OAK RIDGE NATIONAL LABORATORY LIBRARIES
3 4456 0554033 1

ornl

ORNL/TM-7861

OAK
RIDGE
NATIONAL
LABORATORY

UNION
CARBIDE

Analysis of Environmental Issues Related to Small-Scale Hydroelectric Development.

V. Instream Flow Needs for Fishery Resources

James M. Loar
Michael J. Sale

ENVIRONMENTAL SCIENCES DIVISION
Publication No. 1829

OAK RIDGE NATIONAL LABORATORY
CENTRAL RESEARCH LIBRARY
CIRCULATION SECTION
4500N ROOM 175
LIBRARY LOAN COPY
DO NOT TRANSFER TO ANOTHER PERSON
If you wish someone else to see this
report, send in name with report and
the library will arrange a loan.

OPERATED BY
UNION CARBIDE CORPORATION
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

Printed in the United States of America. Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road, Springfield, Virginia 22161
NTIS price codes—Printed Copy: A07 Microfiche: A01

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.

ORNL/TM-7861
Distribution Category UC-97e

Contract No. W-7405-eng-26

ANALYSIS OF ENVIRONMENTAL ISSUES RELATED TO SMALL-SCALE HYDROELECTRIC DEVELOPMENT.
V. INSTREAM FLOW NEEDS FOR FISHERY RESOURCES

James M. Loar
Michael J. Sale

ENVIRONMENTAL SCIENCES DIVISION
Publication No. 1829

Prepared for U.S. Department of Energy, Assistant
Secretary for Conservation and Renewable Energy,
Division of Hydroelectric Resource Development

Date Published: October 1981

OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37830
Operated by
UNION CARBIDE CORPORATION
for the
DEPARTMENT OF ENERGY

OAK RIDGE NATIONAL LABORATORY LIBRARIES
3 4456 0554033 1

ACKNOWLEDGMENTS

We thank William Knapp (U.S. Fish and Wildlife Service, Region 5) and Mark Robinson (Federal Energy Regulatory Commission) for helpful discussions during the preparation of the report and for their constructive comments on the draft manuscript. Dale Huff, Jon Goyert, Stephen Hildebrand, and Webster Van Winkle (Oak Ridge National Laboratory) also reviewed the manuscript and provided many helpful comments and suggestions. Financial support for this activity was provided by the U.S. Department of Energy, Assistant Secretary for Conservation and Renewable Energy, Division of Hydroelectric Resource Development.

PREFACE

The purpose of this document is to provide guidance to developers of small-scale hydroelectric projects on the assessment of instream flow needs. While numerous methods have been developed to assess the effects of stream flow regulation on aquatic biota in coldwater streams in the West, no consensus has been reached regarding their general applicability, especially to streams in the eastern United States. Our presentation and review of these methods (Section 2.0) is intended to provide the reader with general background information that is the basis for the critical evaluation of the methods (Section 3.0). The strategy for instream flow assessment presented in Section 4.0 is, in turn, based on the implicit assumptions, data needs, costs, and decision-making capabilities of the various methods as discussed in Section 3.0.

We have restricted the scope of the document in several areas. Details on the specific procedures to be followed in applying the methods are not given but are available in the literature cited in Section 5.0. Moreover, the document is not intended to be a review of all the literature related to the issue of instream flow. Because determination of the instream flow needs for fishery resources is the most difficult and controversial aspect of the instream flow issue, we have only included those methods that are related to this aspect of the issue. Consequently, methods developed to assess recreational or aesthetic needs are not addressed in the document. Finally, the legal and institutional aspects of the instream flow issue (e.g., negotiation strategies) are not discussed.

This document is the fifth in a series of reports addressing environmental issues and small-scale hydroelectric technology that are being prepared by the Oak Ridge National Laboratory for the U.S. Department of Energy. The other reports in this series are listed below and are available from the National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, Virginia 22161.

1. Loar, J. M., L. L. Dye, R. R. Turner, and S. G. Hildebrand. 1980. Analysis of environmental issues related to small-scale hydroelectric development. I. Dredging. ORNL/TM-7228. Oak Ridge National Laboratory, Oak Ridge, Tennessee. 134 pp.

2. Hildebrand, S. G. [Ed.]. 1980. Analysis of environmental issues related to small-scale hydroelectric development. II. Design considerations for passing fish upstream around dams. ORNL/TM-7396. Oak Ridge National Laboratory, Oak Ridge, Tennessee. 78 pp.

3. Hildebrand, S. G. [Ed.]. 1980. Analysis of environmental issues related to small-scale hydroelectric development. III. Water level fluctuation. ORNL/TM-7453. Oak Ridge National Laboratory, Oak Ridge, Tennessee. 78 pp. plus Appendix.

4. Turbak, S. C., D. R. Reichle, and C. R. Shriner. 1981. Analysis of environmental issues related to small-scale hydroelectric development. IV. Mortality resulting from turbine passage. ORNL/TM-7521. Oak Ridge National Laboratory, Oak Ridge, Tennessee. 112 pp.

ABSTRACT

Protection of instream uses of water, such as fish and wildlife habitat, recreation, and aesthetics, has been identified as a significant environmental issue, especially in the West where water supplies are limited and offstream uses (e.g., irrigation) are well-defined by law. The growing recognition nationwide of the importance of protecting these instream uses of water has coincided with the recent emphasis on the development of small-scale hydropower resources. The issue of instream flow maintenance in hydropower development is essentially a problem of evaluating the effects of planned modifications in hydrologic patterns. Because hydroelectric projects can alter natural flow regimes on both spatial and temporal scales, downstream water users and the aquatic ecosystem can be adversely affected. Assessment of the instream flow needs of aquatic biota (primarily fishes) has been the most difficult and controversial aspect of the instream flow issue.

Numerous methods have been developed to assess the effects of stream flow regulation on aquatic biota and to provide instream flow recommendations. The methods differ in their use of hydrologic records, hydraulic simulation techniques, and habitat rating criteria and in their capability to provide seasonal or species-specific recommendations. Because of these differences in data requirements, application costs and the level of resolution associated with the instream flow recommendations vary greatly. Consequently, guidance is needed to ensure that the most appropriate methods are selected for instream flow assessments at small-scale hydroelectric sites. To provide this guidance to developers of small hydropower projects, the methods were reviewed and evaluated to determine their applicability in the assessment of instream flow needs for fishery resources at small hydropower sites. The methods were grouped into three categories based on (1) level of resolution associated with the instream flow recommendation, (2) data needs, and (3) costs of

application. The categories correspond to different levels of assessment that might be required at a given hydropower site. To select the most appropriate level of analysis, criteria related to both the design and operation of the project and the aquatic resources at the site were identified.

Establishment of an instream flow regime may significantly affect the economic feasibility of many small hydropower projects, since water needed to maintain instream flows is often unavailable for power production. To minimize conflicts between these two uses of water, assessment of instream flow needs must be conducted in the early stages of project planning and development. Final resolution of potential conflicts, however, may require negotiations and, ultimately, some tradeoffs between hydropower requirements and the instream flow needs of the fishery.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES (Continued)

1. INTRODUCTION

The value of instream uses of water (e.g., fish and wildlife habitat, recreation, and aesthetics) is increasing as greater demands are placed on our water resources to meet various industrial, agricultural, and domestic needs (offstream uses). Although the problem of inadequate surface water supply is or will be severe by the year 2000 in many regions of the Midwest and Southwest, some regions of the East may also have water supply problems during low-flow months. The competition between offstream and instream uses will also intensify as a result of the estimated 27% increase in consumptive water use by the year 2000 (U.S. Water Resources Council 1978). Resolution of the conflict between the various uses of water raises important questions regarding the quantity of water that should remain in a stream or river to protect existing instream (nonconsumptive) uses. Because the value of these instream uses has only recently been recognized within a legal/institutional framework, many of the methods* that have been developed to assess instream flow requirements are relatively new.

Instream flow requirements (or needs) refer to the amount of flowing water within a natural stream channel that is needed to sustain the instream values (or uses made of water in the stream channel) at an acceptable level. Such a requirement identifies the flow regime that will maintain <u>all</u> uses of water within the channel, including fish and wildlife populations, recreation, aesthetics, water quality, hydropower generation, navigation, and ecosystem maintenance which includes freshwater inflow to estuaries, riparian vegetation, and floodplain wetlands (Bayha 1978, Wassenberg et al. 1979). Methods have been developed to assess the instream flow requirements

---

*The term 'methodology,' defined as a group of related methods, is often found in the literature on instream flow needs. Because the connotation is frequently ambiguous, we have intentionally avoided use of the term in this report.

associated with many of these uses. For example, mathematical modeling has been an important component in determining instream flow needs related to water quality (e.g., Mar 1973 and 1975 as cited in Wyoming Water Resources Research Institute 1978a; Grenney et al. 1976; Grenney and Porcella 1976; Porcella and Grenney 1976). Methods have also been developed to assess instream flow needs for recreation (Andrews and Madsen 1976; Andrews et al. 1976; Morris 1976; Cortell and Associates, Inc. 1977a,b; Hyra 1978; Wyoming Water Resources Research Institute 1978a) and aesthetics (Andrews and Madsen 1976; Masteller et al. 1976; Mittman 1976; Wyoming Water Resources Research Institute 1978a). The effects of water level changes on riparian and wetland communities have been described (e.g., Teskey and Hinckley 1977), and methods for assessing the effects of water management practices upon riparian vegetation and wildlife are available (Kadlec 1976a,b; Wyoming Water Resources Research Institute 1978b).

Assessment of the instream flow needs of aquatic biota, however, has been the most difficult and controversial aspect of the instream flow issue and is the subject of this report. Numerous methods have been developed to assess the effects of flow regulation on aquatic biota and to provide a basis for the determination of a suitable stream flow recommendation. Although all components of lotic ecosystems are affected by flow regulation (Sect. 1.1.1), the assessment of instream flow needs of aquatic biota has focused primarily on fish species. Only recently have studies of benthic macroinvertebrates been initiated, and these were limited to (1) development of new techniques for assessing instream flow requirements (Gore 1978, Railsback 1981), and (2) compilation and evaluation of habitat suitability data from existing literature (Herricks and Furnish 1980).

Because no consensus has been reached on the site-specific applicability of these methods, especially in the eastern United States, developers of small hydroelectric projects, which, depending upon their design and operation, can alter the natural flow regime

(Sect. 1.3), lack the necessary guidance for assessing the biological effects which might result from such modifications in stream flow. This report has been prepared to provide the guidance that does not currently exist for assessing instream flow needs for fishery resources below hydroelectric projects. The various methods are reviewed (Sect. 2.0) and evaluated (Sect. 3.0), and strategies are presented (Sect. 4.0) for selecting the most appropriate method based on (1) project design and operation, and (2) nature of the aquatic resources. Before discussing specific methods, however, additional background information is provided on the instream flow issue from an historical (Sect. 1.1), regulatory (Sect. 1.2), and hydropower (Sect. 1.3) perspective.

1.1 Historical Background on the Instream Flow Issue

1.1.1 Development in the West

Significant conflicts between offstream and instream uses of water first developed in the West where water supplies are limited and offstream uses (e.g., irrigation) are well-defined by law. Western water law is based on the appropriation doctrine which has two fundamental principles: (1) first in time is first in right and (2) beneficial use of the water is the basis of the right (Gould 1977). Because of the scarcity of water in many regions of the West, water development has been equated with growth, prosperity, and success (Lamb and Bayha 1978). In short, beneficial use was defined in economic terms. In many states, permitting water to remain in the stream (e.g., for the protection of fish and wildlife habitat or recreation and aesthetic values) was not recognized as a beneficial use. Now, however, most western states recognize the need to protect instream values and, in some cases, have been able to acquire protection through legislative changes (e.g., Dewsnup and Jensen 1977; Lamb and Bayha 1978).

The intense competition for water and the growing recognition that instream uses of water must be protected led to the development of numerous methods for assessing instream flow needs. Most of these methods focused on the protection of indigenous fish populations, particularly salmonids, because of their recreational and commercial importance. Some of the earliest studies to determine instream flow needs were conducted below large hydroelectric facilities located on coastal rivers of northern California (e.g., Curtis 1959, Delisle and Eliason 1961, review by Fraser 1972a). After legislation that recognized the importance of maintaining suitable stream flows had been passed in Oregon, field studies were initiated in 1961 to determine specific flow requirements of salmonids at different times of the year (Sams and Pearson 1963, Thompson 1972). In 1962, the U.S. Forest Service developed a transect line, cluster sampling procedure for use on trout streams in Utah and Idaho (Dunham 1972). A few years later, work on the now well-known Tennant or Montana Method (Elser 1972, Tennant 1976) was initiated in Montana.

Beginning in the early 1970's, several workshops were held in the Northwest to discuss the various methods that had been developed. As a result of this communication, methods were compared and modified to incorporate the new information that was being collected on the habitat requirements of salmonids. Several reviews of the methods available for assessing instream flow needs were also published during this period (Fraser 1972a, Giger 1973, Hooper 1973).

At the same time that methods were being developed to assess the instream flow needs of fish species, site-specific studies were conducted to examine the biological consequences of stream flow regulation. Results of these studies showed that the primary impact of reduced flows on fishes was a reduction in usable habitat (Holden 1979). A trans-basin diversion project on the Trinity River in northern California, for example, resulted in a significant reduction in salmonid spawning habitat below the point of diversion (Smith 1976).

In most regulated streams and rivers, major alterations were also observed in the composition of benthic macroinvertebrate communities (see review by Ward and Stanford 1979a). The important factors controlling macroinvertebrates (temperature, flow, and substrate) were also found to affect lower trophic levels (e.g., primary producers such as benthic algae). However, the limited data available on the flora of regulated streams were secondary information obtained during studies of the macroinvertebrate and fish communities (Lowe 1979).

Three of the most significant events in the evolution of instream flow methods in the West occurred within a four-month period in 1976. In April, the results of a study to document and evaluate existing methods for fisheries, wildlife, water quality, recreation and aesthetics were published (Stalnaker and Arnette 1976). This document, an early product of the Western Water Allocation Project in the Office of Biological Services of the U.S. Fish and Wildlife Service, represented the first attempt to compile detailed information on the various fisheries methods and to critically examine them. The next month, a symposium and specialty conference on instream flow needs sponsored by the Western Division of the American Fisheries Society was held in Boise, Idaho. The proceedings of the conference, which addressed the legal, social, and biological aspects of the instream flow issue, were published in a two-volume series (Orsborn and Allman 1976a,b) that "may prove to be a landmark in the history of the subject" (White 1979). Finally, in July 1976, the multidisciplinary Cooperative Instream Flow Service Group (IFG)* in the Office of Biological Services of the U.S. Fish and Wildlife Service was established in Ft. Collins, Colorado. The purpose of the IFG was to advance the "state-of-the-art" and become the center of activity related to instream flow assessments (U.S. Fish and Wildlife Service 1977). Within a short period of time after formation of the

---

*The IFG is now known as the Instream Flow and Aquatic Systems Group.

IFG, the Incremental Methodology (Section 2.8) was developed (Bovee and Cochnauer 1977; Bovee and Milhous 1978; Stalnaker 1978, 1979b; Trihey 1979; Wegner 1979).

The use of comparative field studies to evaluate various fisheries methods is a recent development in the West (R. Giger, personal communication). These studies were funded in 12 western states as part of the Western Water Allocation Project. This comparative approach represents a logical step in the sequence of events that will hopefully lead to insights on the applicability of the various methods. Although many gaps still exist in our knowledge of the relationship between stream flow and fish production, these shortcomings should not prevent users from applying or modifying existing methods. The successful development of adequate methods for assessing instream flow needs will require applications on a wide range of watersheds throughout the country. Although no consensus has yet been reached regarding the "best" method to use in a given situation, additional information acquired from continued application in the field will eventually lead to a better understanding of the applicability of the various methods.

1.1.2 Development in the East

Unlike in the West where instream flow methods evolved over the past 20 years in response to the growing demand for limited water supplies, in the East instream flow needs are just beginning to develop as an issue. With the exception of the method developed by Robinson (1969) for the Connecticut River basin, no formal methods to assess instream flow needs have been documented from the eastern United States until recently (U.S. Fish and Wildlife Service 1981). Eastern initiatives in formulating instream flow policies were largely in response to an increase in the development of small hydropower resources in the Northeast. Because water is more abundant in the East than in the West, conflicts to date have been highly localized. Moreover, water law in most states east of the Mississippi River is based on the riparian doctrine (Table A-1 in Lamb and Bayha 1978). The doctrine equates the existence of a water right with ownership of the land adjacent to the stream (riparian ownership), and each owner has an equal right to reasonable use of the water in the stream (Gould 1977). Depletions of both supply and quality of the water must not prevent downstream users from exercising their reasonable rights to use of the water (Lamb and Bayha 1978). The riparian doctrine is substantially different from the appropriation doctrine of most western states which accommodates offstream uses of water to promote economic development. Both the abundance of water (and, consequently, the absence of significant offstream use for irrigation) and the existence of the riparian doctrine account for the relatively brief history of the instream flow issue in the East.

As in the West, assessment of instream flow requirements in the East was initially associated with controlling the operation of hydroelectric facilities, and, until recently, these assessments were most likely based on historical discharge records and the judgment of biologists. In the late 1970's, methods developed in the West, particularly the Incremental Methodology, were used to assess instream flow needs below dams on the lower Susquehanna River in Pennsylvania (Jackson 1980) and in the upper Delaware River Basin in New York (Sheppard 1980). The Incremental Methodology has also been used on streams in West Virginia, Ohio, Indiana, Kentucky, Tennessee (Bayha and Hardin 1980), and North Carolina (Bain 1980). It is currently being used to survey instream flow requirements on a statewide basis in Illinois (Bayha and Hardin 1980, Herricks et al. 1980). At the same time that formal methods were being exported to the East, instream flow workshops were held. Two workshops sponsored by the Ohio River Basin Commission were held in 1979 and 1980, and an instream flow session was included in the program of the Annual Northeast Fish and Wildlife Conference in 1980 and 1981. A similar session was also included in Waterpower '81, an international conference on small hydropower held in June 1981 in Washington, D.C.

Assessment of the instream flow needs of fishery resources in the eastern United States is confronted by two major problems. First, the only site-specific methods currently being used to assess instream flow needs in the East were developed for salmonid populations in coldwater streams in the West; their applicability to eastern streams that may be water quality- or food-limited has not been rigorously examined. The numerous other methods that were also developed in the West have, with few exceptions, never been used in the East. Second, the concern for instream values over the past 20 years produced a wealth of information on the habitat requirements of salmonids, but a comparable data base for warmwater species, the predominant fishery resource in much of the East, does not exist. As a result, resolution of conflicts among various uses of water, especially instream use for hydroelectric generation versus protection of fish and wildlife habitat, may be more difficult in the East.

1.2 Environmental Regulations Related to Instream Flow

Major federal legislation provides a framework for evaluating the environmental impacts associated with water resource development projects, including the alteration of natural flow regimes below hydroelectric facilities. The Fish and Wildlife Coordination Act of 1934 and 1958 requires the Federal Energy Regulatory Commission (FERC), the agency responsible for the regulation of nonfederal hydroelectric dams under the Federal Power Act of 1920, as amended, to consult with the U.S. Fish and Wildlife Service and the appropriate state agencies to ensure that fish and wildlife conservation needs are adequately considered. Such consultation may result in an instream flow recommendation to protect fish and wildlife habitat. The FERC is also required to consult with the Council on Environmental Quality and the Environmental Protection Agency under the Public Utility Regulatory Policies Act (PURPA) of 1978 (Corso 1979).

Other legislation that relates directly to the environmental impacts of development projects (and indirectly to the instream flow issue) includes the National Environmental Policy Act of 1969, the Wild and Scenic Rivers Act of 1968, the Clean Water Act of 1972 and 1977, the Endangered Species Act of 1973, and the Anadromous Fish Conservation Act of 1965. Obviously, the instream flow issue can be significant if the alteration in stream flow will affect species included under either of the latter two laws. Instream flow needs related to water quality can be considered when application is made for a water quality certificate required under Section 401 of the Clean Water Act.

In addition to these environmental regulations, other legislation has been passed which provides a framework for the regulation and development of small hydropower. Section 10(a) of the Federal Power Act of 1920, as amended in 1935, requires FERC to assure that the proposed development and operation of a project will be best adapted to a comprehensive plan that includes other water uses in addition to hydroelectric generation. Protection of fish and wildlife is considered elsewhere in the Act, particularly Section 30(c). More recent legislation related to small-scale hydropower development was passed as Title IV of the Energy Security Act of 1980 which established incentives for the use of renewable energy resources. Section 408 of Title IV amended Section 405 of PURPA which outlined the granting of exemptions to licensing requirements.

Recognition of the importance of instream uses of water in the planning, development, and management of our water resources recently occurred at the national level. In 1973, the U.S. Water Resources Council issued Principles and Standards for Planning Water and Land Resources which required multiobjective planning for environmental quality as well as national economic development (Schamberger and Farmer 1978). Cooperative resource planning among state, federal, and private groups is emphasized. Among other requirements, information must be obtained about the needs and problems of the project area, including the identification and inventory of the water resource base of the area (Wassenberg et al. 1979). In 1974, the Second National Water Assessment was undertaken by the U.S. Water Resources Council and represented "the first nationwide examination of instream flow conditions and the implications of accelerated offstream uses" (Bayha 1978). In his Water Resources Policy Reform Message of June 6, 1978, President Carter identified water conservation and instream flows as national goals. On July 12, 1978, he issued a directive to federal agencies to improve, where possible and in cooperation with the states (which have principal responsibility for protection of instream flows), the operation and management of existing water resources projects to protect instream uses. Although protection of the instream use of water is now recognized as a national concern, the most difficult aspect of this issue, the assessment of instream flow needs, remains a challenge.

1.3 Effects of Hydroelectric Generation on Instream Flow

The issue of instream flow maintenance in hydropower development is essentially a problem of evaluating the effects of planned modifications in hydrologic patterns. Both large and small-scale hydropower projects can alter natural flow regimes, often with adverse effects on downstream water users and the aquatic ecosystem. The effects of dams on downstream (tailwater) biotic communities were reviewed previously (e.g., Fraser 1972b; Ward and Stanford 1979b; Hildebrand 1980; Loar and Hildebrand, in press) and need not be reiterated. However, it should be noted that while the effects may be relatively well documented, the underlying mechanisms or causal factors responsible for these changes are, with few exceptions, poorly understood.

Alterations in flow regimes below hydroelectric dams can include both spatial and temporal changes in the amount of water moving through a natural stream channel. Large-scale spatial changes occur when water is exported completely out of a watershed and all downstream reaches are affected. Localized changes in stream flow, on the other hand, are characteristic of many small-scale hydropower projects where water is diverted through a flume or conduit to a generator at a lower elevation before being returned to the original stream channel.

Similarly, temporal changes in stream flow can be either long-term or short-term, depending upon the design and operation of the facility. Flood control projects with large storage capacities can retain high flows, which typically occur during the winter and spring, for release during low-flow periods in the summer and early fall. Such modification of pre-project stream flow is on the order of months or even years. By retaining peak flows and augmenting low flows, nonhydroelectric uses (e.g., flood control, irrigation) of impounded streams often reduce the natural amplitude of water level fluctuations in tailwaters (Turner 1980).

Short-term temporal changes, on the other hand, occur over the span of several minutes or hours and are characteristic of hydroelectric projects that are operated in a peaking mode. Because the demand for electricity varies over a 24-h period, water is stored during off-peak hours for generation during the period of greatest demand (e.g., during the late afternoon and evenings on weekdays; Fig. 1-1). The amplitude of the water level fluctuations below peaking projects may be equivalent to that observed in unregulated (e.g., unimpounded) streams which can be subject to enormous natural fluctuations in water level in response to rainfall and subsequent runoff from the watershed (Turner 1980). However, peaking operations often result in a dramatic increase in the frequency and rate of change of major water level fluctuations and a reduction in the duration of a given water level (stage height) in the downstream channel.

Thus, the degree to which spatial and temporal flow patterns are altered is directly related to the design and operation of the

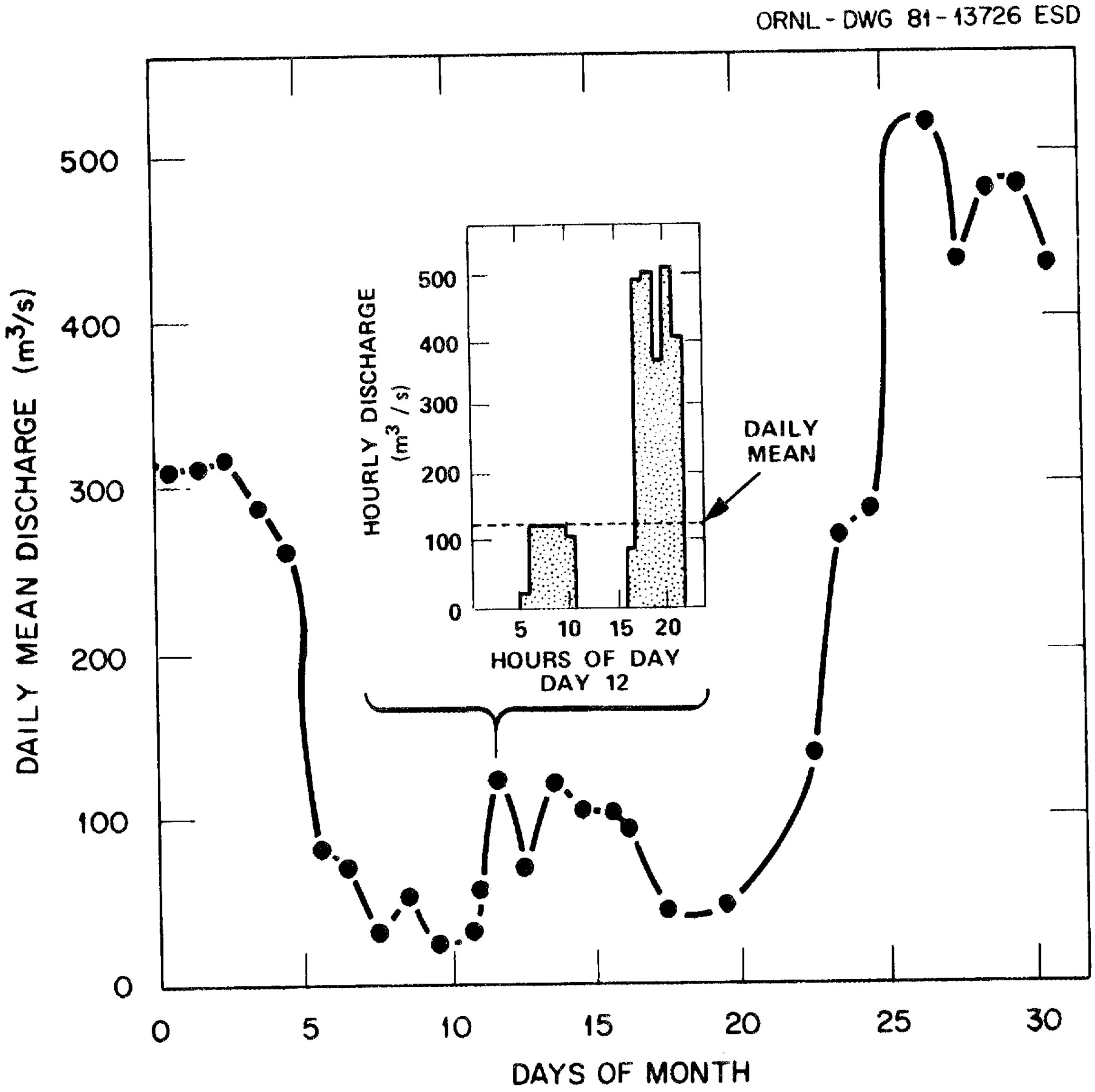

Fig. 1-1. Variation in daily mean discharge from a TVA reservoir during a one-month period of the flood season (approximately mid-October through mid-April). Typical hourly fluctuations about the daily mean are shown for day 12. (Modified from Shane 1981).

facility. Reservoir storage and releases from a dam are related to each other, as shown in the following equation (see also Fig. 1-2):

$$\Delta S = Q_i - Q_g - Q_n - W - E, \qquad (1\text{-}1)$$

where ΔS = change in storage volume of the reservoir over a fixed time interval,

Q_i = reservoir inflow, over the same interval,

Q_g = generating releases passing through the turbines,

Q_n = non-generating releases (e.g., spillage, leakage, or instream releases),

W = consumptive withdrawal from the reservoir, and

E = net evaporative losses from the reservoir.

As described previously, store-and-release facilities rely on available storage to operate in a peaking mode ($\Delta S \neq 0$; Eq. 1-1). Hydroelectric projects can also be operated in a run-of-river mode. As defined in this report, run-of-river facilities are those projects that are operated with no change in reservoir storage ($\Delta S = 0$; Eq. 1-1). In reality, a gradation of project types exists in which the amount of peaking or seasonal storage is constrained by the acceptable water elevation changes within the reservoir (Hildebrand 1980, Szluha et al. 1981).

Another important aspect related to the design of hydroelectric projects is the location of the powerhouse. In the simplest case, the powerhouse is located at the base of the dam, and the distance between the dam and the confluence of the tailrace with the river is minimal ($L \cong 0$; Fig. 1-2). Many small hydropower projects, however, especially those in New England (U.S. Department of Energy 1981), utilize long penstocks or canals to gain additional head. For example, about one-half of all the New England sites under review by FERC since 1979 would require diversions greater than 150 m (Knapp

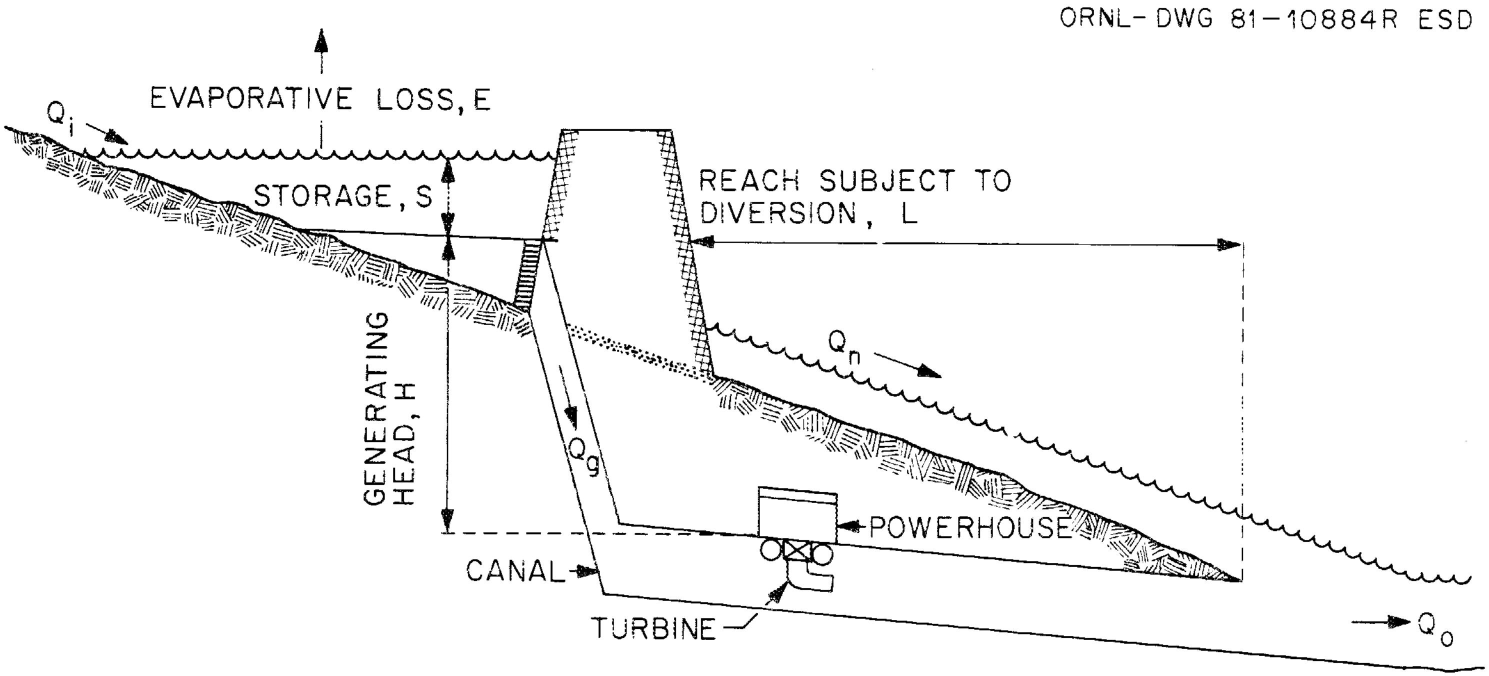

Fig. 1-2. Diagram of a generalized, small-scale hydroelectric project showing the important project characteristics. Total outflow (Q_0) = Q_g + Q_n, as defined in Eq. 1-1.

1981). In these cases, the powerhouse is located below the dam, and that reach of the river between the dam and powerhouse may be subjected to very low flows depending upon the amount of water that is diverted ($L >> 0$ and $Q_n/Q_g << 1$). Such a design can be incorporated in projects that operate in both the store-and-release and run-of-river modes.

In most cases, large-scale spatial changes (e.g., transbasin diversions) and/or long-term temporal changes in stream discharge patterns will not be associated with the development of small hydropower resources, defined as those projects with a potential generating capacity of $\leq$30 MW. Currently, this development is focused on retrofitting existing dams for hydroelectric generation, and at most of these sites, reservoir storage capacity is limited. Consequently, modifications in the natural flow regime will likely consist of short-term (e.g., $\Delta S/Q_i < 24h$; Eq. 1-1) rather than long-term temporal changes if the facility is operated in a peaking mode. If, instead, it is operated in a run-of-river mode, no changes in temporal flow patterns would be expected. Both peaking and run-of-river facilities can, depending upon their design, result in localized spatial changes in stream flow.

In summary, instream flow may be the most significant issue associated with small hydropower development. Unlike the other issues which are either very site-specific (e.g., fish passage, dredging) or related only to projects operated in a particular mode (e.g., water level fluctuations at peaking facilities), the instream flow issue can affect both peaking and those run-of-river projects that utilize long penstocks or canals. Moreover, maintenance of an instream flow regime may reduce the potential energy that can be produced, because water used to maintain instream flows is usually not available for power production (U.S. Department of Energy 1981). In most regions of the United States, hydroelectric generating systems are characterized by the seasonal mismatch between energy demand and stream flow. For example, in some basins like the Columbia River, which is fed by the melting snowpack in late spring and summer, the lowest flows occur in the winter when energy demand is high (Schultz 1979 as cited in Shane 1981). Because the low flow period in many regions of the country, especially the East, typically occurs in late summer, it too coincides with a peak demand period.

In some cases, hydropower development can benefit the fishery resources in the stream or river. Where natural flows provide a suboptimal environment for fish growth and development (e.g., extended periods of low flow), stream flow regulation can enhance production. Storage capacity of reservoirs can be used to augment flows during periods of low stream discharge. The beneficial aspects of a proposed hydropower project in Alaska are described briefly in Section 4.2.3 (Case 2).

Finally, the instream flow issue is related to other ecological issues associated with hydroelectric development. For example, fish passage requires not only bypass facilities at the dam but also adequate stream flows below the dam. At peaking facilities, maintenance of an instream flow regime below the dam is obviously related to changes in reservoir levels above the dam (the water level fluctuation issue). The assessment of instream flow needs must be integrated with these and other relevant environmental considerations; the assessment cannot be conducted in an ecological vacuum.

2.0 EXISTING METHODS FOR INSTREAM FLOW ASSESSMENT

Resolution of the conflict between the instream use of water for hydroelectric generation and other instream uses, such as the maintenance of aquatic habitats, will require information on the flow regimes needed to preserve these habitats. Because numerous methods have been proposed to assess the instream flow needs for fishery resources, it is the purpose of this document to review and evaluate these methods and to recommend a strategy that can be used to assess instream flow needs at small-scale hydroelectric sites. In this way, small-scale hydroelectric developers will have greater access to the existing methods, and assessment studies can be conducted in a more cost-effective manner.

A variety of assessment methods were developed in response to the relatively recent emphasis that was placed on evaluating the biological effects of flow regulation. Our review is not meant to be totally comprehensive but rather is intended to provide a representative summary of approaches which are currently available for quantifying instream flow requirements. This information provides the background for later comparisons and recommendations. For more detailed information on individual techniques, the reader is referred to the list of references (Sect. 5.0). Other reviews of assessment methods for instream flow needs can be found in Stalnaker and Arnette (1976) and in Wesche and Rechard (1980).

Listed below are several general characteristics which are important in distinguishing among the various instream flow assessment methods:

- Use of existing stream flow records,
- Application of hydraulic simulation techniques,
- Use of habitat rating procedures to measure the physical condition of the lotic environment,

- Dimensionality used in mapping the instream habitat, and
- Ability to provide seasonal or species-specific instream flow recommendations.

These characteristics provide a focus for the information presented in this section and are discussed in detail in the comparative analysis presented in Section 3.0.

2.1 Fixed Percentage

The best known of the fixed percentage methods is the Montana Method developed by Tennant (1975, 1976). Because of its relative simplicity and minimal data requirements, the Montana Method is one of the most frequently used methods for determining instream flow needs. The procedure involves calculation of the mean annual flow rate (MAF) at a proposed development site and expression of the instream flow needs in terms of a fixed percentage of the mean annual flow (Tennant 1976). Various levels of flow needs, or what Tennant called "recommended base flow regimens," were identified, including flushing flows (200% MAF), optimum flows for all instream water uses (100 to 60% MAF), and a gradation of lesser conditions ranging from excellent (60 to 40%) to severe degradation (less than 10% MAF). The minimum instantaneous flow recommended to sustain short-term survival habitat for most aquatic biota is 10% MAF. At this flow, channel width, velocity, and depth are significantly reduced and the aquatic habitat is degraded.

The basis for the Montana Method consists of an extensive set of observations on streams in the states north of the Mason-Dixon Line between the Atlantic Ocean and the Rocky Mountains (Tennant 1976). The percentages established for flow needs reflect what has been interpreted to be a consistent relationship between watershed hydrology and physical habitat conditions within the stream channel.

Although the original guidelines include a recommendation that the proposed flow requirements be supported by field data, such as photographs of the proposed development site at critical flows, the method has often been applied with no field work.

Data required to apply a fixed percentage method such as the Montana Method are easily obtained from the published stream gaging records of the U.S. Geological Survey (USGS). Good techniques are available for extrapolating the MAF statistic upstream or downstream from existing gaging stations or estimating MAF on ungaged watersheds (e.g., Chow 1964, Linsley and Franzini 1972). However, because of the skewed nature of stream flow events (floods are relatively rare in occurrence but very signficant in terms of their effect on mean flow values), a sound argument can be made for the fact that the median flow statistic is a more appropriate measure of central tendencies in hydrologic data than the mean flow. The median statistic has been used in other approaches to instream flow assessment (Sect. 2.2).

2.2 Constant Yield

The U.S. Fish and Wildlife Service (USFWS) in Region 5 recently issued guidelines (the New England Flow Recommendation Policy or NEFRP) that establish a process for formulating minimum flow recommendations by using a combination of the median flow and a constant yield statistic to represent watershed hydrology (U.S. Fish and Wildlife Service 1981, Knapp 1980). For unregulated streams with a drainage area greater than 130 km^2 (50 sq miles) and good historical flow records ($\geq$25 years and ±10% accuracy of gage), the median monthly flow (MMF) serves as the datum for evaluation of instream flow needs in the NEFRP. For streams that do not meet these criteria, a constant yield factor, runoff per watershed area, was calculated for the entire New England region and is applied to a specific site to estimate actual flow conditions (Table 2-1). The instream flow recommendation based on this policy is called the Aquatic Base Flow (ABF) and is

Table 2-1. Seasonal instream flow recommendations (= Aquatic Base Flows) for rivers in New England with different flow records. Values are expressed as $m^3/s/km^2$ and $ft^3/s/sq$ mile (in parentheses); MMF = median monthly flow. Source: U.S. Fish and Wildlife Service (1981).

Season	Availability of historical flow records	
	<25 years	≥25 years[a]
Spring[b] (April - mid June)	0.29 (4.0)	100% MMF[c]
Summer (mid June - September)	0.04 (1.0)	100% MMF[c]
Fall/winter[b] (October - March)	0.07 (0.5)	100% MMF[c]

[a] Other criteria, in addition to record length, that are used to decide whether to accept/reject the gaging record include: (1) ±10% accuracy, or better; (2) drainage basin is >130 km^2 (50 sq miles); (3) river is unregulated.

[b] Spawning/incubation periods.

[c] If reservoir inflow is < MMF, then outflow = inflow.

equal to the August MMF or 0.015 $m^3/s/km^2$ (cmsk). The ABF is assumed to be adequate for all periods of the year, unless additional releases are necessary for fish spawning and incubation (U.S. Fish and Wildlife Service 1981). Instream flow releases recommended during the spawning and incubation periods are presented in Table 2-1. Like the Montana Method, the NEFRP relies on flow statistics which can be obtained without extensive field surveys.

The ABF which is calculated by this procedure is recommended as the minimum instantaneous discharge immediately below the dam during normal runoff conditions. During low-flow periods when inflow to the reservoir is less than the ABF, minimum releases equal to the inflow are requested. The NEFRP is unique in that alternative proposals for the flow release locations, schedules, and supplies can be submitted by the developer. Provided that such proposals are supported by biological justification and are found to afford adequate protection to aquatic biota, USFWS personnel may incorporate all or part of such proposals into their recommendations (U.S. Fish and Wildlife Service 1981). Thus, the NEFRP supports the ABF as sufficient to maintain aquatic life but does not preclude the same maintenance (or level of protection) at lower flows (W. Knapp, personal communication).

Other variations of methods that use a constant yield factor as the basis for determining instream flow needs have been proposed by Robinson (1969) for the Connecticut River and by Chiang and Johnson (1976) for streams in Pennsylvania. Robinson's recommendations were somewhat lower than the present New England Flow Recommendation Policy: 0.091 $m^3/s/km^2$ (cmsk) or 1.24 $ft^3/s/sq$ mile (cfsm) for maximum fishery values and 0.026 cmsk (0.36 cfsm) for moderate fishery values. The recommendations of Chiang and Johnson (1976) were based on an even lower set of stream flow statistics, either the 7Q10 (minimum flow which persists for seven days once every ten years) or a yield factor of 0.011 cmsk (0.15 cfsm). These differences in minimum flow requirements reflect the lack of a general consensus on what flows satisfy the needs of aquatic ecosystems as well as differences in basin runoff characteristics.

2.3 Flow Duration Curves

Another approach that has been proposed for deriving instream flow recommedations from historical stream flow records uses flow duration analysis (Fig. 2-1). The concept of flow duration in descriptive hydrology is somewhat of a misnomer. It refers to the discharge level which is equaled or exceeded in a certain percentage of all stream flow observations (i.e., a cumulative probability density function of flow events), but incorporates no direct measure of how long the flow persists. When discussing low flows, the 90 percentile annual flow (calculated from the data set of mean daily flows) would be the stream flow which would be expected to be equaled or exceeded nine out of every ten days of the year. Given a data set of historical flow records, the calculation of percentile flows is a relatively simple procedure common to many applications of descriptive hydrology, including dam and reservoir design.

The Northern Great Plains Resource Program (NGPRP) proposed a method that utilizes stream flow records and flow duration analysis (Anonymous 1974). With this procedure, which requires at least 20 years of daily flow records, a flow recommendation is made for each month of the year to protect all aquatic resources potentially affected by stream flow regulation. Although this method was presented as being applicable to both warm and coldwater rivers in the Midwest, a caution was added that it will not necessarily protect against degradation of aquatic habitats which might occur from high temperatures or low dissolved oxygen during low flows in warm lowland streams.

The NGPRP method includes a step in which flow records are modified by using Student's t distribution to identify and eliminate abnormal events (floods and droughts). After high and low observations are removed from the record for each month, the instream flow recommendation is the flow that is equaled or exceeded by 90% of the observations remaining in the record. This same procedure is

ORNL-DWG 81-10883 ESD

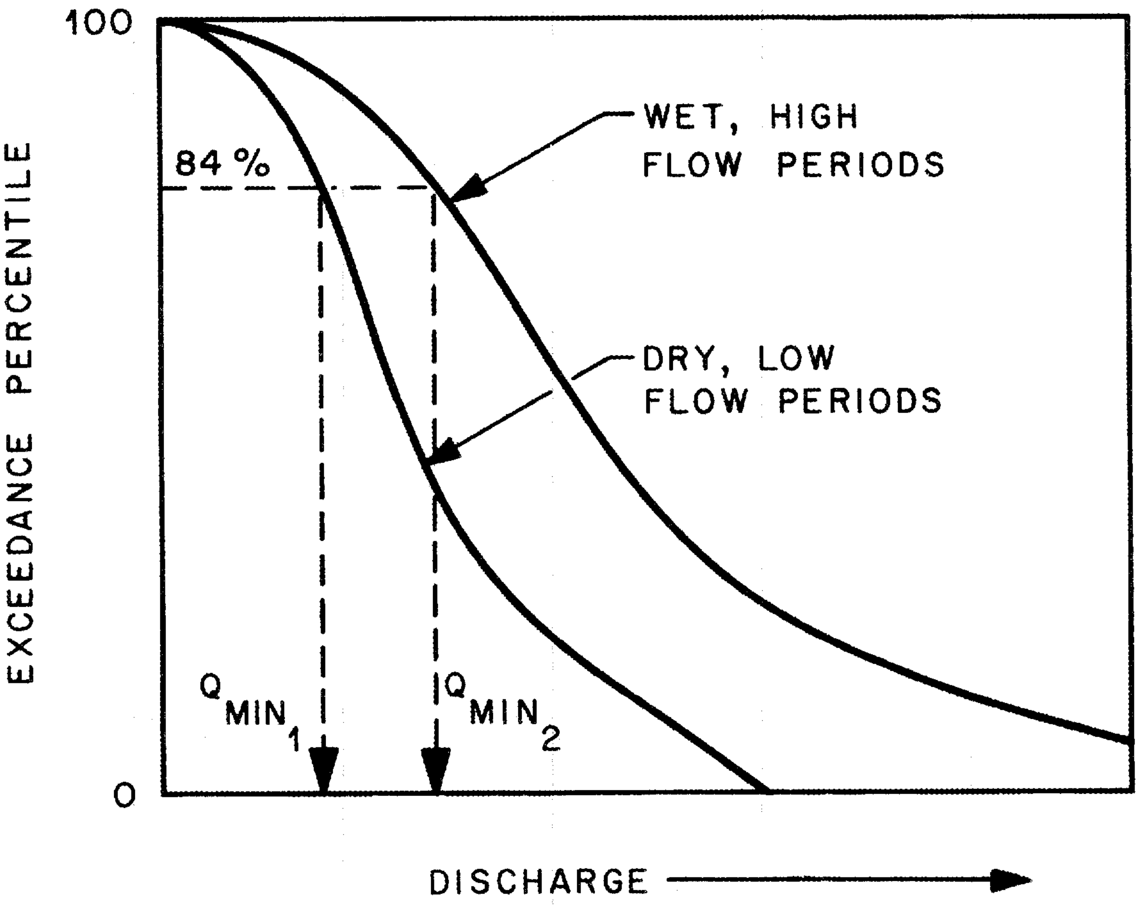

Fig. 2-1. Example of instream flow requirements (Q_{min}) based on flow duration data for two seasons with different hydrologic patterns.

repeated for all months except those in which high flows occur (i.e., the spring months). During high-flow months, the instream flow recommendation was set at the median flow of record (50 percentile).

The flow duration approach was developed for use on midwestern streams to satisfy assessment requirements in which extensive field data collection was not possible. However, it can be applied only where a relatively long historical flow record is available. The state of Iowa currently uses an instream flow policy based on the 84 percentile, annual low-flow statistic (Dougal 1979). Hoppe and Finnell (1970) also used a flow duration analysis on the Frying Pan River in Colorado, but they included equations to extrapolate flows to sites above or below USGS gaging stations based on watershed area.

2.4 U.S. Forest Service Habitat Evaluation

Several offices of the U.S. Forest Service (Regions 1, 2, and 4) developed assessment methods which examine the relationship between stream flow and physical parameters of the aquatic environment (Bartschi 1976, Cooper 1976, Isaacson 1976). All are used primarily in the mountainous, western United States on small, wadable streams (<50 m wide) with relatively low gradients. Site-specific field data (i.e., depth, velocity, and substrate type) are collected at one or more flows along transects across a stream channel and are used to describe the aquatic habitat. Transects are selected to be representative of specific types of stream habitat (e.g., riffles, pools, runs, etc.) which might be affected by alterations in flow. The eventual recommendations for instream flows are based on the actual habitat conditions at a site rather than on stream flow statistics, which were the basis of the three methods discussed previously.

Among the various regional approaches used by the U.S. Forest Service, there are differences in the way in which physical data are obtained and used to describe aquatic habitat. Transect data can be collected either at several different discharges covering the entire range of conditions to be analyzed or at one discharge and then used to calibrate a simulation model which can predict conditions at other discharges. The second approach using hydraulic simulation requires significantly less field work to construct a habitat-discharge curve (see Sect. 2.4.3). Other regional differences are associated with the specific attributes that are used to represent instream habitat conditions.

2.4.1 Habitat-Discharge Curves

Several physical parameters were suggested as the flow-dependent variable to be used in developing habitat-discharge relationships (Bartschi 1976). These attributes can include such hydraulic parameters as stream surface width, wetted perimeter, average water velocity, maximum depth, or cross-sectional area at each transect. Presentation of the data is then made in a graphic format with discharge represented on the "x" axis and the habitat parameter on the "y" axis. For example, in situations where a fisheries biologist is concerned about instream flow needs for fish growth and rearing, wetted perimeter might be chosen to represent habitat condition, under the assumption that food production is proportional to bottom surface area. The habitat-discharge relationship can then be represented as relative changes from some reference flow (Fig. 2-2a) or in absolute terms (Fig. 2-2b).

Two different approaches were used to derive instream flow recommendations from the habitat response curves. The minimum discharge can be set at the flow which produces a fixed percentage reduction from a reference flow in a particular habitat attribute (e.g., 20% reduction in wetted perimeter is maximum degradation allowable; Bartschi 1976). This approach is called a habitat retention criterion. The second approach, which is also included in several other assessment methods, relies on determination of the "inflection point" on a habitat-discharge response curve (e.g., point

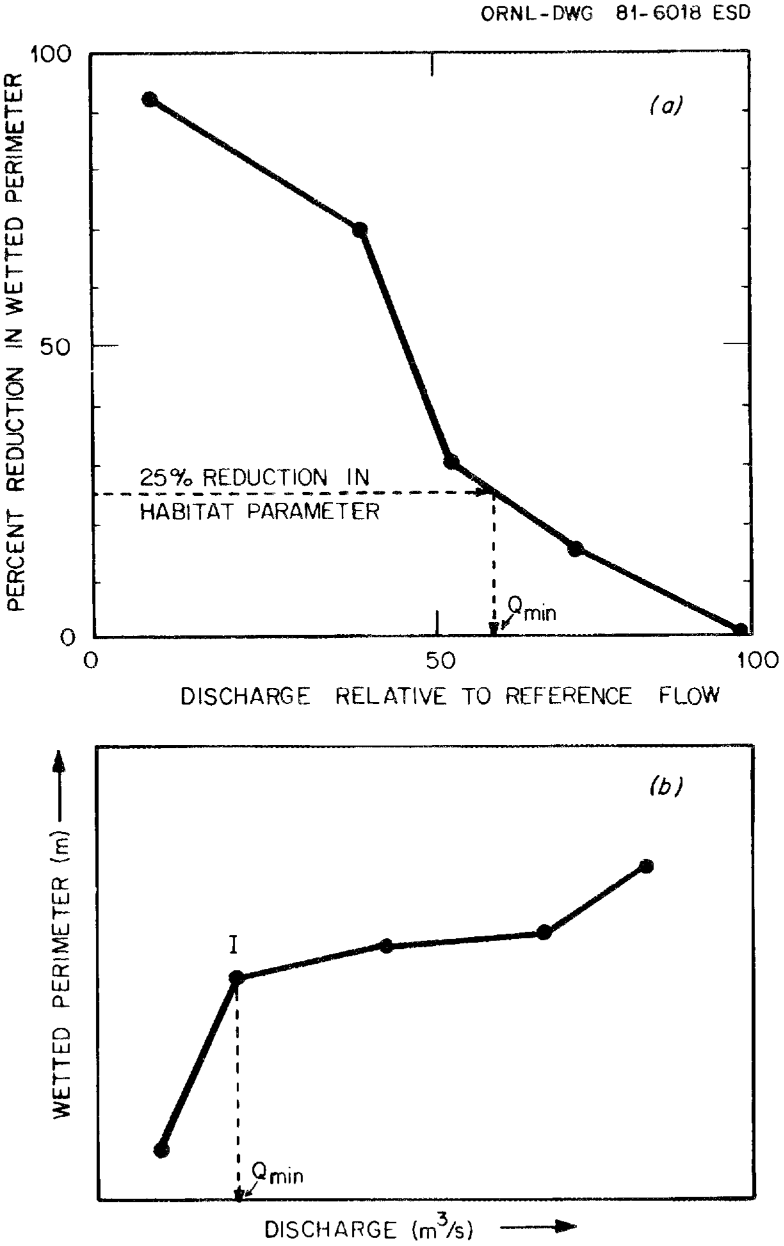

Fig. 2-2. Examples of habitat-discharge relationships developed from U.S. Forest Service procedures: (a) habitat retention criterion, and (b) inflection point (I) criterion.

'I' in Fig. 2-2b). The interpretation of the inflection point on a habitat-discharge curve is somewhat different from the formal definition; it is defined simply as the point where a major change in slope occurs. This approach represents an attempt to use the rate of change in a physical habitat attribute (e.g., meters of wetted perimeter per unit flow) to identify a threshold below which conditions are most rapidly degraded (see Sect. 3.4).

In addition to methods that measure single attributes of habitat condition, U.S. Forest Service personnel developed aggregative indices of habitat quality that incorporate multiple aspects of the aquatic environment (Dunham and Collotzi 1975, Cooper 1976). These procedures are also oriented toward transect-type data sets, but rely on the assignment of nonparametric ratings to "quantify" subjective evaluations by field personnel. Each of four components of habitat, pool measure (percentage of stream width with pool-type habitat), pool structure (quality of pool habitat based on depth, cover, etc.), substrate type, and riparian environment, is rated by assignment of an integer value between 1 and 4. The average of these four variables represents the habitat value index. This procedure is repeated for several different flow conditions, and a graph similar to that shown in Fig. 2-2a is constructed. The instream flow requirement is the discharge that results in 80% of the habitat index at a bank-full reference flow.

2.4.2 Simplified Staff-Gage Analysis

Efforts to develop a relatively simple field method for quantifying the relationship between habitat condition and stream flow led to what can be called staff-gage analyses. This approach is based on a stage-discharge curve similar to that used at USGS stream gaging stations, but a slightly different emphasis is placed on transect location. In contrast to the USGS hydraulic criteria for selecting a transect site, ecological criteria are used, preferably by a qualified fisheries biologist, to identify critical habitat for a target species or life stage in the affected stream. The staff gage, a graduated stick set vertically into the water column, is established at a location representative of this critical habitat. The stage (water surface elevation) is read from the staff gage at several known flows.

An instream flow requirement can be determined by applying a specified habitat criterion (e.g., minimum depth threshold) at the gage location. If upstream control of the stream flow is available and flow rates are known, this analysis can be as simple as raising or lowering the flow until the habitat threshold is satisfied. However, in many other situations, upstream controls will not be available or flow rates will not be known. In these cases, data consisting of discharge measurements and stage heights must be collected. To extrapolate to an unobserved flow which satisfies the habitat threshold, an empirical stage-discharge relationship is derived, either graphically or by calibrating a power function equation:

$$H = a\ Q^{b}, \qquad (2\text{-}1)$$

where H = stage (water surface elevation read from staff gage),

Q = discharge, and

a, b = regression coefficients fitted to field data.

Wesche and Rechard (1980) reported that this type of staff-gage analysis was used by the Bureau of Land Management. Personnel of the U.S. Fish and Wildlife Service also experimented with this technique at small hydroelectric sites in New England (G. Beckett, personal communication).

2.4.3 R-2 Cross

The Region 2 office of the U.S. Forest Service in Lakeland, Colorado, originally developed this analytical procedure for predicting the hydraulic conditions which could be expected at unobserved discharges. All calculations are based on the Manning

Equation (Eq. 2-2) for open channel flow and are used to describe the conditions at a single transect (Stalnaker and Arnette 1976).

$$Q = \frac{1}{n} \cdot A \cdot R^{2/3} \cdot S^{1/2}, \qquad (2\text{-}2)$$

where Q = discharge (m^3/s),
n = roughness coefficient,
A = cross-sectional area (m^2),
R = hydraulic radius (m) = A/wetted perimeter, and
S = energy slope.

The Manning Equation can also be written as

$$V = \frac{1}{n} \cdot R^{2/3} \cdot S^{1/2}, \qquad (2\text{-}3)$$

where V = mean velocity across transect (m/s).

Field data consisting of cross-sectional profiles (transverse distance and elevation), velocity measurements, and water surface slope in the vicinity of a transect are used to calculate the roughness coefficient, n, in Eq. 2-2. Assuming the values of n and S are independent of flow, an iterative computer program can then be applied to find values for average velocity, wetted perimeter, cross-sectional area, maximum depth, or hydraulic radius at discharges other than that observed in the calibration data set. These data are then used to derive a habitat-discharge curve (Sect. 2.4.1) with a minimum of field work. The identification of critical areas along a stream reach and proper transect placement remain important prerequisites with this method. Also, significant errors can result from using R-2 Cross to predict hydraulic conditions at flows greater than 250% or less than 40% of the calibration flow (Bovee and Milhous 1978).

Modifications to the original R-2 Cross model were made to relax some of the simplifying assumptions involved in applying Eq. 2-2 (Wesche and Rechard 1980). The Manning Equation was developed as an empirical description of uniform flows in open channels. In the original model, slope and roughness coefficients are assumed to be independent of stream discharge. However, both of these parameters change as a function of discharge at most locations in natural stream channels. To use this model in a more realistic manner, empirical equations have been proposed which make roughness and slope functions of hydraulic parameters such as Q or R (see Sect. 3.1).

Development of instream flow recommendations with R-2 Cross is essentially the same as that with other habitat evaluation methods. Habitat-discharge curves are drawn, and either a habitat retention criterion [e.g., 25% reduction (or 75% retention) of a habitat attribute from optimum or reference conditions] or an inflection point criterion is applied. The use of this method is restricted to narrow, wadable streams with low roughness (uniform or gradually varied flow).

2.5 WSP Hydraulic Simulation

This method is based on a step-backwater, hydraulic simulation model, Water Surface Profile (WSP), developed by the Bureau of Reclamation. The original purpose of the WSP model was to predict water surface elevations for flood routing problems (the HEC-2 model developed by the U.S. Army Corps of Engineers and PSEUDO developed by the Bureau of Land Management are other examples of this type of simulation model). It has been adapted to instream flow management problems in many of the same ways that R-2 Cross has been used; i.e., to predict changes in physical habitat parameters such as depths, velocities, and wetted perimeter with varying stream discharge (White 1976, Cochnauer 1976, Dooley 1976, Elser 1976, Workman 1976, Bovee and Milhous 1978). The advantage of using this method instead of R-2 Cross is that it uses a more sophisticated approach in modeling open channel flows and can develop a more detailed, multitransect map of the stream environment.

The WSP model employs three basic equations to represent hydraulic dynamics: (1) continuity or conservation of discharge between transects, (2) Manning's Equation (Eq. 2-2), and (3) Bernoulli Energy Equation (Eq. 2-4).

$$H = z + d + v^2/2g, \tag{2-4}$$

where H = total energy head (m),
z = elevation of the stream bed,
d = average depth (m),
v = average velocity (m/s), and
g = force of gravity on water.

These three equations are used to link transect data together to predict depths and velocities longitudinally through a stream reach (Bovee and Milhous 1978). The Bernoulli Equation is used to calculate the change in energy head between transects and the energy slope, S (change in H per longitudinal distance downstream) that is required in the Manning Equation. A "step-backwater" procedure is used to balance energy losses in an iterative process that predicts water surface elevations beginning at the downstream transect and proceeding upstream. The adaptation of the WSP hydraulic simulation method to instream flow analysis may include an additional step of predicting mean water column velocities for multiple subsections of each transect. The use of the step-backwater procedure to predict velocity distributions is the most significant new aspect of WSP applications and requires careful calibration to assure accuracy (Bovee and Milhous 1978). The limitations of this modeling approach are discussed in greater detail in Sect. 3.1.1.

The generation of instream flow recommendations from WSP simulations involves the same type of habitat-discharge curve development described in Sect. 2.4.1. This method has been found to be particularly desirable in modeling large, unwadable rivers without historical flow records (White 1976).

2.6 Usable Width

The terms 'usable width' and 'weighted usable width' originated from assessment methods developed for coldwater, salmonid streams in Oregon (Thompson 1972, 1974; Sams and Pearson 1963). The usable width method is oriented to single transects across critical locations in the stream channel where limiting habitat (e.g., spawning beds) occurs. Instream habitat condition is quantified as the percentage of the total stream width which is "usable," as determined by target fish species, life stage-specific criteria, and field survey data. Habitat-discharge relationships are obtained by repeating transect surveys at several discharges. Originally, the method did not include simulation techniques.

This type of approach is used for assessing flow requirements for fish passage, spawning, incubation, and rearing (i.e., growth and feeding). Applications are limited primarily to salmonid species. Habitat criteria consist of velocities and depths that are associated with the presence of fish. The difference between the usable width (UW) and weighted usable width (WUW) methods lies with the type of criteria used to define habitat usability. The former employs a binary criterion (usable or unusable); for example, portions of the transect that are less than a minimum depth criterion and exceed some maximum velocity criterion have no habitat value. Examples of these criteria for several salmonid species are given in Table 2-2.

Table 2-2. Binary habitat criteria for salmonid passage (from Thompson 1972)

Species	Habitat criteria Minimum depth (m)	 Maximum velocity (m/s)
Chinook salmon	0.24	2.44
Coho and chum salmon, steelhead and large trout	0.18	2.44
Other trout	0.12	1.22

To calculate WUW, on the other hand, the stream transect is uniformly divided into sections, each with a width, average depth, and average velocity. The width of each section of the transect is then multiplied by velocity and depth weighting factors which quantify, in relative terms, the habitat value of each subsection and can vary between 0.0 and 1.0 (Fig. 2-3). This product is summed for each section to compute the WUW for the transect:

$$\mathrm{WUW} = \sum_{i=1}^{n} W(v_i) \cdot W(d_i) \cdot \ell_i, \qquad (2\text{-}5)$$

where $W(v_i)$ = weighting factor for mean velocity in the i^{th} section,

$W(d_i)$ = weighting factor for mean depth in the i^{th} section,

ORNL-DWG 81-6021 ESD

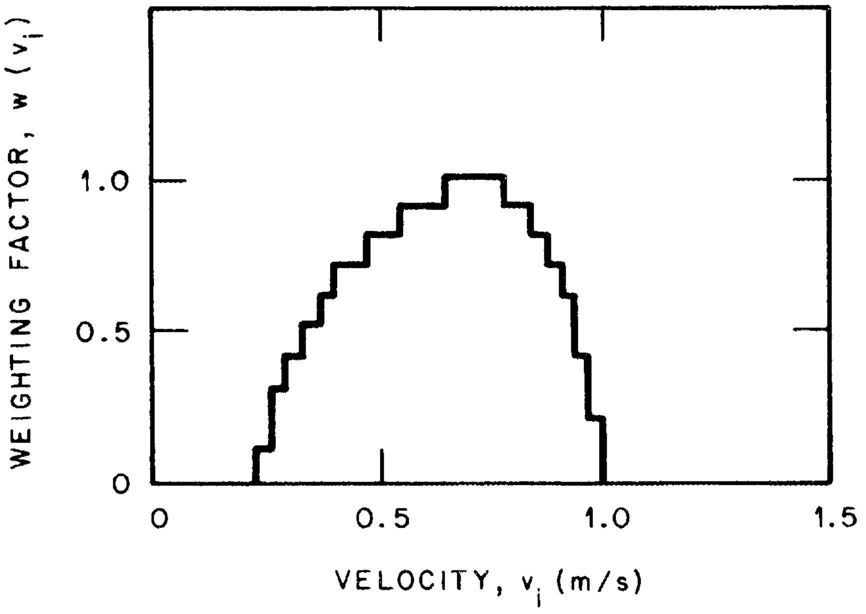

Fig. 2-3. Example of variable weighting factors used in calculating Weighted Usable Width (from Waters 1976).

ℓ_i = width of the i^{th} section, and
n = total number of sections along the transect.

It should be noted that if both weighting factors are given values of one or if one or both are equal to zero, then WUW is equivalent to UW. The techniques used to specify weighting factors have ranged from quantitative expressions based on the opinion of fisheries experts to a probablistic function of fish presence (e.g., Bovee and Cochnauer 1977). In all applications of habitat weighting criteria, however, care should be taken to ensure that the site-specific preferences of fish are addressed as accurately as possible. If existing weighting functions originally developed in other geographic areas are used in an instream flow study, justification for their applicability to local fish populations should be provided.

Instream flow recommendations derived from usable width methods are made by examination of the UW vs discharge curves. The minimum acceptable flow for salmonid migration (passage) is that flow which meets the minimum depth and maximum velocity criteria on at least 25% of the total transect width and on a continuous portion equalling at least 10% of the total width (Thompson 1972). An optimum spawning flow provides suitable flow conditions, with respect to the selected depth and velocity criteria, over the most gravel at critical spawning transects. The discharge that provides suitable flow conditions over 80% of the gravel available at the optimum flow is the minimum requirement for spawning. A major strength of the usable width approaches is that flow recommendations can be made on a seasonal basis with time-variable life stage requirements. An important component of this type of instream flow assessment is the construction of a periodicity chart which indicates the life stages present in each season.

2.7 Preferred Area

Two methods that quantify physical habitat in terms of preferred areas have contributed significantly to the development of instream flow assessment. Both increase the dimensionality of analysis compared to the usable width approaches by using multiple transect data and measuring habitat in units of area rather than of width.

The Washington Department of Fisheries, in cooperation with the USGS, applied a two-dimensional mapping technique, referred to as the Washington Method, to quantify the area of streambed available for salmon spawning (Collings 1972, 1974). Biological criteria for spawning consist of upper and lower bounds on preferred depths and velocities. Depth and velocity measurements are taken across four transects at a potential spawning site, and isopleth maps of the streambed are constructed to show the distribution of hydraulic parameters at a fixed discharge (Fig. 2-4). Areas satisfying both the velocity and depth criteria are designated as spawnable portions of the stream. This procedure is repeated for a minimum of five different stream flow conditions to develop a response curve of spawnable area vs discharge over the range of flows of interest. No hydraulic modeling is used in predicting depths or velocities. The preferred spawning flow is defined as the flow with the maximum spawnable area. Instream flow requirements are set at the flow which maintains 75% of the maximum spawning area. This type of flow recommendation is another example of a habitat retention criterion.

A second approach to quantifying instream habitat on an areal basis was developed by fisheries biologists of the Pacific Gas and Electric Company (Waters 1976). This work, which was initiated in the 1950's in California, predates all of the methods discussed previously. Like the Washington Method, two-dimensional maps of the stream environment are developed from transect data, but continuous weighting criteria for velocity and depth are used to calculate habitat values. Again, no hydraulic simulation modeling is used to

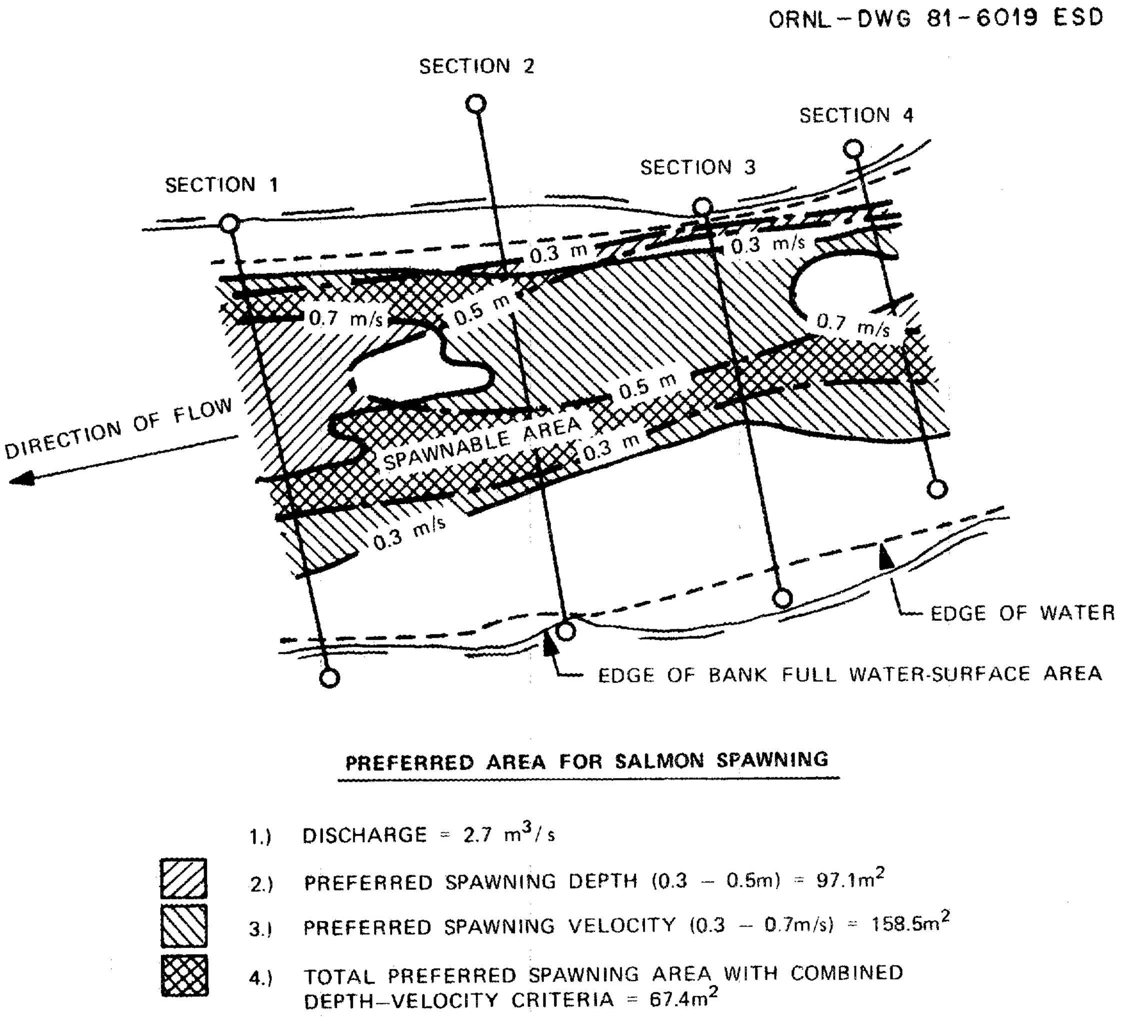

Fig. 2-4. Example of preferred area calculations using the Washington Method (modified from Collings 1972).

predict conditions at flows other than those observed. The habitat quality index used with this method is referred to as Net Preferred Habitat (NPH) and is calculated as:

$$\mathrm{NPH} = \sum_{i=1}^{n} v_i \cdot d_i \cdot \Delta a_i, \tag{2-6}$$

where v_i = velocity weighting factor between 0 and 1,
d_i = depth weighting factor between 0 and 1,
Δa_i = bottom surface area of i^{th} element of stream reach, and
n = number of elements in stream reach.

2.8 IFG Incremental Methodology

The Cooperative Instream Flow Service Group (IFG) of the U.S. Fish and Wildlife Service developed a set of habitat evaluation procedures known as the Incremental Methodology (Stalnaker 1978, 1979b; Trihey 1979). A package of computer programs, collectively called PHABSIM (Physical HABitat SIMulation system), is used to implement this analysis of instream flow needs (Fig. 2-5). The overall approach combines (1) multiple-transect field data from a representative and/or critical river reach, (2) hydraulic simulation models to predict physical habitat parameters such as mean velocity ($\bar{v}$), depth ($\bar{d}$), and substrate ($\bar{s}$), and (3) species-specific suitability functions (S_v, S_d, S_s) similar to those first described by Waters (1976). Suitability functions are used to calculate weighting coefficients representing the habitat preferences of various life stages of target fish species. Finally, measures of habitat suitability and availability (as wetted surface area, $\bar{a}_i$) are used in the computation of Weighted Usable Area (WUA), an index of habitat condition. This index is computed for each life stage [e.g., spawning (S), fry (F), juvenile (J), and adult (A)] and can be plotted against discharge (Fig. 2-5). The intent in developing the Incremental

ORNL-DWG 81-6017 ESD

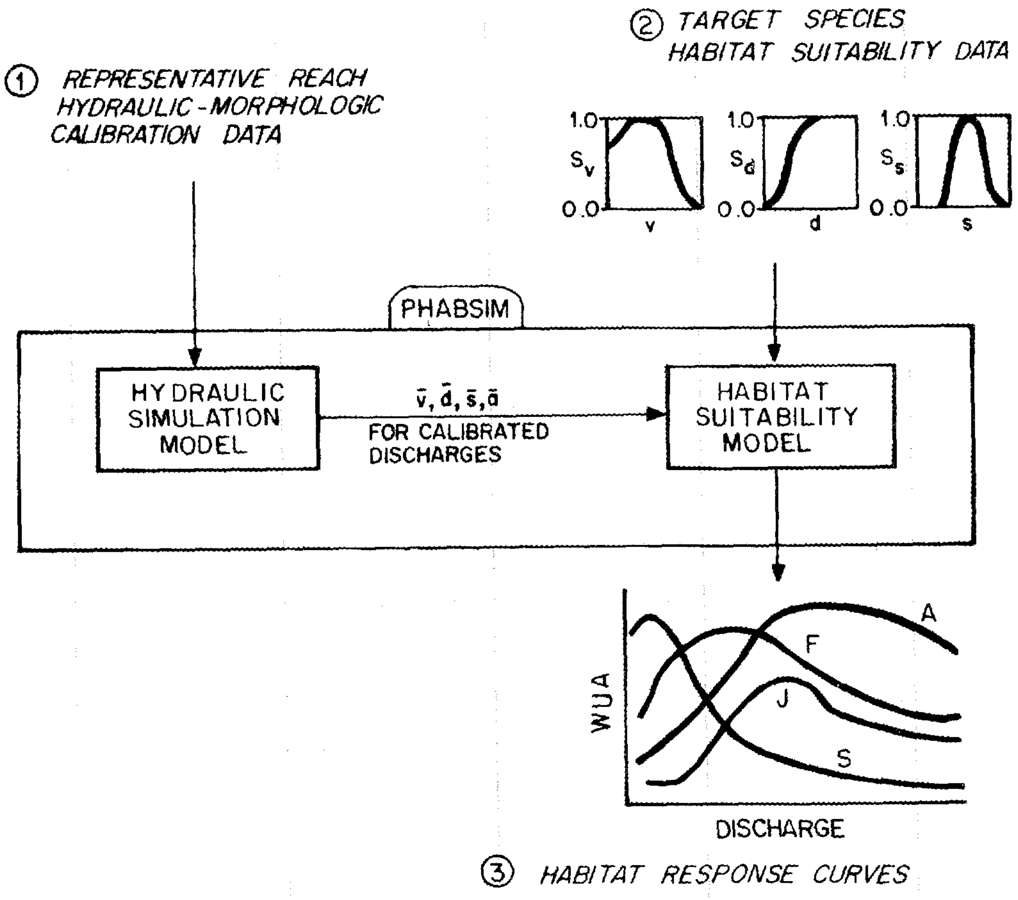

Fig. 2-5. Organization and information processing in the Incremental Methodology for instream flow assessment (from Sale 1980).

Methodology was to create a "state-of-the-art" analytical tool for addressing instream flow questions. Therefore, it incorporates many of the aspects of the methods developed earlier and described in Sections 2.1 to 2.7.

Hydraulic simulation in PHABSIM applications can be carried out using one of two different modeling techniques (Bovee and Milhous 1978, Wegner 1980). The first model of open channel flow, IFG-2, is a step-backwater procedure similar to the WSP model described in Section 2.5. Calibration can be accomplished using one set of velocity/depth transect data if limitations are placed on the range of flows that can be simulated (Bovee and Milhous 1978). Additional calibration steps are necessary beyond normal WSP procedures to maximize the accuracy of velocity predictions in individual cells of each transect (Bovee and Milhous 1978, Wegner 1980).

The second option for hydraulic simulation is IFG-4, a modified stage-discharge regression procedure (Wegner 1980). This model requires two or more (optimally three or more) sets of transect data from distinctly different discharge conditions to achieve good model calibrations (Bovee and Milhous 1978). Individual rating curves are calculated for the stage-discharge and velocity-discharge relationships in each cell along each transect of the representative reach. Although more field data are needed with this approach, the IFG-4 model is relatively less complicated to calibrate and more flexible than WSP in handling more difficult flow conditions (i.e., unsteady or nonuniform flows).

The attribute used to quantify bottom substrate in the Incremental Methodology is a relative index related to Wentworth particle size (Bovee and Cochnauer 1977; Trihey 1979). A coding system is usually established in which substrate types are assigned integer values ranging from 1 to 9; for example, plant detritus, mud, silt, sand, gravel, rubble, boulder, and bedrock bottom types are assigned values of 1 to 8, respectively. Substrate suitability curves are based on this system. Many variations are possible in coding substrate type, including combinations where integer values represent dominant particle size in each mapping cell, and decimal values represent either characteristics of the matrix of smaller sediments in which larger substrate elements are embedded or cover characteristics in each mapping cell (i.e., overhanging vegetation, depth cover, proximity to large boulders, etc.; Bovee 1980). A great deal of flexibility can be incorporated into the substrate index, but as more complexity is included (e.g., addition of substrate and cover), more detailed transect surveys are required. Water temperature is another physical habitat parameter which has been included in calculating WUA indices (Bovee and Cochnauer 1977, Sheppard 1980).

The final output of PHABSIM is usually in the form of either a tabular or graphic relationship between stream flow and Weighted Usable Area (WUA). The calculation of WUA combines a measure of the quality of the physical instream habitat with a quantification of habitat availability by subdividing a stream reach into a matrix of rectangular cells (Fig. 2-6, Eq. 2-7).

$$WUA = \sum_i \hat{S}_i \cdot a_i, \qquad (2\text{-}7)$$

where $\hat{S}_i$ = composite habitat suitability of the ith mapping cell, and

a_i = surface area of the ith mapping cell.

A computer program, HABTAT (or IFG-3), calculates WUA values based on the mean velocity, depth, and substrate data ($\bar{v}$, $\bar{d}$, $\bar{s}$) predicted from hydraulic simulations. Composite habitat suitability, which is the measure of habitat quality, is a multivariate function of the physical parameters of each cell (Eq. 2-8). Several different techniques for calculating $\hat{S}_i$ have been proposed (Orth 1980, Wegner 1980, Voos et al. 1981). The most frequently used composite suitability equation assumes independence among physical parameters and has the following form:

ORNL-DWG 81-13990 ESD

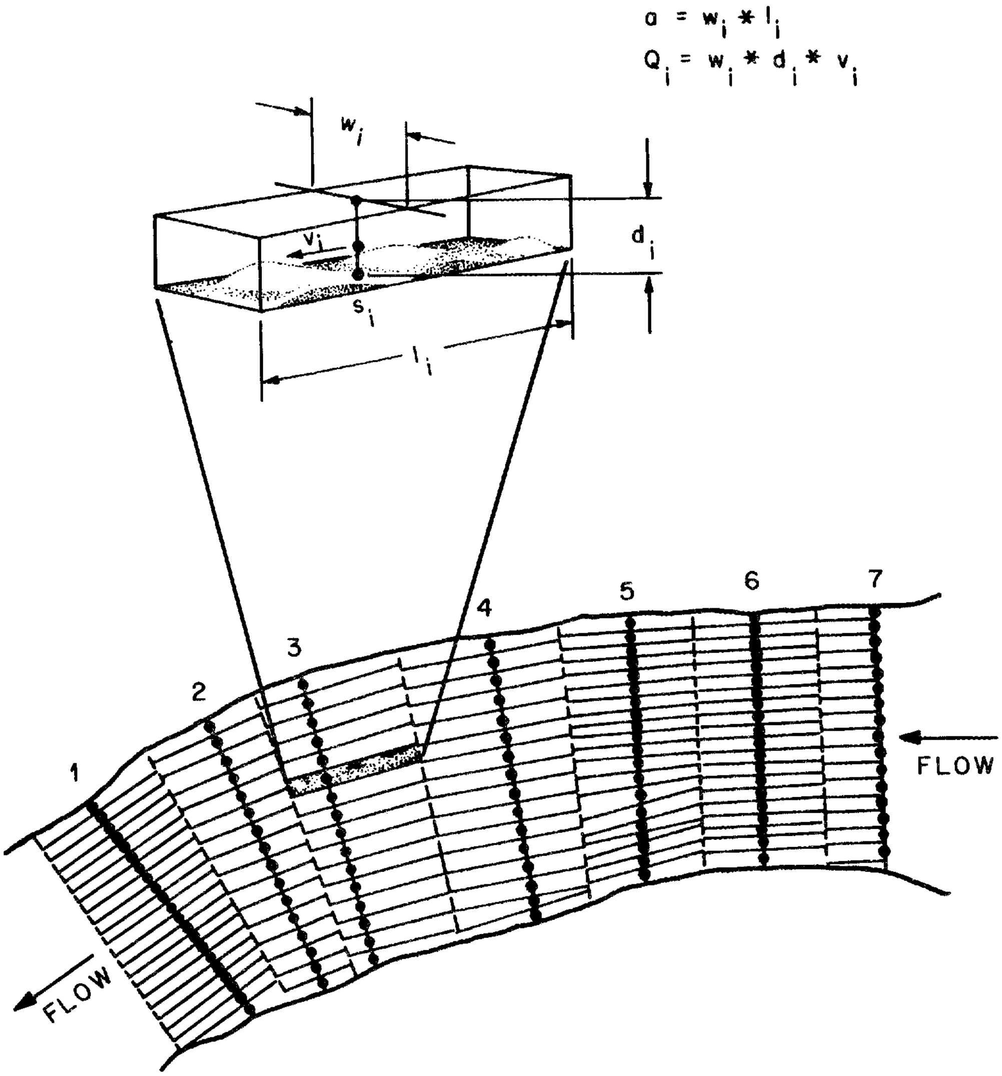

Fig. 2-6. Subdivision of a stream reach into transects and mapping cells for computational purposes with the Incremental Methodology (modified from Bovee and Cochnauer 1977 and Hilgert 1981).

$$\hat{S}_i = S_v(v_i) \cdot S_d(d_i) \cdot S_s(s_i), \tag{2-8}$$

where $S_v(\cdot)$, $S_d(\cdot)$, and $S_s(\cdot)$ = univariate suitability functions predetermined for each target fish species and life stage.

All suitability functions have values between 0.0 and 1.0 (Fig. 2-7). The univariate suitability functions used in calculating WUA can be developed in a variety of ways (Bovee and Cochnauer 1977, Voos et al. 1980). These include the use of field observations, literature sources, and ad hoc or Delphi-type procedures (e.g., Dakley and Helmer 1963). A source file of suitability functions for more than 50 warmwater and coldwater fish species (up to five life stages for each), some families of aquatic insects, and recreational activities such as boating and fishing is maintained by the IFG. Quality ratings (called evaluation criteria by IFG; Bovee and Cochnauer 1977) for all suitability curves in the IFG data base indicate the information source used to construct the curves and provide an excellent way to document the confidence to be placed on analyses made with their use. However, access to the IFG data base is limited to encourage the development of site-specific habitat preference data.

Two alternative methods were proposed for utilizing the WUA information to develop instream flow recommendations. The first method, which was developed by IFG and U.S. Fish and Wildlife Service users, is essentially an examination of the relative change in WUA from optimal conditions with respect to discharge (K. Bovee, personal communication). The discharge level between the monthly median flow and the 90 percentile monthly flow that results in the smallest reduction in WUA relative to the optimum is set as the instream flow requirement for each life stage of a target species. This analysis is

ORNL-DWG 81-6020 ESD

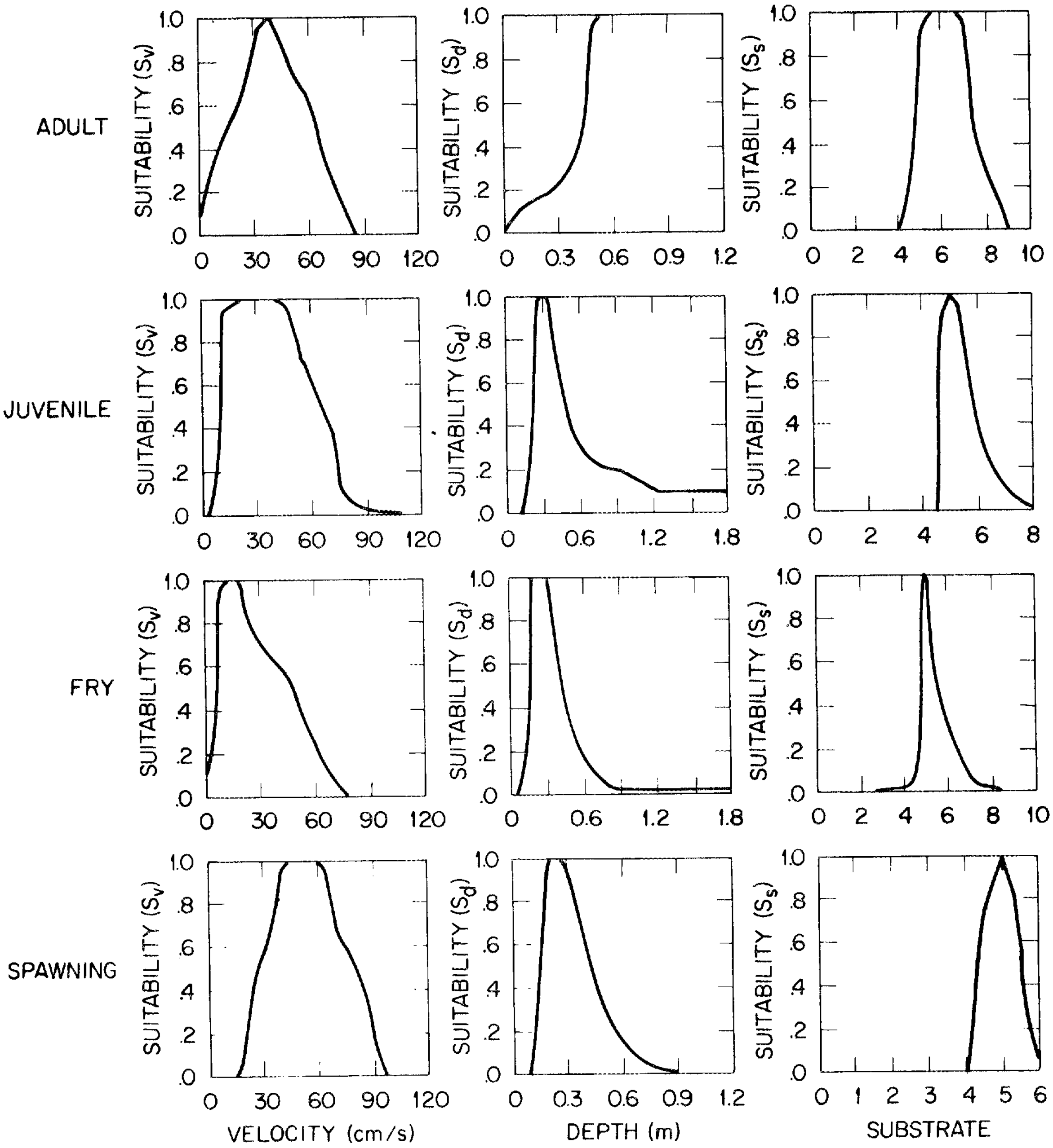

Fig. 2-7. Univariate suitability curves for rainbow trout (<u>Salmo gairdneri</u>) (modified from Bovee 1978).

repeated for each month that a life stage is present and for each target species and life stage of interest. The discharge level which results in the lowest relative change for all species and life stages is often used as the overall minimum flow recommendation for each month. An instream flow regime can be generated by using this procedure for each month of the year. No computer programs have been developed to aid in these computations.

A second application of the WUA-discharge curves was used to provide instream flow recommendations for Illinois streams (Herricks et al. 1980) and to analyze the impacts of reservoir operation schedules (Milhous and Bovee 1978). This approach is analogous to the flow-duration calculations common in descriptive hydrology. A daily flow record is first obtained for the representative stream reach, either from historical, pre-project data or from modification of those data by hypothetical storage and release specifications at a proposed reservoir. Next, the daily flow record is converted to a record of daily WUA values by using the habitat-discharge response curves produced by the Incremental Methodology. This procedure is carried out for different life stages of target species for only those seasons in which they are present. Habitat duration, the percentage of days in which WUA equals or exceeds various levels, is then calculated on either a weekly, monthly, or annual basis.

An instream flow recommendation can also be set at the discharge level which provides a fixed percentile habitat quality (e.g., the minimum monthly flow is the flow which provides the 80 percentile WUA value based on historical records). This habitat-duration approach provides the best available quantification of baseline or preproject habitat conditions against which instream flow recommendations can be made. This type of analysis can be organized into a nomographic calculation by plotting the habitat-discharge response curve and habitat-duration curve on the same set of axes (Fig. 2-8).

The Incremental Methodology is often described as "state-of-the-art" with regard to instream flow assessment methods. However, it

ORNL-DWG 81-10880 ESD

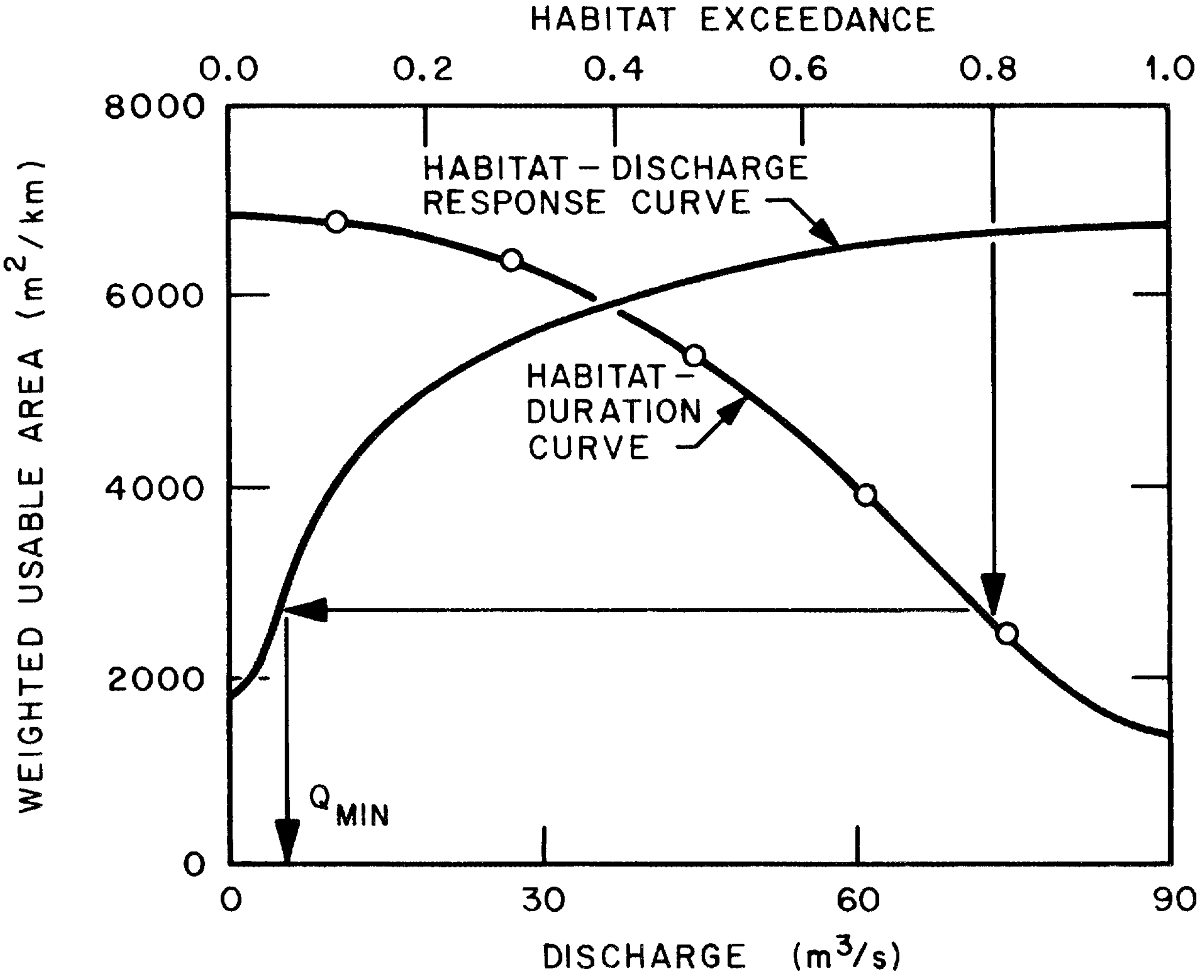

Fig. 2-8. Nomograph calculation of an instream flow recommendation using habitat-duration data and assuming a decision criterion to retain the 80 percentile habitat condition.

also may carry the connotation of being an excessively complex and time- consuming analysis. This latter point of view overlooks the fact that, where appropriate, components of PHABSIM and other software developed by the IFG can be used in more simplistic assessments. For instance, the IFG-4 hydraulic simulation package includes an option to output channel widths with depths equaling or exceeding specified habitat criteria in a manner analogous to the Usable Width method developed in Oregon. The IFG-4 model can also be used on single-transect data with or without the HABTAT program. A computer program called IFG-1 is available which is a slightly modified version of R-2 Cross. Therefore, for an experienced user, the computer packages which have been developed by the IFG provide a truely flexible set of assessment tools for instream flow assessment problems.

2.9 Summary of Available Methods

The five characteristics listed at the beginning of this section can be used to summarize the instream flow assessment methods currently available (Table 2-3). Distinct differences exist in the capabilities of the various methods. For instance, the first three approaches listed in Table 2-3 can be grouped into a category called discharge methods because decisions concerning instream flow needs are based only on historical flow records. The most detailed and the preferred approach in this group would be one based on flow duration data, because this statistic is the most realistic representation of natural stream flow variability at a given site (Stalnaker and Arnette 1976).

A second category of instream flow methods, hydraulic rating methods, includes all the procedures that examine hydraulic parameters for the purpose of developing generalized habitat-discharge relationships. Both single and multiple transect methods can be included in this group if species-specific habitat preferences are not

Table 2-3. Summary of existing instream flow assessment methods

	Characteristics				
Method	Stream flow records	Hydraulic simulation	Habitat rating	Transect data[a]	Species or seasonal specificity
Fixed Percentage (e.g., Montana)	Yes	No	No	None	Little or none
Constant Yield (e.g., NEFRP)	Yes	No	No	None	Some seasonal
Flow Duration	Yes	No	No	None	Some seasonal
USFWS Habitat Evaluation	No	No	Some indirect	Single or multiple	Some species
Stage-discharge Analysis (e.g., R-2 Cross)	No	Yes (Manning's Eq.)	Indirect	Single v/d	No
WSP Simulation (Idaho)	No	Yes (WSP)	Indirect (wetted perimeter)	Multiple v/d	No
Usable Width (Oregon and modifications)	No	No	Yes	Single v/d	Yes
Preferred Area (California and Washington)	No	No	Yes	Multiple v/d/s	Yes
PHABSIM (IFG's Incremental Methodology and modifications)	Some	Yes (WSP or IFG4)	Yes	Multiple v/d/s/c/t	Yes

[a] v = velocity; d = depth; s = substrate; c = cover; t = temperature

evaluated. This group does not involve as much field work as the most data-intensive approaches (e.g., the Incremental Methodology), nor does it utilize stream flow records directly to quantify baseline conditions. The most significant capabilities of this group are (1) introduction of simplified prediction techniques to reduce field survey needs and (2) ability to examine site-specific aspects of streambed morphology. Methods based on stage-discharge, hydraulic rating curves and the Manning Equation, when used within the limits of extrapolation to unobserved flow conditions, are probably the best examples from this group.

The third category includes those methods that apply species-specific habitat criteria in evaluating the condition of a stream environment. The Incremental Methodology is the best example of this group because it combines the habitat weighting concepts first developed in California, Oregon, and Washington with detailed hydraulic simulation models. When stream flow records are used to derive instream flow recommendations from the Incremental Methodology, all five characteristics can be included in the assessment.

These three categories do not include all the methods developed to assess instream flow needs for fishery resources. For example, in some western streams where water quality has been identified as a limiting factor for incubation of salmonid eggs, specialized methods were developed to measure interstitial dissolved oxygen concentrations (Stalnaker and Arnette 1976). The three-tiered categorization, suggested here for purposes of simplification, provides a framework for discussing those methods that will be most useful in assessments of instream flow requirements at small-scale hydroelectric projects.

3. CRITICAL EVALUATION OF EXISTING METHODS FOR INSTREAM FLOW ASSESSMENT

The purpose of this section is to compare and contrast existing instream flow assessment methods. The material presented in Section 2.0, combined with more detailed information available in appropriate references, provides the basis for this evaluation. The recommendations made in Section 4.0 are a reflection of the conclusions presented in this section.

Environmental impacts which result from flow regulation at hydroelectric facilities can be represented in a simplified chain of effects that includes three stages: (1) initial changes in the discharge regime due to project operation, (2) alteration of the physical habitat in the downstream lotic environment, and (3) biological response of the affected aquatic ecosystem (Fig. 3-1). This conceptual model may be oversimplified to some degree, but it provides a useful perspective for describing the capabilities of various assessment methods. Methods used to develop instream flow recommendations which do not analyze the entire impact chain must rely on implicit assumptions about the behavior of regulated stream ecosystems. These assumptions are described more completely in Section 3.1.

Other characteristics that are important in the selection of an appropriate method for a specific application include data requirements for implementation (Sect. 3.2), dollar costs (Sect. 3.3), and decision-making capabilities (Sect. 3.4). For the sake of clarity, discussions of these various characteristics emphasize a three-way classification of methods whenever practical. The three principle types of methods are (1) discharge methods, (2) single-transect methods which develop some type of hydraulic rating analysis (i.e., depth vs discharge or wetted perimeter vs discharge) but stop short of a more detailed analysis, and (3) multiple-transect, habitat rating methods.

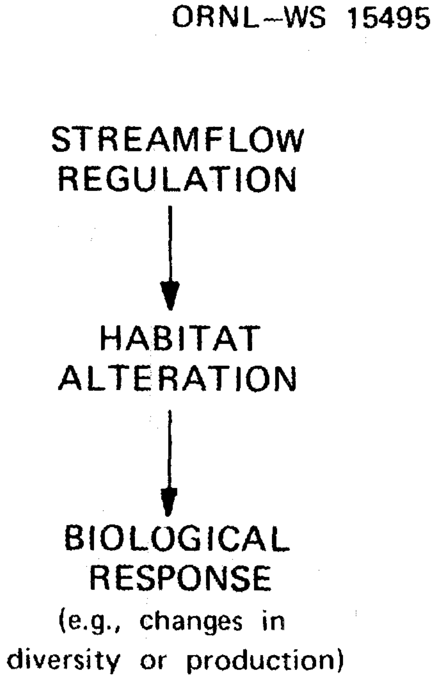

Fig. 3-1. Conceptual basis for instream flow assessment.

3.1 Implicit Assumptions

All of the assessment methods discussed in Section 2.0 involve certain assumptions about stream environments and the behavior of riverine (lotic) ecosystems. A clear understanding of these assumptions is an important prerequisite to selection and application of these methods. In a general sense, the assumptions to be examined fall into one of two categories: those related to the physical behavior of the river system, including its hydraulics and channel morphology, and those associated with prediction of the biological response to alterations in stream flow and habitat condition.

3.1.1 Hydraulics and Channel Morphology

Assumptions related to stream hydraulics or channel morphology are important in two situations: (1) specification of thresholds to be used in developing instream flow recommendations and (2) selection of hydraulic simulation models to predict depth and velocity at unobserved stream flows. The definition of thresholds is most obvious in the discharge approaches (e.g., Montana Method, New England Flow Recommendation Policy, or flow-duration analysis). When Tennant (1976) established 10% MAF as a minimum acceptable flow, it was based on the hypothesis that the amount of water will fill the stream channel to a width and depth adequate to assure short-term survival of aquatic biota. This empirical threshold was determined from observations on a large number of watersheds across the United States.

Hydrologic analyses that described the natural variability in stream flow were the basis of early attempts to establish instream flow requirements. From these analyses arose the concept of the 7Q10 (Sect. 2.2), a statistic that has been used as a criterion to design waste treatment facilities and one that has been offered as a "rule of thumb" for the minimum flow that would assure adequate water quality (Stalnaker 1979a). Although it was developed for water quality purposes and has no ecological basis, it, nevertheless, is still often used to determine instream releases below hydroelectric projects. Use of the 7Q10 statistic in this manner ignores the dynamic nature of fishery requirements and the long-term recovery that is necessary after such a severe low-flow period (Stalnaker 1979a, 1981). While it may be very conservative for designing water treatment facilities, it is not conservative for protecting fishery resources (K. Bovee, personal communication). Use of a single "minimum" flow, such as the 7Q10 statistic, as the instream requirement needed to protect fish and wildlife habitat is not recommended.

The understanding of relationships between the shape of stream channels (i.e., hydraulic geometry) and flow frequency and magnitude has developed out of the combined disciplines of geology and hydrology (Leopold et al. 1964, Schumm 1977). Although most of this work predates concern over instream flow issues, it has direct bearing on the validity of certain assessment methods described in Section 2.0. The power function equations originally proposed by Leopold and Maddock (1953) have been successfully expanded to include flow-frequency parameters (Stall and Fok 1968, Stall and Yang 1970). Watershed area and stream order (e.g., Strahler 1957) have also been incorporated into equations which are widely used to predict hydraulic geometries of stream channels (depths, widths, velocities, etc.) at various locations in a watershed. These types of equations are based on logrithmic regressions of actual field data; for instance:

$$\ln D = \alpha + \beta F + \gamma \ln A, \qquad (3\text{-}1)$$

where D = average depth,
F = frequency of occurrence,
A = watershed area upstream from site, and
α, β, γ = regression coefficients for specific watersheds.

The regression coefficients reflect the influence of factors related to watershed geology, slope, and the aging process of water courses. The coefficients in hydraulic geometry equations such as Eq. 3-1 vary by as much as a factor of three among the watersheds in the State of Illinois (Stall and Fok 1968). Greater variation can be expected among rivers in different states (Stall and Yang 1970). These equations suggest that for maintenance of fixed depth thresholds (Section 2.6) on watersheds with equal areas, different natural flow frequencies would constitute the instream flow requirement. None of the discharge methods discussed in Section 2.0 address this aspect of fluvial geometry. The existing flow-duration methods could be improved by incorporating more geomorphological variables as independent determinants of instream flow requirements.

The Montana Method uses an average flow statistic only and ignores completely the importance of flow variability characteristics of individual watersheds. Both the hydraulic geometry and affected aquatic biota of a stream are adapted to a past flow regime (i.e., a temporal pattern in both magnitude and frequency of occurrence). Using the same percentage of the average stream flow to determine instream flow requirements on different watersheds implies that equivalent flow regimes exist among watersheds. This assumption is not valid and overlooks the fact that local aquatic populations are adapted to natural variations in stream flow. Because temporal patterns are an important determinant in structuring stream fish communities (Horwitz 1978), it is only realistic to set instream flow requirements in reference to flow variability on a watershed-specific basis.

The New England Flow Recommendation Policy (NEFRP) method, which is based on median historical stream flows, incorporates flow variability to a limited extent in that it defines the Aquatic Base Flow (ABF) required to protect aquatic biota as equal to the median monthly flow (MMF) for August. The ABF applies to all times of the year unless superceded by spawning and incubation flow recommendations (100% MMF in the spring and fall). Although the policy recognizes the importance of higher flows at other times of the year, the additional flow variability provided by supercedence flows is not characteristic of all sites (see Table 9 in Cunningham and Knapp, in press).

Even methods that are based on flow duration data and that set the instream flow recommendation equal to a percentile flow do not properly address known properties of hydraulic geometry. A constant percentile instream flow can only supply the same environmental conditions over regions with watershed characteristics that are relatively homogeneous.

Assessment methods other than the discharge methods avoid, at least partially, the problem of unique site-specific influences because they measure directly the physical parameters at actual flow events. Instream flow requirements should still incorporate the influences of natural flow availability, but many assumptions about what physical conditions are provided by specific flow levels can be eliminated with site-specific field surveys.

Methods that use hydraulic simulation models or analytical equations to predict depth and velocity conditions at observed flows often involve significant assumptions about the type of open channel flow that is being modeled. For example, the Manning Equation (Eq. 2-2) was originally developed to predict the relationships among discharge, velocity, hydraulic radius, channel roughness, and energy slope for uniform flow conditions (e.g., Olson 1973). Therefore, methods which rely on this empirically based equation, such as R-2 Cross or the WSP simulation model, may not be valid when applied to streams which deviate strongly from uniform flow (uniform flow is defined as conditions in which velocity, depth, and energy gradients are constant over relatively long distances). Methods employing Manning's Equation can be used with care under gradually varied flow conditions but should not be used under conditions of rapidly varied flow, such as the hydraulic jumps in rapids or stream reaches where the energy slope exceeds 10% (K. Bovee, personal communication).

When uniform or gradually varied flow conditions are satisfied, other assumptions should be examined to ensure the validity of hydraulic simulations. Single-transect methods that are used to develop stage-discharge rating curves all involve assumptions about flow-dependent changes in bottom roughness, n, or slope, S. The original R-2 Cross method used only one set of field data to calibrate the variables n and S in Eq. 2-2, then assumed these values remained constant over a wide range of stream flows. More recent modifications to the single-transect approach have relaxed this assumption somewhat by making roughness a function of other hydraulic parameters such as R, the hydraulic radius. Wesche and Rechard (1980) report that one empirical technique proposed in Colorado to adjust roughness uses the relationship:

$$n_2 = n_1 \cdot \sqrt{R_1/R_2}. \qquad (3\text{-}2)$$

The validity of Eq. 3-2 must be verfied for each site-specific application. The best technique for verifying the predictions of changes in n and S is to collect three or more observations of river stages and to plot the slope-roughness factor, $n/S^{1/2} = AR^{2/3}/Q$, vs discharge to determine the influence of Q. Extrapolations based on data collected at each transect for three or more flows will be the most accurate in modeling the physical stream environment (e.g., Bovee and Milhous 1978).

Other limiting assumptions are important to step-backwater modeling applications such as WSP. The calibration data required for input to the WSP model assume steady flow conditions (i.e., the data from each transect were taken under constant discharge conditions). Also, each set of calibration data is good for simulating only a finite range of discharges. The IFG recommends that WSP predictions can be used over a range of conditions, from 250% above the calibration discharge down to 40% below the calibration discharge (Bovee and Milhous 1978; Wegner 1980). For example, the use of WSP simulations calibrated with data collected at 15 m^3/s (530 cfs) should be limited to a range of 6 to 38 m^3/s (212-1325 cfs). Predictions of hydraulic or habitat conditions outside those ranges require an additional set of calibration data.

All hydraulic simulation models used to date ignore the interactions between bottom substrate (and therefore roughness) and discharge. The assumptions related to these interactions are discussed in detail by Bovee and Milhous (1978). Although this interaction is by no means trivial and is currently under study by the IFG, there are no reliable predictive models which can determine substrate conditions as a function of discharge regimes accurately enough to be useful in developing the habitat-discharge relationships needed in a detailed instream flow analysis.

None of the methods address short-term rapid fluctuations in flow that often occur below peaking projects. The hydraulic simulation models that were developed to predict depth and velocity at unobserved flows assume uniform or gradually varied flow conditions. Thus, the critical assumption is that these same models can be used to assess instream flow needs in riverine environments characterized by rapid fluctuations in flow. In these cases, the rate of change in water levels as well as the interval between major fluctuations are important considerations. Because of the assumption that flows must be uniform or gradually varied, none of the existing models (or methods) may be capable of addressing, in a meaningful way, the ecological implications of rapidly varied flows below peaking projects.

Finally, the concept of a representative reach, which is used in the habitat modeling approaches (e.g., the Incremental Methodology), is assumed to be sufficient to represent long sections of rivers and streams (Bovee and Milhous 1978; Trihey 1979). Although this concept was supported by numerous reviewers of the methodology (e.g., Patten et al. 1979), any application of the Incremental Methodology should include careful placement of one or more representative reaches to ensure that local instream resources are included in the analysis.

3.1.2 Biological Response

The conceptual impact chain of the effects of flow regulation (Fig. 3-1) is important because it indicates what is not explicitly covered by the various assessment methods. Approaches which use only discharge records to determine instream flow recommendations cannot analyze incremental, site-specific habitat alteration or biological responses to flow regulation. Single-transect methods which make decisions based on changes in such hydraulic parameters as wetted perimeter or maximum depth address habitat alteration only in a general sense and usually do not directly consider the needs of specific fish species or life stages. Habitat rating methods such as PHABSIM carry out a relatively detailed analysis of the habitat alteration caused by regulated discharges. In addition, habitat alteration is placed in a biological perspective by including species and life-stage specific preferences for physical parameters in their environment. However, even PHABSIM has limited predictive capability as far as productivity or standing crops of aquatic biota are concerned.

All of the methods that were developed to assess instream flow needs for fishery resources are based on the assumption that habitat is the factor limiting population size. Because many western streams are characterized by very low flows at certain periods of the year, the assumption is made that the decrease in available habitat during these low-flow periods is the key factor. In some cases, however, high flows might be limiting. In eastern streams, fish production is often limited by the available food resources (Patten et al. 1979). Water quality problems are also more significant in the East, and this factor may also be limiting in some streams. In short, the assumption that fish populations are physically limited is critical, because the existing methods have reduced utility when other factors are limiting or controlling population size or production. However, water quality or food limitations should not preclude all instream flow management for physical habitat, especially when future improvements in these limiting factors can be expected. While the Incremental Methodology also assumes that physical habitat is limiting, the IFG emphasizes the importance of evaluating other factors, such as watershed equilibrium and water quality, prior to using the method.

Two important biological assumptions involved in using any of the discharge approaches are (1) affected aquatic resources are a function of past hydrologic conditions which, in turn, can be accurately represented by a particular stream flow statistic, and (2) acceptable management of extant aquatic resources is directed at conserving those past conditions. While these assumptions are reasonable in many situations, they may not always apply due to unique, site-specific opportunities, management objectives, or project characteristics. Aquatic species do adapt to local environmental conditions. However, both the variability and magnitude of stream flow events are important in determining the composition and structure of riverine fish communities (Horwitz 1978).

One situation where aquatic resource management might not be based on conserving past hydrologic conditions occurs when the fisheries resource is dominated by nonindigenous fish species (e.g., stocked salmonids). In this case, fish populations will not be adapted to past conditions, so historical stream flow records may have little value in determining instream flow needs. To accurately determine the benefits of stream flow patterns or release schedules to introduced fish species, a method with more species-specific resolution should be used.

Single-transect hydraulic rating methods that develop relationships between descriptive physical parameters and stream flow eliminate some of the implicit assumptions regarding thresholds of habitat alteration inherent in discharge methods. However, the selection of critical transects and specific hydraulic parameters can again include important assumptions about biological responses. The single-transect methods usually assume that the factors limiting aquatic resources (e.g., fish populations) can be represented by a single hydraulic parameter and that one critical transect accurately represents the influence of that hydraulic parameter throughout a heterogeneous stream reach. Furthermore, these types of analyses often imply that the same limiting factor is active for all seasons and all species.

For single-transect hydraulic rating methods, the choice of parameters and associated limiting factors include the following types of assumptions: spawning and egg incubation are proportional to maximum depth or velocity; cover is proportional to pool depth or exposure of undercut banks; rearing and food production is proportional to wetted perimeter. Whenever a habitat retention or inflection point criterion based on any of these parameters is used, the implication is that a linear relationship exists between the hydraulic parameter and fish production or standing crop (Sect. 3.4).

Of the methods currently available, the Incremental Methodology, PHABSIM, permits the most detailed analysis of the habitat alteration effects caused by changes in stream flow. However, the method has been criticized because of its incomplete representation of biological responses (Patten et al. 1979). The dynamics of aquatic ecosystems are a complex function of a number of different physicochemical and biological factors (Table 3-1). PHABSIM provides a quantitative tool which can be used to examine only two of the general categories of factors, habitat structure and flow regime, that are determinants of biological responses. Therefore, even if Weighted Usable Area (WUA) were a perfect index of habitat condition and its response to changes in stream flow, at least two other factors, water quality and trophic community structure, would be necessary to fully model the biological response. Therefore, WUA is a necessary but not sufficient indicator of ecosystem integrity (Patten et al. 1979). Only in situations where water quality or food resources are not limiting (e.g., coldwater trout streams) can WUA be assumed to be a good predictor (i.e., necessary and sufficient) of parameters such as biomass or production. Validation studies of the Incremental Methodology in western trout streams tend to support this assumption (Stalnaker 1979b).

Table 3-1. Determinants of aquatic ecosystem integrity and productivity as viewed by various investigators

Karr and Dudley (1981)	Pennak (1971)	Patten et al. (1979)	Binns and Eiserman (1979)
Water quality	Summer temperature	Temperature	Maximum summer temperature
	Winter temperature	Dissolved oxygen	Bank erosion
	Dissolved oxygen	Sediment load	NO_3-N
	Turbidity	Nutrients	
	Hardness		
	Total dissolved inorganic matter		
	Total dissolved organic matter		
Habitat structure	Width	Depth	Width
	Velocity	Velocity	Velocity
	Substrate	Substrate	Cover
		Stream morphology	
Flow regime	Flow		Annual variation in flow
			Late summer flow
Trophic community		Food supply	Food supply
Structure		Predation	

The IFG describes its index of instream habitat condition as a measure of habitat usability where usability is the product of two environmental variables, habitat suitability and habitat availability (Voos et al. 1981). Habitat suitability is an index that can range from 0.0 to 1.0. It is a multivariate function of an "organism's voluntary or involuntary preference for combinations of environmental attribute values" (Voos et al. 1981). In other words, a suitability coefficient represents the behavioral tolerances of a specific life stage of a target species to a set of environmental parameters. The calculation of WUA using Eq. 2-7 has the effect of equating an area of suboptimal habitat to a smaller area of optimal habitat. This computation implies that a fish or other aquatic organism can make the same use of 100 m^2 of optimal habitat as it can of 1000 m^2 of available but marginal habitat with a suitability of 0.10. The validity of this assumption will be highly species-specific and is largely untested.

In the version of PHABSIM currently available, the calculation of composite habitat suitability, $\hat{S}_i$ in Eq. 2-8, assumes independence among the influences of depth, velocity, and substrate on composite habitat suitability. This imples, for example, that a fish will have the same preference for various combinations of velocities and substrates at a depth of 0.2 m as it will at 2.0 m. Tests of this assumption of independence have shown that in many cases the influence of the physical habitat dimensions are not independent of each other (Orth 1980, Stein et al. 1980, Voos et al. 1981). Multivariate suitability functions incorporating interaction terms between depth and velocity have been developed for brown trout in Colorado and Wyoming streams (Voos et al. 1981; Voos 1981), but much more work remains to be done in developing, testing, and validating habitat suitability models.

Despite what appears to be significant simplifications in the way the Incremental Methodology represents habitat utilization, some success was reported in using WUA to predict fish standing crops.

Stalnaker (1979b) reported a strong correlation between WUA and standing crop of brown trout in Wyoming streams. Orth (1980) also found significant correlations, especially during summer low-flow conditions, between the standing crop of freckled madtom, stonerollers, and orangebelly darters and WUA in a small warmwater stream in Oklahoma. However, the same type of relationship could not be demonstrated with juvenile or adult smallmouth bass in the same stream.

The assumption that WUA is a limiting factor to fish populations may be valid only during very low or very high flow conditions. At other times, when WUA takes on high values, other factors such as water quality or food resources may be more important than physical habitat in controlling population dynamics. The time series of WUA values created by long sequences of flow events are probably more important than instantaneous discrete WUA values in determining actual biological responses.

Finally, habitat indices, such as WUA and NPH (Sect. 2.7), are composite descriptions of the physical environment and can be linked to the design and operation of dams and reservoirs. How aquatic biota respond to changes in habitat (as measured by some habitat index), however, is largely unknown. To develop methods capable of quantifying or predicting biological responses to flow regulation, including rapid fluctuations in flow, more emphasis must be placed on evaluating the influence of stream flow and habitat regimes on aquatic biota.

3.2 Data Requirements

One or more of three types of data may be required in the application of the assessment methods described in Section 2.0, including:

- stream flow records and/or watershed description
- transect data (depth, velocity, substrate and/or cover)
- target species habitat criteria.

Under certain circumstances it will also be necessary to obtain information on the design and operation of the hydroelectric project in question to determine the significance of the instream flow issue (see Sect. 4.2).

3.2.1 Hydrologic Data

At most sites information on historical flows will be among the easiest data to obtain due to the excellent monitoring system of the USGS throughout the country and the "state-of-the-art" of descriptive hydrology. A large amount of data on surface water is available from the USGS through annual publications of state water resources data, other statistical summaries, and two computerized data processing systems, NAWDEX and WATSTORE. The National Water Data Exchange (NAWDEX) provides a comprehensive list of federal, state, local, academic, and private agencies that collect water data as well as a list of the sites at which those data are available. The National Water Data Storage and Retrieval System (WATSTORE) provides access for subscribers to USGS records describing active stream gaging sites and tapes of daily flow values. Other computerized data bases, such as the U.S. Environmental Protection Agency's STORET system, can provide useful information on historical stream flows. Customized statistical summaries of stream flow records are also often available through regional USGS offices at minimal charge. The types of hydrologic data required for some instream flow assessments are often similar to those required for the design of reservoirs and hydroelectric facilities.

The choice of an appropriate statistic for describing the flow regime at a potential hydropower site is very important to instream flow assessment. Because of the skewed nature of stream flow events, the mean discharge is an unreliable measure of central tendency, especially for the purposes of representing the environment of aquatic biota. The median is a better measure of central tendency with frequency estimates and percentile flows being preferable for describing the natural variation in stream flows. However, the procedures used to calculate flow duration curves can also have a significant effect on instream flow analyses and final recommendations.

Flow duration curves exhibit a consistent trend of becoming flatter (more uniform) as the interval over which flow data are collected becomes longer (e.g., Linsley and Franzini 1972; Fig. 3-2). Consequently, if long intervals are used (e.g., flow duration calculated on mean annual flows), relatively less variation in flow conditions will be obvious and higher instream flow recommendations may result. Flow duration curves used for instream flow recommendations should be based on stream flow data derived over monthly or shorter intervals to represent the type of environmental variation to which fish populations respond and are adapted. In highly regulated streams, daily or even hourly records may be necessary to construct an accurate representation of flow variations. The size of the upstream watershed, which strongly influences flow variability (i.e., large basins have more stable flow patterns, so longer averages may be acceptable), is also important in selecting an appropriate time interval.

Variability in stream flow occurs naturally both between and within annual cycles. The seasonal variation at a project site can be accounted for by separating instream flow recommendations into seasonal intervals. This approach leads to a regimen of instream flow recommendations that will protect complete life cycles of aquatic biota (see Sect. 4.1, item 3).

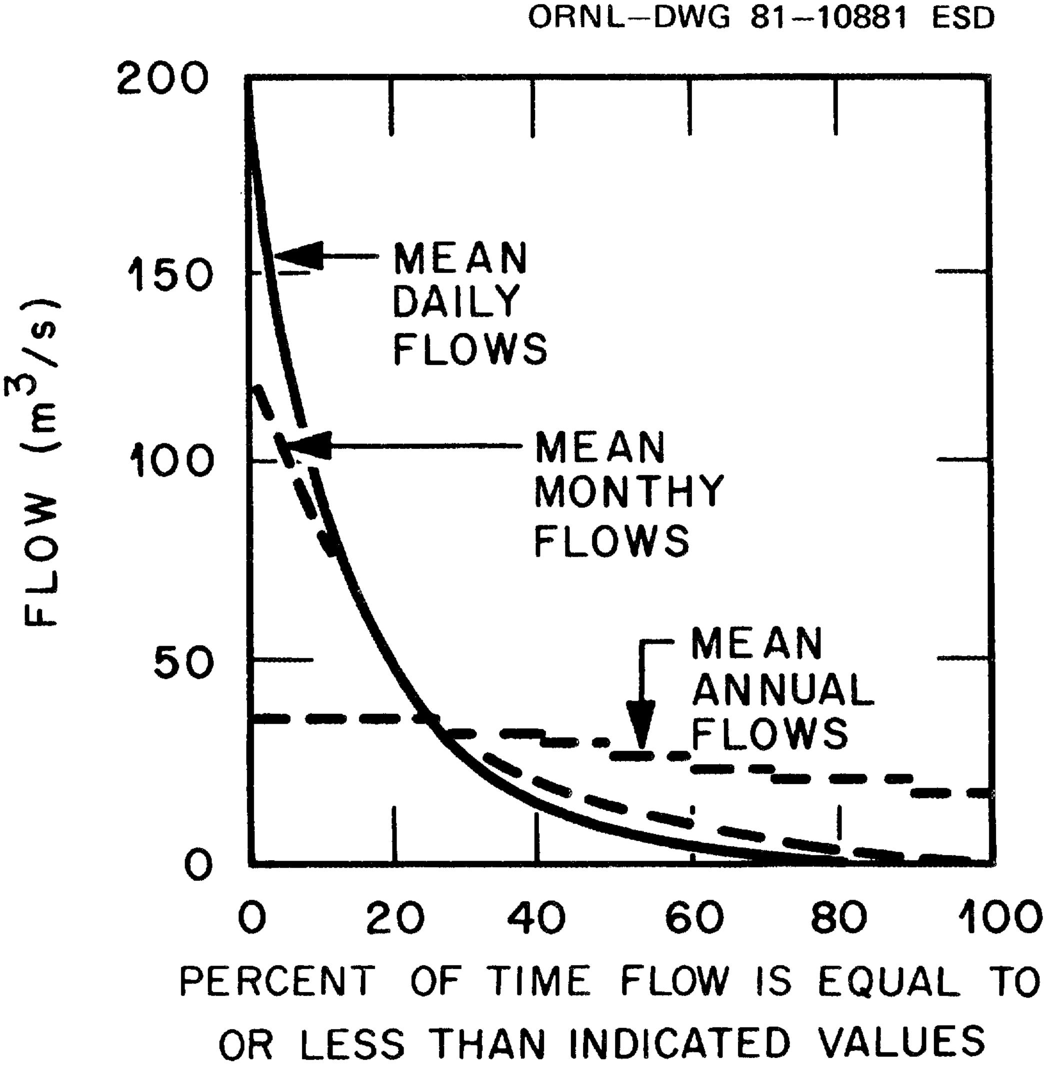

Fig. 3-2. Flow-duration curves calculated on different flow statistics for Cherry Creek near Hetch Hetchy, California, 1941-1950 (Redrawn from Linsley and Franzini 1972, with permission from McGraw-Hill, Inc.).

3.2.2 Transect Data

With the exception of the discharge approaches, all assessment methods will require some level of field survey work. This site-specific description of the physical stream environment can range from a single site visit in which a critical transect is identified and a transverse depth/velocity profile is taken (i.e., R-2 Cross or some other stage-discharge rating method) to multiple site visits involving detailed field surveying and discharge measurements at many transects. The manpower costs of these different levels of effort may differ by an order of magnitude or more (see Sect. 3.3.3). The skills and expertise of the personnel involved in collecting these data will also have to match or exceed the requirements of the particular method.

Assessment methods requiring the most intensive field surveys are those which develop two-dimensional maps of the streambed (i.e., WSP applications, preferred area methods, and PHABSIM). The data elements which must be collected prior to applying these methods are (1) location and elevation of headstakes marking the ends of each transect, (2) elevations and distances separating each set of headstakes, (3) water surface elevation at each transect throughout the reach (assuming steady flow), (4) cross-sectional profile of bed elevation across each transect, including the bank out of the water, (5) discharge measurement at each transect, and (6) bottom substrate and/or cover characterization across each transect (Bovee and Milhous 1978). The use of PHABSIM with the IFG-4 method of hydraulic simulation de-emphasizes the need to link transects and headstakes together but requires discharge measurements at two or more flow conditions (Sect. 2.8). A relatively high proficiency with surveying techniques is required to establish elevations and headstake locations within the necessary accuracy (±0.3 cm for headstakes and water surface elevations; ±3 cm for bed cross-sections). Results from a comparative study of instream flow methods in 12 western states indicate that acceptable proficiency of field crews was obtained after two or three applications of PHABSIM (R. Giger, personal communication).

Procedures for discharge measurements have been well established by USGS and other federal agencies responsible for water resources management (Buchanan and Somers 1968, Bovee and Milhous 1978). A set of depth and velocity measurements are taken at intervals across a transect, and discharge is calculated as

$$Q = \sum_{i=1}^{n} q_i = \sum_{i=1}^{n} (v_i \cdot w_i \cdot d_i), \qquad (3\text{-}3)$$

where Q = total discharge through the cross section,

q_i = discharge through a partial section of the cross section,

v_i = mean water column velocity in the i^{th} section,

w_i = width of the i^{th} section,

d_i = depth of the i^{th} section, and

n = total number of subsections in the cross section.

Standard procedures have been established by the USGS determination of the maximum size of subsections, calculation of v_i, and care and use of current meters. For accurate discharge measurements, for example, the guideline of $q_i \leq 0.05 * Q$ for all i should be followed.

3.2.3 Habitat Criteria

The development of habitat criteria, usually in the form of suitability functions for depth, velocity, substrate, and cover, are associated primarily with high resolution methods such as the Incremental Methodology. This information is readily available for western, coldwater species (Giger 1973, Bovee 1978). With the increasing emphasis on instream flow needs in the eastern United States, habitat preference data are beginning to become available for more warmwater species (Herricks and Klopke 1980, Orth 1980, Stein et al. 1980, Sheppard and Johnson 1981). Although standardized procedures have been developed for collection of field data and calculation of habitat suitability functions (Bovee and Cochnauer 1977, Voos et al. 1981), this work can be extremely time-consuming. When habitat suitability criteria are not available for indigenous fish species at a site, acceptable results might be obtained from PHABSIM by modifying curves developed in other watersheds (e.g., Hilgert 1981). However, considerable caution should be exercised whenever curves that have been developed in the West are modified and applied to other areas of the country, particularly the Northeast, Middle Atlantic, and Southeast regions.

3.3 Costs of Application

The actual dollar costs of applying any particular assessment method will be influenced by such project-specific factors as travel costs, experience and proficiency of personnel, and the availability of baseline data. However, certain generalities can be made regarding the relative costs of the various methods available for instream flow assessment. These costs will vary as a function of the specific requirements for office work, field data collection, and any computer analysis or other data processing costs with each method. Finally, selection of an appropriate method will depend, in part, on the target species (and life stages) of interest (Sect. 4.2.2), and some cost may be incurred in obtaining the "baseline" biological information needed to determine the target species and life stages present and their seasonal occurrence. The cost of obtaining this information, which is a key element in the initial stages of any assessment, regardless of the method that is ultimately chosen, is not included in the analysis that follows. In many cases, however, selection of target species and life stages might not require new site-specific data but rather would be based on existing data and/or on the expertise of local/regional fisheries biologists.

3.3.1 Discharge Approaches

Methods based on the examination of flow records (Sects. 2.1, 2.2., 2.3) are the least expensive to use because the analyses can be conducted without a site visit. For example, the Montana Method requires only that the mean annual flow at a project site be calculated and a fixed percentage of that statistic set as the instream flow recommendation (Sect. 2.1). These types of assessment methods will usually require less than one man-day (Wesche and Rechard 1980; R. Giger, personal communication).

Some variation in time requirements may result if flow duration calculations are required or if site visits are made to obtain photographs and other reconnaissance data to support the flow recommendation. Although it is recommended that some cursory field data be collected to substantiate instream flow requirements (Tennant 1976), the need for a site visit would eliminate some of the cost advantage of these methods. Requests to USGS for customized data analysis may cause some time delay but only minor dollar costs. In most cases, flow duration curves will have been developed as part of the design of a hydroelectric facility (e.g., Dixon 1979). Other complications in calculating an appropriate flow statistic may arise on regulated or ungaged watersheds. Techniques for handling these probelms are available and are not excessively complex (Emmert and Heitz 1979).

3.3.2 Single-Transect, Hydraulic Rating Approaches

Methods that are based on single-transect data and that develop some type of hydraulic rating curve (e.g., depth vs discharge, or wetted perimeter vs discharge) are intermediate in cost. The analysis of historical flow records is replaced by site visits, some type of stream survey, and simplified analytical calculations. Although computer software, such as IFG-1, has been developed to aid in data analysis, hand calculators with programming capabilities and graph paper are usually sufficient for these types of methods.

Estimates of manpower requirements for single-transect methods are one to four man-days in the field, depending on the number of flows observed, and less than one to three man-days in the office (Wesche and Rechard 1980; R. Giger, personal communication). Travel time, which is not included in this estimate, can be more significant than the time actually spent in applying the method. Also, the ability to physically control stream flow (e.g., below existing dams) will reduce application time drastically. The past experience of personnel is a major factor in both the time requirements and the success of this approach as well as the next.

3.3.3 Habitat Modeling Approaches

As previously mentioned, application of multiple-transect methods with complete habitat rating is by far the most expensive approach for assessing instream flow needs. In general, it can be expected that an application of the Incremental Methodolgy will involve at least an order of magnitude more in terms of manpower requirements compared to the single-transect hydraulic rating approaches (Table 3-2). These cost estimates will again be highly variable depending on the project specifications and assessment needs (R. Giger, personal communication). Instream flow assessments of small slow-moving streams which are wadable and which approach uniform flow conditions will be among the easiest and least expensive.

The construction of suitability curves for target fish species may also be a major expense (Sect. 2.8). Development and testing of multivariate habitat suitability models is not within the scope of most environmental assessment work conducted at small-scale hydroelectric projects. Therefore, it is expected that application of the Incremental Methodology at these projects would have to rely on existing habitat suitability data that have been modified to represent local conditions, as necessary (see Hilgert 1981 for an example of modifying existing suitability curves; also Sect. 3.2.3).

Table 3-2. Approximate manpower requirements (man-days) for application of the Incremental Methodology, excluding travel costs. Field crews are assumed to have some experience. Requirements are for one representative reach consisting of eight transects (K. Bovee, personal communication).

Study phase	Wadable streams[a]	Large rivers[b]
Presurvey planning	0.5-1	1-2
Field survey[c]		
WSP data (1 flow)	6	12
IFG-4 data (3 flows)	15	30
Data preparation		
Organization of field notes	1	1
Computer input	0.5	0.5
Hydraulic model calibration		
WSP simulation	2	2
IFG-4 simulation	<1	<1
Habitat modeling		
Construction of suitability curves[d]	0.5-2	0.5-2
HABTAT execution	<1	<1
Flow recommendation	1	1
Range for total study	10-25	20-40

[a] Optimal field crew size is 2 to 3 people.

[b] Optimal field crew size is 3 to 4 people.

[c] Surveying requirements increase by 50% if high precision is required or if cover is included as an element of physical habitat. WSP assumes only one set of transect data while IFG-4 requires data sets from three different discharges. WSP modeling may require more data sets to cover the entire range of flow conditions.

[d] Minor modification of existing curves and/or consultation with fisheries experts. Creation of completely new suitability data can easily double study costs because of the extensive field work required.

Data processing costs associated with these habitat modeling approaches need not be excessive but do require some expertise in computer programming. Also, past experience has shown that some minimal level of proficiency in the use of PHABSIM is necessary to obtain good results (R. Giger, personal communication). For a five-transect reach with 20 cells per transect and six extrapolated flows, Wegner (1980) estimates that computing charges on the Colorado State University CYBER computer would average $5.00 for IFG-4 hydraulic simulations, $7.00 for WSP hydraulic simulations, and less than $10.00 for a single-species HABITAT (IFG-3) run for five life stages. Access to the PHABSIM software is available commercially through the Boeing EKS-1 commercial computing system in more than 170 cities in the United States (Wegner 1980). Many government agencies can obtain access to PHABSIM through the computer system operated by the Water and Power Resources Service at Colorado State University. At the present time, this software is compatible only with Control Data Corporation NOS operating systems.

3.4 Decision-Making Capabilities

As referred to in this section, decision-making capabilities refer to the manner in which the data obtained from the application of a paticular method are used to generate a final recommendation for instream flow regimes. Unfortunately, this capability is one of the most important, and most frequently neglected, aspects of the assessment of instream flow needs. For example, the only reference in the accessible literature that approaches an explicit set of directions for using the Incremental Methodology output to generate instream flow recommendations is a short example by Stalnaker (1979b). Reasons for this lack of guidance may include (1) unsettled legal status of instream water uses throughout the United States, (2) reluctance of water managers to fully integrate environmental quality into multiobjective water resource planning, and/or (3) hesitancy of biologists to depend on tentative assumptions that may require further investigation.

With the possible exception of the discharge approaches, all the methods develop some type of response relationship between a descriptive parameter of habitat condition and stream flow. With the Incremental Methodology, this habitat-response information is complicated by the need to consider multiple time periods and multiple target species and their life stages. Without some set of standardized information-processing procedures, it is very easy to reach a point at which the output becomes overwhelming and even obscures any final recommendation. Furthermore, an assessment method should be considered incomplete without these integrating procedures (Sale 1980).

Some of the techniques available for selecting minimum discharge points from habitat-response curves are clearly better than others. The "inflection point" techniques used with the R-2 Cross, WSP, and usable width methods are ill-defined and can lead to ambiguous analyses. The shape of a wetted perimeter vs discharge response curve and the presence of an inflection point is dependent upon the cross-sectional configuration of the stream channel (Fig. 3-3). Examination of these curves and the "inflection points" chosen to generate an instream flow recommendation often leaves an objective reviewer baffled by the criterion that was used (e.g., Nelson 1980, Prewitt and Carlson 1979, Pruitt and Nadeau 1978). Use of this technique can create rather than alleviate controversy over water allocation needs.

Habitat-retention criteria are much less ambiguous than inflection-point calculations and are preferable because the value judgments are clear and relatively more defensible. If methods that base habitat retention calculations on some reference stream flow are used, then justification should be provided concerning the significance of that datum point. Final recommendations will also have to be defensible from the point of view of why a specific

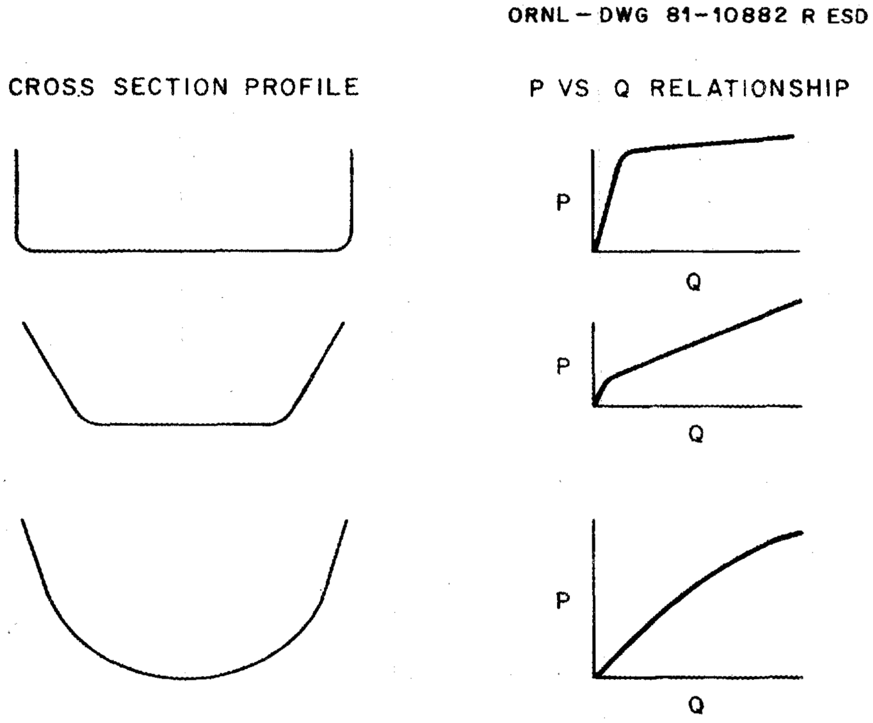

Fig. 3-3. Relationship between channel cross-sectional profile and the shape of the wetted perimeter (P) vs discharge (Q) curve (from Bovee and Milhous 1978).

percentage of the reference habitat condition is desirable. Given the present understanding of aquatic ecosystem dynamics, these habitat-retention criteria will usually have to be based on the subjective impressions of fisheries biologists.

In addition to their use in setting absolute minimum thresholds, habitat-discharge response curves can be used as value functions in either a formal or informal optimization procedure. The negotiation framework most commonly encountered in water allocation conflicts would be an example of an informal optimization procedure (Wassenberg et al. 1979, Lamb and Sweetman 1979, White et al. 1980). The IFG has a great deal of practical experience regarding the type of negotiations involved in obtaining instream flow allocations from federal water projects.

Formal optimization to obtain instream flow allocations refers to the application of water resource systems analysis models with the habitat-response functions (WUA vs discharge) used either as objectives or constraints. Optimization models have already been applied to the design and operation of water projects for the purposes of improving water yield, power generation, flood protection, and economic efficiency. Linear programming and dynamic programming models are highly efficient in analyzing the tradeoffs involved with water allocation issues. Sale (1980) demonstrated how the habitat-response curves could be utilized as objective functions in a nonlinear programming model to improve the performance of a multipurpose reservoir in central Illinois. This type of modeling approach, combined with multiobjective optimization techniques and further research, can be very useful in finding operating rules which protect instream values affected by water development systems, including hydroelectric facilities. Initiatives in these areas are currently being pursued both at ORNL and by the IFG.

4. CONCLUSIONS AND RECOMMENDATIONS

The need for water to generate electricity often conflicts with other instream flow needs, such as recreation, aesthetics, water quality, and fish and wildlife habitat. With the recent emphasis on the development of small hydropower resources, these conflicts may intensify. Resolution of the problem will likely focus on tradeoffs between water needed for hydroelectric generation and water required for the protection of fisheries. Although many methods have been developed in the West over the past 10 to 15 years to assess instream flow needs related to fishery resources, very little is known about their applicability to watersheds with different hydrologic characteristics. Our examination of the instream flow issue has been directed toward a review (Sect. 2.0) and evaluation (Sect. 3.0) of these existing methods. The results of this analysis have led to (1) several general conclusions regarding the instream flow issue (Sect. 4.1) and (2) a proposed strategy to assist developers of small-scale hydroelectric projects in assessing the issue at a given site (Sect. 4.2).

4.1 General Conclusions

1. The potential for conflict between water needed for hydroelectric generation and that required for other instream uses, especially maintenance of fish and wildlife habitat, _must_ be assessed in the initial stages of project planning and development (i.e., in the feasibility study). Consultation with personnel in the appropriate local, state, and federal agencies or organizations is an important component in this assessment.

2. Using the methods currently available, it is difficult, if not impossible, to generate an absolute threshold for instream releases needed to protect instream resources. That is, all the methods have an element of subjectivity. Professional judgment must be exercised in formulating the actual recommendation (Sect. 3.4). The methods should be viewed as tools that assist in or provide a basis for decision-making.

3. The instream flow recommendation should be based on an annual discharge regime. Differences between seasons of the year are considered by varying the recommendation through the year. The variability in discharge between years, on the other hand, can be taken into account by establishing recommendations based on normal and dry years. In short, use of a single minimum flow value (the threshold concept) to represent the instream flow recommendation is not advisable because (1) the minimum flow becomes the average condition as additional water is appropriated out-of-stream (Stalnaker 1979a, b) and (2) the assumption that only flows below the minimum will be detrimental is often not valid (U.S. Fish and Wildlife Service 1979). Thus, the 7Q10 statistic should not be recommended as the single minimum flow needed to protect fish and wildlife habitat (Sect. 3.1.1).

4.2 Guidelines for Assessing Instream Flow Needs Related to Fishery Resources at Small-Scale Hydropower Sites

Based on the review and evaluation of existing instream flow assessment methods presented in Sections 2.0 and 3.0, respectively, a strategy was developed for addressing instream flow issues at small hydropower sites. The strategy represents a hierarchical approach and is delineated in this section of the report by both explanation and example. The hierarchy consists of four classes of methods (or levels of analysis) that differ in the degree of resolution provided (Sect. 4.2.1). Consequently, selection of the most appropriate method is dependent upon the level of resolution required. Criteria are proposed to assist developers in this determination (Sect. 4.2.2). Finally, implementation of the hierarchical approach is examined by providing examples to illustrate the association between selected criteria and a given level of analysis (Sect. 4.2.3).

A similar analytical approach to that proposed for assessing instream flow needs was recommended by Cairns (1980) to assess the risk associated with chemical pollutants. In the latter case, sequential tests (e.g., LC_{50} determinations, chronic toxicity tests, life cycle studies, etc.) are performed in screening chemicals to evaluate their potential hazard in the environment. These tests are arranged into tiers for the purpose of progressively narrowing the confidence intervals around the concentration or exposure level associated with "no adverse biological effects." Unlike the field of water quality assessment where biological thresholds are often explicitly identified, water quantity or stream flow assessments are based on thresholds that have been implicitly identified; i.e., the existence of such a biological threshold associated with stream flow is implied whenever an assessment of instream flow needs is performed. Nevertheless, the basic approach in evaluating both water quality and quantity issues is similar and can be based on a hierarchical scheme that provides greater resolution at the higher tiers or levels of investigation. Such an analytical approach was also proposed for evaluating watershed processes, sedimentation, and water quality as part of the overall IFG Incremental Methodology (Mar et al. 1979, Simons et al. 1979).

4.2.1 Levels of Analysis

The hierarchical approach proposed for evaluating instream flow needs at small-scale hydropower sites includes four levels of analysis which differ in (1) data needs, (2) cost, and (3) level of resolution associated with instream flow recommendations (Fig. 4-1).

The first level (Level I) usually requires no site-specific field work (but see Sect. 3.3), only an evaluation of stream flow statistics. Because existing data are used, costs are very low. On the other hand, a relatively large possibility for error exists in the selection of the instream flow requirement (in either direction from the "optimum"), because site-specific factors related to habitat requirements are either ignored or considered only in very general terms. Level I-type analyses were used for reconnaissance purposes to assess instream flow needs at both the national (Bayha 1978) and regional levels (Washington State Department of Ecology 1979; U.S. Fish and Wildlife Service 1981). Flow duration analysis coupled with instream flow recommendations that are based on seasonal percentile flows is the preferred method at this level.

The next level of analysis requires a relatively modest amount of field work (transect surveying) at the proposed hydropower site. Consequently, costs are somewhat greater than for Level I, but the resolution is higher. A hydraulic rating method, such as R-2 Cross, IFG-1, or IFG-4 with only one transect and no habitat suitability (HABTAT) analyses, is the appropriate choice at this level. The dependent variable (plotted as a function of stream flow) would be a hydraulic parameter such as maximum depth or wetted perimeter. Although the level of resolution is higher than Level I, the instream flow recommendations produced at this level of analysis would not, in most cases, be based on a detailed knowledge of the habitat requirements of any species. Instead, Level II recommendations would be directed at preserving general hydraulic conditions in ecologically significant areas affected by flow regulation.

ORNL-WS 15911 R

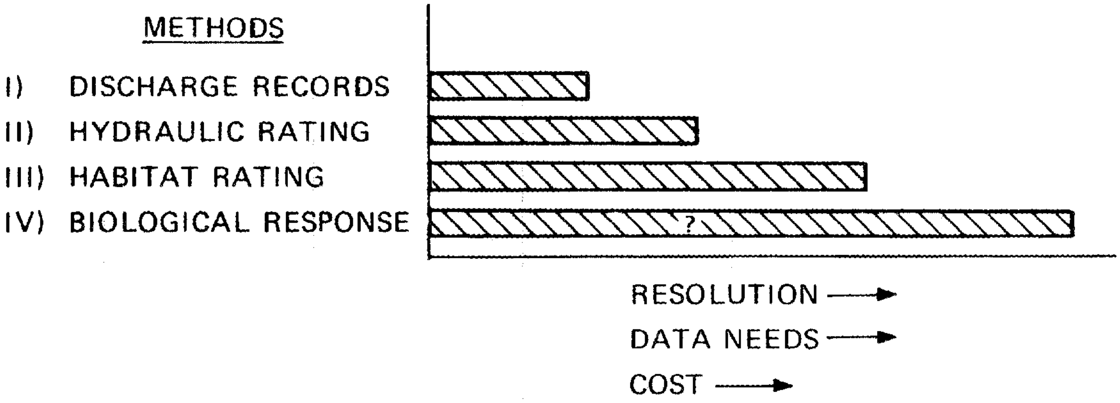

Fig. 4-1. Four levels of analysis for assessing instream flow needs at small-scale hydroelectric sites. Existing methods fall into a hierarchical arrangement with progressively greater resolution, data needs, and costs.

The third level of analysis requires habitat evaluations that are based on species-specific requirements (habitat suitability curves), representative reach mapping using multiple transects, and the development of habitat vs discharge response curves. The greater data needs associated with Level III analyses will significantly increase the cost compared with Levels I and II. Costs for Level III analyses can vary considerably, depending on (1) size and discharge characteristics of stream and river and (2) need for site-specific data to develop/modify habitat suitability curves (see Sect. 3.2).

The fourth level of analysis, which is currently in the research-and-development stage, would employ ecological modeling techniques to investigate and predict biological responses to flow regulation. Responses could be evaluated at any one of several levels of organization (e.g., survivorship or fecundity of individuals, production of a given species, alterations in fish community structure, changes in ecosystem structure and function). Efforts to develop a fish population model that includes parameters such as WUA (Sect. 2.8) were recently initiated by the Susquehanna River Basin Commission (Williams 1980). Patten et al. (1979) recommended that the Incremental Methodology include several parameters, in addition to the existing physical variables (e.g., v, d, s), that reflect chemical and biological processes of ecosystems, noting that the existence and status of fisheries is related to the status of stream ecosystems. Recognizing the present "state-of-the-art" in understanding and modeling stream ecosystems, and given the complexity and cost of modeling biological responses in general, Level IV analyses would be beyond the scope of the type of environmental assessment usually associated with small-scale hydroelectric projects. Until the tools needed to quantify/predict these responses can be developed, a Level III analysis provides the greatest level of resolution for identifying the instream flow needs of aquatic biota. Modeling coupled with the appropriate field experiments could, nevertheless, provide valuable insights to the biological consequences of flow regulation.

4.2.2 Criteria for Selecting Among Levels

Although numerous methods currently exist for assessing instream flow needs related to fishery resources, there is no general consensus regarding their applicability among watersheds with different physical and hydrologic characteristics. In spite of the comparative studies conducted by the U.S. Fish and Wildlife Service (R. Giger, personal communication), not enough experience has been obtained in evaluating several methods on the same stream at the same time. Consequently, our initial attempt to rigorously define limits on the applicability of the methods presented in Section 2.0 was unsuccessful. However, the methods can be categorized into three major groups according to the level of resolution associated with their instream flow recommendations. Given the "state-of-the-art" of the methods at each level of analysis (e.g., most have not been applied in the East where water quality problems are likely to be more significant than in the West), it is very difficult to specify exactly what level of resolution is associated with each of the methods discussed in Sections 2.0 and 3.0. Thus, we chose to identify several groups of methods that differ in the level of resolution provided. From this hierarchy, guidelines in the form of criteria can be established for determining the level of resolution required at a given site or project.

Instead of providing an exhaustive list of criteria that includes economic, institutional, and environmental factors, we focused on the nature and magnitude of the potential environmental impacts associated with changes in the existing hydrologic regime at small-scale hydroelectric sites. The degree of impact is influenced by the design and operation of the facility (the causative agent) and the nature of the ecological resources in the stream or river (the affected agent). Thus, the level of analysis (or the degree of precision associated with the estimate of instream flow needs) that is selected is a policy decision that should be based on an evaluation of several factors (criteria) that are the primary determinants of the nature and magnitude of the environmental impacts.

The design of small-scale hydroelectric facilities can affect stream flow if the powerhouse is not located at the dam. The use of long penstocks or canals to gain additional head can result in periods of very low or no flow in that reach of the stream between the dam and the confluence of the tailrace with the river (Sect. 1.3). The flow regime can be further altered if the facility is operated in a peaking mode. Projects operated strictly in a run-of-river mode, on the other hand, would not alter the flow regime downstream of the project because no change in reservoir storage would occur. Thus, the potential impacts on downstream aquatic ecosystems could range from negligible for run-of-river projects without canals or penstocks to potentially significant in the case of peaking facilities that are designed with long headraces.

In assessing the potential impacts of small-scale hydroelectric projects on instream uses (e.g., fish and wildlife habitat), the ecological characteristics of the stream or river must also be considered. Some of the most important aquatic resources are threatened or endangered species, or their critical habitat, and anadromous fish species which provide important commercial and sport fisheries (e.g., Pacific salmon in the Northwest) or are the focus of restoration programs (e.g., Atlantic salmon and American shad in the Northeast). Other migratory species, such as walleye or white bass, often utilize the tailwaters below dams and provide important recreational fisheries. The selection of target species should also include evaluation of their temporal (life-cycle) requirements; i.e., critical life stages should be considered. To identify the significant aquatic resources, which in some cases may be an entire stream or watershed rather than a particular fishery or species population, personnel in the appropriate local, state, and/or federal agencies and organizations should be consulted during the early stages of project planning and development.

4.2.3 Applications

To illustrate the application of the hierarchical approach in assessing instream flow needs at small hydropower sites, two case studies (Levels II and III) are described. While no specific examples of a Level I application are presented, this type of analysis has been used in various reconnaissance-type surveys (Sect. 4.2.1). This level of analysis can also be used to quickly evaluate the potential for conflict at a given site during the early stages of project planning, especially if the project is to be operated in a peaking mode. In these cases, a developer may not wish to conduct a detailed Level II or III assessment because of time constraints. Thus, a very cursory, early evaluation of the potential for conflict may be obtained by using a simple Level I-type analysis; a more detailed assessment would be conducted at a later stage (e.g., feasibility study). Finally, no examples of a Level IV application are available, although such an approach was recently initiated to assess instream flow needs in the Susquehanna River basin (Williams 1980).

Case 1: Level II analysis*

The Mystic Lake power project (FERC No. 2301) is an existing facility located on West Rosebud Creek in southcentral Montana. The project consists of a high-elevation storage reservoir (Mystic Lake) and a powerhouse located 3.2 km below the dam. The reach between the dam and powerhouse is a high gradient (difference in elevation between the reservoir and powerhouse is 343 m), coldwater stream with a drainage area of 135 km^2. Mean daily flow for the period of record is 0.96 m^3/s and ranges from 5.97 m^3/s in June during snowmelt runoff to 0.08 m^3/s in the winter (January through April). Excess spillage over Mystic Dam normally occurs over a seven-week period in midsummer. Rainbow trout (*Salmo gairdneri*) and brown trout (*S. trutta*) spawn in

---

*Source of information: Montana Power Company (1979).

the 3.2-km reach, although the latter species is confined to a 500-m section just above the powerhouse. The recreational fishery in this reach is insignificant.

An instream flow study was conducted to determine the minimum releases required on West Rosebud Creek between the dam and powerhouse to "protect and enhance the fishery resource of the creek." The Oregon Method (Thompson 1972), or the Usable Width method as described in Section 2.6, was used to assess the flow requirements for fish passage at critical transects (those located in broad shallow reaches that were judged to be critical to the passage of large fish). The assumption was made that flows sufficient for fish passage would also satisfy other requirements (i.e., spawning, incubation, and rearing). Measurements of depth, velocity, and width were recorded on five occasions along each of three transects located in two general regions of the 3.2-km reach. The minimum flow for fish passage was defined as that flow which met the minimum depth criterion of 0.12 m on at least 25% of the total width and on a continuous portion equal to 10% of the total width. Total width was defined as the stream width corresponding to the mean daily flow.

Additional studies were also undertaken as part of the overall assessment of instream flow needs in West Rosebud Creek. The relationship between $s^{\frac{1}{2}}/n$ and cross-sectional area was examined by correlation analysis for each of the six transects. Manning's equation was then used to generate plots of Q vs width and to extrapolate to unobserved flows (e.g., wet width at the mean daily flow). The fisheries study conducted as part of the instream flow study included (1) estimates of standing crop in three stream reaches, (2) length-frequency analysis, (3) computation of length-weight relationships, and (4) evaluation of condition factors. Finally, it should be noted that the study was conducted with the cooperation of the Montana Department of Fish, Wildlife, and Parks and the U.S. Fish and Wildlife Service. Both agencies were requested to review the proposed study and were kept informed of the progress.

Case 2: Level III analysis*

The proposed Terror Lake hydroelectric project (FERC No. 2743) includes a 20-MW baseload facility that would be located in the northeastern portion of Kodiak Island, Alaska. The project would require the inundation of Terror Lake, a 109-ha natural lake, to create a 344-ha impoundment. Up to 90% of the discharge from Terror Lake would be diverted through a 9-km-long power tunnel/penstock to a powerhouse located in the Kizhuyak River basin about 5 km upstream from the head of Kizhuyak Bay. Diversion dams would also be constructed on four small tributary streams and the flow diverted to the power tunnel.

Pre-project mean monthly flows in the Kizhuyak River range from 0.68 m^3/s in March to 15.72 m^3/s in June; similar variability in flow exists in the Terror River at the lake outlet. During an average water year, operation of the project would reduce the mean annual discharge near the mouth of Terror River by about 35% and would increase the mean annual discharge of the Kizhuyak River at a point 2.5 km below the powerhouse by approximately 69%. Because of the diversion dams, flows in the river above the powerhouse would be reduced by about 41%.

The project will also significantly alter seasonal stream flow patterns. Although flows below Terror Lake would not be modified from December through April, flows during the remainer of the year would be significantly reduced. Peak flows during June and July, for example, would decrease by approximately 46%. The post-project flow in the Kizhuyak River below the powerhouse would be approximately 5.66 m^3/s from November through April, compared to existing flows of 0 to 3.00 m^3/s.

The primary fishery resources in both the lower Terror and Kizhuyak Rivers are pink and chum salmon (Oncorhynchus gorbuscha and

---

*Source of information: Federal Energy Regulation Commission (1981); Wilson et al. (1981).

O. keta, respectively). Both species contribute to an important commercial fishery and constitute a significant seasonal food resource of the Kodiak brown bear. These species enter the rivers in early July and spawn through August and early September. The primary spawning habitat exists in the lower (2.5-km) reaches of the mainstem and adjacent channels of both rivers, although the runs in the Kizhuyak River are smaller. The outmigration of fry occurs during April and May, soon after emergence. Other less abundant species that inhabit the two rivers include coho salmon (O. kisutch) and Dolly Varden (Salvelinus malma) which spawn from late summer through early fall. No fish occur in Terror Lake or the tributary streams where diversion dams will be constructed due to their precipitous nature.

The implications of the changes in post-project stream flows on fish habitat in the Terror and Kizhuyak Rivers were evaluated using the Incremental Methodology. Four reaches in each river were studied intensively using the IFG-4 (6 reaches) and the IFG-2 (2 reaches) hydraulic simulation models. Important life stages and target species included spawning (pink, chum, coho, Dolly Varden), fry (coho and Dolly Varden), and juveniles (coho and Dolly Varden). Interim suitability curves were initially developed based on discussions with state and federal fisheries biologists and a search of the relevant literature (from Alaska only). Important habitat parameters included depth, velocity, and substrate for spawning and depth and velocity for rearing (fry and juveniles). Suitability curves for temperature were not developed because the project would not significantly alter the thermal regimes of the rivers. Similarly, cover surveys indicated that adequate cover was available throughout the watersheds. Final site-specific suitability curves were developed later on the basis that the nature of the available habitat and the microhabitat preferences of a species in a particular river could vary significantly within the region.

To evaluate the effects of the proposed project on salmonid resources, the percent reduction in WUA from the optimum discharge (defined as that discharge which optimizes WUA for more than one species and more than one life stage concurrently) was examined for average and 1-in-10 low water years under pre- and post-project conditions. In the primary spawning area of the lower Terror River, post-project 1-in-10 low water year conditions would result in a 10 to 15% reduction in optimal WUA during late summer. Instream releases of 4.25 m^3/s, if required, would conserve approximately 95% of optimal WUA for spawning. The decrease in flow in the upper Kizhuyak River (above the powerhouse), where the gradient is steep and the substrate large, would result in an 18% increase in spawning WUA during an average water year and no change during a 1-in-10 low water year. A small decrease in WUA (1-2%) would occur in that portion of the river below the powerhouse. The higher post-project discharges in both the lower Kizhuyak and Terror Rivers during the normally low-flow period in winter could enhance the survival of salmon eggs and fry.

In both of the above examples, the level of analysis is commensurate with the degree of impact associated with alterations in the natural flow regime. Often the choice will be obvious; the presence of threatened or endangered species near the site dictates that the error bounds on the instream flow recommendation be as small as possible, so a Level III analysis would be required. However, this level of analysis is not required in every case involving potential conflicts over water use. Other approaches (e.g., R-2 Cross, Usable Width) that usually require considerably less time and money may be appropriate. The criteria presented in Section 4.2.2 should assist developers (or other users) in determining the required level of analysis. The importance of consultation with the appropriate local, state, and/or federal fishery agencies or groups during the initial stages of project planning when the instream flow issue is first addressed cannot be emphasized enough.

4.3 Planning for Instream Flow Assessments

As noted previously, instream flow needs must be assessed in the early stages of project development. Because stream flow characteristics are used in evaluating the size of the turbine(s) to be installed, any restrictions on the flow available for generation, such as that required to meet the instream needs of fisheries, must be identified prior to ordering the generating equipment. Consequently, the issue of instream flow is most appropriately addressed in the feasibility study. This initial assessment should be conducted in consultation with those state and/or federal agencies that have responsibility for establishing instream flow requirements. Failure to consult in the very early stages of project development will only result in costly delays later. The approach recommended in Section 4.2 is designed to provide the guidance necessary to assess instream flow needs during these early stages. If conflicts between hydropower generation and other instream uses are identified, sufficient time should still be available for resolving the conflicts before a license or exemption application is submitted to the Federal Energy Regulatory Commission. Resolution will likely involve tradeoffs among the various users which, in most cases, will involve negotiations between hydropower developers and fishery managers. For recent information on this aspect of the instream flow issue, see Knapp (1980), Sweetman (1980), and White et al. (1980).

5. LITERATURE CITED

Andrews, W. H., and G. E. Madsen. 1976. Assessment of recreation and aesthetic stream flow methodologies. pp. 364-378. In J. F. Orsborn and C. H. Allman (eds.), Instream Flow Needs, Vol. I. American Fisheries Society, Bethesda, Maryland. 551 pp.

Andrews, W. H., M. B. Masteller, D. E. Massey, R. J. Burdge, and G. E. Madsen. 1976. Measuring the impact of changing streamflow on recreation activity. pp. 148-166. In C. B. Stalnaker and J. L. Arnette (eds.), Methodologies for the Determination of Stream Resource Flow Requirements: An Assessment. FWS/OBS-76/03. Utah State University, Logan, Utah. 199 pp.

Anonymous. 1974. Instream needs subgroup report, Work Group C: Water. Northern Great Plains Resource Program. U.S. Fish and Wildlife Service, Billings, Montana. Unpubl. manuscript. 35 pp.

Bain, W. 1980. Instream flow experiences: Studies/needs. Panel discussion at the 2nd Annual Instream Flow Seminar/Workshop sponsored by the Ohio River Basin Commission, Ft. Mitchell, Kentucky. North Carolina Department of Natural Resources and Community Development, Raleigh, North Carolina.

Bartschi, D. K. 1976. A habitat-discharge method of determining instream flows for aquatic habitat. pp. 285-294. In J. F. Orsborn and C. H. Allman (eds.), Instream Flow Needs, Vol. II. American Fisheries Society, Bethesda, Maryland. 657 pp.

Bayha, K. 1978. Instream flow methodologies for regional and national assessments. Instream Flow Information Paper No. 7. FWS/OBS-78/61. Cooperative Instream Flow Service Group, U.S. Fish and Wildlife Service, Ft. Collins, Colorado. 98 pp.

Bayha, K., and T. Hardin. 1980. Impacts of coal technologies' water requirements on instream flow uses for fisheries of the Ohio River Basin. Cooperative Instream Flow Service Group, U.S. Fish and Wildlife Service, Ft. Collins, Colorado. Unpubl. report. 156 pp.

Beckett, G., U. S. Fish and Wildlife Service, Concord, New Hampshire, personal communication to M. J. Sale, March 1981.

Binns, N. A., and F. M. Eiserman. 1979. Quantification of fluvial trout habitat in Wyoming. Trans. Am. Fish. Soc. 108(3):215-228.

Bovee, K. D., and T. Cochnauer. 1977. Development and evaluation of weighted criteria, probability-of-use curves for instream flow assessments: Fisheries. Instream Flow Information Paper No. 3. FWS/OBS-77/63. Cooperative Instream Flow Service Group, U.S. Fish and Wildlife Service, Ft. Collins, Colorado. 39 pp.

Bovee, K. D. 1978. Probability-of-use criteria for the family Salmonidae. Instream Flow Information Paper No. 4. FWS/OBS-78/07. Cooperative Instream Flow Service Group, U.S. Fish and Wildlife Service, Ft. Collins, Colorado. 80 pp.

Bovee, K. D., and R. T. Milhous. 1978. Hydraulic simulation in instream flow studies: Theory and techniques. Instream Flow Information Paper No. 5. FWS/OBS-78/33. Cooperative Instream Flow Service Group, U.S. Fish and Wildlife Service, Ft. Collins, Colorado. 125 pp.

Bovee, K. D. 1980. Cover analysis with PHABSIM. Unpublished memorandum to PHABSIM users. Cooperative Instream Flow Service Group, U.S. Fish and Wildlife Service, Ft. Collins, Colorado. 13 pp.

Bovee, K. D., Instream Flow and Aquatic Systems Group, U.S. Fish and Wildlife Service, Ft. Collins, Colorado, personal communications to J. M. Loar, November 1980 and M. J. Sale, February 1981.

Buchanan, T. J., and W. P. Somers. 1968. Stage measurements at gaging stations. USGS-TWRI Book 3, Chapter A7. U.S. Geological Survey. Arlington, Virginia. 28 pp.

Cairns, J., Jr. 1980. Estimating hazard. BioScience 30(2):101-107.

Chiang, S. L., and F. W. Johnson. 1976. Low flow criteria for diversions and impoundments. J. Water Res. Plan. Manag. Div., Am. Soc. Civ. Eng. 102(WR2):227-238.

Chow, V. T. 1964. Handbook of Applied Hydrology. McGraw-Hill Book Co., New York. 1418 pp.

Cochnauer, T. 1976. Instream flow techniques for large rivers. pp. 387-399. In J. F. Orsborn and C. H. Allman (eds.), Instream Flow Needs, Vol. II. American Fisheries Society, Bethesda, Maryland. 657 pp.

Collings, M. R. 1972. A methodology for determining instream flow requirements for fish. pp. 72-86. In Proc., Instream Flow Methodology Workshop. Washington State Department of Ecology, Olympia, Washington. 130 pp. + Appendix.

Collings, M. R. 1974. Generalization of spawning and rearing discharges for several Pacific salmon species in western Washington. U.S. Geological Survey Open File Report. 39 pp.

Cooper, J. L. 1976. United States Forest Service stream survey procedure--Northern Region. pp. 300-313. In J. F. Orsborn and C. H. Allman (eds.), Instream Flow Needs, Vol. II. American Fisheries Society, Bethesda, Maryland. 657 pp.

Corso, R. A. 1979. Federal jurisdiction in the development of small-scale hydropower. Conference on Small-Scale Hydroelectric Power in the Southeast, June 14-15, 1979, Atlanta, Georgia. Mimeo. 12 pp.

Cortell, J. M., and Associates, Inc. 1977a. Recreation and instream flow, Volume I: Flow requirements, analysis of benefits, legal and institutional constraints. DIOLS 78-01. Jason M. Cortell and Associates, Inc., Waltham, Massachusetts. 157 pp.

Cortell, J. M., and Associates, Inc. 1977b. Recreation and instream flow, Volume II: River evaluation manual. DIOLS 78-02. Jason M. Cortell and Associates, Inc., Waltham, Massachusetts. 96 pp.

Cunningham, C., and W. Knapp. Downstream releases: Implications for hydroelectric development and natural resource management. Proc., Waterpower '81: An International Conference on Small-Scale Hydropower, June 22-24, 1981, Washington, D.C. (in press).

Curtis, B. 1959. Changes in a river's physical characteristics under substantial reductions in flow due to hydroelectric diversion. Calif. Fish Game 45(3):181-181.

Dakley, N., and O. Helmer. 1963. An experimental application of the Delphi Method to the use of experts. Manage. Sci. 9:458.

Delisle, G. E., and B. E. Eliason. 1961. Stream flows required to maintain trout populations in the Middle Fork Feather River Canyon, Report No. 2. Water Projects Branch, Calif. Dept. Fish and Game.

Dewsnup, R. L., and D. W. Jensen. 1977. State laws and instream flows. FWS/OBS-77/27. Western Energy and Land Use Team, U.S. Fish and Wildlife Service, Ft. Collins, Colorado. 72 pp.

Dixon, J. H. 1981. Practical hydrology for hydroplant planning and design. pp. 210-217. In Proc., Waterpower '79: International Conference on Small-Scale Hydropower. U.S. Government Printing Office, Washington, D.C. 870 pp.

Dooley, J. M. 1976. Application of U.S. Bureau of Reclamation Water Surface Profile Program (WSP). pp. 478-495. In J. F. Orsborn and C. H. Allman (eds.), Instream Flow Needs, Vol. II. American Fisheries Society, Bethesda, Maryland. 657 pp.

Dougal, M. D. 1979. Roles and alternatives of state agencies in regulating stream alterations. Paper presented at the Stream Alterations Symposium, Midwest Fish and Wildlife Conference, Champaign, Illinois. Iowa State University, Ames, Iowa. Unpubl. manuscript. 11 pp.

Dunham, D. K. 1972. Habitat and channel cross-sectioning of mountain streams in Utah, Idaho, and Wyoming. pp. 16-23. In Proc., Instream Flow Requirement Workshop. Pacific Northwest River Basins Commission, Vancouver, Washington. 104 pp.

Dunham, D. K., and A. Collotzi. 1975. The transect method of stream habitat inventory - Guidelines and applications. U.S. Forest Servce, Intermountain Region, Ogden, Utah. Unpubl. manuscript. 98 pp.

Elser, A. A. 1972. A partial evaluation and application of the "Montana Method" of determining stream flow requirements. pp. 3-15. In Proc., Instream Flow Requirement Workshop. Pacific Northwest River Basins Commission, Vancouver, Washington. 104 pp.

Elser, A. A. 1976. Use and reliability of Water Surface Profile program data on a Montana prairie stream. pp. 496-504. In J. F. Orsborn and C. H. Allman (eds.), Instream Flow Needs, Vol. II. American Fisheries Society, Bethesda, Maryland. 657 pp.

Emmert, R., and L. Heitz. 1979. Determination of flow-duration curves at ungaged points in regulated streams. pp. 218-225. In Proc., Waterpower '79: International Conference on Small-Scale Hydropower. U.S. Government Printing Office, Washington, D.C. 870 pp.

Federal Energy Regulatory Commission. 1981. Draft Environmental Impact Statement: Terror Lake Hydroelectric Project, FERC No. 2743. FERC/EIS-0026/D. Office of Electric Power Regulation, Federal Energy Regulatory Commission, Washington, D.C.

Fraser, J. C. 1972a. Regulated stream discharge for fish and other aquatic resources: An annotated bibliography. FAO Fisheries Tech. Paper No. 112 (FIRI/T111). FAO/UN, Rome, Italy. 103 pp.

Fraser, J. C. 1972b. Regulated discharge and the stream environment. pp. 263-285. In R. T. Oglesby, C. A. Carlson, and J. A. McCann (eds.), River Ecology and Man. Academic Press, Inc., New York. 465 pp.

Giger, R. D. 1973. Streamflow requirements for salmonids. Job Final Report, Project AFS-62-1. Oregon Wildlife Commission, Portland, Oregon. 117 pp.

Giger, R. D., Water Resources Activities Leader, U.S. Fish and Wildlife Service, Office of Biological Services, Portland, Oregon, personal communication to M. J. Sale, January 1981.

Gore, J. A. 1978. A technique for predicting in-stream flow requirements of benthic macroinvertebrates. Freshwater Biol. 8:141-151.

Gould, G. A. 1977. Preserving instream flows under the appropriation doctrine: Problems and possibilities. pp. viii-xiv. In R. L. Dewsnup, D. W. Jensen, E. Hoban, G. Horak, M. Lewis, and W. Nelson, Promising Strategies for Reserving Instream Flows. FWS/OBS-77/29. Western Energy and Land Use Team, U.S. Fish and Wildlife Service, Ft. Collins, Colorado. 64 pp.

Grenney, W. J., and D. B. Porcella. 1976. Mathematical modeling of sediment transport as a methodology for determining instream flow requirements. pp. 515-526. In J. F. Orsborn and C. H. Allman (eds.), Instream Flow Needs, Vol. II. American Fisheries Society, Bethesda, Maryland. 657 pp.

Grenney, W. J., D. B. Porcella, and M. L. Cleave. 1976. Water quality relationships to flow-streams and estuaries. pp. 35-88. In C. B. Stalnaker and J. L. Arnette (eds.), Methodologies for the Determination of Stream Resource Flow Requirements: An Assessment. FWS/OBS-76/03. Utah State University, Logan, Utah. 199 pp.

Herricks, E. E., and J. K. Furnish. 1980. Assessment of the availability and quality of information needed to calculate habitat suitability curves for selected benthic invertebrates. Eastern Energy and Land Use Team, U.S. Fish and Wildlife Service, Kearneysville, West Virginia. Unpubl. manuscript. 28 pp.

Herricks, E. E., and D. J. Klopke. 1980. Development of suitability curves for Illinois fish. Paper presented at the 2nd Annual Instream Flow Seminar/Workshop sponsored by the Ohio River Basin Commission, Ft. Mitchell, Kentucky. University of Illinois at Urbana-Champaign, Urbana, Illinois. Unpubl. manuscript. 15 pp.

Herricks, E. E., J. B. Stall, J. W. Eheart, A. E. Libbey, S. F. Railsback, and M. J. Sale. 1980. Instream flow needs analysis of the Little Wabash River Basin. Environmental Engineering Series No. 61. University of Illinois at Urbana-Champaign, Urbana, Illinois. 151 pp.

Hildebrand, S. G. (Ed.). 1980. Analysis of environmental issues related to small-scale hydroelectric development. III. Water level fluctuation. ORNL/TM-7453. Oak Ridge National Laboratory, Oak Ridge, Tennessee. 78 pp. + Appendix.

Hilgert, P. 1981. Evaluation of instream flow methodologies and determination of water quantity needs for stream fisheries in the State of Nebraska. Nebraska Game and Parks Commission, Lincoln, Nebraska. 119 pp.

Holden, P. B. 1979. Ecology of riverine fishes in regulated stream systems with emphasis on the Colorado River. pp. 57-74. In J. V. Ward and J. A. Stanford (eds.), The Ecology of Regulated Streams. Plenum Press, New York. 398 pp.

Hoppe, R. A., and L. M. Finnell. 1970. Aquatic studies on Frying Pan River, Colorado - 1969-70. Division of River Basin Studies, U.S. Bureau Sport Fisheries and Wildlife, Albuquerque, New Mexico. Mimeo Report. 12 pp.

Hooper, D. R. 1973. Evaluation of the effects of flows on trout stream ecology. Pacific Gas and Electric Company, Emeryville, California. 97 pp.

Horwitz, R. J. 1978. Temporal variability patterns and the distributional patterns of stream fishes. Ecology 48:307-321.

Hyra, R. 1978. Methods of assessing instream flows for recreation. Instream Flow Information Paper No. 6. FWS/OBS-78/34. Cooperative Instream Flow Service Group, U.S. Fish and Wildlife Service, Ft. Collins, Colorado. 44 pp.

Isaacson, J. A. 1976. Determining instream flows using the sag-tape method and R2cross x computer program. pp. 314-321. In J. F. Orsborn and C. H. Allman (eds.), Instream Flow Needs, Vol. II. American Fisheries Society, Bethesda, Maryland. 657 pp.

Jackson, D. R. 1980. Engineering and biological problems in instream flow studies in the Susquehanna Basin. Paper presented at the 36th Annual Northeast Fish and Wildlife Conference, Ellenville, New York. Susquehanna River Basin Commission, Harrisburg, Pennsylvania. Unpubl. manuscript. 34 pp.

Kadlec, J. A. 1976a. Methodologies for assessing instream flows for wildlife. pp. 139-147. In C. B. Stalnaker and J. L. Arnette (eds.), Methodologies for the Determination of Stream Resource Flow Requirements: An Assessment. FWS/OBS-76/03. Utah State University, Logan, Utah. 199 pp.

Kadlec, J. A. 1976b. Methodologies for assessing instream flows for wildlife. pp. 355-363. In J. F. Orsborn and C. H. Allman (Eds.), Instream Flow Needs, Vol. I. American Fisheries Society, Bethesda, Maryland. 551 pp.

Karr, J. R., and D. R. Dudley. 1981. Ecological perspective on water quality goals. Environ. Manage. 5(1):55-68.

Knapp, W. E. 1980. Instream flow policy: A stimulus for attitudinal change. Paper presented at the HCRS Conference on River Conservation and Revitalization: Agenda for the 1980's, October 20, 1980, Lake Mohonk, New York. Mimeo. 38 pp.

Knapp, W. E. 1981. Hydropower 1980: Implications for fishery science and management. Paper presented at the 37th Northeast Fish and Wildlife Conference, April 19-23, 1981, Virginia Beach, Virginia. Mimeo. 21 pp.

Knapp, W. E., Regional Activities Leader for Power Plants/Water Resources Analysis, U.S. Fish and Wildlife Service, Newton Corner, Massachusetts, personal communication to J. M. Loar, July 1981.

Lamb, B. L., and K. D. Bayha. 1978. Legal and institutional aspects related to instream flow. pp. 75-82. In K. Bayha, Instream Flow Methodologies for Regional and National Assessments. FWS/OBS-78/61. Cooperative Instream Flow Service Group, U.S. Fish and Wildlife Service, Ft. Collins, Colorado. 89 pp.

Lamb, B. L., and D. Sweetman. 1979. Guidelines for preparing expert testimony in water management decisions related to instream flow issues. Instream Flow Information Paper No. 1. Cooperative Instream Flow Service Group, U.S. Fish and Wildlife Service, Ft. Collins, Colorado.

Leopold, L. B., and T. Maddock, Jr. 1953. The hydraulic geometry of stream channels and some physiographic implications. U.S. Geological Survey Professional Paper 252. U.S. Government Printing Office, Washington, D.C. 53 pp. + Appendices.

Leopold, L. B., M. G. Wolman, and J. P. Miller. 1964. Fluvial Processes in Geomorphylogy. W. H. Freeman, San Francisco, California. 522 pp.

Linsley, R. K., and J. B. Franzini. 1972. Water-Resources Engineering. McGraw-Hill Book Co., New York. 690 pp.

Loar, J. M., and S. G. Hildebrand. A comparison of the environmental issues related to development of small hydropower resources at new versus existing sites. In T. N. Veziroglu (ed.), Proc., 3rd Miami International Conference on Alternative Energy Sources, Miami Beach, Florida, December 15-17, 1980 (in press).

Lowe, R. L. 1979. Phytobenthic ecology and regulated streams. pp. 25-34. In J. V. Ward and J. A. Stanford (eds.), The Ecology of Regulated Streams. Plenum Press, New York. 398 pp.

Mar, B. W., et al. 1979. Module II: Instream water quality. pp. 83-138. In G. L. Smith (ed.), Proc., Workshop in Instream Flow Habitat Criteria and Modeling. Information Series No. 40. Colorado Water Resources Research Institute, Colorado State University, Ft. Collins, Colorado. 244 pp.

Masteller, M. B., W. H. Andrews, L. C. Langord, and G. E. Madsen. 1976. Measurement of streamflow aesthetic values. pp. 167-199. In C. B. Stalnaker and J. L. Arnette (eds.), Methodologies for the Determination of Stream Resource Flow Requirements: An Assessment. FWS/OBS-76/03. Utah State University, Logan, Utah. 199 pp.

Milhous, R. T., and K. D. Bovee. 1978. The stochastic variation of instream values in rivers. pp. 630-637. In Verification of Mathematical and Physical Models in Hydraulic Engineering, Proceedings of an ASCE Hydraulic Division Conference. American Society of Civil Engineers, College Park, Maryland.

Mittman, H. J. 1976. Esthetic considerations for instream flow determination. pp. 322-333. In J. F. Orsborn and C. H. Allman (eds.), Instream Flow Needs, Vol. II. American Fisheries Society, Bethesda, Maryland. 657 pp.

Montana Power Company. 1979. West Rosebud Creek Minimum Flow Study: Final Report. Montana Power Company, Butte, Montana. 53 pp. + Appendices.

Morris, J. A. 1976. Instream flow evaluation for outdoor recreation. pp. 352-358. In J. F. Orsborn and C. H. Allman (eds.), Instream Flow Needs, Vol. II. American Fisheries Society, Bethesda, Maryland. 657 pp.

Nelson, F. A. 1980. Evaluation of four instream flow methods applied to four trout rivers in southwest Montana. Montana Department of Fish, Wildlife and Parks, Bozeman, Montana. 105 pp.

Olson, R. M. 1973. Essentials of Engineering Fluid Mechanics. Intext Educational Publishers, New York.

Orsborn, J. F., and C. H. Allman (eds.). 1976a. Instream Flow Needs, Vol. I. American Fisheries Society, Bethesda, Maryland. 551 pp.

Orsborn, J. F., and C. H. Allman (eds.). 1976b. Instream Flow Needs, Vol. II. American Fisheries Society, Bethesda, Maryland. 657 pp.

Orth, D. J. 1980. Evaluation of a methodology for recommending instream flows for fisheries. Ph.D. Thesis. Oklahoma State University, Stillwater, Oklahoma. 175 pp.

Patten, B. C., et al. 1979. Module III: Instream fishery ecosystems. pp. 139-166. In G. L. Smith (ed.), Proc., Workshop in Instream Flow Habitat Criteria and Modeling. Information Series No. 40. Colorado Water Resources Research Institute, Colorado State University, Ft. Collins, Colorado. 244 pp.

Pennak, R. W. 1971. Toward a classification of lotic habitats. Hydrobiologia 38(2):321-334.

Porcella, D. B., and W. J. Grenney. 1976. An assessment of water quality relationships to flow in streams and estuaries. pp. 340-347. In J. F. Orsborn and C. H. Allman (eds.), Instream Flow Needs, Vol. I. American Fisheries Society, Bethesda, Maryland. 551 pp.

Prewitt, C. G., and C. A. Carlson. 1979. Evaluation of four instream flow methodologies used on the Yampa and White Rivers, Colorado. Department of Fishery Biology, Colorado State University, Ft. Collins, Colorado. 65 pp.

Pruitt, T. A., and R. L. Nadeau. 1978. Recommended stream resource maintenance flows on seven southern Idaho streams. Instream Flow Information Paper No. 8. Cooperative Instream Flow Service Group, U.S. Fish and Wildlife Service, Ft. Collins, Colorado. 60 pp.

Railsback, S. F. 1981. A technique for modeling aquatic insect habitat. M.S. Thesis. University of Illinois, Urbana, Illinois. 24 pp.

Robinson, E. H. 1969. A procedure for determining desirable stream flows for fisheries. U.S. Fish and Wildlife Service, Concord, New Hampshire. Mimeo Report. 12 pp.

Sale, M. J. 1980. Optimization techniques for instream flow allocations. Ph.D. Thesis. University of Illinois at Urbana-Champaign, Urbana, Illinois. 165 pp.

Sams, R. E., and L. S. Pearson. 1963. A study to develop methods for determining spawning flows for anadromous salmonids. Oregon Fish Commission. Unpubl. manuscript. 56 pp.

Schamberger, M., and A. Farmer. 1978. The habitat evaluation procedures: Their application in project planning and impact evaluation. pp. 274-283. In Trans., 43rd North American Wildlife Natural Resource Conference. Wildlife Management Institute, Washington, D.C.

Schumm, S. A. 1977. Applied fluvial geomorphology. pp. 119-156. In J. R. Hails (ed.), Applied Geomorphology. Elsevier Scientific Publishing Co., Amsterdam, The Netherlands.

Shane, R. M. 1981. Scheduling model development for multipurpose multiple reservoir systems: The state-of-the-art. pp. 2-1 to 2-16. In S. G. Hildebrand and L. B. Goss, Hydroelectric Operation at the River Basin Level: Research Needs to Include Ecological Issues in Basin-Level Hydropower Planning. EPRI WS-80-155. Electric Power Research Institute, Palo Alto, California.

Sheppard, J. D. 1980. New York reservoir releases monitoring and evaluation program, Delaware River, July 1978 - December 1979. Tech. Rep. 80-1. New York State Department of Environmental Conservation, Albany, New York. 62 pp.

Sheppard., J. D., and J. H. Johnson. 1981. Preference assessments of depth, velocity, and substrate types for juvenile salmonids and adult blacknose dace in Lake Ontario tributary streams. Paper presented at the 37th Northeast Fish and Wildlife Conference, Virginia Beach, Virginia. New York State Department of Environmental Conservation, Albany, New York.

Simons, D. B., et al. 1979. Module I: River mechanics, morphology, watershed processes. pp. 45-82. In G. L. Smith (ed.), Proceedings, Workshop on Instream Flow Habitat Criteria and Modeling. Information Series No. 40. Colorado Water Resources Research Institute, Colorado State University, Ft. Collins, Colorado. 244 pp.

Smith, F. E. 1976. Water development impact on fish resources and associated values of the Trinity River, California. pp. 98-111. In J. F. Orsborn and C. H. Allman (eds.), Instream Flow Needs, Vol. II. American Fisheries Society, Bethesda, Maryland. 657 pp.

Stall, J. B., and Y. S. Fok. 1968. Hydraulic geometry of Illinois streams. Research Report 15. University of Illinois Water Resources Center, Urbana, Illinois. 47 pp.

Stall, J. B., and C. T. Yang. 1970. Hydraulic geometry of 12 selected stream systems of the United States. Research Report No. 32. University of Illinois Water Resources Center, Urbana, Ilinois.

Stalnaker, C. B., and J. L. Arnette (eds.). 1976. Methodologies for the Determination of Stream Resource Flow Requirements: An Assessment. FWS/OBS-76/03. Utah State University, Logan, Utah. 199 pp.

Stalnaker, C. B. 1978. The IFG Incremental Methodology for physical instream habitat evaluation. pp. 126-135. In D. E. Samuel et al. (eds.), Surface Mining and Fish/Wildlife Needs in the Eastern United States. FWS/OBS-78/81. U.S. Fish and Wildlife Service, Washington, D.C. 386 pp.

Stalnaker, C. B. 1979a. Myths concerning instream flows: A background to understanding instream uses. pp. 1-7. In P.S. Wassenberg, S. Olive, J. L. DeMott, and C. B. Stalnaker, Elements in Negotiating Stream Flows Associated with Federal Projects. Instream Flow Information Paper No. 9. FWS/OBS-79/03. Cooperative Instream Flow Service Group, U.S. Fish and Wildlife Service, Ft. Collins, Colorado. 41 pp.

Stalnaker, C. B. 1979b. The use of habitat structure preferenda for establishing flow regimes necessary for maintenance of fish habitat. pp. 321-337. In J. V. Ward and J. A. Stanford (eds.), The Ecology of Regulated Streams. Plenum Press, New York. 398 pp.

Stalnaker, C. B. 1981. Low flow as a limiting factor in warmwater streams. pp. 192-199. In L. A. Krumholz, C. F. Bryan, G. E. Halls and G. B. Pardue (eds), The Warmwater Streams Symposium, A National Symposium on Fisheries Aspects of Warmwater Streams. Southern Division, American Fisheries Society, Lawrence, Kansas. 422 pp.

Stein, R. A., C. S. Wilcos, and R. F. Carline. 1980. Microhabitat selection by smallmouth bass in an artificial stream tank. Paper presented at 2nd Annual Instream Flow Seminar/Workshop sponsored by the Ohio River Basin Commission, Ft. Mitchell, Kentucky. Ohio State University, Columbus, Ohio. Mimeo. 2 pp.

Strahler, A. N. 1957. Quantitative analysis of watershed geomorphology. Trans. Am. Geophys. Union 38(6):913-920.

Sweetman, D. A. 1980. Protecting instream flows in Montana: Yellowstone River reservation case study. Instream Flow Information Paper No. 10. FWS/OBS-79/36. Cooperative Instream Flow Service Group, U.S. Fish and Wildlife Service, Ft. Collins, Colorado. 85 pp.

Szluha, A. T., J. M. Loar, R. R. Turner, and S. G. Hildebrand. 1981. Analysis of environmental impacts of water level fluctuation in reservoirs at hydroelectric sites. pp. 498-503. In Proc., Waterpower '79: International Conference on Small-Scale Hydropower. U.S. Government Printing Office, Washington, D.C. 870 pp.

Tennant, D. L. 1975. Instream flow regimens for fish, wildlife, recreation, and related environmental resources. U.S. Fish and Wildlife Service, Billings, Montana. Unpubl. manuscript. 18 pp.

Tennant, D. L. 1976. Instream flow regimens for fish, wildlife, recreation, and related environmental resources. pp. 359-373. In J. F. Orsborn and C. H. Allman (eds.), Instream Flow Needs, Vol. II. American Fisheries Society, Bethesda, Maryland. 657 pp.

Teskey, R. O., and T. M. Hinckley. 1977. Impact of water level changes on woody riparian and wetland communities, Vol. I: Plant and soil responses to flooding. FWS/OBS-77/58. National Stream Alteration Team, U.S. Fish and Wildlife Service, Columbia, Missouri. 30 pp.

Thompson, K. E. 1972. Determining stream flows for fish life. pp. 31-50. In Proc., Instream Flow Requirement Workshop. Pacific Northwest River Basins Commission, Vancouver, Washington. 104 pp.

Thompson, K. E. 1974. Salmonids. pp. 85-103. In K. Bayha (ed.), Anatomy of a River: An Evaluation of Water Requirements for the Hells Canyon Reach of the Middle Snake River. Hells Canyon Controlled Flow Task Force, Pacific Northwest River Basins Commission, Vancover, Washington. 202 pp.

Trihey, E. W. 1979. The IFG Incremental Methodology. pp. 24-62. In G. L. Smith (ed.), Proc., Workshop in Instream Flow Habitat Criteria and Modeling. Information Series No. 40. Colorado Resources Research Institute, Colorado State University, Ft. Collins, Colorado.

Turner, R. R. 1980. Impacts of water level fluctuation on physical and chemical characteristics of rivers downstream from dams. pp. 39-43. In S. G. Hildebrand (ed.), Analysis of Environmental Issues Related to Small-Scale Hydroelectric Development. III: Water Level Fluctuation. ORNL/TM-7453. Oak Ridge National Laboratory, Oak Ridge, Tennessee. 78 pp. + Appendix.

U.S. Department of Energy. 1981. Report of the White House Interagency Task Force on Small Hydropower. DOE/RA-0060. Assistant Secretary for Resource Applications, U.S. Department of Energy, Washington, D.C. 97 pp.

U.S. Fish and Wildlife Service. 1977. Cooperative Instream Flow Service Group: The First Year. FWS/OBS-77/36. Biological Services Program, U.S. Fish and Wildlife Service, Ft. Collins, Colorado. Pamphlet. 8 pp.

U.S. Fish and Wildlife Service. 1979. Cooperative Instream Flow Service Group. September 1977 through December 1978. FWS/OBS-79/27. Biological Services Program, U.S. Fish and Wildlife Service, Ft. Collins, Colorado. Pamphlet. 16 pp.

U.S. Fish and Wildlife Service. 1981. Interim Regional Policy for New England Stream Flow Recommendations. Memorandum from H. N. Larsen, Director, Region 5 of U.S. Fish and Wildlife Service, Newton Corner, Massachusetts, February 13, 1981. Mimeo. 3 pp.

U.S. Water Resources Council. 1978. The Nation's Water Resources 1975-2000, Second National Water Assessment Vol. I: Summary. U.S. Government Printing Office, Washington, D.C. 86 pp.

Voos, K. A. 1981. Simulated use of the exponential polynomial/maximum likelihood technique in developing suitability of use functions for fish habitat. Ph.D. Thesis. Utah State University, Logan, Utah. 85 pp.

Voos, K. A., W. J. Grenney, and K. P. Burnham. 1981. A model for fish habitat usability. Cooperative Instream Flow Service Group, Ft. Collins, Colorado. Unpubl. manuscript. 23 pp.

Ward, J. V., and J. A. Stanford. 1979a. Ecological factors controlling stream zoobenthos with emphasis on thermal modification of regulated streams. pp. 35-55. In J. V. Ward and J. A. Stanford (eds.), The Ecology of Regulated Streams. Plenum Press, New York. 398 pp.

Ward, J. V., and J. A. Stanford (eds.). 1979b. The Ecology of Regulated Streams. Plenum Press, New York. 398 pp.

Washington State Department of Ecology. 1979. Final Environmental Impact Statement, Western Washington Instream Resources Protection Program. Appendix IV: Program Overview. Washington State Department of Ecology, Olympia, Washington.

Wassenberg, P. S., S. Olive, J. L. Demott, and C. B. Stalnaker. 1979. Elements in negotiating stream flows associated with federal projects. Instream Flow Information Paper No. 9. FWS/OBS-79/03. Cooperative Instream Flow Service Group, U.S. Fish and Wildlife Service, Ft. Collins, Colorado. 41 pp.

Waters, B. F. 1976. A methodology for evaluating the effects of different streamflows on salmonid habitat. pp. 254-266. In J. F. Orsborn and C. H. Allman (eds.), Instream Flow Needs, Vol. II. American Fisheries Society, Bethesda, Maryland. 657 pp.

Wegner, D. L. 1979. Computer simulation - A means of developing an aquatic mitigation plan. pp. 516-519. In G. A. Swanson (ed.), The Mitigation Symposium: A National Workshop on Mitigating Losses of Fish and Wildlife Habitats. General Technical Report RM-65. Rocky Mountain Forest and Range Experiment Station, U.S. Department of Agriculture, Ft. Collins, Colorado. 684 pp.

Wegner, D. 1980. Users guide to the physical habitat simulation model. Instream Flow and Aquatic Systems Group, U.S. Fish and Wildlife Service, Ft. Collins, Colorado. Unpubl. manuscript. 164 pp.

Wesche, T. A., and P. A. Rechard. 1980. A summary of instream flow methods for fisheries and related research needs. Eisenhower Consortium Bulletin No. 9. Eisenhower Consortium for Western Environmental Forestry Research, U.S. Government Printing Office, Washington, D.C. 122 pp.

White, M. R., F. D. Valdez, and M. D. White. 1980. Instream flow negotiation: Review of practices. FWS/OBS-80/53. Office of Biological Services, U.S. Fish and Wildlife Service, Washington, D.C. 78 pp.

White, R. J. 1976. A methodology for recommending stream resource maintenance flows for large rivers. pp. 376-386. In J. F. Orsborn and C. H. Allman (eds.), Instream Flow Needs, Vol. II. American Fisheries Society, Bethesda, Maryland. 657 pp.

White, R. J. 1979. Book review: Proceedings of the Symposium and Specialty Conference Instream Flow Needs, Boise, Idaho, May 3-6, 1976, J. F. Orsborn and C. H. Allman (eds.). Trans. Am. Fish. Soc. 108(6):654-655.

Williams, F. M. 1980. A fish population model responsive to instream flow. Paper presented at the 2nd Annual Instream Flow Seminar/ Workshop sponsored by the Ohio River Basin Commission, Ft. Mitchell, Kentucky. Penn State University, State College, Pennsylvania. Mimeo. 2 pp.

Wilson, W. J., E. W. Trihey, J. E. Baldrige, C. D. Evans, J. G. Thiele, and D. E. Trudgen. 1981. An assessment of environmental effects of construction and operation of the proposed Terror Lake hydroelectric facility, Kodiak, Alaska: Instream flow studies, Final Report. Arctic Environmental Information and Data Center, University of Alaska, Anchorage, Alaska. 419 pp.

Workman, D. L. 1976. Use of the water surface profile program in determining instream flow needs in Sixteenmile Creek, Montana. pp. 505-513. In J. F. Orsborn and C. H. Allman (eds.), Instream Flow Needs, Vol. II. American Fisheries Society, Bethesda, Maryland. 657 pp.

Wyoming Water Resources Research Institute. 1978a. Determining Instream Flows for Management of Aquatic and Riparian Ecosystems. Vol. I: Manual. Water Resources Research Institute, University of Wyoming, Laramie, Wyoming.

Wyoming Water Resources Research Institute. 1978b. Determining Instream Flows for Management of Aquatic and Riparian Ecosystems. Vol. II: Review of Literature. Water Resources Research Institute, University of Wyoming, Laramie, Wyoming.

INTERNAL DISTRIBUTION

1-2. S. I. Auerbach
3. L. W. Barnthouse
4. G. F. Cada
5. C. C. Coutant
6. M. P. Farrell
7. J. C. Goyert
8-107. S. G. Hildebrand
108. D. D. Huff
109. C. T. Hunsaker
110. B. L. Kimmel
111-115. J. M. Loar
116. R. V. O'Neill
117. D. E. Reichle
118. R. D. Roop
119-123. M. J. Sale
124. V. R. Tolbert
125. W. Van Winkle
126. G. T. Yeh
127. H. E. Zittel
128. Central Research Library
129-140. ESD Library
141-142. Laboratory Records Department
143. Laboratory Records, ORNL-RC
144. ORNL Patent Office
145. ORNL Y-12 Library

EXTERNAL DISTRIBUTION

146. Advisor on Environmental Quality, Federal Energy Regulatory Commission, 825 N Capitol St., NE, Washington, DC 20426
147. Air, Land and Water Use, Environmental Protection Agency, 401 M. St., SW, Washington, DC 20460
148. Alabama Energy Management Board, Montgomery, AL 36130
149. F. J. Andrew, International Pacific Salmon Fisheries Commission, New Westminster, British Columbia, Canada V3L 4X9
150. Area Director, Alaska Area, U.S. Fish & Wildlife Service, 1011 E. Tudor Rd., Anchorage, AK 99503
151. H. Scotty Arnowitz, Project Manager, CH$_2$M Hill, Inc., 1500 114th Avenue, SE, Bellevue, WA 98004
152. Harpal Arora, Law Engineer Testing Co., 2749 Delk Rd., Marietta, GA 30067
153. Assistant Administrator, Planning & Management, Environmental Protection Agency, 401 M. St., SW, Washington, DC 20460
154. Assistant Administrator, Water & Waste Management, Environmental Protection Agency, 401 M. St., SW, Washington, DC 20460
155. Assistant Administrator, Research and Development, Environmental Protection Agency, 401 M. St., SW, Washington, DC 20460
156. Assistant Commissioner Engineering and Research, Bureau of Reclamation, E & R Center, Bldg. 67, Denver Federal Center, Denver, CO 80225
157. Assistant to the Governor for Energy Affairs, c/o Secretary of State, P.O. Box 1401, Townsend Building, Dover, DE 19901
158. Assistant Director, Environmental Programs, Office of the Chief of Engineers, Army Corps of Engineers, Forrestal Bldg., Washington, DC 20314
159. Assistant Secretary for Fish, Wildlife, and Parks, Department of the Interior, Interior Bldg., C St. between 18th and 19th, NW, Washington, DC 20240

160. Assistant to the Secretary and Science Advisor, Department of the Interior, Interior Bldg., C St. between 18th and 19th, NW, Washington, DC 20240
161. Associate Director-Environment, U.S. Fish & Wildlife Service, Washington, DC 20240
162. Associate Director-Research, U.S. Fish & Wildlife Service, Washington, DC 20240
163. Fred J. Ayer III, Kleinschmidt & Dutting, 75 Main Street, Pittsfield, ME 04967
164. Richard A. Azzaro, Esq., Hydroelectric Licensing, Office of General Counsel, Federal Energy Regulatory Commission, 825 North Capitol Street, NE, Washington, DC 20426
165. Mark B. Bain, Massachusetts Cooperative Fishery Research Unit, 204 Holdsworth Hall, University of Massachusetts, Amherst, MA 01003
166. P. K. Banerjee, Government of India, Department of Science and Technology, Technology Bhavan, New Mehrauli Road, New Delhi - 110 016, INDIA
167. Carl Baren, U.S. Fish & Wildlife Service, Fishery Assistance, Federal Building, P.O. Box 1140, Montpelier, VT 05602
168. R. M. Baxter, Applied Research Division, Canada Centre for Inland Waters, Burlington, Ontario, Canada L7R 4A6
169. Milo C. Bell, College of Fisheries, University of Washington, Seattle, WA 98195
170. E. L. Bourodimos, College of Engineering, Rutgers University, New Brunswick, NJ 08903
171. Ken Bovee, Cooperative Instream Flow Service Group, U.S. Fish & Wildlife Service, 2625 Redwing Rd., Drake Creekside Bldg. #2, Ft. Collins, CO 80526
172. Daniel E. Boxer, Pierce, Atwood, Scribner, Allen, Smith & Lancaster, One Monument Square, Portland, ME 04101
173. R. P. Breckenridge, Earth and Life Sciences, EG&G Idaho, Inc., P.O. Box 1625, Idaho Falls, ID 83415
174. Robert W. Brocksen, Manager, Ecological Programs, Electric Power Research Institute, P.O. Box 10412, Palo Alto, CA 94303
175. Peter Brown, Franklin Pierce Law Center, Energy Law Institute, Concord, NH 03301
176. Barry Brown, California Energy Commission, 1111 Howe Avenue, Mail Stop 32, Sacramento, CA 95828
177. D. Buechler, U.S. Fish & Wildlife Service (OBS), Lloyd 500 Bldg., Portland, OR 97232
178. Dewey Bunting, Department of Zoology, University of Tennessee, Knoxville, TN 37916
179. Stephen F. Burke, J. Kenneth Fraser & Associates, P.C., 620 Washington Ave., Rensselaer, NY 12144
180. John Burnes, Department of the Army, Philadelphia District, Corps of Engineers, 2D and Chestnut Streets, Philadelphia, PA 19106
181. Ralph Burr, Resource Applications, Department of Energy, 12th and Pennsylvania Avenue NW, Washington, DC 20461
182. Charles Edington, Office of Health and Environmental Research, Department of Energy, Washington, DC 20545

183. California Energy Commission, 1111 Howe Avenue, Sacramento, CA 95825
184. J. Thomas Callahan, Associate Director, Ecosystems Studies Program, National Science Foundation, Washington, DC 20550
185. K. Perry Campbell, Ph.D., Assistant Manager, Beak Consultants Incorporated, Eighth Floor Loyalty Bldg., 317 SW Alder, Portland, OR 97204
186. Jay Carter, Stanley Consultants, Inc., Premier Bldg., Suite 306, 1725 Eye Street NW, Washington, DC 20545
187. Daniel J. Castellani, Project Manager, Environmental Division, Gilbert Associates, Inc., P.O. Box 1498, Reading, PA 19603
188. John P. Chandler, Consulting Engineer, Murray Hill Road, Hill, NH 03243
189. Chief, Division of Ecological Services, U.S. Fish & Wildlife Service, Washington, DC 20240
190. Chief, Environmental Analysis Branch, Federal Energy Regulatory Commission, 825 N Capitol St., NE, Washington, DC 20426
191. Chief, Office of Biological Services, U.S. Fish & Wildlife Service, Washington, DC 20240
192. Chief, Office of Environmental Coordination, U.S. Fish & Wildlife Service, Washington, DC 20240
193. Robert E. Cleary, U.S. Fish & Wildlife Service (OBS), Lloyd 500 Bldg., Portland, OR 97232
194. J. P. Clugston, U.S. Fish & Wildlife Service, 206 Highway 123 By-Pass, Clemson, SC 29631
195. Ries Collier, Division of Ecological Services, U.S. Fish & Wildlife Service, 310 New Bern Ave., Room 468, Raleigh, NC 27601
196. Leon Cook, Hydrologic Engineering Section, Water Management Division, Department of Natural Resources, Steven T. Mason Bldg., Box 30028, Lansing, MI 48909
197. William J. Coppoc, Texaco, Inc., P.O. Box 509, Beacon, NY 12508
198. Ronald Corso, Director, Division of Licensing, Federal Energy Regulatory Commission, 825 North Capitol Street NE, Washington, DC 20426
199. William D. Countryman, Aquatec Inc., 75 Green Mountain Drive, South Burlington, VT 05401
200. Norman Crawford, Hydrocomp, 210 San Antonio Circle, Mountain View, CA 94040
201. Leo Creighton, NUS Corporation, Southwest Environmental Center, 14011 Ventura Boulevard, Sherman Oaks, CA 91423
202. Robert Curran, Curran Associates, Inc., 182 Main Street, Northampton, MA 01060
203. Kevin D. Curry, Unity College, Unity, MA 04988
204. Roger C. Dahlman, Office of Health and Environmental Research, Department of Energy, Washington, DC 20545
205. Steven C. Davis, Vice President, Technical Operations, Jason M. Cortell & Associates, Inc., 244 Second Avenue, Waltham, MA 02154

206. Gregory De Camp, Commonwealth Associates, Inc., 209 E. Washington Ave., Jackson, MI 49201
207. Mike Dell, Grant County Public Utilities Division, P.O. Box 878, Ephrata, WA 98823
208. Department of Conservation, P.O. Box 44275, Baton Rouge, LA 70804
209. Department of Energy, Region I, 150 Causeway Street, Boston, MA 02114
210. Department of Energy, Region II, 26 Federal Plaza, New York, NY 10007
211. Department of Energy, Region III, 1421 Cherry Street, Philadelphia, PA 19102
212. Department of Energy, Region IV, 1655 Peachtree Street, NE, Atlanta, GA 30309
213. Department of Energy, Region V, Federal Office Building, 175 West Jackson Boulevard, Chicago, IL 60604
214. Department of Energy, Region VI, 2626 Mockingbird Lane, P.O. Box 35228, Dallas, TX 75270
215. Department of Energy, Region VII, 324 East 11th Street, Kansas City, MO 64106
216. Department of Energy, Region VIII, P.O. Box 26247-Belmar Branch, 1075 South Yukon Street, Lakewood, CO 80226
217. Department of Energy, Region IX, Barclay Bank Boulevard, 111 Pine Street, San Francisco, CA 94111
218. Department of Energy, Region X, 1962 Federal Building, 915 2nd Avenue, Seattle, WA 98174
219. Department of Energy, 101 Commerce Street, Newark, NJ 07102
220. Department of Energy, 528 Cottage Street, NE, Salem, OR 97310
221. Department of Energy and Minerals, P.O. Box 2770, Sante Fe, NM 87501
222. Department of Planning and Economic Development, P.O. Box 2359, Honolulu, HI 96804
223. Deputy Assistant Administrator, Water Planning & Standards, Environmental Protection Agency, 401 M. St., SW, Washington, DC 20460
224. Deputy Director, National Science Foundation, Washington, DC 20550
225. Director, Alaska Region, National Marine Fisheries Service, NOAA, P.O. Box 1668, Juneau, AK 99802
226. Director, Bureau of Land Management, Department of the Interior, Interior Bldg., C St. between 18th and 19th, NW, Washington, DC 20240
227. Director, Northeast Fisheries Center, National Marine Fisheries Service, NOAA, Woods Hole, MA 02543
228. Director, Northeast Region, National Marine Fisheries Service, NOAA, 14 Elm St., Federal Bldg., Gloucester, MA 01930
229. Director, Northwest and Alaska Fisheries Center, NOAA, 2725 Montlake Blvd. East, Seattle WA 98112
230. Director, Northwest Region, National Marine Fisheries Service, NOAA, 1700 Westlake Ave., North Seattle, WA 98109
231. Director, Office of Environmental Affairs, Bureau of Reclamation, Washington, DC 20240

232. Director, Office of Environmental Project Review, Department of the Interior, Interior Bldg., C St. between 18th and 19th, NW, Washington, DC 20240
233. Director, Office of Water Research and Technology, Department of the Interior, Interior Bldg., C St. between 18th and 19th, NW, Washington, DC 20240
234. Director, Office of Regulatory Analysis, Federal Energy Regulatory Commission, 825 N. Capitol St., NE, Washington, DC 20426
235. Director, Southeast Fisheries Center, NOAA, 75 Virginia Beach Dr., Miami, FL 33149
236. Director, Southeast Region, National Marine Fisheries Service, NOAA, 9450 Koger Blvd., Dural Bldg., St. Petersburg, FL 33702
237. Director, Southwest Fisheries Center, National Marine Fisheries Service, NOAA, P.O. Box 271, La Jolla, CA 92038
238. Director, Southwest Region, National Marine Fisheries Service, NOAA, 300 S. Ferry St., Terminal Island, CA 90731
239. Director, U.S. Fish & Wildlife Service, Department of the Interior, Interior Bldg., C St. between 18th and 19th, NW, Washington, DC 20240
240. Director, National Fishery Research Laboritories, P.O. Box 818, La Crosse, WI 54601
241. Director, Columbia National Fishery Research Laboratory, R.D. 1, Columbia, MO 65201
242. Director, National Reservoir Research Program, 100 W. Rock St., Fayetteville, AR 72701
243. Director, Great Lakes Fishery Laboratory, 1451 Green Rd., Ann Arbor, MI 48105
244. Director, National Fishery Research Laboratory, Bldg. 737 IFAS, Univ. of Florida, Gainesville, FL 32611
245. Director, Research Triangle Park, Environmental Protection Agency, National Environmental Research Center, Triangle Park, NC 27711
246. Director, Corvallis National Environmental Research Center, Environmental Protection Agency, 200 SW 35th St., Corvallis, OR 97330
247. Director, Cincinnati National Environmental Research Center, Environmental Protection Agency, 5555 Ridge Ave., Cincinnati, OH 45268
248. Director, Las Vegas National Environmental Research Center, Environmental Protection Agency, P.O. Box 15027, Las Vegas, NV 89114
249. Director, Office of Biological Services, U.S. Fish & Wildlife Service, Washington, DC 20240
250. Chief Engineer, Army Corps of Engineers, P.O. Box 80, Vicksburg, MS 39180
251. Chief Engineer, Army Corps of Engineers, P.O. Box 103, Downtown Sta., Omaha, NB 68101
252. Chief Engineer, Army Corps of Engineers, 424 Trapelo Rd., Waltham, MA 02154
253. Chief Engineer, Army Corps of Engineers, 90 Church St., New York, NY 10007

254. Chief Engineer, Army Corps of Engineers, 536 S. Clark St.,
Chicago, IL 60605
255. Chief Engineer, Army Corps of Engineers, 220 NW 8th Ave.,
Portland, OR 97209
256. Chief Engineer, Army Corps of Engineers, P.O. Box 1159,
Cincinnati, OH 45201
257. Chief Engineer, Army Corps of Engineers, Bldg. 230, Ft.
Shafter, HI, APO San Francisco, CA 96558
258. Chief Engineer, Army Corps of Engineers, 510 Title Bldg.,
Atlanta, GA 30303
259. Chief Engineer, Army Corps of Engineers, 630 Sansom St., San
Francisco, CA 94111
260. Chief Engineer, Army Corps of Engineers, Main Tower Bldg.,
1200 Main St., Dallas, TX 75202
261. Director, Office of Biological Services, U.S. Fish & Wildlife
Service, Washington, DC 20240
262. J. Michael Donovan, Environmental Protection Specialist,
USDA/Rural Electric Administration, 14th Street and
Independence Ave., SW, Washington, DC 20250
263. Vaughn Douglass, U.S. Fish & Wildlife Service, Route 3,
Box 44, Kearneysville, WV 25430
264. Thomas Doyle, Michigan Department of Natural Resources,
Fisheries Division, Box 30029, Lansing, MI 48909
265. C. Dunn, U.S. Fish & Wildlife Service (OBS), Lloyd 500 Bldg.,
Portland, OR 97232
266. Dennis J. Dunning, Ph.D., Power Authority, of the State of
New York, 10 Columbus Circle, New York, NY 10019
267. Wesley Ebel, National Marine Fisheries Service, Northwest,
Alaska Fisheries Center, 2725 Montlake Boulevard, Seattle,
WA 98112
268. Phil Edmunds, U.S. Fish & Wildlife Service, 112 W. Foster
Avenue, State College, PA 16801
269. Quentin Edson, Federal Energy Regulatory Commission, 825 N.
Capitol Street, Washington, DC 20426
270. Clayton Edwards, International Joint Commission,
100 Ouellette Ave., 8th Floor, Windsor, Montreal,
Canada N9A6T3
271. Rex Elder, Bechtel Corporation, P.O. Box 3965, San Francisco,
CA 94119
272. Energy Capability and Management, State Energy Office,
Providence, RI 02903
273. Energy Conservation and Policy Office, 960 Plaza West
Building, Little Rock, AR 72205
274. Energy Division, Department of Planning and Energy Policy,
80 Washington Street, Hartford, CT 06115
275. Energy Management Division, North Carolina Department of
Commerce, 215 East Lane Street, Raleigh, NC 27601
276. Energy Management Office, Edgar Brown Building,
1205 Pendleton Street, Columbia, SC 29201
277. Energy Policy Office, State Department of Natural Resources,
301 West Preston Street, Baltimore, MD 21201
278. Environmental Specialist, Bureau of Reclamation, E & R
Center, Bldg. 67, Denver Federal Center, Denver, CO 80225

279. Rosemary Fei, Jason M. Cortell and Associates, 244 Second Avenue, Waltham, MA 02154
280. Robert Ferguson, B. C. Hydro, Harbor Center, P.O. Box 12121, 555 Hastings Street, Vancouver, British Columbia, VCB 4T6
281. Duane H. Fickeisen, Freshwater Sciences Section, Battelle Pacific Northwest Laboratories, P.O. Box 999, Richland, WA 99352
282. Frederick Fiechter, Hydro Corporation of Pennsylvania, P.O. Box 34, Chatham, PA 19318
283. Joseph A. Fischer, Director, Geoscience Services, The Tifa Building, 50 Division Avenue, Millington, NJ 07946
284. James Folin, Applied Physics Laboratory, John Hopkins University, Laurel, MD 20810
285. Dennis Ford, Environmental Laboratory, USAE - Waterways Experiment Station, Box 631, Vicksburg, MS 39180
286. Jack Fritz, Office of Energy, Agency for International Development, Room 306, SA-18, Washington, DC 20523
287. Fuel and Energy Division, Governor's Office of Economic and Community Development, 1262 1/2 Greenbriar Street, Charleston, WV 25305
288. James Furse, Division of Hydroelectric Resource Development, Department of Energy, 12th and Pennsylvania Avenue, NW, Washington, DC 20461
289. Robert Gay, 4423 SW Hamilton Terrace, Portland, OR 97201
290. Thomas G. Gebhard, Jr., Consulting Engineer, 5819 Westmont Drive, Austin, TX 78731
291. Brook Gebow, Energy Research and Applications, Inc., 1820 14th Street, Santa Monica, CA 90404
292. Glen H. Geen, Department of Biological Sciences, Simon Fraser University, Burnaby, British Columbia, Canada V5A 1S6
293. Chief of Engineers, Office of the Chief of Engineers, Army Corps of Engineers, Forrestal Bldg., Washington, DC 20314
294. Raymond P. Genereaux, Consulting Engineer, 1018 Kent Road, Wilmington, DE 19807
295. Len Gerardi, P.O. Box 128, Lyndon, VT 05849
296. Donald A. Giampaoli, Deputy Director, Division of Licensed Projects, Office of Electric Power Regulation, Federal Energy Regulatory Commission, 825 North Capitol Street, NE, Washington, DC 20426
297. Richard D. Giger, U.S. Fish & Wildlife Service, 500 NE Multnomah St., Portland, OR 97232
298. Charles Gilmore, Chief, Advanced Technology Branch, Department of Energy, 550 Second Street, Idaho Falls, ID 83401
299. Kip Gjerde, Bureau of Land Management, P.O. Box 30157, Billings, Montana 59107
300. John S. Gladwell, Division of Water Sciences, 7, place de Fontenoy, 75700 Paris
301. Norman R. Glass, National Ecological Research Laboratory, U.S. Environmental Protection Agency, 200 Southwest 35th Street, Corvallis, OR 97330

302. Steven Gloss, Department of Natural Resources, Fernow Hall, Cornell University, Ithaca, NY 14853
303. Bruce G. Goodale, Associate Water Resources Engineer, Office of Environmental Planning, State of New York Public Service Dept., 3 Rockefeller State Plaza, Albany, NY 12309
304. Jack Gordon, Department of Civil Engineering, Tennessee Technological University, Cookeville, TN 38501
305. Barry Goss, TVA, Energy Demonstrations and Technology, 1110 Chestnut Street Towers - 2, Chattanooga, TN 37401
306. Governor's Council on Energy, 26 Pleasant Street, Concord, NH 03301
307. Governor's Energy Council, State and Third Streets, Harrisburg, PA 17120
308. Steve Graham, 149 New Montgomery St., San Francisco, CA 94105
309. J. Graybill, FERC/DEA, 825 North Capitol Street, NE, Washington, DC 20426
310. John Gregg, Chief Engineer, Douglas County Public Utilities Division, 1151 Valley Mall Parkway, E. Wenatchee, WA 98801
311-330. George Grimes, Division of Hydroelectric Resource Development, Department of Energy, 12th & Pennsylvania Avenue, NW, Washington, DC 20461
331. Clem Griscom, Division of Marine Resources, Graduate School of Oceanography, University of Rhode Island, Kingston, RI 02881
332. John Gulliver, St. Anthony Falls Hydraulic Laboratory, Mississippi River at 3rd Avenue SE, Minneapolis, MN 55414
333. Jim Haas, Department of Fish and Wildlife, P.O. Box 3503, Portland, OR 97208
334. Peter Hackney, Tennessee Valley Authority, 455 Evans Bldg., Knoxville, TN 37902
335. Bob Halbriter, Obrien and Gere, 1304 Buckley Road, Syracuse, NY 13221
336. Carl Hall, City Light Bldg., 1015 3rd Ave., Seattle, WA 98101
337. George R. Hall, Commissioner, Federal Energy Regulatory Commission, 825 North Capitol Street, NE, Washington, DC 20426
338. Gordon Hall, Tennessee Valley Authority, Evans Building, Knoxville, TN 37902
339. Heyward Hamilton, Jr., Ecological Research Division, Office of Health and Environmental Research, Department of Energy, Washington, DC 20545
340. James R. Hanchey, Institute for Water Resources, Kingman Building, Ft. Belvoir, VA 22060
341. Lynn Heckman, Ketron, Inc., 1700 N. Moore St., Arlington, VA 22209
342. Jack M. Heinemann, Advisor on Environmental Quality, Office of Regulatory Analysis, Federal Energy Regulatory Commission, 825 North Capitol Street, NE, Washington, DC 20426
343. Paul G. Heisey, RMC - Ecological Division, Muddy Run Ecological Laboratory, P.O. Box 10, Drumore, PA 17518
344. Tim Heizenrader, Bonneville Power Administration, P.O. Box 3621, Portland, OR 97208

345. Stephen Henry, Massachusetts Division of Fisheries & Wildlife, Field Headquarters, Westboro, MA 01581
346. Pedro A. Hernandez, P. E., Department Head - Hydrology, Diaz-Seckinger & Associates, Inc., DSA Building, 2005 Pan Am Circle, Tampa, FL 33607
347. Edwin E. Herricks, 3215 Civil Eng. Bldg., VIVC, 208 N. Romine, Urbana, IL 61801
348. Billie Hicks, Information Specialist, U.S. Fish & Wildlife Service, Richard Russell Bldg., Atlanta, GA 30303
349. William Hinkley, Environmental Administrator, Office of Special Projects, Florida Department of Environmental Regulation, 2600 Blair Stone Road, Tallahassee, FL 32301
350. James Hoecker, Esq., Regulatory Development, Office of General Counsel, Federal Energy Regulatory Commission, 825 North Capitol Street, NE, Washington, DC 20426
351. Karen Hoffman, Environmental Activities Dept., Consumers Power Company, 1945 West Parnall Road, Jackson, MI 49201
352. Matthew Holden, Jr., Commissioner, Federal Energy Regulatory Commission, 825 North Capitol Street, NE, Washington, DC 20426
353. David A. Hoopaugh, Department of Fish & Game, P.O. Box 1480, Redding, CA 96099
354. Peter House, Office of Technology Impacts, Department of Energy, Washington, DC 20545
355. David Hughes, Commissioner, Federal Energy Regulatory Commission, 825 North Capitol Street, NE, Washington, DC 20426
356. Hydropower Study Manager, New England River Basins Commission, 53 State Street, Boston, MA 02109
357. Angelo Incerpi, Vermont Fish & Game Department, Montpelier, VT 05602
358. Indiana Energy Group, 115 North Pennsylvania Street, Indianapolis, IN 46204
359. Institute of Natural Resources, 309 West Washington Street, Chicago, IL 60606
360. Iowa Energy Policy Council, 707 East Locust Street, Des Moines, IA 50319
361. Bard Jackson, National Rural Electric Cooperative Assoc., 1800 Massachusetts Avenue, NW, Washington, DC 20036
362. Robert M. Jenkins, U.S. Fish & Wildlife Service, National Reservoir Research Program, Fayetteville, AR 72701
363. Neal C. Jennings, Director, Division of Hydropower Resources Analysis, Office of Electric Power Regulation, Federal Energy Regulatory Commission, 825 North Capitol Street, NE, Washington, DC 20426
364. Joseph T. Johnson, Environmental Assessment and Support Staff, Energy Demonstrations and Technology, 1110 Chestnut Street, Tower II, Chattanooga, TN 37401
365. K. Randell Jones, Water Resources Engineer, Law Engineering Testing Company, 2749 Delk Road, SE, Marietta, GA 30067
366. Nancy Kaiser, Southern States Energy Board, One Exchange Place, 2300 Peachford Rd., Suite 1230, Atlanta, GA 30338

367. Peter Kakela, Department of Resource Development, Michigan State University, East Lansing, MI 48824
368. Jennifer Kauffman, Ayres, Lewis, Morris and May, Inc., 3983 Research Park Drive, Ann Arbor, MI 48104
369. John Kauffman, P.O. Box 66, Free Union, VA 22940
370. Tom Keevin (ED-BA), U.S. Army Corps of Engineers, 210 N. Tucker Blvd., St. Louis, MO 63101
371. Senator John Kelly, P.O. Box 30036, Lansing, MI 48909
372. Rob Kelsey, U.S. Fish & Wildlife Services, Ecological Services, 1825B Virginia St., Annapolis, MD 21401
373. John Kelso, Department of Fisheries and Oceans, 875 Queen Street, E. Sault Ste. Marie, Ottawa, Ontario, Canada P6A 2B3
374. H. T. Kemp, U.S. Fish & Wildlife Service (OBS), Lloyd 500 Bldg., Portland, OR 97232
375. Kentucky Department of Energy, Capitol Plaza Tower, Frankfort, KY 40601
376. William Knapp, Northeast Power Plant Activities Leader, U.S. Fish & Wildlife Service, One Gateway Center, Newton Corner, MA 02158
377. Alexis E. Knight, Division of Fishery Services, U.S. Fish & Wildlife Services, Federal Building, Room 124, Laconia, NH 03246
378. Michael Kowalchuk, Direction des Eaux Interieures, 1901 Avuenue Victoria, Regina, Saskatchewan, S4P 3R4 Canada
379. Boyd Kynard, Mass. Cooperative Fishery Research Unit, U.S. Fish & Wildlife Service, Holdsworth Hall, University of Massachusetts, Amherst, MA 01003
380. George W. LaBar, Wildlife & Fisheries Biology, University of Vermont, Burlington, VT 05405
381. Jim LaBounty, Water and Power Resources Service, P.O. Box 25007, Building 67, Denver Federal Center, Denver, CO 80225
382. Robert Lackey, U.S. Fish & Wildlife Service, Eastern Land Use Team, Route 3, Box 44, Kearneysville, WV 25430
383. Wayne Lasch, Michael Baker, Jr., Inc., 4301 Dutch Ridge Road, Box 280, Beaver, PA 15009
384. George H. Lauff, W. K. Kellogg Biological Station, Michigan State University, Hickory Corners, MI 49060
385. Bernie Leman, Chelan County Public Utility District, Wenatchee, WA 98801
386. S. A. Levin, Ecology and Systematics Department, Cornell University, Ithaca, NY 14850
387. Hiram Li, Oregon State Fisheries and Wildlife, 104 Nash Hall, Oregon State University, Corvallis, OR 97331
388. Scott Lindsey, Stetson-Dale, 185 Genosee St., Utica, NY 13501
389. Charles Liston, Department of Fisheries and Wildlife, Michigan State University, East Lansing, MI 48824
390. Cliff Long, National Marine Fisheries Service, Northwest and Alaska Fisheries Center, 2725 Montlake Boulevard East, Seattle, WA 98112
391. Tom MacDonald, California Energy Commission, 1111 Howe Ave., MS-20, Sacramento, CA 95825

392. Murdock M. MacKenzie, L.A., New York State Dept. of Environmental Conservation, 50 Wolf Road, Albany, NY 12233
393. V. R. Maddineni, P.E., 117-1, Middlesex Rd., Waltham, MA 02154
394. H. L. Magleby, Supervisor, Hydropower Loan Program, EG&G Idaho, Inc., P.O. Box 1625, Idaho Falls, ID 83415
395. J. J. Magnuson, Department of Zoology, University of Wisconsin, Madison, WI 53706
396. Edward Mains, U.S. Army Engineer Division, North Pacific Division, P.O. Box 2870, Portland. OR 97208
397. Ross Manes, Allard Inc., P.O. Drawer 3, Ellsworth, KS 67439
398. Susan Mara, INTASA, 1030 Curtis, Menlo Park, CA 94025
399. Gordon Marker, 6 Essex St., Lawrence, MA 01840
400. John T. Marlar, Water Quality Management Branch, Environmental Protection Agency, 345 Courtland Street, Atlanta, GA 30308
401. Massachusetts Energy Policy Office, 73 Tremont Street, Boston, MA 02108
402. David Master, 90 Washington Street, Suite 30, Dover, NH 03820
403. Dilip Mathur, RMC - Ecological Division, Muddy Run Ecological Laboratory, P.O. Box 10, Drumore, PA 17518
404. Howard A. Mayo, Jr., Manager, Market Development, Hydro-Turbine Division, Allis-Chalmers Corporation, Box 712, York, PA 17405
405. Helen McCammon, Director, Division of Environmental Research, Office of Health and Environmental Research, Department of Energy, Washington, DC 20545
406. Richard McDonald, Institute for Water Resources, Kingman Building, Ft. Belvoir, VA 22060
407. William G. McDonald, Executive Director, Federal Energy Regulatory Commission, 825 North Capitol Street, NE, Washington, DC 20426
408. Georgia McKay, Envirocon Limited, 300-475 West Georgia St., Vancouver, British Columbia, Canada V6B 4M9
409. James J. McKevitt, U.S. Department of the Interior, Fish and Wildlife Service, Division of Ecological Services, 2800 Cottage Way, Room E-2727, Sacramento, CA 95825
410. J. D. McKinney, EG&G Idaho Inc., Box 1625/WCB, Idaho Falls, ID 83415
411. Estyn R. Mead, U.S. Fish & Wildlife Service, 100 Grange Place, Cortland, NY 13045
412. Tony Meier, U.S. Army Corp of Engineers, St. Louis District, 210 Tucker Blvd. N, St. Louis, MO 63101
413. J. A. Miakisz, Environmental Analyst, Niagara Mohawk Power Corporation, 300 Erie Boulevard West, Syracuse, NY 13202
414. Michigan Energy Administration, Michigan Department of Commerce, Law Building - 4th Floor, Lansing, MI 48913
415. Peter Milloy, MMWEC, P.O. Box 426, Ludlow, MA 01056
416. Minnesota Energy Agency, 740 American Center Building, 160 East Kellogg Boulevard, St. Paul, MN 55101
417. Mississippi Fuel and Energy Management Commission, Woolfolk State Office Building, Jackson, MS 39302

418. Missouri Energy Program, Department of Natural Resources, P.O. Box 1039, Jefferson City, MO 65101
419. Montana Energy Office, Capitol Station, Helena, MT 59601
420. David Morantz M. Sc., Watercourse Alteration Unit, Resource Branch, P.O. Box 550, Halifax, Nova Scotia, B3J 2S7
421. J. Emil Morhardt, Director(2), Western Operations, Ecological Analysts, Inc., 2150 John Glenn Drive, Concord, CA 94520
422. Municipal Planning Office, Executive Office of the Mayor, District Building, 13th and E Streets, NW, Washington, DC 20004
423. Haydn H. Murray, Director, Department of Geology, Indiana University, Bloomington, IN 47405
424. Nebraska Energy Office, P.O. Box 95085, Lincoln, NE 68509
425. Nevada Department of Energy, 1050 East Will - Suite 405, Carson City, NV 89710
426. New York State Energy Office, Agency Building No. 2, Empire State Plaza, Albany, NY 12223
427. John O'Leary, MA Cooperative Fishery Research Unit, U.S. Fish & Wildlife Service, 4 Whalley Street, Hadley, MA 01035
428. R. Malcolm Odell, Conservation Authories, Water Management Branch, Room 5620, Whitney Block, Queen's Park, MTA 1W3, Canada
429. Office of Assistant Manager for Energy Research and Development, Department of Energy, Oak Ridge Operations Office, Oak Ridge, TN 37830
430. Office of Economic Planning and Development, Capitol Tower, Phoenix, AZ 85007
431. Office of Emergency and Energy Services, 7700 Midlothian Turnpike, Richmond, VA 23235
432. Office of Energy Policy, State Capitol, Pierre, SD 57501
433. Office of Energy Resources, Office of Planning and Budget, 270 Washington Street, S.W., Atlanta, GA 30334
434. Office of Energy Resources, 55 Capitol Street, Augusta, ME 04339
435. Office of the Governor, Minnillas Government Center, North Building, P.O. Box 41089, Minnillas Station, Santurce, PR 00940
436. Office of State Planning and Energy, 1 Wilson Street, Madison, WI 53702
437. Ohio Energy and Resource Development Agency, State Office Tower, 30 East Broad Street, Columbus, OH 43215
438. Oklahoma Department of Energy, 4400 North Lincoln Boulevard, Oklahoma City, OK 73105
439. Raymond C. Oligher, Walla Walla District, Corps of Engineers, Building 602, City-County Airport, Walla Walla, WA 99362
440. Paul Orser, Stone and Webster Engineering, P.O. Box 2325, Boston, MA 02107
441. W. S. Osburn, Division of Ecological Research, Office of Health and Environmental Research, Department of Energy, Washington, DC 20545
442. Robert G. Otto, Robert G. Otto and Associates, 1808 Dixon Road, Baltimore, MD 21209

443. Merlyn Paine, Center 4 Engineering, 523 South 7th Street, Suite A, P.O. Drawer A, Redmond, OR 97756
444. John Palensky, Bonneville Power Administration, P.O. Box 3621, Portland, OR 97208
445. Steve Parker, Federal Energy Regulatory Commission, 825 N. Capital St., NE, Washington, DC 20426
446. Donald G. Pauken, Stanley Consultants, Inc., Stanley Building, Muscatine, IA 52761
447. Barbara Pearson, State of Washington, Department of Ecology, Mail Stop PV-11, Olympia, WA 98504
448. R. Peterson, U.S. Fish & Wildlife Service (OBS), Lloyd 500 Bldg., Portland, OR 97232
449. H. J. Petrimoulx, Environmental Resources Management, Inc., Executive Center, 999 West Chester Pike, West Chester, PA 19380
450. Douglas Pewitt, Acting Director, Office of Energy Research, ER-1, Department of Energy, Washington, DC 20545
451. Ralph C. Pisapia, U.S. Fish & Wildlife Service (OBS), Lloyd 500 Bldg., Portland, OR 97232
452. Program Coordinator, Biological Services, U.S. Fish & Wildlife Service, Washington, DC 20240
453. Program Coordinator, Land and Water Resource Development Planning, U.S. Fish & Wildlife Service, Washington, DC 20240
454. Robert Rabin, National Science Foundation, Washington, DC 20545
455. Robert Raleigh, U.S. Fish & Wildlife Service, 2625 Redwing Road, Ft. Collins, CO 80521
456. Walter Rast, International Joint Commission, 1717 H. Street, NW, Room 203, Washington, DC 20440
457. Gerald J. Rausa, Environmental Protection Agency, 401 M Street, NW, Washington, DC 20460
458. Regional Administrator, U.S. Environmental Protection Agency - Region I, John F. Kennedy Building, Boston, MA 02203
459. Regional Administrator, U.S. Environmental Protection Agency - Region II, 26 Federal Plaza, New York, NY 10007
460. Regional Administrator, U.S. Environmental Protection Agency - Region III, 6th and Walnut Streets, Philadelphia, PA 19106
461. Regional Administrator, U.S. Environmental Protection Agency - Region IV, 345 Courtland Street, NE, Altanta, GA 30308
462. Regional Administrator, U.S. Environmental Protection Agency - Region V, 230 South Dearborn Street, Chicago, IL 60604
463. Regional Administrator, U.S. Environmental Protection Agency - Region VI, First International Building, 1201 Elm Street, Dallas, TX 75270
464. Regional Administrator, U.S. Environmental Protection Agency - Region VII, 1735 Baltimore Street, Kansas City, MO 64108
465. Regional Administrator, U.S. Environmental Protection Agency - Region VIII, 1860 Lincoln Street, Denver, CO 80203
466. Regional Administrator, U.S. Environmental Protection Agency - Region IX, 215 Fremont Street, San Francisco, CA 94105
467. Regional Administrator, U.S. Environmental Protection Agency - Region X, 1200 6th Street, Seattle, WA 98101

468. Regional Director, Bureau of Reclamation, Lower Colorado Region, P.O. Box 427, Boulder City, NV 89005
469. Regional Director, Bureau of Reclamation, Lower Missouri Region, Bldg. 20, Denver Federal Center, Denver, CO 80225
470. Regional Director, Bureau of Reclamation, Mid-Pacific Region, 2800 Cottage Way, Sacramento, CA 95825
471. Regional Director, Bureau of Reclamation, Pacific Northwest Region, P.O. Box 043, U.S. Court House, 550 W. Fort St., Boise, ID 83724
472. Regional Director, Bureau of Reclamation, Southwest Region, Herring Plaza, Box H-4377, Amarillo, TX 79101
473. Regional Director, Bureau of Reclamation, Upper Colorado Region, P.O. Box 11568, Salt Lake City, UT 84111
474. Regional Director, Bureau of Reclamation, Upper Missouri Region, P.O. Box 2553, Billings, MT 59103
475. Regional Director, North Central Region, U.S. Fish & Wildlife Service, Federal Bldg., Fort Snelling, Twin Cities, MN 55111
476. Regional Director, Northeast Region, U.S. Fish & Wildlife Service, 1 Gateway Center, Newton, MN 02158
477. Regional Director, Pacific Region, U.S. Fish & Wildlife Service, 500 NE Multnomah St., Portland, OR 97232
478. Regional Director, Southeast Region, U.S. Fish & Wildlife Service, Federal Bldg., 75 Spring St., SW, Atlanta, GA 30303
479. Regional Director, Southwest Region, U.S. FISH & WILDLIFE, Dennis Chaves Bldg., U.S. Courthouse, 500 Gold Ave., SW, Albuquerque, NM 87103
480. Regional Director, Denver Region, U.S. Fish & Wildlife Service, P.O. Box 25486, Denver Fed. Center, Denver, CO 80225
481. Suzanne Reichelderser, Spokane County Planning Dept., North 721 Jefferson, Spokane, WA 99260
482. J. J. Reisa, Office of Toxic Substances, Environmental Protection Agency, Washington, DC 20460
483. Bill Renfro, Northeast Utilities Service Company, P.O. Box 270, Hartford, CT 06101
484. John Reynolds, Consumers Power Company, 1945 Parnell Road, Jackson, MI 49201
485. Graham A. Richard, President, Midwest Hydro Corporation, P.O. Box 5343, Fort Wayne, IN 46895
486. F. Paul Richards, Chas. T. Main, Inc., Environmental & Resource Planning Division, Prudential Center, Boston, MA 02199
487. W. A. Richtus, Martin Marietta Environmental Center, 1450 S. Rolling Rd., Baltimore, MD 21227
488. Bud Ris, New England River Basins Study Commission, 53 State St., Boston, MA 02109
489. Paul G. Risser, Office of the Chief, Illinois Natural History Survey, Natural Resources Building, 607 E. Peabody Ave., Champaign, IL 61820
490. Ben Rizzo, U.S. Fish & Wildlife Service, One Gateway Center, Newton Corner, MA 02158
491. John Robinson, HARZA Engineering Co., 150 South Wacker Drive, Chicago, IL 60606

492. Mark Robinson, Federal Energy Regulatory Commission, 825 N. Capitol Street, Washington, DC 20426
493. Janice Rosenberg, Wapora Inc., 35 East Wacken Drive, Chicago, IL 60601
494. Richard E. Rosenthal, Management Science Program, University of Tennessee, Knoxville, TN 37916
495. James Ruane, Tennessee Valley Authority, 246 401 Building, Chattanooga, TN 37401
496. C. P. Ruggles, Executive Biologist, Montreal Engineering, Ltd., Garrison Place, 1526 Dresden Row, Halifax, Nova Scotia B3J 3J1
497. J. J. Sartoris, Water and Power Resources Service, P.O. Box 25007, Building 67, Denver Federal Center, Denver, CO 80225
498. George Saunders, Office of Health and Environmental Research, Department of Energy, Washington, DC 20545
499. D. Scarrett, St. Andrews Biological Station, New Brunswick, Canada E0G 2X0
500. William M. Seawell, Tennessee Valley Authority, Evans Building, Knoxville, TN 37902
501. Richard M. Shane, TVA, Office of Natural Resources, Division of Water Resources, Norris, TN 37828
502. T. L. Shaw, Rock Cottage, Blagdon, Bristol BS18 6TW, Great Britain
503. Hon. Georgiana Sheldon, Acting Chairman, Federal Energy Regulatory Commission, 825 North Capitol Street, NE, Washington, DC 20426
504. Dean Shumway, Federal Energy Regulatory Commission, 825 N. Capitol Street, Washington, DC 20426
505. Carl Shuster, Office of Regulatory Analyses, Federal Energy Regulatory Commission, 825 N. Capital St., NE, Washington, DC 20426
506. Lorna Sicarello, U.S. Fish & Wildlife Service, Coastal Ecosystems, 1612 June Avenue, Panama City, FL 32405
507. Joseph Silvey, Envirosphere Company, 130 Newport Center Drive, Newport Beach, CA 92660
508. Ernest E. Sligh, Chief, Basin & Project Plans Branch/DHRA, Office of Electric Power Regulation, Federal Energy Regulatory Commission, 825 North Capitol Street, NE, Washington, DC 20426
509. K. E. H. Smith, Freshwater and Anadromous Division, Resource Branch, Department of Fisheries and Oceans, P.O. Box 550, Halifax, Nova Scotia B3J 2S7
510. Ronald Smith, National Conference of State Legislatures, 1405 Curtis Street, Denver, CO 80202
511. Everett Spencer, President, Merrymeeting Bay Chapter #329, 44 Mallett Drive, Topsham, Maine 04086
512. Clair Stalnaker, Cooperative Instream Flow Service Group, U.S. Fish & Wildlife Service, 2625 Redwing Rd., Drake Creekside Bldg. #2, Ft. Collins, CO 80526
513. State Energy Office, Mackay Building, 338 Denali Street, Anchorage, AK 99501

514. State Energy Office, State Capitol, Denver, CO 80203
515. State Energy Office, State House, Boise, ID 83720
516. State Energy Office, 108 Collins Building, Tallahassee, FL 32304
517. State Office of Energy Management, Capitol Place Office, 1533 North 12th Street, Bismarck, ND 58501
518. State Planning Coordinator, 2320 Capitol Avenue, Cheyenne, WY 82002
519. State of Kansas Energy Office, 503 Kansas Avenue, Topeka, KS 66603
520. Q. J. Stober, Fisheries Research Institute, College of Fisheries, University of Washington, Seattle, WA 98195
521. Andrew V. Stout, Coordinator, The International Atlantic Salmon Foundation, New England Office, Box 651, 9 South Main Street, Hanover, NH 03755
522. Blair Swezey, Energy Study Center, Electric Power Research Center, P.O. Box 10412, Palo Alto, CA 94303
523. Thomas Tatham, Charles T. Main Inc., c/o Power Authority, State of New York, 10 Columbus Circle, (17th Floor), New York, NY 10019
524. Maurice H. Taylor, U.S. Fish & Wildlife Service (OBS), Lloyd 500 Bldg., Portland, OR 97232
525. Tennessee Energy Authority, 250 Capitol Hill Building, Nashville, TN 37219
526. Texas Energy Advisory Council, 7703 North Lamar Boulevard, Austin, TX 78752
527. David Thomas, Charles T. Main, Inc., S.E. Town, Prudential Center, Boston, MA 02199
528. Kent W. Thornton, Environmental Laboratory, United States Army Corps of Engineers, Waterways Experiment Station, Vicksburg, MS 39180
529. Ann Thrupp, Worldwatch Institute, 1776 Massachusetts Avenue, NW, Washington, DC 20036
530. Joseph Tieger, Division of Ecological Services, U.S. Fish & Wildlife Service, 18th & C. Sts., NW, Washington, DC 20240
531. Alta Turner, Envirosphere Company, Two World Trade Center, New York, NY 10048
532. Gerald Ulrickson, Science Applications, Inc., 800 Oak Ridge Turnpike, Oak Ridge, TN 37830
533. Richard Urban, TVA, Office of Natural Resources, Division of Water Resources, FDB Building, Muscle Shoals, AL 35660
534. Utah Energy Office, 231 East 400 South, Salt Lake City, UT 84111
535. Kathey Veit, Office of Federal Activities, U.S. Environmental Protection Agency, Mail Code A104, 401 M Street, SW, Washington, DC 20460
536. Vermont Energy Office, Pavilion Office Building, 109 State Street, Montpelier, VT 05602
537. Erdie Vinson, Facility Siting Division, Department of Natural Resources and Conservation, 32 South Ewing, Helena, MT 59601
538. Harold Wahlquist, Regional Activities Leader, Power Generation/Water Resources, U.S. Fish & Wildlife Service, Federal Bldg., 75 Spring St., SW, Atlanta, GA 30303

539. William W. Walker, Environmental Engineer, 1127 Lowell Road,
Concord, MA 01742

540. Gary Walterbaugh, Pacific Northwest River Basin Commission,
One Columbia River, Vancouver, WA 98660

541. Philip Wampler, U.S. Fish & Wildlife Service (Fisheries
Assistance), 2625 Parkmont Lane, Bldg. A, Olympia, WA 98504

542. John Warner (MCFRU), 310 Holdsworth Hall, University of
Massachusetts, Amherst, MA 01003

543. Cal Warnick, Idaho Water Research Institute, University of
Idaho, Washington Energy Office, 400 East Union Street,
Olympia, WA 98504

544. John L. Warren, President, Southeast Hydro Corporation,
5708 Dedmon Court, Durham, NC 27713

545. Walton Watt, Head, Fish Habitat Protection Freshwater and
Anadromous Division, Resource Branch, Department of Fisheries
and Oceans, P.O. Box 550, Halifax, Nova Scotia B3J 2S7

546. Robert L. Watters, Office of Health and Environmental
Research, Department of Energy, Washington, DC 20545

547. Don Weitkamp, Parametrix, Inc., 13020 Northup Way, Suite 8,
Bellevue, WA 98005

548. Rod Wentworth, 201 Hills Bldg., University of Vermont,
Burlington, VT 05401

549. Leigh Whitlock, U.S. Fish & Wildlife Service, P.O. Box 1306,
Albuquerque, NM 87103

550. Frank J. Wobber, Office of Environmental Research, Division
of Ecological Research, Department of Energy, Mail Stop E201,
Washington, DC 20545

551. Robert W. Wood, Office of Health and Environmental Research,
Department of Energy, Washington, DC 20545

552. William B. Wren, Tennessee Valley Authority, Athens, AL 35611

553. R. A. Wright, Manager, Hydraulic Plant Equipment, Ontario
Hydro, 700 University Avenue, Toronto M5G 1Xb, Canada

554. Kathy Yergeau (MCFRU), 310 Holdsworth Hall, University of
Massachusetts, Amherst, MA 01003

555. David Zoellner, National Electric Cooperative Association,
1800 Massachusetts Ave., NW, Washington, DC 20036

556-765. Given distribution as shown in DOE/TIC-4500 under category
UC-97e, Hydroelectric Power Generation

☆U.S. GOVERNMENT PRINTING OFFICE: 1981-740-062/259