Energy
Washington, D.C.

Panelists: Quentin Edson
Chief, Environmental Analysis Branch
Federal Energy Regulatory Commission
Washington, D.C.

Dean Shumway
Alternate Chief, Environmental Analysis
Branch
Federal Energy Regulatory Commission
Washington, D.C.

Fred Springer
Chief, Applications Branch
Federal Energy Regulatory Commission
Washington, D.C.

Harry Thomas
Chief, Inspections Branch
Federal Energy Regulatory Commission
Washington, D.C.

Gerald R. Wilson, Jr.
Chief, Project Analysis Branch
Federal Energy Regulatory Commission
Washington, D.C.

Summary

The Hydropower Licensing workshop was conducted by a panel of the Staff members of the Federal Energy Regulatory Commission (FERC) in response to the need for developers, consulting firms, manufacturers, and

Federal and State agencies to become cognizant of Federal licensing requirements and procedures. The workshop consisted of a brief overview of Federal licensing jurisdiction under the Federal Power Act, FERC licensing regulations, and FERC Staff procedures.

After opening remarks by the panel Chairman, Mr. Springer described the reasons for FERC jurisdiction over non-Federal hydro projects. He also provided a brief review of procedures for processing applications for preliminary permits and licenses and, more importantly, a description of the FERC program to simplify regulations and expedite the entire licensing process.

Mr. Wilson described the functions of his branch and provided an explanation of FERC methodologies for analyzing the structural stability of dams, economic and financial feasibility, and comprehensive river basin development.

Mr. Thomas discussed the FERC dam safety program and its regulations implementing that program.

Messrs. Edson and Shumway provided some insight to the kinds of environmental concerns associated with small hydro developments and the application of the revised regulations to meet those concerns. Particular focus was drawn to water quality and fish and wildlife matters.

Questions from the participants focused primarily on the new regulations, application processing procedures, and the cost and time required to obtain a license or permit.

Postscript

The Commission's revision of its regulations to simplify and expedite preliminary permits and licenses is now complete for new and existing projects involving existing dams. In addition to the Short-Form License regulations (Order No. 11) issued in September 1978, the FERC has promulgated final regulations to revise and simplify general license and permit requirements, permit filing requirements, and license requirements for projects at existing dams with an installation of more than 1,500 kW (Orders Nos. 54 and 59).

WORKSHOP SIX

Engineering

Chairman: George Smith
Manager, Hydroelectric Project
Idaho National Engineering Laboratory
U.S. Department of Energy
Idaho Falls, Idaho

Panelists: C. T. Advani
Director of the Department of Dams
and Waterpower for the Sogreah Company
Grenoble, France

John D. Lawrence
Project Manager, Acres American, Incorporated
Columbia, Maryland

Michael J. McLatchy
Hydropower Specialist
U.S. Department of Energy
Washington, D.C.

Emil F. Mosonyi
Professor of Hydraulic Engineering
University of Karlsruhe
German Federal Republic

James V. Williamson
Partner, R. W. Beck & Associates
Seattle, Washington

Introduction

During the course of the conference the Engineering Workshop was held three times. A fourth session, scheduled at the last minute on the basis of first day sign ups did not materialize. The workshop format was informally structured and consisted of an opportunity for attendees in the audience to generate discussion by asking questions to a panel of experts.

First Session

Following the opening remarks by Chairman Smith a question was asked which prompted discussion throughout the remainder of the session. The question was: In assessing the feasibility of a site, what should come first—equipment or engineering? The party asking the question parenthetically added that if there is an existing decommissioned powerhouse at the site, this may dictate.

From this starting point much discussion evolved about feasibility assessments in general. Several points were raised during the discussion, including those that follow. Civil constraints may be a major consideration and could override what an existing powerhouse may otherwise dictate. In Germany, environmental concerns will make one plant under consideration a long drawn out process. Fish passage requirements may be an immediate constraint precluding feasibility. The smaller the plant; the more versatile the engineer has to be to reduce costs.

Lest one hastily draw the conclusion that what is required in a feasibility assessment is relatively site specific, the panel strongly emphasized the need to reduce the degree of sophistication in performing such assessments. Standardization was strongly encouraged—not so much the equipment standardization which has been evident of late, but rather standardization of assessment techniques.

The suggestion was made that perhaps two levels of assessment might be appropriate. The first would be an initial reconnaisance visit to the site to gather only the minimum amount of information needed to determine whether the second level of a full blown site feasibility were warranted. At least one panel member was adamantly opposed to such a concept claiming it was ridiculous to make a study to determine if a study should be made, and study costs under such a procedure could be greater than construction costs at some sites.

The relative advantages of modularization and of turnkey construction projects were briefly mentioned. The session concluded with an announcement that the preparation of a six volume guide manual entitled "Feasibility Studies for Small Scale Hydropower Additions" had just been completed by the Corps of Engineers and some advance copies had already been distributed. It was suggested that those interested in obtaining a copy should contact either: The Hydrologic Engineering Center, 609 2nd Street, Davis CA 95616 or The Institute for Water Resources, Kingman Building, Fort Belvoir, VA 22060.

Second Session

The second session began with a question about what influences cost. A general discussion ensued that touched on the relative costs of civil, mechanical and electrical engineering costs with no clear conclusions made.

A question was raised as to what a flow duration curve is used for. The panel explained the importance of the flow duration curve, which plots flow rates as a function of the percent of time they are exceeded, in determining the

equipment size for a given site and computing the resultant energy that could be produced based on the chosen equipment size. It is common to select equipment to handle flow rates equalled or exceeded 30% of the time but in some cases a design flow as high as the 15% exceedence flow rate is used. A head duration curve is an important companion to the flow duration curve. One needs to be careful in the use of a flow duration curve at sites having significant storage capacity. Such curves are most useful in run-of-the-river analyses.

A question was raised concerning how to interest large utilities in purchasing the power from small hydroplants where the power capacity is not firm. The panel cited a case in Massachusetts where the purchase of non-firm power from a small hydro site was justified on its being bought at the price of oil equivalent replacement. When water is available to generate power, it is used and oil is saved. When water is not available oil is used to generate the power.

The discussion was then turned to the topic of load rejection and pressure surge problems during gate closure. Some points of interest that were brought out during this part of the discussion follow. Francis turbines will reach between 80 and 100% overspeed during load rejection before they are at the runaway equilibrium condition, while Kaplan turbines run as high as 300% overspeed at the runaway equilibrium condition. Though the turbines, themselves, can generally tolerate these runaway conditions, it is not economically practical to purchase generators that can safely handle such high overspeeds. During load rejection a turbine will reach approximately 125% nominal speed (25% overspeed) during the first 6-7 seconds. Since generators can handle such conditions, one way of attaching the load rejection problem is to have built-in gate closure mechanisms that close the control gates quick enough to avoid runaway conditions but not so quick as to create excessively high pressure surges in the penstock. Other approaches to the problem include: dummy load governors, electro magnetic cluthes, overspeed bolts, and head reduction devices. The dummy load governor approach is a means by which an artificial load can be put on the line to replace the rejected load, an artificial load being any significant load at the site of a power house which consumes energy primarily for the purpose of maintaining a load on the generator. Electromagnetic clutches would disengage the turbine from the generator, allowing the turbine to go to a runaway equilibrium condition without driving the generator beyond tolerable overspeed conditions. Overspeed bolts would serve the same purpose as clutches by shearing at some overspeed condition and thus disengaging the generator from the turbine. Of course, the bolts would have to be replaced before additional power could be generated by the affected unit. One possible head reduction device suggested was a butterfly valve that would operate to create large enough headlosses in the flow passageways during load rejections so as to prevent excessive equipment overspeed without entirely shutting off the flow and thus creating excessive pressure surges.

The closing topic of discussion concerned European bulb turbine experience. The main point brought out in this brief discussion was that bulb turbines can be used inspite of their small rotational inertia because they receive governing from the system.

Third Session

There was sparse attendance at this session attributed to shuttle bus service for the executive reception on capitol hill scheduled to begin shortly after the workshop started. Consequently, not much discussion was generated and the workshop adjourned about 15-20 minutes after it began.

One topic of discussion centered around spillway design and the size of flood a spillway should be able to pass. It was brought out that the design flood is generally a function of the age of the dam, the height of the dam, the storage capacity behind the dam, and the hazard potential below the dam. Past experience was cited in which various design floods had been specified for various projects relative to the variables envolved. The four design floods mentioned were: the probably maximum flood, the 100 year flood, the 1/2 probable maximum flood, and the standard project flood.

Another discussion topic centered around what can be done to reduce costs of low head sites. The complexity of controls was one item considered and the relative merits of automatic versus semi-automatic controls were briefly touched upon. Other cost reduction possibilities mentioned were the use of induction generators as opposed to synchronous generators, the use of fixed blade turbines rather than variable pitch turbines, and the elimination of wicket gates. The session ended with a brief description of the DOE Program Announcement soliciting proposals containing cost reduction ideas relating to either civil modifications for retrofitting existing dams or innovative concepts to improve manufacturing processes and materials.

WORKSHOP SEVEN

Dam Inspection, Safety and Adequacy

Chairman: Robert Philleo
Chief, Structures Branch
Civil Works
Office of the Chief of Engineers
Washington, D.C.

Panelists: Ernest L. Dodson
Chief, Geotechnical Branch
Civil Works
Office of the Chief of Engineers
Washington, D.C.

George Fink
President
Wahler Associates
Palo Alto, California

Vernon K. Hagen
Chief, Hydraulic and Hydrology Branch
Civil Works
Office of the Chief of Engineers
Washington, D.C.

Robert J. Smith
Chief, Structural Engineering Section
Civil Works
Office of the Chief of Engineers
Washington, D.C.

The attendees largely were people who owned small dams or who had the responsibility for approving modifications of existing dams for hydropower. A principal point of discussion was the manner in which inspections by the Corps of Engineers under the National Program of Inspection of non-Federal dams could be a part of the system. It was pointed out that the Corps inspects dams as they are currently used and does not comment on their suitability for other uses. Futhermore, many dams being considered for small hydropower are too small to be inspected under current criteria. The Corps is not operating a free engineering service for dam owners. It is operating a program to protect the health and safety of the public, particularly that segment of the public which lives downstream from non-Federal dams.

The technical discussion was devoted primarily to the pitfalls in adapting non-hydro dams to hydro. The effect of different operating procedures, such as rapid reservoir and drawdown must be investigated both as it applies to the dam and to the reservoir. Disturbing the toe of a dam for powerhouse construction can also be critical. Techniques for inspecting existing dams were also discussed.

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

WORKSHOP EIGHT

Environmental Issues

Chairman: Dr. Stephen G. Hildebrand
Oak Ridge National Laboratory
P.O. Box X
Oak Ridge, Tennessee

Panelists: Dr. Al Eipper
U.S. Fish and Wildlife Service
One Gateway Center
Newton Corner, Massachusetts

Dr. Robert Brocksen
Electric Power Research Institute
P.O. Box 1042
Palo Alto, California

Professor Milo Bell
The University of Washington
College of Fisheries WH-10
Seattle, Washington

Format and Organization of Workshop

The purpose of this workshop was to identify and discuss specific environmental issues that may be constraints to small-scale hydroelectric development. Four separate one-hour workshops were conducted, each with a different group of participants. Each workshop was directed by the four-member panel. During the first 15 minutes of each session, the chairman presented a list of potential environmental issues that may relate to small hydroelectric development at both existing and new dam sites. The participants were then encouraged to add or delete issues from the initial list. The remaining 45 minutes of each workshop was left open for participants to ask questions of the panel, or to relate specific experiences in assessing the magnitude and mitigating adverse environmental impacts of small-hydro development projects.

The total number of individuals estimated to have participated in the four environmental workshops was 100, or about 10% of those attending the conference. The average group size of 25 was optimal for the short time available for each session.

Summary of Environmental Issues Identified and Discussion

Fish Passage Requirements

The possible requirement of facilities to pass migrating fish around dams was raised in each workshop and resulted in considerable discussion. There appear to be two facets to this issue:

1. If fish passage facilities are required by state and/or Federal agencies, who should pay for them.
2. Do we have the capability to design facilities to achieve desired passage efficiency.

Discussion related to "who pays" included: (1) The developer should pay because he is using the water resource, (2) fisherman should pay because they are the beneficiaries, (3) state or Federal agencies should pay because they are requiring them, (4) low interest loans and tax incentives should be made available to the developer, and (5) many combinations of the above. It was generally concluded that the expertise is available within the Fish and Wildlife Service, National Marine Fisheries Service, select universities, and some consulting firms to design proper fish passage facilities. However, successfully passing downstream migrants is still an issue in the West. A very significant question regarding fish passage is how many potential small-hydro sites in the United States may be required to install passage facilities. A preliminary analysis by the Fish and Wildlife Service estimates approximately 20% of the sites in New England *might* be required to include fish passage facilities.

Instream Flow Requirements

The determination of and setting requirements for minimum/optimum river flows to maintain fish and wildlife habitat and other surface water use was discussed at length during one workshop session. The panel members suggested this issue may be one of the most significant environmental problems for small-hydro development. Although methodologies are being developed to determine minimum flows that will not adversely impact fish and wildlife, no tested and acceptable methodology is being consistently applied.

Water Level Fluctuation

Water level fluctuation due to store and release hydroelectric generation can cause adverse impacts on the biological communities in reservoirs and tailwaters and also cause associated recreational and aesthetic impacts. The potential impacts of water level fluctuation should not be a concern at strict

run-of-the-river small-hydro sites. Most workshop participants felt that this issue should be carefully analyzed at store and release small-hydro sites, and sites where the addition of flashboards is included in the design.

Water Quality

Water quality degradation in rivers below dams (low dissolved oxygen, high levels of some metals, altered thermal regimes) has been documented at some hydroelectric sites. This type of problem, when observed, is usually associated with large dam impoundment systems and is a function of thermal stratification in the impoundment and the depth of water withdrawal. It is not known to what extent this issue may be a problem at small-hydro sites. The panel and participants felt in general that this issue would not be a factor at small-hydro sites that do not include impoundments with water depths greater than 10-15 meters.

Dredging Impacts

If extensive dredging is required to clear intakes or increase the storage capacity of an impoundment behind a small-hydro facility, potential adverse environmental impacts may occur. Potential impacts include resuspension of sediments, mobilization of nutrients and contaminants from sediments into water, loss of biotic production due to increased turbidity, destruction of benthic habitat, and secondary effects on biota due to increased levels of nutrients and contaminants. The potential significance of these impacts depends on the physical-chemical characteristics of the sediment to be dredged and the amount of dredging. If dredging is required in development efforts, a careful analysis should be conducted to minimize/mitigate environmental impacts.

Other Issues Discussed

In the West the need for transmission line construction or above-ground penstocks may result in adverse impacts on wildlife (interference with migration or behavior). The need for carefully evaluating aesthetic impacts and impacts on historic sites in development efforts was mentioned. It was generally felt that noise levels generated in re-development efforts would not be a significant problem. One final point (need for holistic basin planning) received considerable discussion in one workshop session. The majority of participants recognized a need for river basin level environmental planning and analysis. However, the nature of the key environmental impacts (fish passage, instream flow, water fluctuation, water quality) requires site specific analysis. River basin level planning cannot replace entirely the need for site specific environmental review. However, a review of individual sites while ignoring river basin level issues may also lead to poor overall management decisions. River basin level analysis methodology, which factors in both environmental and economic considirations, should receive appropriate development effort.

Summary

There was a general consensus among workshop participants and panel members that adverse environmental impacts can occur as a result of development of existing dams for hydroelectric generation. Issues resulting in the most discussion were fish passage, instream flow requirements, and water level fluctuation. The participants generally agreed that initial feasibility studies should include a careful identification of environmental issues that merit analysis. Issue identification should include input from state and Federal agencies as well as the public. When agreement on potentially significant issues is achieved, appropriate analysis of these issues should be conducted to determine significance and mitigation efforts required.

APPENDICES

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

APPENDIX A: GLOSSARY

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

GLOSSARY

ABUTMENT OF A DAM
That section of a dam which is located adjacent to one of the river banks.

ADJUSTABLE BLADE TURBINE
A propeller type turbine with a hydraulic servomotor mechanism which permits rotation of the runner blades to suit load conditions and thereby improve efficiency.

APPLICATION FOR F.E.R.C. LICENSE
A formal document prepared by the owner of an existing, or proposed, hydraulic project which follows a prescribed format and describes the project in considerable detail. The Federal Energy Regulatory Commission generally issues a 50 year license for a new project, said license authorizing the construction, operation and maintenance of the project works.

AVAILABILITY FACTOR
The ratio of the time a piece of equipment or a unit is ready for or in service to the total time interval under consideration.

AVERAGE MAXIMUM DEMAND
The average, used for billing or other purposes, of a specified number of the greatest maximum demands as normally measured in similar specified periods of equal length occurring within a specified total period of time.

AVERAGE STREAM FLOW
The average rate of discharge during a specified period.

AXIAL FLOW
A flow of water essentially parallel to the main axis of a hydraulic turbine, pump, or water passage.

BACKWATER CURVE
A curve which shows the actual, or estimated, water levels at selected points located upstream of a dam for varying flow conditions.

BASE LOAD (ASA)
The minimum load over a given period of time.

BASE LOAD STATION
A generating station which is normally operated to carry base load.

BASCULE GATE
A steel crest gate which is hinged along its bottom edge and raised and lowered by hydraulic operators at each end; it is very efficient for passing ice flows and large debris.

BULB UNIT

A unit consisting of a horizontal shaft hydraulic turbine and close coupled generator which are both enclosed in a single steel watertight bulb located directly in the water passage.

BUTTERFLY VALVE

A disc type water control valve which is usually opened and closed by a hydraulic operator and is suitable for heads up to 500 feet.

CAPACITY FACTOR (ASA)

The ratio of the average load on a machine or equipment for the period of time considered, to the rating of the machine or equipment.

CONNECTION CHARGE

A fixed amount to be paid by the customer in a lump sum, or in installments, for connecting the customer's facilities to the supplier's facilities.

CONTINUOUS POWER

Hydroelectric power available from a plant on a continuous basis under the most adverse hydraulic conditions contemplated.

DEMAND

The load at the terminals of an installation or system averaged over a specified interval of time. Demand is expressed in kilowatts, kilovolt amperes or other suitable units.

DEMAND CHARGE

That portion of the charge for electric service based upon the customer's demand characteristics.

DEMAND FACTOR (ASA)

The ratio of the maximum demand of a system, or part of a system, to the total connected load of the system, or part of the system, under consideration.

DRAFT TUBE

That section of the turbine water passage which extends from the discharge side of the turbine runner to the downstream extremity of the powerhouse structure.

DRAWDOWN

The distance that the water surface of a reservoir is lowered as the result of the withdrawal of water.

EARTH DAM

A dam constructed of earthen materials, such as sand, gravel, clay, glacial till, or a random mix.

ELECTRIC POWER
A term used in the electric power industry to mean inclusively power and energy, expressed in kilowatts and kilowatt-hours.

ELECTRIC RATE
The unit prices and the quantities to which they apply as specified in the rate schedule.

ELECTRIC RATE SCHEDULE
A statement of the electric rate and the terms and conditions governing its application.

ELECTRIC SYSTEM
All physically connected electric facilities operated as a unit under one control.

EXCITER
An electrical device which supplies direct current excitation to the generator field during startup of the unit. It may be a rotating shaft mounted type, or a static rectifier type.

FIRM FLOW
That flow which is equalled, or exceeded, a specified percent of the time.

FIRM POWER
That amount of power which could be produced continuously during a repetition of the most adverse hydro year of record.

FISH COLLECTION BARGE
A floating barge provided with high capacity pumps and a system of louvers, screens, and pipes for attracting and collecting downstream migrant fingerlings.

FISH LADDER (FISHWAY)
A structure containing a series of overflow weirs, which are arranged in steps that rise about one foot in from 10 to 15 feet horizontally, and serve as a means for transporting upstream migrant fish past a dam.

FIXED COSTS
Costs associated with investment in plant.

FIXED OPERATING COSTS
Costs, other than those associated with investment in plant, which do not vary or fluctuate with changes in operation or utilization of plant.

FLAT AND METER RATE SCHEDULE
A rate schedule of two components the first of which is a customer or service charge, and the second of which is a price for the energy consumed.

FLAT DEMAND RATE SCHEDULE

A rate schedule that is based on the billing demand and provides no charge for energy.

FLAP GATE

A swinging type of gate which is hinged at the top and allows flow in one direction only. Such a gate is usually installed at the discharge end of a pipe or water conduit.

FLAT RATE SCHEDULE

A rate schedule that provides for a specified charge irrespective of the energy used or demand.

FLASHBOARDS

These usually consist of timber planks installed horizontally between steel pipe pins located at the crest of a dam and are used to maintain a higher reservoir level. Generally, the flashboards are washed out during flood flows and must be replaced.

FLOOD FREQUENCY CURVE

A curve which shows the frequency of floods of different magnitudes which have occurred historically. The curve also can be extrapolated to cover even larger floods that may occur in the future.

FLOOD RIGHTS

Legal rights obtained from a property owner which permits periodic flooding of his land due to backwater effects from hydro project reservoir operations during periods of high river flows.

FLOOD STORAGE CAPACITY

That portion of the reservoir capacity which is reserved for the temporary storage of flood waters to reduce downstream flows.

FLOW METER

A mechanical device which can be calibrated to indicate the approximate rate of flow in a pipe or water conduit.

FOREBAY

This generally refers to the reservoir area located immediately upstream of a dam or powerhouse.

FRANCIS TURBINE

A reaction turbine which has fixed runner buckets and can be designed for operating heads ranging from 50 ft. to 2,000 ft.

GENERATOR

A machine which converts the mechanical output of the hydraulic turbine into electrical energy. Most large hydro project generators are of a synchronous type and produce 3 phase, 60 cycle power at a rated voltage of 13,800V

GENERATOR/MOTOR

A reversible type machine which can operate as either a generator, or a motor, depending upon the direction of rotation. It is used specifically for pumped storage hydro plants.

GENERATOR FLOOR

The floor which supports the generator and is generally the main floor in a powerhouse.

GRAVITY DAM

A concrete dam which has sufficient mass to be inherently stable under all externally applied loads.

GROSS GENERATION

The total amount of electric energy produced by a generating station or stations.

GROSS HEAD

The difference of elevations between water surfaces of the forebay and tailrace under specified conditions.

HEADWATER LEVEL

The water surface level in the reservoir just upstream of a dam or powerhouse structure.

HORSEPOWER

Mechanical energy equivalent to 550 ft. lbs. per second of work.

HYDRAULIC GRADIENT

The hydraulic pressure profile which exists along a pipe or conduit which is flowing full.

INDOOR POWERHOUSE

A powerhouse which is completely enclosed, and having a fixed type of superstructure.

INSTALLED CAPACITY

The total of the capacities as shown by the name plates of the generating units in a station or system.

INSTANTANEOUS DEMAND

The demand at any instant, usually determined from the readings of indicating or graphic instruments.

INTAKE STRUCTURE

A concrete structure arranged to control the flow of water from a reservoir to the ultimate point of use. This structure usually contains either intake gates, or large valves, for regulating the rate of flow and for shutoff purposes.

KAPLAN TURBINE
An adjustable blade propeller turbine named after the Austrian inventor who developed the original design.

KILOWATT
A thousand watts.

KINGSBURY BEARING
A segmented, shoe type, oil lubricated bearing developed by Mr. Albert Kingsbury, which is capable of carrying heavy loads at low rotational speeds. It is widely used for generator thrust bearings.

KVA
Abbreviation for kilo-volt-ampere.

LOAD CURVE
A curve of demand versus time showing the magnitude of the load for each unit of the period covered.

LOAD FACTOR (ASA)
The ratio of the average load over a designated period to the peak load occurring in that period.

LOAD FACTOR RATE SCHEDULE
A rate schedule in which the number of kilowatt-hours in any energy block is based on a demand characteristic, such as the equivalent number of hours use of maximum demand. For example: 3 cents per kilowatt-hour for the first 30 kilowatt-hours per kilowatt of the maximum demand; 1 1/2 cents per kilowatt-hour for energy in excess of 30 kilowatt-hours per kilowatt of the maximum demand.

MAXIMUM STREAM FLOW
The maximum rate of discharge during a specified period.

MEDIAN STREAM FLOW
The rate of discharge for which there are equal numbers of greater and lesser flow occurrences during a specified period.

MEGAWATT (MW)
One thousand kilowatts.

MINIMUM STREAM FLOW
The minimum natural or regulated rate of flow during a specified period.

NET GENERATION
Gross generation less plant use.

NET HEAD
The gross head less all hydraulic losses except those chargeable to the turbine.

OGEE SPILLWAY
An overflow spillway whose surface has a parabolic shape.

OUTPUT
The amount of power or energy delivered from a piece of equipment, station or system.

PEAK LOAD (ASA)
The maximum load consumed or produced by a unit or group of units in a stated period of time.

PEAK LOAD STATION
A generating station which is operated to provide peaking capacity.

PEAKING CAPACITY
Generating capacity available to assist in meeting that portion of peak load which is above base load.

PEAKING PLANT
A power plant which serves the uppermost portion of the system load curve where the load is of short duration and energy requirements are minimal.

PELTON WHEEL
An impulse type hydraulic turbine which is shaped like a wheel and has a series of cast steel buckets attached to its periphery.

PENSTOCK
A large water conduit which is subjected to high internal pressures and is fully self-supporting.

PLANT FACTOR (ASA)
The ratio of the average load on the plant for the period of time considered to the aggregate rating of all the generating equipment installed in the plant.

PONDAGE
Storage of only sufficient magnitude for daily or week-end regulation of flow.

POTENTIAL HYDRO ENERGY
The aggregate energy capable of being developed over a specified period by practicable use of the available stream flow and river gradient.

POWER FACTOR
The ratio of kilowatts to kilovolt-amperes.

POWER POOL, ELECTRIC
Two or more electric systems interconnected and operating on a regional basis.

PRELIMINARY PERMIT (F.E.R.C.)
A permit which is issued by the Federal Energy Regulatory Commission and allows the permittee up to 3 years to study the feasibility of a proposed hydroelectric development. During this period, all affected Federal lands are held in a status quo condition.

PROBABLE MAXIMUM FLOOD (PMF)
A hypothetical flood which is determined from an analysis of the maximum potential rainfall and runoff which could occur over a given area in a given length of time.

PUMPED STORAGE PLANT
A hydro plant which utilizes off peak power from an external source to pump water from a lower reservoir to an upper storage reservoir, and then uses this water to generate power during periods of high load demand by reversing the direction of flow.

RATED HEAD
The net head in feet at which a hydraulic turbine is to produce a specified amount of power.

RATED OUTPUT
The guaranteed output of a hydraulic turbine when operating at rated head.

REREGULATING RESERVOIR
A reservoir used for the purpose of regulating the outflow received from another reservoir or hydroelectric plant.

RESERVE CAPACITY
Capacity in excess of that required to carry peak load.

RESERVOIR CAPACITY
Total storage space in a reservoir, below a designated elevation.

REVERSIBLE PUMP TURBINE
A Francis type hydraulic turbine which is designed to operate as a pump in one direction of rotation, and as a turbine in the opposite direction of rotation. Good efficiencies can be achieved with both modes of operation.

RUNNER BLADES

The propeller like vanes of a hydraulic turbine which convert the kinetic energy of the water into mechanical power.

SCROLL CASE

The intake section of a large vertical shaft turbine, which has a scroll like shape in plain view.

SLIDE GATE

A hydraulic gate which operates in vertical guides and has no wheels, rollers, or other friction reducing devices. Normally, such a gate must be opened or closed under balanced head conditions.

SLUICE GATE

A vertical shaft slide gate which is often used for passing water through a dam. Manual, or motor operated floor stands, are used to raise and lower sluice gates.

SPECIFIC SPEED

The speed in RPM at which a turbine of homologous design would operate, if the runner were reduced to a size which would develop one horsepower under a one-foot head.

SPHERICAL VALVE

A heavy duty valve generally used for penstock shutoff purposes on high-head projects. The valve body consists of a rotating sphere which provides a full port in the open position. Double seals of a retractable type are generally provided.

SPILLWAY CAPACITY CURVE

A curve which shows the discharge capacity of a spillway gate for different reservoir elevations.

SPILLWAY DESIGN FLOOD

That pattern of flood inflow (hydrograph) which is to be used to size the spillway gates and determine the required freeboard for dam design purposes.

SPIRAL CASE

The steel inlet section for a Francis type turbine, which has a spiral shape in plan view.

SURGE TANK

A vertical chamber connected to the downstream end of a closed conduit. It usually has a free water surface and serves as a reservoir to decrease and dampen pressure surges during acceleration or deceleration of flow.

TAILWATER LEVEL

The water level measured in the tailrace area immediately downstream from a hydro plant.

THRUST BEARING

A bearing which supports the entire weight of the rotating parts of a vertical shaft turbogenerating unit, plus the maximum hydraulic thrust developed by the turbine.

TIMBER CRIB DAM

A dam constructed of timber crib cells filled with rock ballast and covered with sheathing on the water side to minimize leakage.

TRANSMISSION SYSTEM

An interconnected group of electric conductors and associated equipment for the transporting or conveying of electric energy in bulk to convenient points at which it is subdivided for delivery to distribution systems.

TRASH RACK

A coarse screen constructed of flat steel bars at a prescribed spacing, which are welded to supporting steel beams. Trash racks are installed at water intake structures to prevent the entry of any relatively large debris.

TRAVELING WATER SCREEN

A fine mesh traveling screen of an endless belt type which is motor driven and installed at intake structures to prevent the entrance of debris and small fish.

TURBINE

A hydraulic machine used to convert the energy in flowing water to mechanical power.

TURBINE CLASSES

Modern hydraulic turbines are divided into two classes: impulse and reaction turbines.

Impulse Turbines

An impulse turbine is one having one or more free jets discharging into an aerated space and impinging on the buckets of the runner, means of controlling the rate of flow, a housing and a discharge passage. The water supplies energy to the runner in kinetic form.

Reaction Turbine

A reaction turbine is one having a water supply case, a mechanism for controlling the quantity of water and for distributing it equally over the entire runner intake, and a draft tube. The water supplies energy to the runner in kinetic form.

Francis Turbine

A Francis turbine is one having a runner with a large number of fixed buckets, usually nine or more, to which the water is supplied in a whirling radial direction.

Adjustable-Blade Propeller Turbine

An adjustable-blade propeller turbine is one having a runner with a small number of blades, usually four to eight, to which the water is supplied in a whirling axial direction. The blades are angularly adjustable in the hub.

Fixed-Blade Propeller Turbine

A fixed-blade propeller turbine is one having a runner with a small number of blades, usually four to eight, to which the water is supplied in a whirling axial direction. The blades are rigidly fastened to the hub.

TURBINE EFFICIENCY

The overall mechanical efficiency of the turbine, in developing the total potential energy. Maximum turbine efficiency may reach as high as 94 percent.

TUBULAR TURBINE

An axial flow propeller type turbine which may have either a vertical, horizontal, or inclined shaft.

UNIT EFFICIENCY

The combined overall efficiency of a hydraulic turbine and its driven generator.

UTILIZATION FACTOR (ASA)

The ratio of the maximum demand of a system or part of a system, to the rated capacity of the system or part of the system, under consideration.

WATTHOUR METER

A meter which continuously records and integrates the watt hour output of a generating unit. It is used during performance testing to obtain an accurate measure of unit efficiency.

WEIR

A structure which is designed to permit flow over its crest.

WHEELING SERVICE

An electric operation wherein transmission facilities of one system are utilized to transmit power of another system.

UNITS OF ENERGY AND OF POWER

ENERGY

Basic cgs unit = 1 erg

1 erg = 1 dyne-centimeter = 624 x 10^9 electron volts

1 joule (absolute) = 1 watt-second
= 0.000 000 372 505 horsepower-hour
= 0.000 947 8 Btu
= 0.737 56 foot-pound

1 foot-pound = 1.355 8 joules
= 0.000 376 6 watt-hour
= 0.000 000 505 05 horsepower-hour
= 0.001 285 1 Btu

1 kilogram-meter = 9.806 65 joules
= 0.002 724 1 watt-hour
= 0.000 003 653 horsepower-hour
= 0.009 295 Btu

1 kilogram-calory = 4 186.7 joules
= 3.968 3 Btu
= 3 088 foot-pounds
= 1.163 0 watt-hours
= 0.001 559 6 horsepower-hour

1 British thermal unit (Btu) = 1 055.0 joules
= 0.293 07 watt-hour
= 0.000 393 01 horsepower-hour
= 778.156 foot-pounds

POWER

Basic cgs unit = 1 erg per second = 0.000 000 1 watt

1 foot-pound per second = 8.295 3 kilogram-meters per minute
= 1.355 8 watts
= 0.001 818 18 horsepower

1 kilogram-meter per minute = 0.163 44 watt
= 0.000 219 18 horsepower

1 Btu per minute = 17.584 watts
= 0.023 580 5 horsepower

1 watt = 10 000 000 ergs per second
= 1 joule per second
= 0.101 972 kilogram-meter per second
= 0.001 341 0 horsepower

watts = volts x amperes x cos angle of lag or lead

volt-amperes = volts x amperes
= watts ÷ cos angle of lag or lead

1 horsepower = 7 457 000 000 ergs per second
= 4 562.4 kilogram-meters per minute
= 745.7 watts
= 42.408 Btu per minute
= 33 000 foot-pounds per minute
= 1.013 87 metric horsepower

1 kilowatt = 6 118 kilogram-meters per minute
= 1 000 watts
= 1.341 0 horsepower
= 56.87 Btu per minute
= 737.56 foot-pounds per second
1 watt-hour per second = 3 600 watts
1 kilowatt-hour per minute = 60 kilowatts
1 watt-hour = 3 600 joules
= 0.001 341 0 horsepower-hour
= 3.412 Btu
1 watt-second = 1 joule
1 kilowatt-hour = 3 600 000 joules
= 1 000 watt-hours
= 1.341 0 horsepower-hours
= 3 412 Btu
= 2 655 000 foot-pounds
1 megawatt-hour = 1 000 kilowatt-hours
1 horsepower-second = 745.7 joules
= 550 foot-pounds
1 horsepower-hour = 2 684 500 joules
= 2 544.5 Btu
1 megawatt = 1 000 000 watts

MISCELLANEOUS

1 acre-foot = unit of volume in a reservoir
= 43 560 cubic feet
= 1 233 cubic meters
= 325 851 U.S. gallons
= 0.5042 second-foot day
1 second-foot (1 cfs) = unit of flow
= 1 cubic foot per second
= 0.028 32 cubic meters per second
= 7.480 5 gallons per second
= 723.97 acre-feet per year

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

APPENDIX B: TECHNICAL PAPER SESSION AND WORKSHOP CHAIRMEN

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

TECHNICAL PAPER SESSION AND WORKSHOP CHAIRMEN

Mr. David C. Auslam, Jr.
President
Auslam and Associates, Inc.
601 University Avenue
Sacramento, California 95825

Chairman
Workshop One
Finance and Marketing

Dr. Lewis H. Blakey
Chief
Office of Policy
Civil Works Directorate
U.S. Army Corps of Engineers
20 Massachusetts Avenue N.W.
Washington, D.C. 20314

Chairman
Session Six
Water: Management and Use

Mr. Peter Brown
Director
Energy Law Institute
Franklin Pierce Law Center
No. 2 White Street
Concord, New Hampshire 03301

Chairman
Workshop Three
Developing Policy/Legal Context

Mr. Ralph Burr
Hydroelectric Resources Development Staff
U.S. Department of Energy
1200 Pennsylvania Avenue, N.W.
Washington, D.C. 20461

Chairman
Workshop Four
Government Funding

Mr. John Casazza
President
Ransom and Casazza
1000 Connecticut Avenue, N.W.
Washington, D.C. 20036

Chairman
Session Twenty
Development and Operation Economics

Mr. Ronald A. Corso
Deputy Director
Division of Licensed Projects
Federal Energy Regulatory Commission
825 N. Capitol Street, N.E.
Washington, D.C. 20426

Chairman
Workshop Five
Licensing

Mr. George B. Fink
President
W.A. Wahler and Associates
1023 Corporation Way
Palo Alto, California 94303

Chairman
Session Nineteen
Redevelopment II

Mr. Augustine Jay Fredrich
Professor, Civil Engineering Technology
Indiana State University
1108 Glenmoore Court
Evansville, Indiana 47715

Chairman
Session Eighteen
Planning for Development III

Mr. Charles E. Gilmore
Chief
Advanced Technology Branch
U.S. Department of Energy
550 Second Street
Idaho Falls, Idaho 83401

Chairman
Session Nine
Case Studies and Demonstration Projects I

Mr. John S. Gladwell
Director
Resources Research Institute
University of Idaho
Moscow, Idaho 03043

Chairman
Session Sixteen
Planning for Development II

Mr. George B. Grimes, Jr.
Hydroelectric Resources Development Staff
U.S. Department of Energy
1200 Pennsylvania Avenue, N.W.
Washington, D.C. 20461

Chairman
Session Twenty-Three
Problems, Economics and Ideas

Mr. Vernon Hagen
Engineering Division
U.S. Army Corps of Engineers
20 Massachusetts Avenue, N.W.
Washington, D.C. 20314

Chairman
Session Four
Hydraulics and Hydrology

Mr. James R. Hanchey
Acting Director
Institute for Water Resources
U.S. Army Corps of Engineers
Kingman Building
Fort Belvoir, Virginia 22060

Chairman
Session Twenty-Two
New Techniques and Projects

Mr. Holsey G. Handyside
Acting Principal Deputy
Assistant Secretary
Office of International Affairs
U.S. Department of Energy
1200 Pennsylvania Avenue, N.W.
Washington, D.C. 20461

Chairman
International Perspectives
Plenary Session

Major General E. R. Heiberg III
Director of Civil Works
U.S. Army Corps of Engineers
20 Massachusetts Avenue, N.W.
Washington, D.C. 20314

Chairman
Engineering
Plenary Session

Dr. Peter Henault
Director
Department of Environmental
Affairs
Seattle City Light
1015 Third Avenue
Seattle, Washington 98104

Chairman
Session Thirteen
Environmental Issues and
Impacts

Dr. Stephen G. Hildebrand
Research Staff Member
Oak Ridge National Laboratory
P.O. Box X
Oak Ridge, Tennessee 37830

Chairman
Workshop Eight
Environmental Issues

Dr. Allan Hirsch
Director
Office of Biological Services
U.S. Fish and Wildlife Service
Department of the Interior
Washington, D.C. 20240

Chairman
Session Fifteen
Social and Environmental
Analyses II

Dr. Alan B. Jacobs
Chief
Energy Office
Agency for International
Development
Washington, D.C. 20523

Chairman
Session Ten
Development Experiences

Mr. Howard A. Mayo
Manager
Product Promotion and Market
Development
Allis-Chalmers Corporation
P.O. Box 712
York, Pennsylvania 17405

Chairman
Session Twenty-One
New Ideas, Concepts and
Technology II

Mr. Richard J. McDonald
Institute for Water Resources
U.S. Army Corps of Engineers
Kingman Building
Fort Belvoir, Virginia 22060

Chairman
Session Twelve
New Ideas, Concepts and Technology I

Mr. Eugene O'Brien
Partner
Water Resources Division
Tippetts-Abbett-McCarthy-Stratton
655 Third Avenue
New York, New York 10017

Chairman
Session Fourteen
Energy

Mr. Robert Philleo
Chief
Structures Branch
Office of the Chief of Engineers
U.S. Army Corps of Engineers
20 Massachusetts Avenue, N.W.
Washington, D.C. 20314

Chairman
Workshop Seven
Dam Inspection, Safety and Adequacy

Dr. Bernard Richert
Economic Development Planning Specialist
Economic Development Administration
Department of Commerce
Washington, D.C. 20230

Chairman
Session Seven
Social and Environmental Analyses I

Bridagier General Hugh Robinson
Deputy Director U.S. Army Corps of Engineers
Civil Works
20 Massachusetts Avenue, N.W.
Washington, D.C. 20314

Chairman
Policy Plenary Session
Chairman
Special Plenary Session
Chairman
Conference Luncheon

Mr. William E. Rumberger
Manager
Electrical Systems Programs
Niagara Mohawk Power Corporation
300 Erie Boulevard West
Syracuse, New York 13202

Chairman
Session Three
Generation Systems

Mr. Robert M. Shepard
Senior Vice President
Public Finance Department
Donaldson, Lufkin and Jenrette
140 Broadway
New York, New York 10005

Chairman
Session Five
Public and Private Finance

Mr. Farwell Smith
Acting Resource Manager
Small-Scale Hydroelectric Applications
U.S. Department of Energy
1200 Pennsylvania Avenue, N.W.
Washington, D.C. 20461

Chairman
Session Seventeen
Case Studies and Demonstration Projects II

Mr. George Smith
Manager
Hydroelectric Project
Idaho National Engineering Laboratory
U.S. Department of Energy
Idaho Falls, Idaho 83401

Chairman
Session One
Equipment
Chairman
Workshop Six
Engineering

Mr. James J. Victory
Vice President
Kvaerner-Moss, Inc.
800 Third Avenue
New York, New York 10022

Chairman
Session Eleven
Technology

Mr. J. Gavin Warnock
Vice President and General Manager
Acres American, Inc.
Clark Building
Columbia, Maryland 21045

Chairman
Session Two
Redevelopment I

Mr. Stanley I. Weiss
Deputy Assistant Secretary for Utility and Industrial Applications
U.S. Department of Energy
1200 Pennsylvania Avenue, N.W.
Washington, D.C. 20461

Chairman
Planning, Information and Methods
Plenary Session

Mr. David C. Willer
Project Manager
Tudor Engineering Company
149 New Montgomery Street
San Francisco, California 94105

Chairman
Workshop Two
Planning

Dr. David R. Zoellner
Environmental Planner
Institute for Water Resources
U.S. Army Corps of Engineers
Kingman Building Complex
Fort Belvoir, Virginia 22060

Chairman
Session Eight
Planning for Development I

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

APPENDIX C: EXHIBITORS

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

EXHIBITORS

The conference co-sponsors wish to thank the following exhibitors for their participation and support for Waterpower 79:

Acres American Incorporated
Suite 329, Clark Building
Columbia, Maryland 21045
(301) 992-5300

Allis-Chalmers Corporation
Box 712
York, Pennsylvania 17405
(717) 792-3511

ASEA, Inc.
4 New King Street
White Plains, New York 10604
(914) 428-6000

Axel Johnson Corporation
1 Market Plaza, Suite 445
San Francisco, California 94105
(415) 777-3800

BOFORS-NOHAB, Inc.
One World Trade Center
Suite 10225
New York, New York 10048
(212) 466-0157

Brown Boveri Corporation
1460 Livingston Avenue
North Brunswick, New Jersey 08902
(201) 932-6000

General Electric Company
One River Road, Building 23-254
Schenectady, New York 12306
(518) 385-2211

Hydro Research Science
3334 Victor Court
Santa Clara, California 95050
(408) 988-1027

Independent Power Developers
Route 3, Box 285, Mountain View Road
Sandpoint, Idaho 83864
(208) 263-2166

Kvaerner-Moss
800 Third Avenue
New York, New York 10022
(212) 752-7310

Leroy-Somer, Inc.
405 W. University Drive
Arlington Heights, Illinois 60004
(312) 398-1370

Charles T. Main, Inc.
Southeast Tower
Prudential Center
Boston, Massachusetts 02199
(617) 262-3200

McKay Water Power Limited
P.O. Box 488
Port Colborne, Ontario, Canada
L3K 5X7
(416) 835-1551

Morrison-Knudsen Company, Inc.
One Morrison-Knudsen Plaza
P.O. Box 7808
Boise, Idaho 83707

Oy Tampella AB
Madden Service Corporation
9 Rockefeller Plaza
New York, New York 10020
(212) 246-4025

China National Machinery
and Equipment Export Corporation
12, Fu Xing Men Wai Street
Peking, China
Telex: 23186 EQUIP CN
Cables: EQUIPEX Peking

Radiation Management Corporation
Ecological Division
3508 Market Street, Suite 400
Philadelphia, Pennsylvania 19104
(215) 243-2905

SOGREAH
BP172X38042
Grenoble, CEDEX, France

Sulzer Escher Wyss
200 Park Avenue
New York, New York 10017
(212) 949-0999

TAMS
655 Third Avenue
New York, New York 10017
(212) 867-1777

U.S. Army Corps of Engineers
20 Massachusetts Avenue N.W.
Washington, D.C. 20314
(202) 272-0011

U.S. Department of Energy
550 2nd Street
Idaho Falls, Idaho 83401
(208) 526-0111

U.S. Geological Survey
12201 Sunrise Valley Drive
Reston, Virginia 22090
(703) 860-7000

Worthington Pump, Inc.
270 Sheffield Street
Mountainside, New Jersey 07092
(201) 654-3300

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

APPENDIX D: AUTHORS

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

AUTHORS

	Page
Ahimaz, Franklin J.	743
Allen, Arthur E.	163
Armstrong, Ellis	69
Armstrong-Evans, Rupert J.	782
Baird, Hamilton	382
Baker, G. C.	550
Balls, M.	550
Barnes, Samuel E.	504
Bates, Edmond R.	586
Baxter, Loran R.	448
Beckwith, Robert W.	196
Bell, Milo C.	411
Bergseng, Johan.	202
Besel, Hermann J.	202
Binli, Deng	755
Bondy, Richard L.	662
Bourne, Peter.	63
Broome, Kenneth R.	539
Brown, Peter W.	738
Brown, Ruben S.	350
Butz, Horst	202
Calvert, James D., Jr.	633
Carlisle, Richard K.	492
Chan, Man-Loong	527
Chavez, Pablo	464
Chow, W. Y.	608
Clapp, Norman M.	27
Clemence, Shirlene.	404
Dalton, James G.	234
Damstrom, Emory K.	273
Davis, Darryl W.	520
DeHeer, Lee	460
Dixon, John H.	210
Dolcimascolo, Anthony R.	317
Durkin, John A.	55
Emmert, Rickey	218
English, J. Morley.	720
Ferreira, Antonio.	378
Fisher, Gary J.	667
Franc, Gary M.	234
French, R. Lewis.	265
Fritz, Edward J.	260

Page

George, Alexander C. ... 441
Gibson, R. A. ... 550
Gladwell, John S. ... 796
Glazer, Sarah J. ... 693
Goodman, Alvin S. ... 350
Gravel, Mike ... 79
Grimes, George B., Jr. ... 682
Grimsrud, G. Paul ... 527
Grover, Kenneth ... 748
Hamlin, Roger E. ... 486
Hanchey, James R. ... 675
Hartmann, Otto ... 99
Heiderstadt, Richard T. ... 418
Heitz, Leroy F. ... 218
Hildebrand, Stephen G. ... 411, 498, 682
Hingorani, Narian G. ... 185
Hobart, Larry ... 652
Hoffman, Philip R. ... 388
Holland, J. Keen ... 646
Hough, Thomas C. ... 597
Ingersoll, Alfred C. ... 720
Jacobs, Nelson J. ... 424
Jarecki, Eugene A. ... 323, 591
Johnson, James F. ... 670
Kersten, Robert D. ... 776
Klock, Thomas E. ... 431
Klotz, Louis H. ... 533
Lauerman, Eugene J. ... 626
Lawrence, John D. ... 108
Lee, Stephen T. ... 527
Limaye, Dilip R. ... 597
Linzell, Lewis E. ... 169
Little, Gordon E. ... 568
Loar, James M. ... 498
Lystra, Donald W. ... 361, 492
Maloney, Timothy J. ... 302
Manasse, Fred K. ... 533, 720
Mankauskas, J. J., Jr. ... 617
Marsh, Eric ... 527
Master, David B. ... 533, 720
Masters, Glenn H. ... 527
Mayo, Howard A., Jr. ... 89, 539
McLeod, Hugh W. ... 708
McConnell, Daniel R. ... 323
McIsaac, George S. ... 17
Mercure, Alex, P. ... 39

Page

Meroney, William 597
Miller, H. 550
Miller, K. Thomas 265
Mittlestadt, Richard L. 727
Moentenich, Brian 575
Morris, J. W., Lt. Gen 11
Mosonyi, Emil F. 45
Novak, William J. 418
Opp, Weldon A. 448
Papsidero, Thomas F. 591
Pietz, A. Wayne 452
Plantico, Reuben C. 688
Purdy, C. C. 176
Riezinger, Friedrich 202
Rømcke, Nils 764
Rudavsky, Alexander B. 226, 608
Satir, Kemal 368
Sattler, H. 306
Schneider, Daniel J. 273
Searls, James P. 342
Sheldon, Georgina 33
Slapp, John 185
Sligh, Ernest E. 323
Stadler, Gerald J. 575
Stapenhorst, F. W. E. 142
Steiner, Daniel E. 157
Stritt, Albert R. 157
Szluha, Adam T. 498
Taylor, Robert J. 700
Tegtmeyer, Rene D. 394
Telaar, William B. 711
Threadgill, J. Randall 527
Trott, Alfred G. 154
Tseng, Alexander A. 755
Turner, Ralph R. 498
Tuttle, George L. 657
Vanderburgh, Malcolm R. 333
Wachter, Grover F. 116
Waring, John A. 715
Warnick, Calvin C. 796
Warren, John L. 603
Watson, Jack H., Jr. 1
Watts, Abner W. 527
Wenshen, Mao 755
Willer, David C. 561

Willett, David C. 333
Williamson, James V. 452
Wilson, E. M. 550
Wright, E. S. 617
Yuan, Sun-Quan 226
Zhaoxiang, Tu 755

☆ U.S. GOVERNMENT PRINTING OFFICE: 1980 O— 721-569

ACKNOWLEDGMENTS

As chairman of the WATERPOWER '79 Conference Planning Committee, I would like to express my sincere appreciation to those organizations and individuals who devoted much of their own time and energy to the success of this conference. In particular, I would like to thank the Technical Program Committee members: David R. Zoellner, Chairman; Sharon Blake and Darrell Nolton of the Institute for Water Resources, U.S. Army Corps of Engineers; Lu DuCharme, Office of the Chief of Engineers, U.S. Army Corps of Engineers, and the Workshop Program Committee members: Margaret McClements Lambie, Chairman, Small-Hydro Program Staff, U.S. Department of Energy; David Auslam, President, Auslam and Associates; Peter Brown, Energy Law Institute, Franklin Pierce Law Center; Ralph Burr, Small-Hydro Program Staff, U.S. Department of Energy; Ronald Corso, Federal Energy Regulatory Commission, U.S. Department of Energy; Stephen G. Hildebrand, Oak Ridge National Laboratory, U.S. Department of Energy; Robert Philleo, Engineering Laboratory, U.S. Department of Energy; and David Willer, Head, Water Resources Programs, Tudor Engineering Company. Also deserving particular mention are Wesley Copeland and Dorothy Bomberger of the International Science and Technology Institute for their efforts in coordinating the logistics of the conference. Finally, I would like to thank June Fratus, Water Resources Support Center, and Darell Nolton and David Zoellner, Institute for Water Resources, U.S. Army Corps of Engineers, for collecting and editing the presentations for publication.

JAMES R. HANCHEY
Acting Director
Institute for Water Resources

RECEIVED BY TIC FEB 23 1981

WATERPOWER '79

an international conference on small-scale hydropower

October 1-3, 1979

EXECUTIVE SUMMARY

U.S. ARMY CORPS OF ENGINEERS

U.S. DEPARTMENT OF ENERGY

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

CONFERENCE CO-CHAIRMEN

Lt. Gen. J.W. Morris, Chief of Engineers, U.S. Army Corps of Engineers
George S. McIssac, Assistant Secretary, Resource Applications, U.S. Department of Energy

STEERING COMMITTEE

Brig. Gen. Hugh Robinson, Chairman, Deputy Director, Civil Works, U.S. Army Corps of Engineers
James R. Hanchey, Acting Director, Institute for Water Resources, U.S. Army Corps of Engineers
Richard McDonald, Resource Manager, Hydroelectric Program, U.S. Department of Energy
Alex Shwaiko, Chief, Planning Division, Office of the Chief of Engineers, U.S. Army Corps of Engineers

TECHNICAL PROGRAM COMMITTEE

David Zoellner, Chairman, Institute for Water Resources, U.S. Army Corps of Engineers
Margaret McClements Lambie, Small Hydroelectric Resource Development Program, U.S. Department of Energy
Sharon Blake, Institute for Water Resources, U.S. Army Corps of Engineers
Lu DuCharme, Office, Chief of Engineers, U.S. Army Corps of Engineers
Darrell Nolton, Institute for Water Resources, U.S. Army Corps of Engineers

WORKSHOP PROGRAM COMMITTEE

Margaret McClements Lambie, Chairman, Small Hydro Program Staff, U.S. Department of Energy
David Auslam, President, Auslam & Associates
Peter Brown, Energy Law Institute, Franklin Pierce Law Center
Ralph Burr, Small Hydro Program Staff, U.S. Department of Energy
Ronald Corso, Federal Energy Regulatory Commission, U.S. Department of Energy
Stephen G. Hildebrand, Oak Ridge National Laboratory, U.S. Department of Energy
Robert Philleo, Engineering Division, U.S. Army Corps of Engineers
George Smith, Idaho National Engineering Laboratory, U.S. Department of Energy
Edward Tanzman, Argonne National Laboratory, U.S. Department of Energy
David Willer, Head, Water Resources Program, Tudor Engineering Co.

PARTICIPATING ASSOCIATIONS

Institute of Electrical and Electronics Engineers, Inc.
National Society of Professional Engineers
American Society of Civil Engineers
American Society of Mechanical Engineers
Society of American Military Engineers

CONFERENCE PLANNING AND MANAGEMENT SUPPORT

International Science & Technology Institute, Inc., Washington, DC

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

WATERPOWER '79

EXECUTIVE SUMMARY







DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED









I. CONFERENCE PROFILE

Waterpower '79 was held October 1-3, 1979 at the Washington Hilton Hotel, Washington, D.C.

PURPOSE

The purpose of the conference was an exchange of information among those in the public, private and international sectors who are either actively working in hydropower or have a strong interest in the subject.

ATTENDANCE

The attendance exceeded 1200 and included representatives from many sectors—Federal Government, State and Local Government, Architect-Engineer firms, financial institutions, utilities, associations, U.S. and foreign manufacturers, universities, international organizations, foreign countries, and many others

TECHNICAL PROGRAM

The technical program consisted of: a White House executive address; plenary sessions dealing with topics in engineering, policy, planning and international experiences; two special Congressional addresses; twenty-three technical sessions in which eighty-nine papers were delivered in topics ranging from social, economic and environmental concerns to innovation, facility design and international assistance; thirty-two exhibition booths and a film and slide theatre; and workshops which were offered on a repeating basis and dealt with topics on financing and marketing, planning, development policy and legal context, government funding, licensing, engineering, dam inspection, and environmental issues.

SPECIAL EVENTS

An exhibitors' reception with canape's and drinks in the exhibit hall, a Congressional reception for 1200 - 1300 was held on the Hill and catered by the Senate caterer, and a conference luncheon was held featuring as guest speaker, the Chairman, Hydraulic Resources Division of the World Energy Conference Commission on Energy Conservation.



II. CONFERENCE FINDINGS

POTENTIAL

There is considerable potential for hydropower development via upgrading, retrofit and new work in both the U.S. and other countries.

- U.S.—Northeast, Southeast and Lake Central areas have the most potential with roughly 5,000 MW at 4,800 sites, most of which are in New England.
- Examples of countries that are actively installing and/or inventorying small-scale potential include, New Guinea, Peru, Peoples' Republic of China, and others.

METHODOLOGIES

Technical methodologies have been and are being developed at universities, research institutes, regional, federal and state government agencies in such topics as hydrologic and hydraulic based feasibility assessments, computer assisted techniques for inventories, modeling and various approaches to environmental, economic and social assessments.

INTEREST

The interest in small-scale hydropower is part of the larger interest in technologies utilizing renewable energy resources. The large conference turnout of over 1200 when 700 were expected, the large number of international requests for conference proceedings, the heavy attendance at DOE regional workshops in hydropower, the formation at WATERPOWER '79 of a professional society of small-scale hydropower, and the inundation of FERC with license applications and requests for information all indicate a growing interest in small-scale hydropower.

ROLE

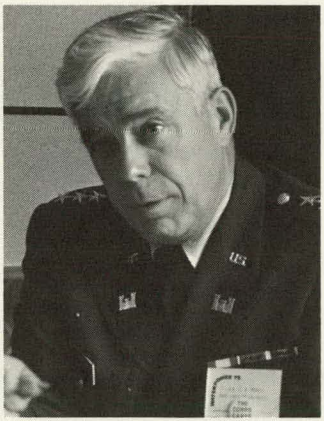
The role for hydropower in the future while not a major energy supply is an important one. Relatively inexpensive energy, minimal environmental damage and the ability to provide large centralized as well as small decentralized power will help our energy supply system.

This role has been assured by both the Administration as well as the Congress. Recent initiatives from the President are designed to provide hydropower to rural America and to install low head turbines in locks and dams along the Mississippi River. Legislation from the Congress has provided tax incentives for developers.

MANUFACTURERS

Vendors are continuing to develop new equipment appropriate to small-scale hydropower. Turbines are being marketed which are designed for low flows, low heads and have standard sizes. Breakthroughs lowering power house costs are continually pursued. U.S. manufacturers are competing in the world market, but they must also compete with foreign manufacturers at home.

CONFERENCE CO-CHAIRMAN



LTG JOHN W. MORRIS
Chief of Engineers
U.S. Army

"Since 1900 we moved across the country from coast to coast like a giant machine harvesting the choice hydropower sites."

"Hydroelectric power development at many dam projects which had not been economically feasible in the past, have suddenly become attractive investments."

"We are now retracing our steps, gleaning the potential power sites we overlooked before the escalating cost of fossil fuels made hydropower more competitive."

"There are five Corps power projects under construction which will have an installed capacity of almost 1.4 million KW. Four power projects now in operation have authorized power additions. There are 9 power projects authorized, but not yet under construction. Nine existing power projects will require authorization to install additional units. Fifty existing projects have potential for installation of power generating units. Finally, 35 potential projects not yet authorized have a power potential greater than the Corps current installed electric capacity."

"The development of all of these potential sources of hydropower would more than triple the current generating capacity at Corps projects."

"We have been working closely with the Department of Energy as this jointly-sponsored symposium shows. We are developing the data base on which a sound national hydropower development program can be planned and executed. The cooperation of many Federal, State and local interests is essential to the achievement of that goal."

"The Corps of Engineers has the organization and capability to interface effectively with the private sector in the development of water resources, including hydropower. Its network of field offices reaches all sections of the country. The Corps is used to working effectively with State and local officials and individuals in its many programs involving planning, cost sharing, public participation and regulatory functions. Our track record for obtaining the cooperation of the public and private sector is a good one. I pledge the full cooperation of the Corps in the development of our total national hydropower potential."

CONFERENCE CO-CHAIRMAN



GEORGE S. McISSAC
Assistant Secretary for
Resource Applications
U.S. Department of Energy

"The most urgent aspect of the energy problem is our over dependence—I think of it as an addiction—to oil, particularly imported oil."

"We still must provide energy to support our industrial base and provide for the legitimate needs of our people. Thus, we must develop alternative sources of energy."

"This is the context in which we view small hydro. It is an available source of energy that has not been fully exploited. . . . It is reasonably economic, environmentally benign and directly applicable to power generation. It is part of the solution."

"There are four impediments to the widespread use of small-scale hydropower. These are: (1) lack of knowledge about the size, location and nature of the resource base; (2) lack of understanding of the pricing aspects of small-scale hydropower; (3) lack of proof, through actual demonstrations, that modern small-scale hydro technology works; and (4) difficulty of transferring information to potential decision makers."

In order to overcome these barriers, DOE has structured a four-part program:

1. *Special studies:*
   - *impediments to development and incentives for power-on-line*
   - *national assessment of small-scale hydro*
   - *state surveys*
   - *technical overviews*
   - *cost reduction and extended technology*
   - *implementation of state hydro legislation*
2. *Grants for feasibility studies and licensing assistance*
3. *On-going and planned demonstration projects*
4. *Regional informational workshops and developing user documents.*

EXECUTIVE ADDRESS



JACK H. WATSON, JR.
Assistant to the President for
Intergovernmental Affairs and
Secretary to the Cabinet
The White House

"The energy challenge, I think, poses some very fundamental questions to us . . . it poses questions about our capacities to respond to change, to discipline ourselves, our capacity to be a generation of Americans and citizens of the world on the . . . cutting edge of an era, the outlines of which we cannot, do not perceive yet."

"We have a kind of mega solution syndrome in a time in which there aren't any mega solutions. It's a syndrome from which we must escape."

"We need to do many things in the energy area, things of a dispersed nature that need to be done by local communities, with local initiative, for local pay-off . . . I am predicting, I think absolutely safely, that our attention has turned, and will continue to turn, to the smaller scale effort."

". . . They involve no new environmental impacts, generally speaking.
. . . They are virtually non-polluting.
. . . They are using a renewable resource.
. . . They are small and, almost invariably can be aesthetically acceptable, even pleasing.
. . . The technology for the hydroplants is established.

"Part of the benefit which I hope will result from a conference and other conferences like this one will be an exchange of expertise and technical knowledge with respect to the standardization and mass-production of that small scale hydroelectric power generation."

"It's interesting to note, and important I think, that A.I.D. in this country as well as the international finance community at large are recognizing increasingly the potential for small-scale hydropower and they are expressing interest in participating in the implementation of projects identified in those assessments."

". . . This energy crisis . . . gives us a chance to reexamine, at a pivotal moment, just exactly what kind of legacy we want to leave to our children and their children."

III. THEMES & TOPICS

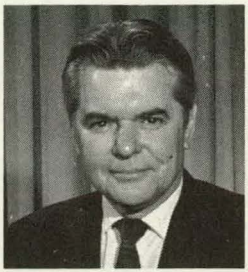
A number of themes with key topics were woven through the conference fabric. The general conference spirit was one of optimism.

- engineering is meeting the challenge with such items as turbines requiring no dam, turbines designed for low head, standardized sizes, and so on.
- incentives are beginning to be developed through legislation for licensing exemption for facilities with small size and special purpose, for ownership transfer and for government subsidies through grants, loans and low tax rates.
- government planning programs are identifying opportunities through many state activities and Federal programs in the Corps, Water and Power Resources Service, Water Resources Council and others.
- problems exist, but are being identified and dealt with—environmental mitigation costs, financial assistance, marketing, powerhouse costs, for example.
- demonstration projects show where problems will occur, but also show it can be done in the case of new equipment, ideas, etc.
- many countries have much to offer either in the way of experience with small-scale hydropower or in potential for development.
- many analytical techniques exist or are being developed for planning, inventories, field surveys, economic assessments, hydrologic potential, environmental impacts, and so on.
- financial opportunities exist through the private sector also, via long term loans, and low interest rates to individuals and companies.



IV. TECHNICAL PROGRAM

Engineering



PLENARY

". . . small hydroelectric development is not only an idea whose time has come, but is also a practical and feasible energy development whose time has come."

NORMAN M. CLAPP
Former Administrator
Rural Electrification Administration
U.S. Dept. of Agriculture

There is considerable encouragement in the size of the total small-scale potential available. Of 54,000 dams surveyed the Corps found that roughly 10 percent, 5,424 sites, were technically feasible. Preliminarily, the capacity of these sites has been put at 94,636 MW.

DOE demonstration sites are also showing encouraging feasibility results. Of 54 studies, 60% were found to be feasible, though many were marginal. Facility costs generally ranged from $1000 to $2500 per kilowatt and energy costs from 20 to 45 mills. Additional demonstration projects are underway, with an expanded loan program for feasibility studies and licensing costs. Recent program opportunity notices have gone out seeking proposals for both larger scale demonstration studies as well as innovative demonstration projects.

Currently pending legislation would, if enacted in present terms, provide tax credits for small hydro facilities at existing dams of 25 MW or less capacity, including added investment tax credits for fish ways, transmission facilities, turbines, and civil works. It would also permit accelerated depreciation on small hydro facilities.

PANEL

Howard A. Mayo, Jr., *Marketing Development, Allis-Chalmers Corp.*
David C. Willer, *Manager, Water Resources, Tudor Engineering*
Robert H. Bruck, *Chief, Electrical & Mechanical Branch, Engineering Division Corps of Engineers*
William Love, *Superintendant of Utilities, Vanceburg, Kentucky*
William Lawson, *Director, Office of Technology Assessment and Forecast, U.S. Patent Office*

PAPER SESSIONS

Equipment — *small hydropower equipment for development and operation.*

Redevelopment — *existing facilities, historic sites — planning and structural considerations, application of "Mini Units", dam safety, retired plant potential and minimizing capital costs.*

Generation systems — *power station operation, equipment and new developments.*

Hydraulics and hydrology — *techniques for investigation, planning, design and problem analysis.*

New ideas, concepts and technology — *low velocity water currents, hybrid power plants, site built components and new applications, identification of research, hydraulic ram, hydropower without dams, appropriate technology.*

Development and operations economics — *busbar costs, evaluation of small-scale plants, conceptual run of river model and comparative project economics.*

Planning, Information and Methods



PLENARY

"Low-head hydro could conceivably produce all of the energy necessary by electric cooperative systems in this country to 1995."

ALEX P. MERCURE
Assistant Secretary for Rural Development
U.S. Department of Agriculture

In the past several years there has been tremendous growth in small communities in rural America. According to demographers, small towns are now growing, generally about twice as fast as our big cities. There has also been a tremendous diversification in the location of America's industry and REA is an important, though not exclusive, element in that development.

If, for their $10 million, DOE was able to finance only 100 demonstration plants which averaged 5 MW, they would produce a total capacity of 500 MW. In REA, 500 MW of capacity would represent $500,000,000 in loans. That gives some idea of how important it is to aggregate these diverse sources of energy.

It's time to think about what small units aggregated and dispersed could do—it isn't difficult for REA to integrate small quantities of electricity, particularly if it's baseload, into the transmission systems that those electric coops already have. Small irrigation diversion dams and larger erosion control dams have power producing potential.

The coops are beginning to show an impressive initiative not only in hydropower, but in a range of several solutions to help capture the waste of energy.

PANEL

Robert Cross, *Administrator, Alaska Power Authority*
Ronald Corso, *Deputy Director, Licensed Projects, Federal Energy Regulatory Commission*
Jerry D. Priscolli, *Sr. Social Scientist, Institute for Water Resources, Corps of Engineers*
Mike Spear, *Associate Director, Environment, U.S. Fish & Wildlife Service*

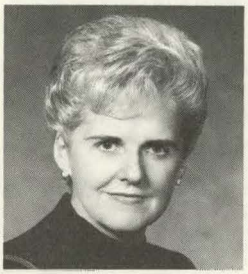
PAPER SESSIONS

Social and Environmental Analyses — *community impacts, historic preservation, fish passage technology, employment possibilities, assessment methodologies, water level fluctuations and institutional arrangements.*

Planning for development — *inventories, resource assessment, screening methodologies and statewide coordination, planning hydro additions, financial planning, state planning and optimizing feasibility studies, factors affecting feasibility, mapping systems, evaluation models and supporting services.*

Case studies and demonstration projects — *feasibility investigations, innovative state legislation, powerhouse reconstruction, unit size selection, tidal power, power projects and preliminary feasibility studies.*

Policy



PLENARY

"Clearly, small-scale hydropower can play a major role in a short term solution of our energy needs. And it must be a vital part of our long term energy program."

GEORGIANA SHELDON
Commissioner
Federal Energy Regulatory Commission

The Commission has made recent efforts to simplify and expedite the licensing process. In September of 1978 the FERC simplified the licensing procedure for power projects with a capacity under 1.5 MW which lessens detail and information required, and revises comment procedure. In March 1979 requirements were put forth which simplified filing related to amendments, cancellations and reducing exhibits from 9 to 4. In April 1979 procedures were proposed which streamlined the processes at existing sites, reducing exhibits from 23 to 7. A final phase of reform in FERC licensing will apply to new projects of capacity greater than 1.5 MW.

In April 1979 FERC exempted licensing requirements of projects 15 MW or less located on man-made conduits for generating power only.

Some 17 different federal statutes have vested various federal agencies with jurisdiction over some aspect of hydropower. A successful program must involve the cooperation of other agencies, special interest groups and licensees as well. State and Federal agencies must devise new processes of interagency coordination so that required considerations are expeditiously carried out in the public interest.

Licensees must recognize and accept the responsibilities and obligations of utilizing a public resource, availing themselves of agency staff expertise and entering into effective dialogue with special interest groups.

PANEL

Alex Radin, *Executive Director, American Public Power Association*
Leo Eisel, *Director, U.S. Water Resources Council*
Robert Smythe, *Sr. Staff, Council on Environmental Quality*
Lawrence F. Kramer, *Mayor, City of Paterson, N.J.*

PAPER SESSIONS

Public and private finance & policy issues — *recommendations, constraints and marketability*

Water: Management and use — *potential considerations, water rights, planning guidelines and policy recommendations.*

Environmental issues and impacts — *small scale impacts, DOE's program plan, land use consideration and legislation.*

Energy — *institutional, economic and environmental constraints, future alternatives, generation in rural areas and application to a utility system.*

International Perspectives



PLENARY

"I am devoted to hydropower. It is the most exciting professional subject . . . implementation of hydropower projects require the broadest application of several disciplines of engineering."

EMIL F. MOSONYI
Professor, Hydraulic Engineering
University of Karlsruhe
German Federal Republic

In the world, in many countries, not only the small-scale dam power plants, but also the typical low-head, run-of river stations located on low gradient streams will gain in importance.

In all stages of hydropower construction the process has been accelerated, particularly in the phases of foundation and tunneling works, machine assembly at site and prefabrication. Economic stimuli for water power utilization have been provided by advances in tunneling techniques. Examples of underground projects exist in Canada, Austria, Sweden, Norway, Italy and Switzerland.

Many river stretches and dam sites can be selected which have not been realized before as offering the chance for hydropower implementation. From the economically feasible potential of 4 million MW, only roughly 10% has been presently utilized.

Several aspects will contribute to a successful program in small-scale hydropower: true allocation of investment, realistic assumptions of equipment and structure lifetimes, up-to-date assessment of plant capacity, future contingency planning, feasibility study requirements in balance with economic and human values, midget plants that do not require sophisticated equipment, reduced planning and construction time, hydropower as an integral part of engineering education, and accelerated decision-making.

PANEL

Peter Bourne, *Assistant Secretary General, UN Water Decade*
Charles Weiss, *Science Advisor, World Bank*
Alan B. Jacobs, *Director, Energy Office, AID*
Francis X. Gannon, *Advisor to Secretary General, OAS*
Ricardo Saettone, *Director, Superior Vice Minister of Energy & Mines, Peru*

PAPER SESSIONS

Development experiences — *regulation comparison, non-oil producing nations, foreign aid for developing countries and development in the Peoples' Republic of China.*

Technology — *experience with small-scale turbines, appropriate technology and viable alternatives.*

V. WORKSHOPS

Eight workshops were held several times each during the conference. Each session lasted approximately 2 hours with a panel presentation followed by audience interaction.

The workshops and example topics with which they dealt were:

Finance and Marketing

Chairman: David Auslam, Auslam & Assoc.

Financing hydro projects, raising private backing, tax credits, investment bankers, marketing and calculating investment return.

Planning

Chairman: David Willer, Tudor Engineering

A feasibility study locating Information and resources, designing, planning and implementing a project, converting into a utility grid, and wheeling power.

Developing Policy/Legal Context

Chairman: Peter Brown, Franklin Pierce Law Center

Identifying Federal, State, regional and municipal policies, government regulations, conflicting water uses.

Government Funding

Chairman: Ralph Burr, U.S. Dept. of Energy

Obtaining government funds, government programs.

Licensing

Chairman: Ronald Corso, Federal Energy Regulatory Commission

Applying optimal resource use, inspections, engineering and economic studies, preliminary permit, feasibility.

Engineering

Chairman: George Smith, U.S. Dept. of Energy

Assessing requirements, stream potential, power system, automatic vs. semi automatic.

Dam Inspection, Safety and Adequacy

Chairman: Robert Philleo, U.S. Army Corps of Engineers

Assessing a dam structure, matters and considerations to address.

Environmental Issues

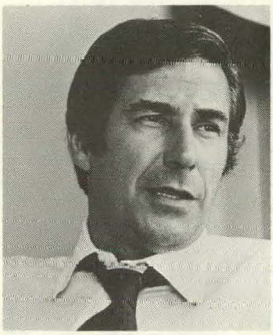
Chairman: Stephen Hildebrand, Oak Ridge National Lab

Issues affecting development, mitigation, issue solution, impacts, and regulations.



VI. SPECIAL PRESENTATION

Special addresses were given to the attendees of Waterpower '79 by members of the Congress and the World Energy Conference.



HON. MIKE GRAVEL
D Alaska
U.S. Senate

The outlook for hydropower as an alternative energy source in the 1980's is integrally tied to the overall consideration and development of a comprehensive and effective national energy policy. To assess the future of hydropower in the next decade, it is necessary to understand and consider the current direction of this country's energy policies.

The development of hydroelectric power has always been subject to the market. Hydropower provided the foundation for the industrial development of this Nation and continued to grow until the regulation of natural gas took hold in the early 1960's.

In August Senator Mark Hatfield and Senator Gravel were joined by several other Senators in introducing Senate Bill 1641, the Small Hydroelectric Power Development Act of 1979. This bill will set up a continuing authority for the Corps of Engineers to site select, plan, design, and construct new low-head hydroelectric facilities. This authority is set up on a turn-key basis with the non-Federal entity owning and operating each facility and agreeing to pay back 100 percent of the Federal cost of construction plus interest over a fifty year period. Projects constructed under this act shall be limited to an installed capacity of twenty-five magawatts.

Most important, Senate Bill 1641 is designed specifically to provide small low-income communities with a source of renewable energy immune to rising oil prices. These projects will help provide such communities with a stable economic base for economic development in the 1980's.



SPECIAL PRESENTATION



HON. JOHN A. DURKIN
D-N.H.
U.S. Senate

In the state of New Hampshire it has been suggested that up to a third of the electrical power can be generated by retrofitting existing dams and taking advantage of some of the flood control dams.

Hydropower is currently very economical, but future costs of pursuing oil-based emergency energy resources, particularly in terms of military security, are equally important. By 1984 and perhaps sooner the Soviets will stop exporting one million bbls of oil per day to the West, they will become importers of oil and the pressure on the price and availability in the Middle East and elsewhere in the OPEC countries is going to be tremendous.

There are several things we must work on; make money available for loan guarantees; increase the investment tax credit for the businessman and the entrepreneur; set equitable power rates in the utility section; provide incentives to power generated from small-scale hydro and other small alternative energy sources; assist municipalities through loan guarantees.

We must use energy efficiently, otherwise we're not going to preserve economic standards and be independent.

The states can do a lot to help. The closer the spending of the money is to the taxpayer, the more efficient the distribution and utilization of the money.

"We are the most efficient in the world, but also the most energy intensive in the world. . . . inflation is hitting the necessities and it's primarily energy induced. We are never going to get it under control in my area of the country until we solve the energy problem. Hydro has a tremendous potential."



SPECIAL PRESENTATION



ELLIS L. ARMSTRONG
Chairman, Hydraulic Resources Division
World Energy Conference Commission on Energy Conservation
(Former Chairman, U.S. National Committee of The World Energy Conference)

The potential of developing small-scale hydropower is promising, but as with most things, there is no magic. Accomplishment takes work and effort and time. The challenges for development to occur become more difficult and more widespread as we have more people. And this is a fact that no fantasy or wistful thinking is going to change; more and more and more people are coming down the road.

The World Energy Conference Conservation Commission study concluded that the worldwide hydropower installations will increase about five times by 2020. It is expected the present 60,000 MW will be about double in the United States.

The challenge is for all of us to more realistically face up to the fundamental problems of mankind in order to meet the needs of the growing numbers of people in our world. Meeting the needs of people, both in the developed and the undeveloping countries, basically involves energy, water, and food; interrelationships are varied and complex. For instance, in the more affluent countries where food supplies seem assured, at least for the present, the emphasis is directed toward a fuller life, including increased services and cultural activity in an unpolluted quality environment. This requires greater energy from cleaner sources, and better management and control of water. In the developing countries, the emphasis is on adequate food, goods and services that reduce risks to life, and improve human conditions so that life is less arduous and more worthwhile. Worldwide, all are striving toward individual betterment, justice, harmony, and peace; these goals require economic growth and improvement, and this requires increased use of energy and better and increased utilization of water.



VII. WHERE DO WE GO FROM HERE

1. Results from current studies by the Corps of Engineers, Water and Power Resources Services, New England River Basin Commission and others will soon determine the feasibility and potential of hydropower and additional demonstrations funded by DOE will exhibit innovation, test equipment and prove economic viability. These results will lead the way for viable programs for both large and small-scale development.

2. Legislation is continuing to be developed which will assist in streamlining government agency procedures and providing technical assistance and incentives to private and public developers.

3. The attention of decision-makers must continue to be kept on the viability of small- scale renewable energy resources such as hydropower and efforts to refine and innovate the technology must go forward.

4. In order to maintain the momentum for international information exchange in hydropower, Waterpower '81 is being planned.

Date: June 22-24, 1981
Location: Shoreham Hotel, Washington, D.C.
Program: Plenaries, Papers, Workshops, Exhibits, Special Events
Sponsor: Corps of Engineers and other organizations interested in co-sponsoring or cooperative assistance

For more information, contact:

Waterpower '81
2033 M Street, N.W.
Suite 300
Washington, D.C. 20036

REPRESENTATION AT WATERPOWER '79

States — 46

Alabama
Alaska
Arizona
Arkansas
California
Colorado
Connecticut
Florida
Georgia
Hawaii
Idaho
Illinois
Indiana
Iowa
Kentucky
Louisiana
Maine
Maryland
Massachusetts
Michigan
Minnesota
Mississippi
Missouri
Montana
Nebraska
Nevada
New Hampshire
New Jersey
New York
North Carolina
Ohio
Oklahoma
Oregon
Pennsylvania
Rhode Island
South Carolina
Tennessee
Texas
Utah
Vermont
Virginia
Washington
Washington, DC
West Virginia
Wisconsin
Wyoming

Countries — 22

Austria
Canada
China (Peoples Republic)
Egypt
England
Finland
France
Germany(West)
Israel
Jamaica
Japan
New Guinea
Norway
Panama
Peru
Philippines
Portugal
Puerto Rico
Scotland
Spain
Sweden
Switzerland

Registration at WP '79 by Sectors

[decreasing frequency]

1. Federal Government
2. A-E Firms
3. U.S. Manufacturers
4. Consultants
5. Universities
6. Foreign Manufacturers
7. State Governments
8. Local Governments
9. Public Utilities
10. Foreign Governments
11. Private Utilities
12. International Organizations
13. Private Individuals
14. U.S. Finance
15. Special Interests (Energy)
16. International Finance
17. Congress (Staff)
18. Trade Associations
19. Special Interests (Environment)
20. Special Interests (Other)

EXHIBITORS

Acres American Incorporated
Suite 329, Clark Building
Columbia, MD 21044

Allis-Chalmers Corporation
Box 712
York, PA 17405

ASEA, Inc.
4 New King Street
White Plains, NY 10604

Axel Johnson Corporation
1 Market Plaza, Suite 445
San Francisco, CA 94105

BOFORS-NOHAB, Inc.
One World Trade Center
Suite 10225
New York, NY 10048

Brown Boveri Corporation
1460 Livingston Avenue
North Brunswick, NJ 08902

Charles T. Main, Inc.
Southeast Tower
Prudential Center
Boston, MA 02199

General Electric Company
One River Road
Building 23-254
Schenectady, NY 12345

Hydro Research Science
3334 Victor Court
Santa Clara, CA 95050

Independent Power Developers
Route 3, Box 285
Sandpoint, Idaho 83864

KVAERNER-BRUG A/S —
SORUMSAND VERSTED A/S
800 Third Avenue
New York, NY 10022

Leroy-Somer, Inc.
405 W. University Drive
Arlington Heights, IL 60004

McKay Water Power Limited
P.O. Box 448
Port Colborne,
Ontario, Canada
L3K 5X7

Morrison-Knudsen Co. Inc.
One Morrison-Knudsen Plaza
P.O. Box 7808
Boise, Idaho 83729

Oy Tampella Ab
c/o Madden Service Corporation
9 Rockefeller Plaza
New York, NY 10020

Radiation Management Corp.
Ecological Division
3508 Market Street, Suite 400
Philadelphia, PA 19104

SOGREAH
BP172X38042
Grenoble, CEDEX, France

Sulzer Escher Wyss
200 Park Avenue
New York, NY 10017

TAMS
655 Third Avenue
New York, NY 10017

The Peoples' Republic of China
2300 Connecticut Avenue., NW
Washington, DC 20008

U.S. Army Corps of Engineers
20 Massachusetts Avenue, N.W.
Washington, DC 20314

U.S. Department of Energy
Idaho Falls, Idaho

U.S. Geological Survey
301 National Center
12201 Sunrise Valley Drive
Reston, VA 22092

Worthington Pump, Inc.
270 Sheffield Street
Mountainside, NH 07092

WATERPOWER '79 PUBLICATIONS

Conference Paper Proceedings

This publication contains a collection of all the technical session and plenary session papers, all special presentations, keynote address, executive addresses and workshop summaries. Copies may be ordered from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

Conference Abstract Book

This publication contains a collection of all the paper abstracts for the technical sessions and an author index. Copies may be ordered from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

Conference Tapes

All sessions of the technical program, plenaries, technical papers, keynote, executive, special addresses and the workshop sessions are recorded on tape. The price is $6.50 per cassette. Tapes may be ordered from: Eastern Audio Associates, Inc., 9505 Berger Road, Columbia, MD 21046.

For further information on other available hydropower publications, contact:

National Hydropower Study
U.S. Army Corps of Engineers
Institute for Water Resources
Kingman Building
Ft. Belvoir, VA 22060

Small Hydropower Applications
Room 3344
U.S. Department of Energy
Washington, D.C. 20461