PNL-5925
UC-94e

18L

# Underground Energy Storage Program

## 1985 Annual Summary

August 1986

Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

Pacific Northwest Laboratory
Operated for the U.S. Department of Energy
by Battelle Memorial Institute

Battelle

PNL-5925

**DISCLAIMER**

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

PACIFIC NORTHWEST LABORATORY
*operated by*
BATTELLE
*for the*
UNITED STATES DEPARTMENT OF ENERGY
*under Contract DE-AC06-76RLO 1830*

Printed in the United States of America
Available from
National Technical Information Service
United States Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22161

NTIS Price Codes
Microfiche A01

Printed Copy

| Pages | Price Codes |
|---|---|
| 001-025 | A02 |
| 026-050 | A03 |
| 051-075 | A04 |
| 076-100 | A05 |
| 101-125 | A06 |
| 126-150 | A07 |
| 151-175 | A08 |
| 176-200 | A09 |
| 201-225 | A010 |
| 226-250 | A011 |
| 251-275 | A012 |
| 276-300 | A013 |

3 3679 00057 0285

PNL-5925
UC-94e

# UNDERGROUND ENERGY STORAGE PROGRAM

# 1985 ANNUAL SUMMARY

J. R. Raymond
L. D. Kannberg

August 1986

Prepared for
the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

Pacific Northwest Laboratory
Richland, Washington 99352

# PREFACE

This is the 1985 Annual Summary for the Underground Energy Storage Program, which is administered by the Pacific Northwest Laboratory (PNL) for the U.S. Department of Energy (DOE). This document describes all of the major research funded under this program during the period from April 1985 through March 1986.

The report summarizes the activities and notable progress toward program objectives in seasonal thermal energy storage (STES). Readers wishing additional information on specific topics are invited to contact Landis Kannberg at PNL.

The work described in this report represents one segment of a continuing effort to encourage development and implementation of advanced energy storage technology. The results and progress reported here rely on earlier studies and will, in turn, provide a basis for continued efforts to develop STES technologies.

L. D. Kannberg, Manager
Underground Energy Storage Program

SUMMARY

Underground Energy Storage (UES) Program activities during the period from April 1985 through March 1986 are briefly described. Primary activities in STES involved field testing of high-temperature [$>$100°C (212°F)] aquifer thermal energy storage (ATES) at St. Paul, monitoring of the University of Alabama Student Recreation Center in Tuscaloosa, Alabama, and limited numerical modeling efforts in support of these subcontracts.

The first long-cycle test at the University of Minnesota field test facility was completed. Initiated in November 1984, it consisted of approximately 59 days of heated water injection, 64 days of storage, and 58 days of heated water recovery. To overcome problems caused by calcium precipitation encountered during the short-cycle tests, an ion-exchange water softener was installed in the system. The softener, after debugging, allowed injection to proceed with few interruptions. A total of 9.21 x $10^4$ $m^3$ of heated water was stored during the injection phase. During recovery, 9.22 x $10^4$ $m^3$ of water were extracted at a mean temperature of 74.7°C (166.5°F). Flow during recovery averaged 18.4 ℓ/sec. Using the energy that was added to the water as a base, 62% of the stored energy was recovered. If the ambient ground-water temperature is used as a base, 65% of the energy was recovered. The significant amount of energy recovered and the relatively slow decline in temperature during the early portion of the recovery period suggest that a significant amount of useful thermal energy may be recovered in seasonal operation.

Chemistry of the recovered water was close to what was expected. However, a significant quantity of sodium, added by the water softener, was not returned during recovery. The fate of the sodium is being investigated. Modeling efforts performed in support of this test indicate good agreement between model-generated results and actual field data. The data generated by the models accurately predicted final withdrawal temperatures and aquifer thermal efficiencies for both the long-cycle test and the four short-cycle tests (performed in FY84), with differences of no more than $\pm$8°C ($\pm$46°F).

Limited experimentation was done by PNL to characterize physical and chemical processes at the ATES test facility. Efforts included testing at

the site to characterize fluid injectability and geochemical studies to investigate chemical reactions resulting from alterations to the aquifer's thermal regime. Membrane filter tests, conducted during injection and withdrawal pumping periods to anticipate well impairment by particle plugging, indicated that fluids injected had very low suspended solids. Overall, the filter tests results indicate that, at temperatures to 115°C (239°F), well impairment due to suspended solids is not a problem. Onsite core flooding tests, conducted to aid in determining response of the aquifer formation to the injected fluid, demonstrated that over 20,000 pore volumes of fluid in the 93 to 110°C (199 to 230°F) temperature range can be passed through representative core samples with no significant loss in permeability.

A chill ATES monitoring project, initiated at the Student Recreation Center on the University of Alabama campus, continued during the reporting period. Instrumentation and a computerized data acquisition system were installed to obtain and record data on ATES parameters. However, problems with both hardware and software still must be corrected. As a result, data that were to be automatically collected by the computer system during 1985 were obtained manually. ATES system temperatures, flow rates, ground-water levels, and electrical energy inputs were monitored, and system performance was evaluated. Additional tests were conducted to better define aquifer characteristics of transmissivity, hydraulic conductivity, and hydraulic gradient. During CY 1985, more than 64,400 $m^3$ (17 million gallons) of water were chilled and injected into the aquifer; more than 75,700 $m^3$ (20 million gallons) of ground water were pumped from the aquifer to air condition the recreation center. The system has shown a general recovery of about 38% with some additional losses in the building air conditioning system. Changes are being made to increase the water temperature differential in the building. In addition, a large mass of cold ground water moves down gradient and is lost as a result of the natural flow. Methods for correcting this loss are being investigated.

Numerical modeling efforts were continued at a minimum level by PNL to support field studies. The Aquifer Thermal Energy Storage System Simulator (ATESSS) code was modified to allow quantification of the impact of permeability differences on the ATES system's thermal efficiency. A suite of simulations has been performed to establish whether a set of dimensionless parameters can be related to the thermal efficiency. The chill ATES facility at the University of Alabama Student Recreation Center was simulated with the Unconfined Aquifer Thermal Energy Storage (UCATES) model to examine the effect of different injection/recovery patterns on the system's thermal performance. The simulation showed that, by using the up-gradient wells to mitigate the regional drift encountered at the site, a significant improvement in thermal efficiency may be possible. An ATES facility being proposed at the General Motors Rochester plant will also be simulated with the UCATES code. Again, mitigating the regional flow at this site is the primary concern.

Underground Energy Storage Program researchers and DOE staff participated in international exchange of technical information on a number of STES concepts and systems. Many nations are making substantial investments in research, demonstration, and pilot commercial projects in STES. Pacific Northwest Laboratory continued its participation, on behalf of DOE, in the IEA Task III (ATES field testing) of the Energy Storage Programme.

## CONTENTS

## FIGURES

## TABLES

## ACKNOWLEDGMENTS

Progress achieved during the April 1985 through March 1986 reporting period is attributed to multiple subcontractors working with the Underground Energy Storage Program staff. These included M. Walton and M. Hoyer, Minnesota Geological Survey, Minneapolis, Minnesota; S. Richards, University of Minnesota, Minneapolis, Minnesota; and W. J. Schaetzle and C. E. Brett, University of Alabama, Tuscaloosa, Alabama.

The program task and project leaders from the Pacific Northwest Laboratory also merit acknowledgment. These researchers include J. R. Raymond, P. J. Mitchell, L. W. Vail, and S. C. Blair (formerly of PNL).

D. Segna, U.S. Department of Energy, Richland Operations Office, and E. Reimers, U.S. Department of Energy, Washington, D.C., have provided direction to the program and served as program monitors at their respective operations centers. Management assistance has also been provided by I. Gyuk.

Credit for developing the draft and final versions of this report goes to S. J. Arey of PNL. A. J. Currie of PNL edited the report.

The dedicated efforts of all these individuals are acknowledged and greatly appreciated.

UNDERGROUND ENERGY STORAGE PROGRAM
1985 ANNUAL SUMMARY

# 1.0 INTRODUCTION

As a nation, we are challenged with the need to develop alternative energy sources and find ways of using existing energy supplies more efficiently. Our economic and strategic security may be at risk if we do not accept and meet this challenge.

The U.S. Department of Energy (DOE) established a program to encourage timely implementation of underground energy storage (UES) concepts as one of many ways to meet this challenge. The overall goal of the DOE program is to reduce the technical and economic uncertainties inhibiting development and implementation of promising underground energy storage concepts. If this were achieved, the residential, commercial, and industrial energy users could reduce energy consumption, increase the efficiency of existing energy supply capacity, reduce their reliance on scarce energy resources, and take greater advantage of alternative energy sources.

Studies have shown that two UES concepts--seasonal thermal energy storage (STES) and compressed air energy storage (CAES)--are technically feasible and, under certain conditions, can offer significant cost savings for utilities, industry, and, in some cases, commercial building developers and operators. Both of these technologies contribute to the reduction in national consumption of petroleum resources and more efficient use of present electric generation capacity. Department of Energy-sponsored CAES studies were transferred to the private sector in 1984, and the technology is now being commercially applied at two sites in the U.S.

Seasonal storage and retrieval of thermal energy, using heat or cold available from waste or other sources, shows great promise to reduce peak demand, reduce electric utility load problems, and contribute to establishing favorable economics for district heating and cooling systems. The numerous motivations for storing large quantities of thermal energy on a long-term basis include

- the need to store solar heat, collected in the summer, for use in the winter
- the cost-effectiveness of utilizing heat now wasted in electrical generation plants
- the need to profitably use industrial waste heat
- the need to more economically provide summer cooling for buildings.

Aquifers, ponds, earth, lakes, and engineered structures have potential for seasonal storage. It has been estimated that STES is technically capable of reducing peak national demand for energy by as much as 7.5%.

Storage in aquifers appears to be one of the most economical and widely applicable seasonal thermal energy storage techniques. Most geologists and ground-water hydrologists agree that heated and chilled water can be injected, stored, and recovered from aquifers. Geologic materials can be good thermal insulators, and potentially suitable aquifers are distributed throughout the aquifer thermal energy storage (ATES) system.

Many potential energy sources exist for use in an ATES system. These include solar heat, power plant cogeneration, winter chill, and industrial waste heat sources such as aluminum plants, paper and pulp mills, food processing plants, refuse incineration units, cement plants, and iron and steel mills. Energy sources ranging from 50°C (122°F) to over 250°C (482°F) are available for heating. Potential energy uses include individual- or district-scale space heating, industrial or institutional plant heating, and heat for processing/manufacturing. Studies and small-scale field experiments have reported energy recovery ratios above 60% for seasonal storage; values over 70% are expected to be readily obtainable. Other STES methods also appear feasible. Ice generation or harvesting followed by seasonal storage may augment or replace substantial portions of building space air conditioning, which accounts for summer electrical peak demand for many utilities. Alternatives such as lakes, ponds, and moist or dry earth for thermal storage are also viable for exploiting the seasonal characteristics of energy availability and requirements. These methods are probable candidates where siting conditions are favorable.

In 1979, the Pacific Northwest Laboratory (PNL)[a] was selected as DOE's lead laboratory in researching and developing STES technology. As lead laboratory, PNL has managed a comprehensive research and development program to advance STES to the point of adoption by the private sector.

This report documents the work performed and progress made toward resolving and eliminating technical and economic barriers associated with STES technologies. The reporting period extends from April 1985 to March 1986. Work performed prior to April 1985 was documented in previous annual reports (Minor 1980, 1981; Kannberg et al. 1982, 1983, 1984, 1985). The Underground Energy Storage Program approach, structure, history, and milestones are described in Section 2.0. Section 3.0 summarizes technical activities and progress in the STES component of the program.

(a) Operated for the U.S. Department of Energy by Battelle Memorial Institute

## 2.0 UNDERGROUND ENERGY STORAGE PROGRAM

In 1979, Pacific Northwest Laboratory was selected as lead laboratory to investigate STES. Seasonal thermal energy storage concepts can achieve reduced energy consumption, more effective use of current energy capacity, reduced reliance on scarce energy resources, and enhanced use of alternative energy sources. The lead laboratory assignment included responsibility for development and management of the program. Figure 2.1 shows the current configuration of the DOE-funded UES Program.

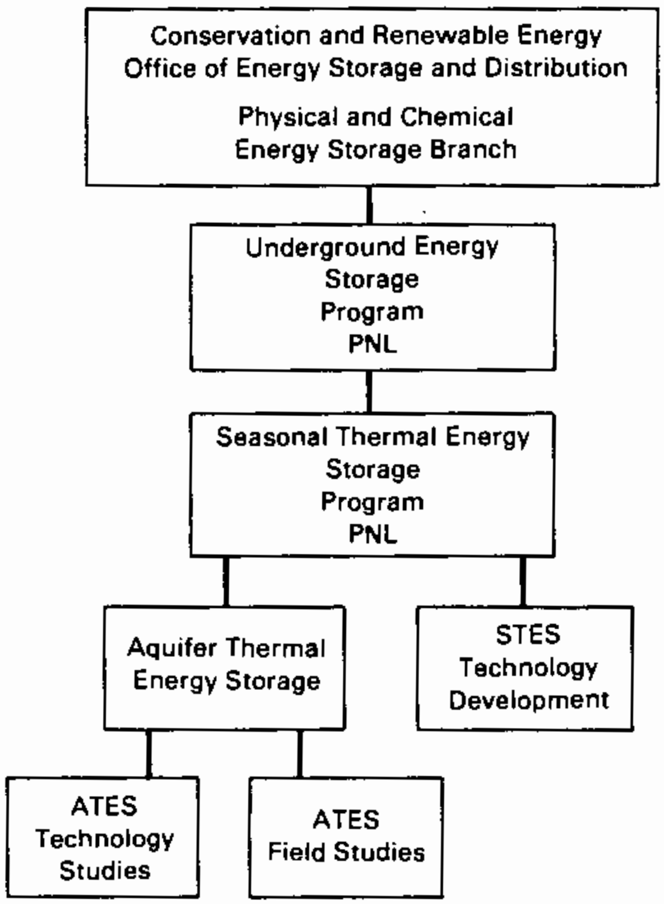



FIGURE 2.1. Department of Energy Programs to Pursue Development of Underground Energy Storage

## 2.1 APPROACH

The general strategy for encouraging timely implementation of UES technologies was to identify the major factors inhibiting development and implementation and then perform the necessary research and development to eliminate technical concerns, clarify nontechnical concerns, and assist private or public groups in the implementation of these technologies. For STES, the following factors inhibit implementation:

- STES methods have not been thoroughly characterized and are considered unproven.
- Potential STES users are unfamiliar with the technology, do not perform research and development, and are technically conservative.
- Some of the most promising STES methods are highly site-specific and require substantial exploratory site investigation; their development can involve extensive interaction with regulatory agencies.
- The economic character of STES methods has not been well defined and varies significantly among sites.
- The annual nature of STES cycles makes technology development a multiyear effort.
- STES technologies typically require significant front-end expenditures.
- STES methods are typically not patentable.
- The wide range of STES system configurations, especially when integrated with heat pumps, makes system selection difficult and confusing.

Early studies indicated that STES utilizing aquifers would be, by far, the most economical STES concept and that promising sites could be found across much of the U.S. It was further recognized that aquifers promised the greatest technical challenge because of the wide range of potential site conditions and because of the breadth of technical issues that would have to be explored and resolved. Therefore, ATES became the prime technology for study in the STES Program.

## 2.2 HISTORICAL SCOPE AND MILESTONES

The historical scope of the DOE-sponsored STES studies is shown in Figure 2.2. Seasonal thermal energy storage studies began in 1975 with field testing at Mobile, Alabama. Other supporting analyses have also been conducted, including numerical modeling, laboratory testing, system studies, economic analyses, and geochemical studies. In 1979, a major effort to demonstrate STES technology was initiated at three sites in the U.S. In 1981, changes in the direction and funding of DOE studies resulted in termination of two of the studies and redirection of the third (at St. Paul, Minnesota) to that of a high-temperature test facility.

The major UES projects conducted in 1985 are indicated in Figure 2.3. It is the policy of the Energy Storage and Distribution Office of DOE to select a few critical milestones for tracking progress in the various programs. These milestones for the UES Program are shown in Figure 2.4.

## 2.3 RESOURCE REQUIREMENTS

The funding requirements, over time, for STES and CAES are shown in Figure 2.5. Historically, funding has been substantially higher than current levels. The current scope of activities stresses more cost-sharing in STES field activities and reduced investigation of STES economics, system behavior, and new STES concepts.

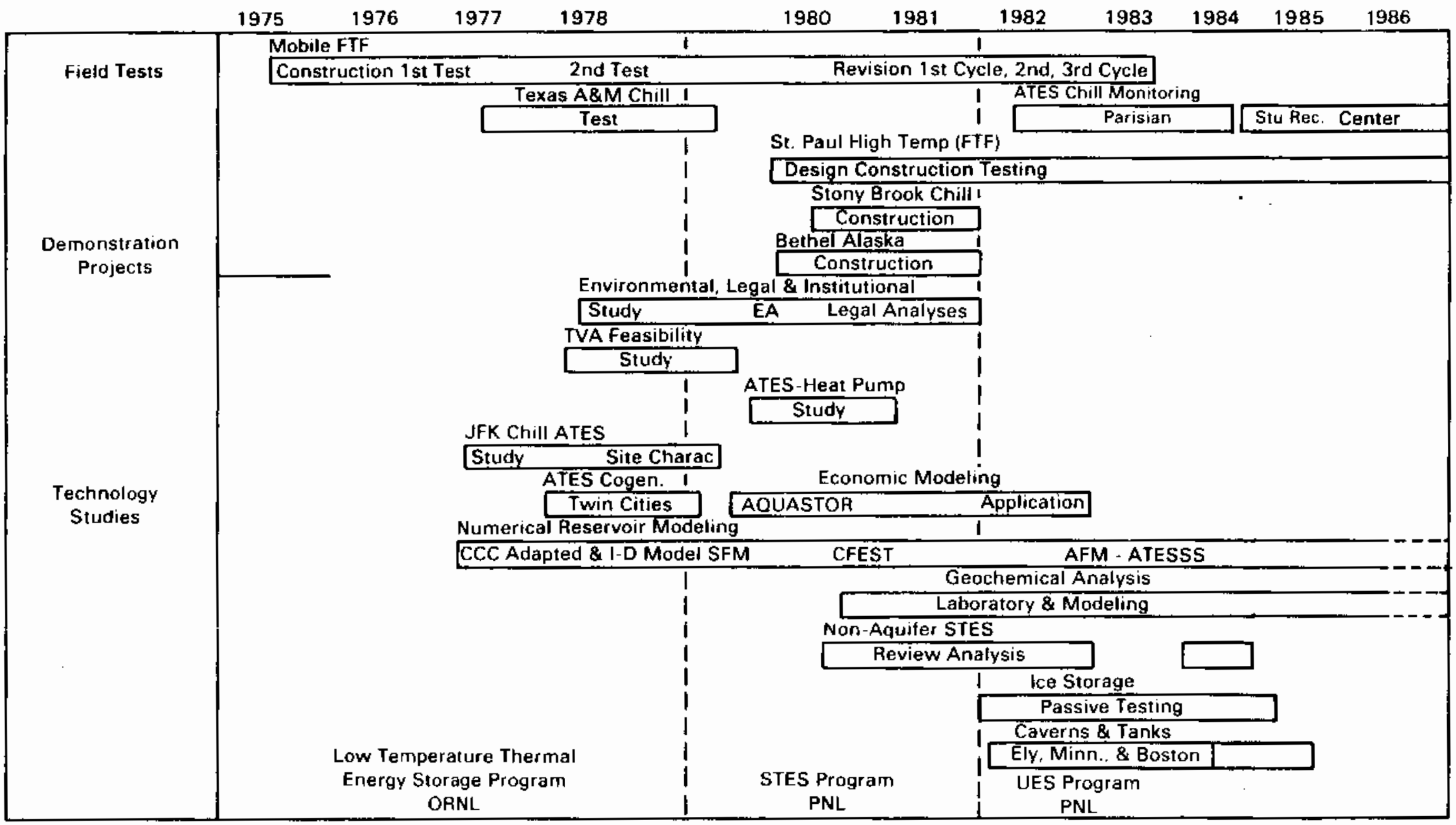
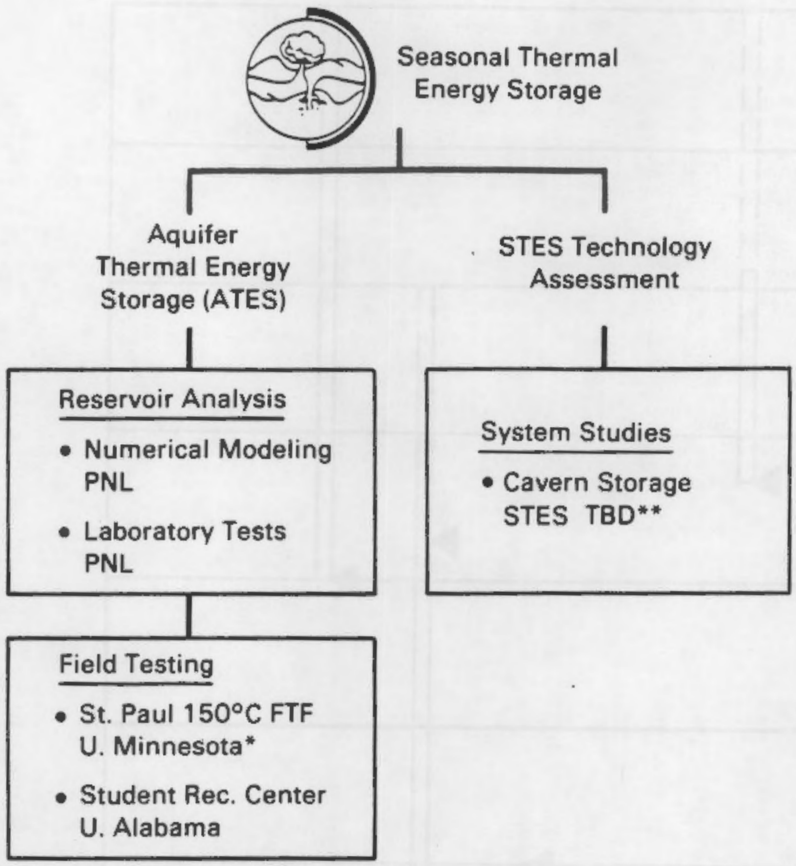



FIGURE 2.2. Department of Energy Seasonal Thermal Energy Storage Program History




*Joint Funded
** To Be Determined

FIGURE 2.3. Underground Energy Storage Program Structure

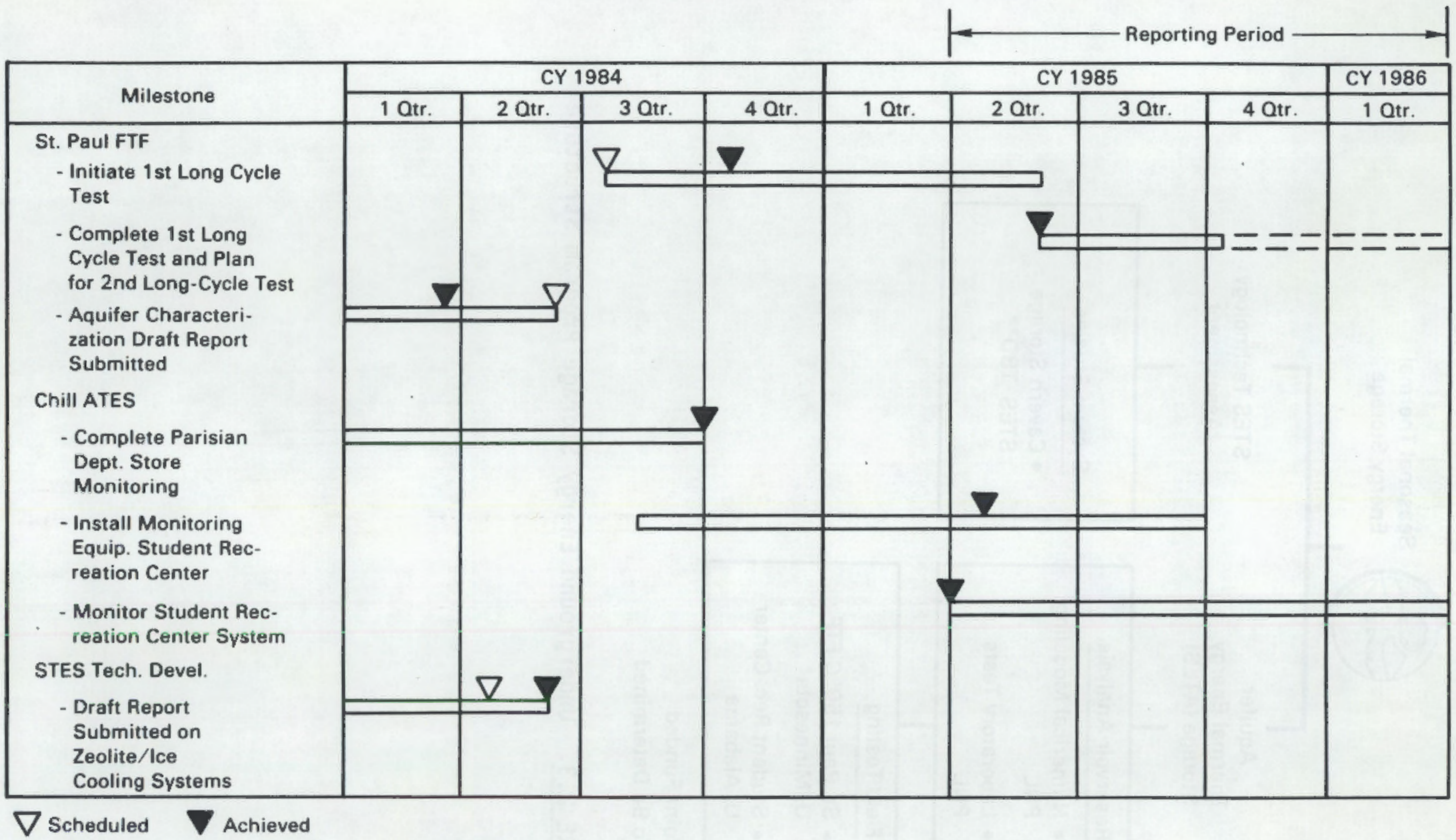



FIGURE 2.4. Underground Energy Storage Program Major Milestones During Reporting Period

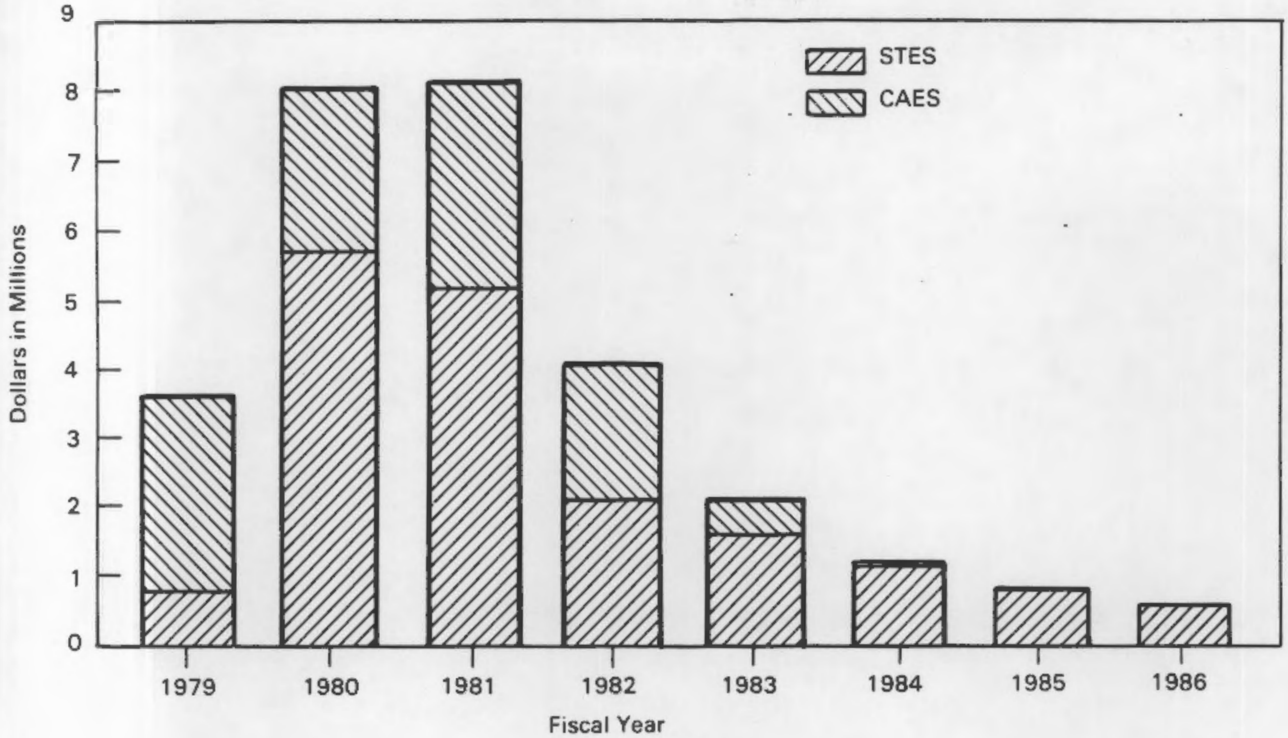



FIGURE 2.5. Underground Energy Storage Program Funding History

## 3.0 SEASONAL THERMAL ENERGY STORAGE

Many nations are currently involved in the research and development of STES technology. Principal among these are France, Denmark, and Canada with their activities related to ATES, and other Scandinavian and European nations in other STES technologies. Typically, the STES development and implementation efforts in these countries are part of national energy conservation efforts funded by the respective governments. With the exception of the U.S., there appears to be no privately funded development of STES; however, current projects include interaction with private organizations in a technology transfer effort.

The studies performed in the U.S. have concentrated on ATES because of its relatively low life-cycle cost and its wide siting opportunities. In particular, a DOE-sponsored study of high-temperature ATES [>100°C (212°F)] has been the major STES-funded activity during the reporting period. Additional studies have been conducted on related ATES technical issues and other STES technologies. Many of these additional studies have attempted to take advantage of public or commercial interest in constructing STES-related systems.

The STES Program is divided into two major elements: ATES Technology Studies and Technology Assessment and Development. The former deals with the technical research and development of ATES and includes laboratory testing, numerical modeling, and field testing of ATES reservoir performance. The latter involves technical studies of other STES concepts.

The major activities of the STES Program are illustrated in Figure 2.3. Subsequent sections briefly discuss progress on these activities during the reporting period. This is followed by a short discussion of the international activities in STES.

### 3.1 ATES TECHNOLOGY STUDIES

Aquifer thermal energy storage technology studies include laboratory and numerical modeling studies as well as field studies. The field studies require the largest portion of the STES budget, receiving about 70% of all STES funding in FY 1985 and a larger portion in FY 1986. As such, field activities will be discussed at greater length than other activities.

### 3.1.1 St. Paul Field Test Facility[a]

The purposes of the University of Minnesota ATES project are to design, construct, and operate a field test facility (FTF) to study the feasibility of moderately high-temperature [up to 150°C (302°F)] thermal energy storage in a confined aquifer. The St. Paul FTF is designed to inject and recover heat at a rate of 5 MW (thermal) using a well doublet spaced at 255 m, operating at 18.9 ℓ/sec injection/recovery rate and maximum water temperature of 150°C (302°F). Figure 3.1 shows an artist's conceptual drawing of the FTF. Figure 3.2 shows the orientation of the injection/supply wells, the core boring, and the monitor wells.

The first phase of testing at the St. Paul FTF consisted of four short-term test cycles of heated water injection-storage-recovery and was completed in December 1983. The first of two planned long-term test cycles was completed in May 1985. Timing of the second test cycle and final pumpout are contingent on agency review of the first cycle and site monitoring before proceeding with the second cycle.

During this reporting period, the first long-term cycle was completed, post-test monitoring and sampling were done, compilation of the cycle data from the long-term cycle was largely completed, and analytical data from the water sampling was completed. Reports on these efforts are in progress.

Long-Term Test Cycle 1

The first long-term cycle consisted of approximately 59 days of heated water injection, 64 days of storage, and 58 days of heated water recovery (Table 3.1 and Figure 3.3). It was conducted from November 1984 to May 1985. For the long-term cycle, an ion-exchange water softener was installed between the source well and the condenser (Figure 3.4). The water softener consists of three tanks containing the ion exchange resin, a brine tank, and a control system.

A new operations permit was required to inject softened water into the aquifer. Special provisions of the variance include a limit of 180 mg/ℓ

(a) The discussion of the St. Paul FTF was prepared by Dr. M. Hoyer of the Minnesota Geological Survey and subsequently edited by PNL.

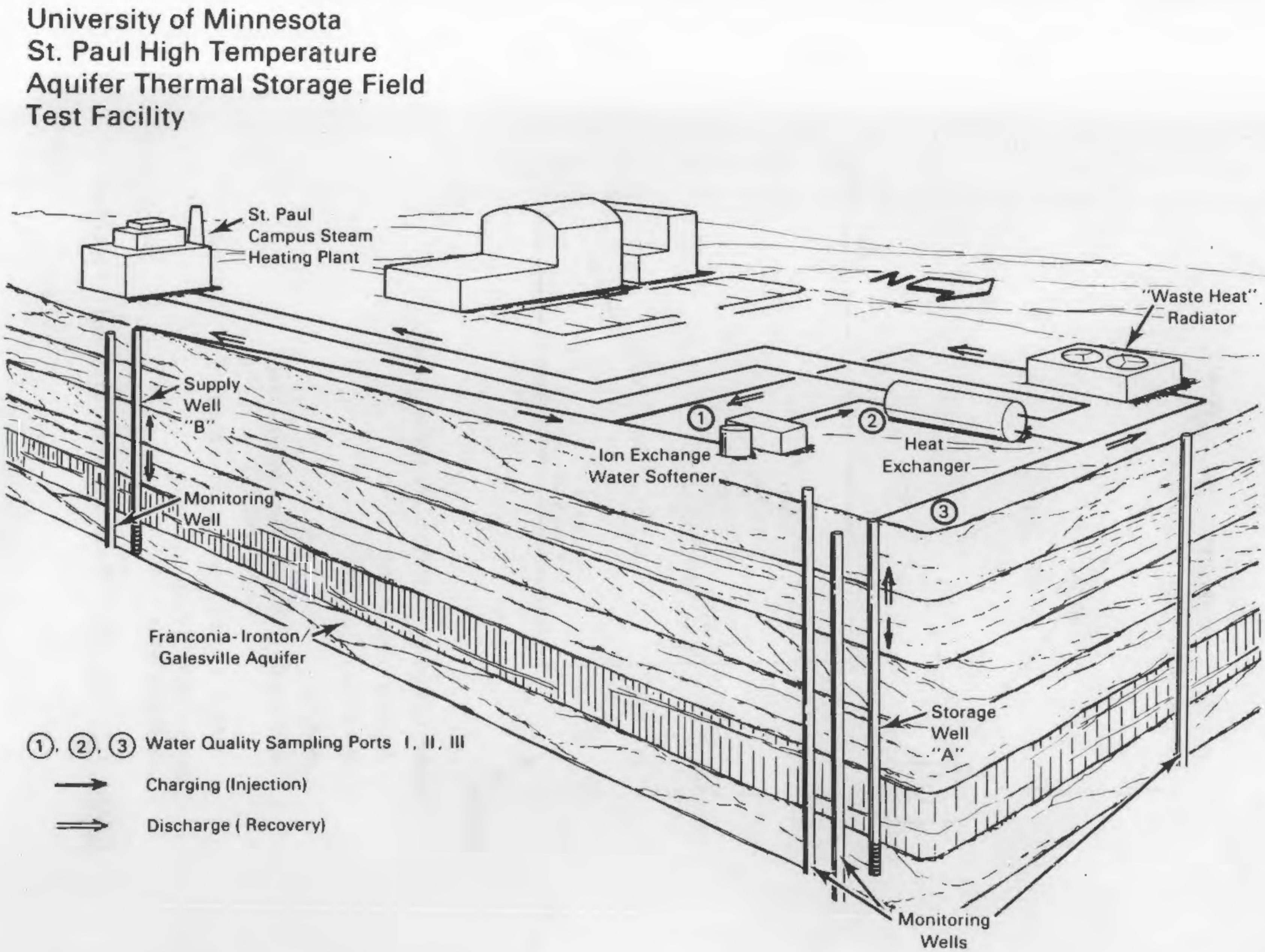
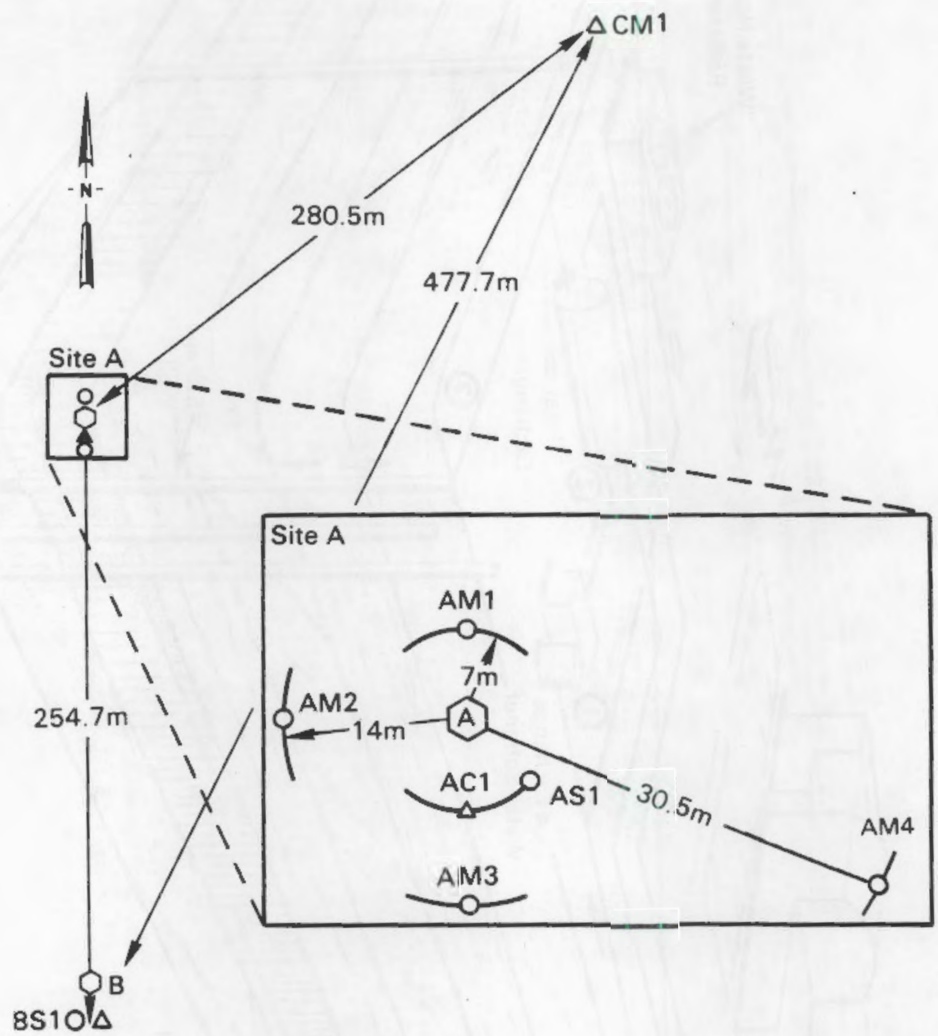



FIGURE 3.1. Artist's Conceptual Drawing of St. Paul FTF




Location Diagram of Test Wells and Monitor Wells

A = Heat Injection Well

B = Water Supply Well

AC1, BC1 = Core Borings

AS1 and BS1 = Supplemental Monitor Wells for AC1 and BC1

AM1, 2, 3, and 4, CM1 = Monitor Wells

5 Monitor Wells, 2 Production Wells
2 Core Boring Wells

FIGURE 3.2. St. Paul Field Test Facility Well Locations

TABLE 3.1. Summary of Test Cycles, University of Minnesota Field Test Facility

| | Cycle 1 | Cycle 2 | Cycle 3 | Cycle 4 | Long-Term |
|---|---|---|---|---|---|
| Duration (days) | | | | | |
| Injection - pumping | 5.2 | 8.0 | 7.7 | 7.7 | 59.1 |
| Injection - total | 17 | 10.0 | 10.4 | 12.0 | 74.7 |
| Storage | 13 | 90.0 | 9.7 | 10.1 | 64.0 |
| Recovery - pumping | 5.2 | 8.0 | 7.7 | 7.7 | 58.0 |
| Recovery - total | 5.2 | 8.0 | 8.0 | 7.7 | 58.8 |
| Temperature (°C) | | | | | |
| Source water | 11.0 | 20.5 | 36.1 | 52.6 | 19.7 |
| Injected water | 89.4 | 97.4 | 106.1 | 114.8 | 108.5 |
| Recovered water | 59.2 | 55.2 | 81.1 | 89.1 | 74.7 |
| Flow rate (ℓ/sec) | | | | | |
| Injection | 18.4 | 17.6 | 18.3 | 17.9 | 18.0 |
| Recovery | 18.1 | 17.8 | 17.3 | 17.8 | 18.4 |
| Volume ($10^4$ $m^3$) | | | | | |
| Injection | 0.83 | 1.22 | 1.22 | 1.19 | 9.21 |
| Recovery | 0.81 | 1.23 | 1.18 | 1.19 | 9.22 |
| Energy (GWh) | | | | | |
| Added | 0.770 | 1.084 | 0.989 | 0.867 | 9.47 |
| Recovered | 0.453 | 0.495 | 0.617 | 0.503 | 5.86 |
| Energy recovery factor | | | | | |
| Using source temperature | 0.59 | 0.46 | 0.62 | 0.58 | 0.62 |
| Using ambient temperature | 0.59 | 0.52 | 0.71 | 0.75 | 0.65 |

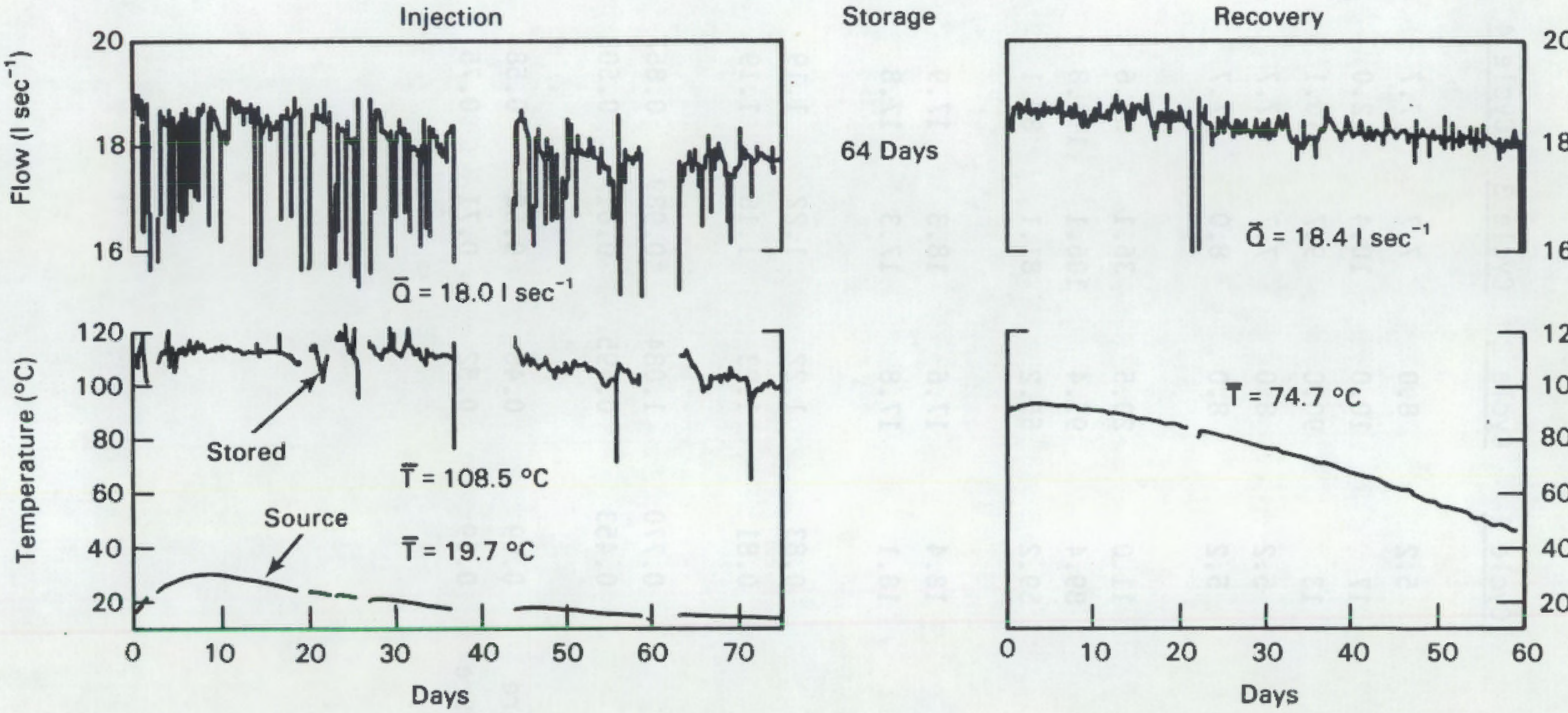



FIGURE 3.3. Heated Water Flow and Temperature During Long-Term Cycle 1 at the University of Minnesota ATES Field Test Facility

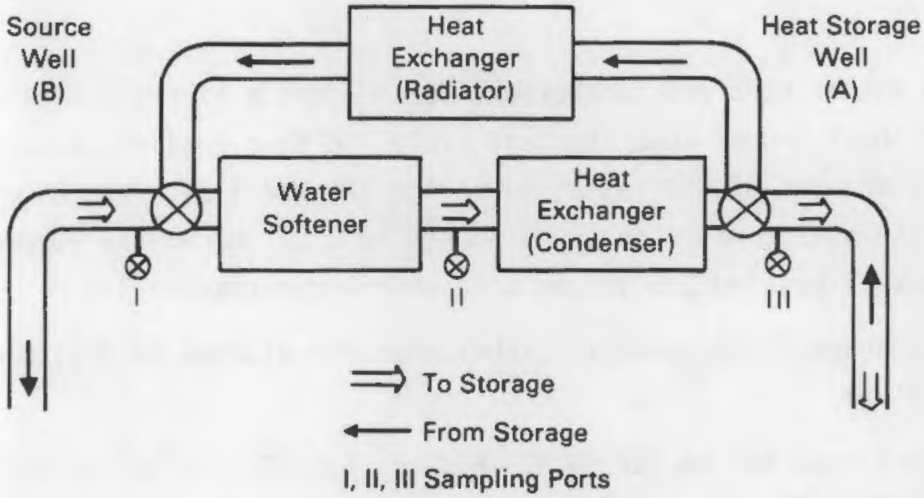



FIGURE 3.4. Above-Ground Water Treatment and Heating System During Long-Term Cycle 1 at the University of Minnesota ATES Field Test Facility

for sodium concentration, 2 years of post-test monitoring, and pumping out of treated water in the aquifer.

An additional monitoring well, AM4 (located 30.5 m from the storage well), was also added to the system. The new monitor well allowed monitoring of the aquifer at a point closer to the thermal front than would have been possible with the previous monitoring wells.

Following initial testing and debugging of the water softening system, injection began on November 14, 1985. The softener allowed injection to proceed with few interruptions.

Performance

The injection phase of the long-term test cycle consisted of 59.1 days of injection spread over 74.7 days. Mean flow rate was 18.03 ℓ/sec, mean source water temperature was 19.7°C (67.5°F), mean injected water temperature was 108.5°C (227.3°F), and mean ΔT was 88.6°C (191.5°F). A total of $9.21 \times 10^4$ $m^3$ of heated water was stored. A total of 9.47 GWh of energy, added to the stored water by steam, was stored. A total of 10.4 GWh (above ambient conditions) was stored in the aquifer; the difference was supplied in the source water.

The source waters were not isothermal, but reached a high temperature of 30.5°C (86.9°F) about 8 days into the test cycle and then declined slowly to 13°C (55.4°F) by the end of the injection period (Figure 3.3). The highest temperature of the source water occurred about the time the volume pumped from the source well equaled the volume of a short-term test cycle.

The storage phase lasted 64 days rather than the planned 60 days because of equipment failure.

Recovery continued for 58 (of 58.8) days until $9.22 \times 10^4$ $m^3$ of stored water was recovered. The temperature of the recovered water reached a high of 93.3°C (199.9°F) after about 2 days of pumping. The final water temperature was 45.6°C (114.1°F). Mean temperature of the recovered water was 74.7°C (166.5°F). Flow during recovery averaged 18.4 ℓ/sec.

Thermal Response

The first thermal response noted in the monitor wells during injection occurred after less than 2 days. (The same response was observed during the short-term cycles.) Figure 3.5 plots temperatures at five thermocouples in well AS1 during the injection and recovery phases of the cycle. Notice that the arrival of heat is not uniform and that the response to pump shutoff is different at different levels in the aquifer. Temperatures in the upper Ironton-Galesville and lower Franconia change quite dramatically with pump shutoff, probably the result of the interbedded nature of the aquifer. Figure 3.6 plots temperature in AS1 at six times during the cycle. There is an indication of thermal tilting in the upper Franconia portion of the storage zone during the cycle.

Temperatures in porous and permeable portions of the aquifer declined during the recovery phase. The heat that entered the lower Franconia portion of the aquifer and confining beds remained. Note the temperature increase throughout recovery in the St. Lawrence formation (Figure 3.5).

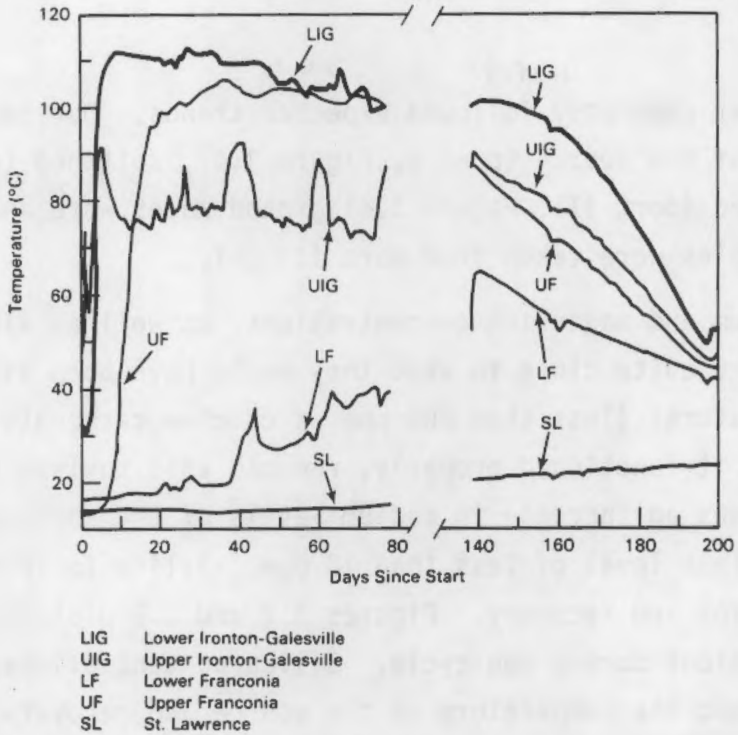



FIGURE 3.5. Water Temperatures in the Lower and Upper Ironton-Galesville, Lower and Upper Franconia, and St. Lawrence Intervals in Well AS1 During Long-Term Cycle 1

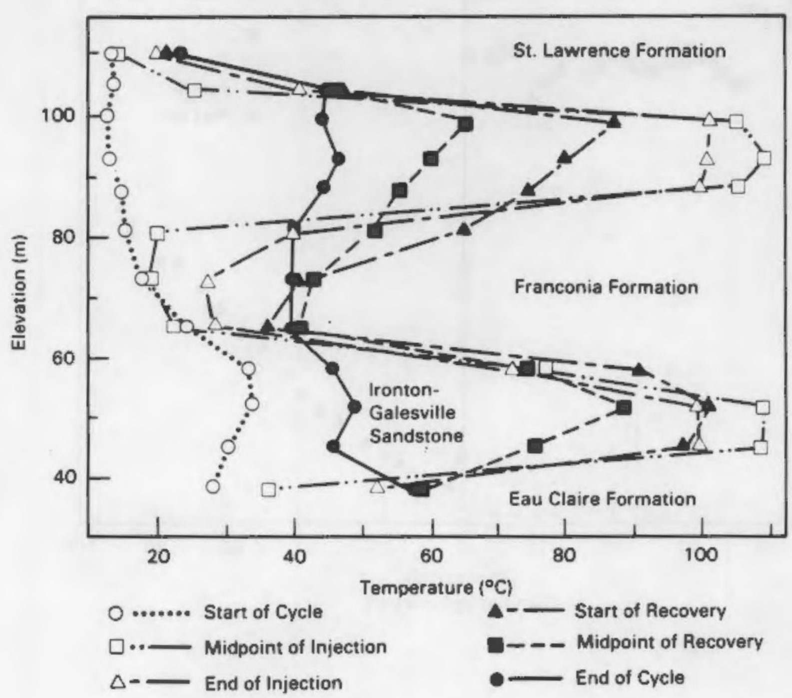



FIGURE 3.6. Temperature Profiles of Well AS1 During Long-Term Cycle 1

## Water Chemistry

In general, water chemistry followed expected trends. During the injection phase, samples of the source (port I, Figure 3.4), softened (port II, Figure 3.4) and heated (port III, Figure 3.4) ground water were analyzed. During recovery, samples were taken from port III only.

Trends of calcium and magnesium concentrations, as well as alkalinity in the source water, were quite close to what they would have been with entirely ambient water temperatures (less than 200 ppm as calcium carbonate). The water softener, when it functioned properly, reduced this to less than 20 ppm of hardness. There was an increase in sodium levels of the softened water to 113 ppm from the ambient level of less than 10 ppm. Silica followed temperature trends during injection and recovery. Figures 3.7 and 3.8 plot the calcium and sodium concentrations during the cycle. Silica concentrations, plotted in Figure 3.9, followed the temperature of the source and recovery water. In each figure, the mineral concentration is plotted against cumulative volume; negative volumes occur during injection, and positive volumes occur during recovery.

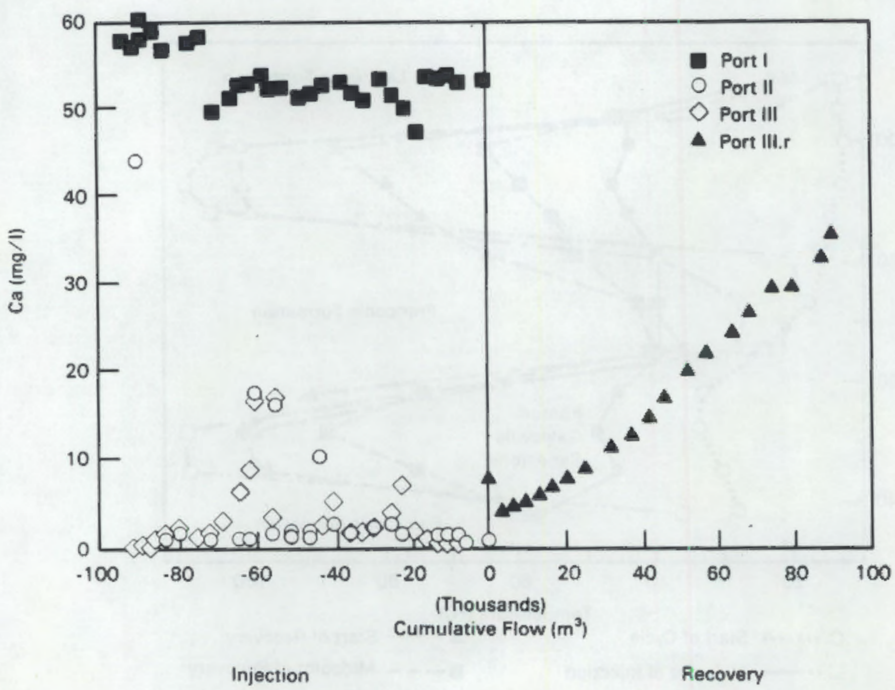



FIGURE 3.7. Calcium Concentrations in Pumped Ground Water During Long-Term Cycle 1

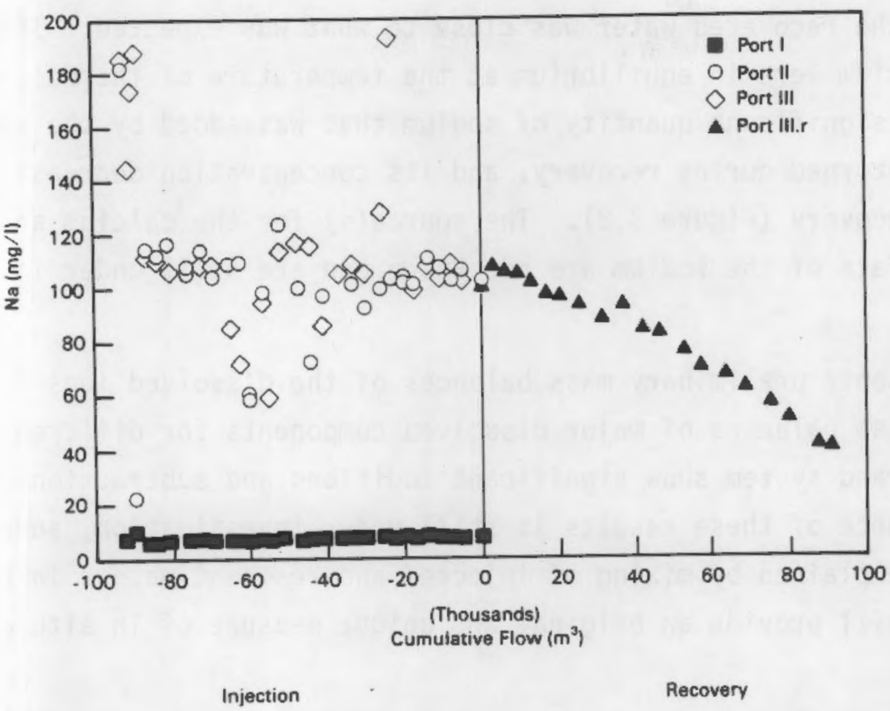



FIGURE 3.8. Sodium Concentrations in Pumped Ground Water During Long-Term Cycle 1

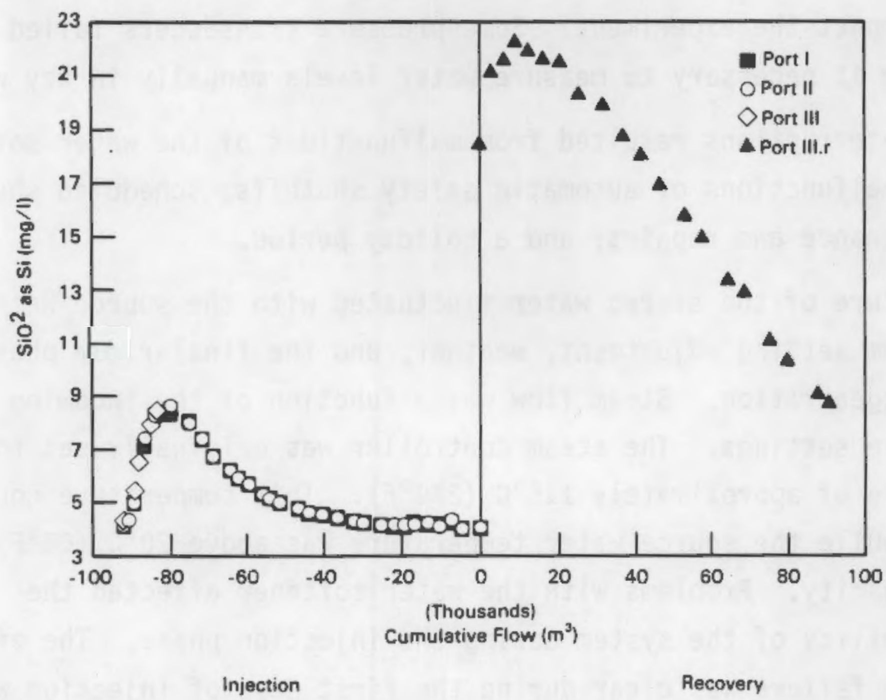



FIGURE 3.9. Silica Concentrations in Pumped Ground Water During Long-Term Cycle 1

Chemistry of the recovered water was close to what was expected. Silica, calcium, and magnesium were in equilibrium at the temperature of the recovered water. However, a significant quantity of sodium that was added by the water softener was not returned during recovery, and its concentration decreased with time during recovery (Figure 3.8). The source(s) for the calcium and magnesium and the fate of the sodium are not known and are still under investigation.

Table 3.2 presents preliminary mass balances of the dissolved ions for the test cycle. Mass balances of major dissolved components for different parts of the cycle and system show significant additions and subtractions. While the significance of these results is still under investigation, several features could be explained by mixing of injected and resident waters in blind pores. If so, it will provide an original and unique measure of in situ ground water mixing.

Operations and Problems

Problems with the water softener, weather, monitoring equipment, and flowmeter were encountered at different times during the cycle, but they did not materially impact the experiment. Some pressure transducers failed during the cycle, making it necessary to measure water levels manually in key wells.

Injection interruptions resulted from malfunctions of the water softener; weather-related malfunctions of automatic safety shutoffs; scheduled shutdowns for system maintenance and repairs; and a holiday period.

The temperature of the stored water fluctuated with the source-water temperature, steam-setting adjustment, weather, and the final-rinse phase of water softener regeneration. Steam flow was a function of the incoming steam pressure and valve settings. The steam controller was originally set to maintain a temperature of approximately 115°C (239°F). This temperature could be maintained only while the source-water temperature was above 20°C (68°F) because of the system capacity. Problems with the water softener affected the temperature capability of the system during the injection phase. The effect of water softener failure was clear during the first days of injection with the decrease in injected water temperature (while steam pressure increased) as the condenser lost efficiency. Extremely cold weather [less than -20°C

TABLE 3.2. Mass Balances on Cation Exchanger, Heat Exchanger, Storage, and Entire ATES Cycle

| | Water Softener Port II - Port I (Injection) | | Heat Exchanger Port III - Port II (Injection) | | Aquifer Storage Port III - Port III (Recovery) (Injection) | | Total Cycle Port III - Port I (Recovery) (Injection) | |
|---|---|---|---|---|---|---|---|---|
| | Mass Added[a] | Standard Deviation | Mass Added | Standard Deviation | Mass Added | Standard Deviation | Mass Added | Standard Deviation |
| Silica (kg) as Si | 0.8 | 2.2 | 1.7 | 2.2 | 1025.0[b] | 3.0 | 1027.0[b] | 3.0 |
| Sulfate (kg) as S | 11.4[b] | 1.16 | 0.7 | 0.82 | 28.6[b] | 7.42 | 40.6[b] | 7.42 |
| Chloride (kg) | 404.0[b] | 6.6 | 219.0[b] | 5.1 | 730.0[b] | 9.6 | 1353.0[b] | 9.2 |
| Fluoride (kg) | 0.25 | 0.33 | 0.12 | 0.25 | 15.0 | 8.1 | 15.0 | 8.1 |
| Calcium (kg) | -4268.0[b] | 3.8 | -54.0[b] | 2.7 | 1349.0[b] | 3.0 | -2973.0[b] | 3.0 |
| Magnesium (kg) | -1247.0[b] | 6.2 | -72.0[b] | 4.4 | 390.0[b] | 7.7 | -928.0[b] | 7.7 |
| Sodium (kg) | 8520.0[b] | 143.0 | 799.0[b] | 100.0 | -2800.0[b] | 105.0 | 6520.0[b] | 108.0 |
| Potassium (kg) | -428.0[b] | 2.5 | 27.0[b] | 1.8 | 540.0[b] | 36.0 | 130.0[b] | 36.0 |
| Iron (kg) | -58.1[b] | 1.18 | -3.8[b] | 0.84 | 23.7[b] | 2.0 | -38.2[b] | 2.0 |
| Total carbon (kmol) | -5.0 | 646.0 | -40.0 | 632.0 | 50.0 | 905.0 | 1.0 | 203.0 |

(a) Difference in mean values measured at respective sampling ports. Negative values indicate mass removed from system. Standard deviation values are offered for the reader to assess the significance of differences between measured mean values.
(b) Significantly different from zero at the 0.001 level.

(normal for January)] affected incoming steam pressure because of other campus heating loads. The abrupt decrease in temperature of the injected water beginning at day 63 of injection (Figure 3.3) was caused by low steam pressure. The final-rinse phase of water softener regeneration briefly decreased the flow to the storage well and increased the temperature. The spikes on the flow curve (Figure 3.3) are the result of these regenerations.

Storage was extended to 64 days to repair leaks in the radiator and to replace the flowmeter.

Energy Recovery

Using the energy that was added to the source ground water as a base, 62% of the stored energy was recovered. If the ambient ground-water temperature is used as a base, 65% of the energy was recovered. The temperature curve during recovery is noticeably convex (Figure 3.3). Plotting temperature against cumulative flow makes the convexity clearer (Figure 3.10). The significant

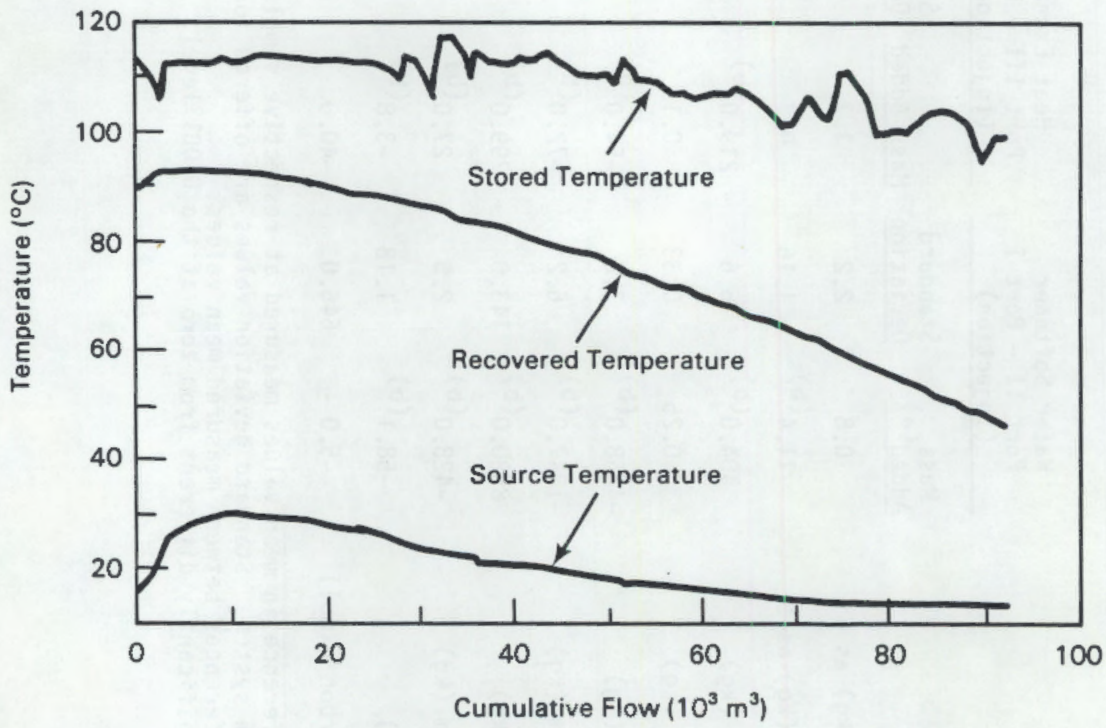



FIGURE 3.10. Temperature of Source, Stored, and Recovered Ground Water During Long-Term Cycle 1 Plotted Against Cumulative Flow

amount of energy recovered and the relatively slow decline in temperature during the first third of the recovery period suggest that a significant amount of useful thermal energy may be recovered in seasonal operation.

Modeling

Modeling efforts during the year were a continuation of efforts from previous years. A preliminary, fully three-dimensional flow and thermal energy transport model was constructed to incorporate the anisotropy of the aquifer. Analytical solutions of anisotropic ground-water flow around a doublet well system were used to specify model boundary conditions for simulation of heat injection. This approach simplifies modeling of the doublet well system because only the heat injection well needs to be simulated.

The model was calibrated under isothermal conditions with data obtained from an 8-day ambient temperature injection test at 18.9 ℓ/sec. Pressure changes in the injection well (A) and in observation wells 7 m from the injection well and open to the upper Franconia and Ironton-Galesville (FIG) portions of the aquifer were used for calibration. The calibrated isothermal model then was used to simulate the 400-day period during which the four short-term heat-injection-test cycles were conducted. Table 3.3 summarizes model-computed and field-recorded values of final withdrawal temperature in the production well and aquifer thermal efficiency.

The low aquifer thermal efficiency for short-term cycle 2 is attributed to a 90-day storage period. The data indicate that the model accurately predicted final withdrawal temperatures and aquifer thermal efficiencies. Results of modeling long-term test cycle 1 are also reasonably close to the field results. The data in Table 3.3 indicate that the model-computed temperatures compared favorably with field-recorded temperatures, with differences of no more than ±8°C (46°F). For each test cycle, model-computed aquifer thermal efficiency, defined as total heat withdrawn divided by total heat injected, was within ±2% of the field-calculated values.

Monitoring After Long-Term Cycle 1

The variance allowing the operation of the FTF, granted in August 1984, requires monitoring of the site and quarterly sampling of monitoring wells between cycles and during closeout. Analysis of samples collected from the

TABLE 3.3. Model-Computed and Field-Recorded Values of Final Withdrawal Temperature in the Production Well and Aquifer Thermal Efficiency by Cycle

| Short-Term Cycle | Final Withdrawal Temperature (°C) | | Efficiency (percent) | |
|---|---|---|---|---|
| | Model | Field | Model | Field |
| 1 | 39.4 | 39.4 | 60.1 | 59.0 |
| 2 | 39.4 | 39.4 | 49.4 | 46.0 |
| 3 | 58.3 | 56.7 | 58.0 | 62.0 |
| 4 | 64.4 | 63.9 | 62.0 | 59.0 |

monitoring wells after the cycle was completed indicate that sodium levels in the FIG aquifer have remained close to levels measured in the recovery water near the end of the long-term cycle (20 to 40 mg/ℓ). Samples collected from well AS1-Mt. Simon have concentrations of sodium of 20 to 30 mg/ℓ, in contrast to pre-long-term cycle levels of about 10 mg/ℓ. Samples from BC1-Mt. Simon are at precycle (ambient) concentrations; samples from the Jordan wells are very close to precycle concentrations.

These results were not available until late February because the atomic absorption analysis unit was unusable for several months. When these results became available, thermal profiles of AS1, AC1, and BC1, which extend to the Mt. Simon aquifer, were made. The profiles, together with the analytical data suggest that there is communication between the FIG and the Mt. Simon aquifers, and that it probably takes place in or along AC1 or AS1. Further testing to resolve this issue is underway. Appropriate regulatory agencies have been informed of the situation and are being advised of the additional investigations.

### 3.1.2 University of Alabama Student Recreation Center Chill ATES Monitoring

University of Alabama researchers are monitoring an operating chill ATES system installed at the university's Student Recreation Center in Tuscaloosa. The objectives of this effort are

- to characterize this ATES system and its performance through analysis of geohydrothermal flow field data and energy flow data, respectively

- to estimate system economics in terms of life-cycle costs and simple payback period.

The system being studied consists of cooling coils, cooling tower, wells, and the aquifer storage system. These elements are portrayed schematically in Figure 3.11. System operation is based on the direct cooling concept, in which water is chilled in the cooling tower during cold periods, then stored in an aquifer for later recovery as needed for air conditioning.

The overall system operates between 2°C (36°F) and 16°C (60°F). The cooling tower operates whenever the wet-bulb temperature drops below 7°C (45°F). Cooling tower operation is related to weather only, and is independent of heating load.

Access to the unconfined water table aquifer is provided by wells drilled between the surface and the aquifer base. Three "warm" wells and three "cold" wells comprise the aquifer system, as shown in Figure 3.12. Each well contains a submersible three-stage pump and return riser. Warm well pump capacity is 9.47 ℓ/sec (150 gpm) at 43-m (140-ft) head, and cold well capacity is 7.57 ℓ/sec

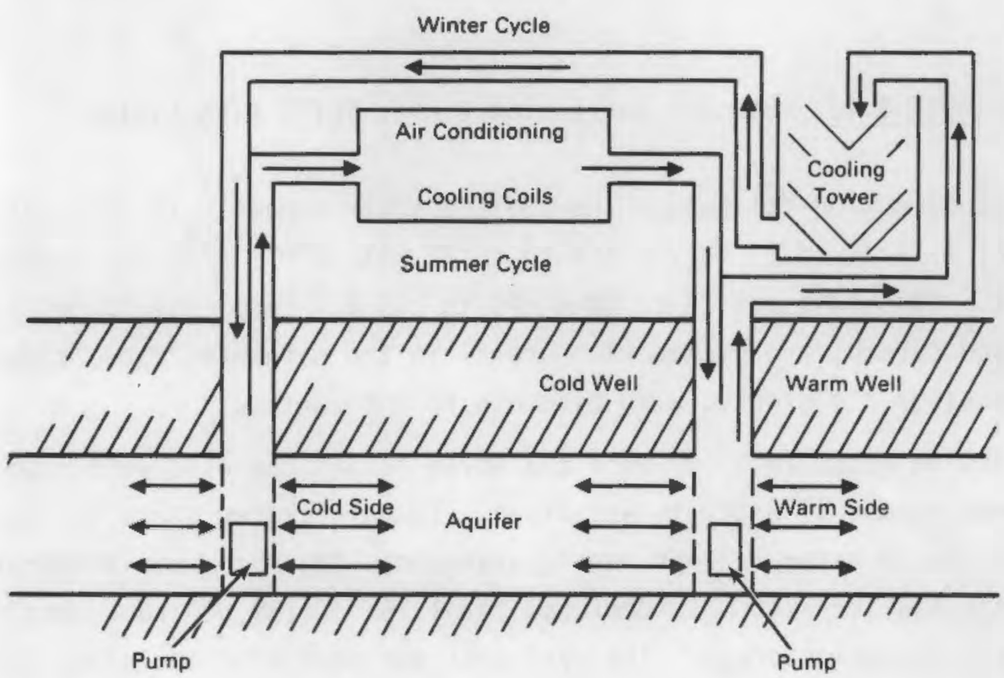



FIGURE 3.11. Chill ATES System

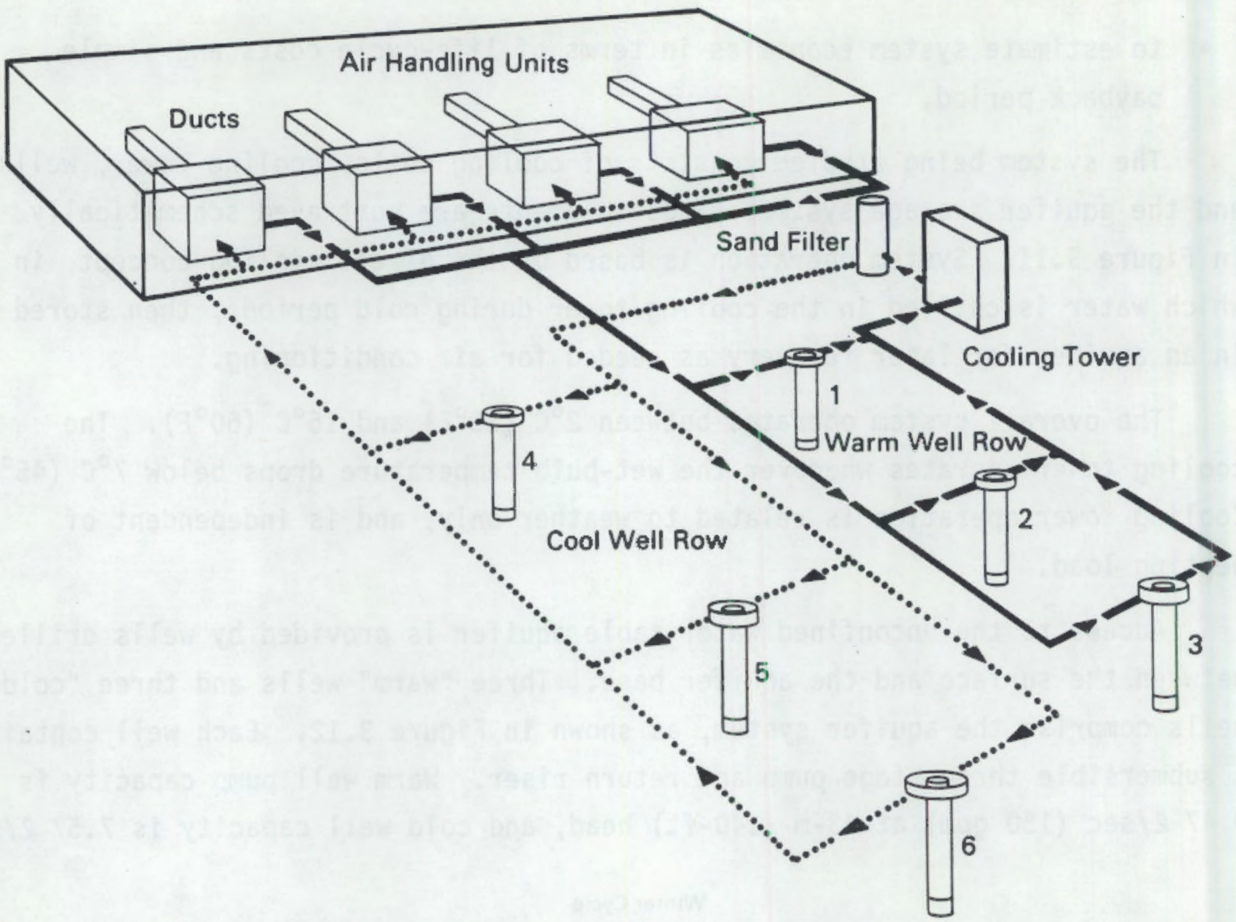



FIGURE 3.12. Student Recreation Center Chill ATES System

(120 gpm) at 61-m (200-ft) head. The cooling tower capacity is 28.4 ℓ/sec (450 gpm) of water from 13 to 7°C (55 to 45°F) with 4°C (39°F) wet-bulb ambient temperature. The wells are 27 to 30 m (90 to 100 ft) deep, use 25-cm (10-in.) PVC sand screen, are packed with gravel in the saturated zone, cased with solid PVC casing, and grouted with concrete to the surface.

Water is injected into one well and moves toward the next well from which an equivalent amount of water is withdrawn. In this system there is essentially zero volume use of water, except during winter cooling when some evaporation occurs. This aquifer system is designed for 1.76 TJ (139,000 ton-hours) per year of chill thermal storage. The HVAC cost was $485,000, including $190,000 for the wells, pump, cooling tower, filter, and other items related to the ATES system.

The system began operation in late 1982 following construction of the recreation center. The maximum building cooling load is 521 kJ (148 tons). Some chilling of water took place during the 1982-83 winter. The system has successfully met essentially 100% of the 5700 $m^2$ (62,000-$ft^2$) facility's air conditioning needs during the summers of 1983, 1984, and 1985.

The monitoring effort began in late 1984 with construction of 15 monitoring wells located within the ATES system, as shown in Figure 3.13. These include three background head monitoring wells, three additional head monitoring wells, and nine temperature monitoring wells. All 15 wells are cased with 5-cm (2-in.) PVC pipe. Each of the six head wells is fitted with a sand screen near the bottom.

In conjunction with the "warm" and "cold" wells and the cooling tower, these monitoring wells provide

- water head measurements
- water temperature
- water flow injection and recovery rates with temperature
- power input (pumps and cooling tower fans).

These data are used to define and characterize the aquifer, determine natural flow, provide three-dimensional temperature distributions over time, and compute energy consumption. From these analyses, aquifer performance and energy recovery are determined in addition to air conditioning system performance.

During this reporting period, instrumentation and a computerized data acquisition system were installed to obtain and record data on ATES parameters. System temperatures, flow rates, ground-water levels, and electrical energy inputs were monitored during CY 1985, and system performance was evaluated. Additional tests were conducted to better define aquifer characteristics of transmissivity, hydraulic conductivity, and hydraulic gradient.

Instrumentation

The computerized data acquisition system was designed to obtain, process, and record operational data from the ATES system. The design calls for primary production well and cooling tower data to be recorded directly by computer. This computer-recorded data will be provided by transducers with outputs of $\pm$10 V, converted to digital outputs on a TECMAR Labmaster, and recorded on disks

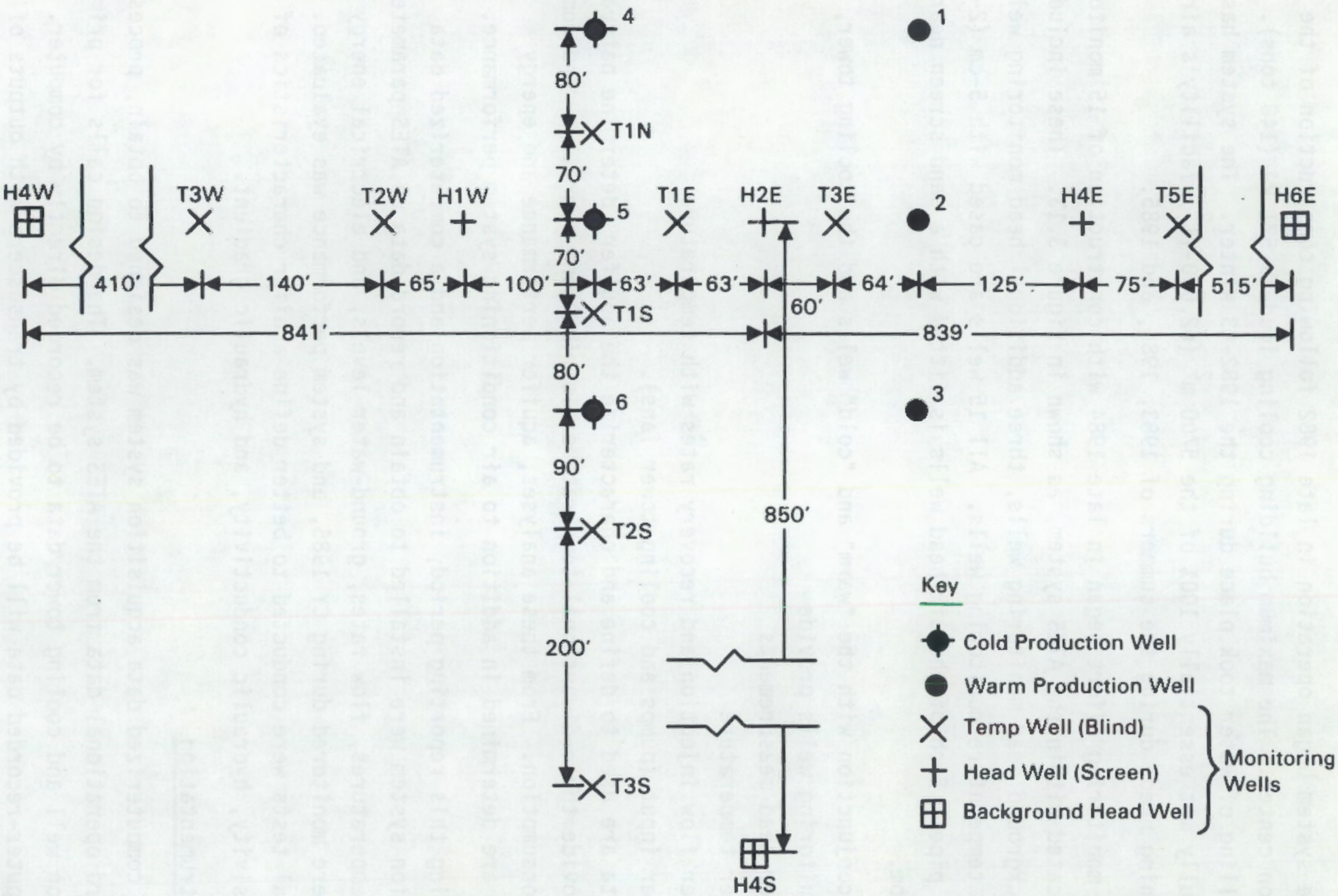



FIGURE 3.13. Well Locations for Production Wells (Enumerated in Figure 3.11) and Monitoring Wells. ("Temp" wells are used to measure aquifer temperatures at several elevations. Head wells are used to monitor aquifer standing water elevation.)

with an IBM PC (Figure 3.14). Over 100 channels are available for data acquisition.

The computer data will be recorded every 15 minutes. Incoming flow rates will be taken from each production well using calibrated Venturi flowmeters with pressure transducers. The computer will be used to calculate the total flow rates into and out of the building. Water weight will be measured in each production well using a pressure transducer on a bubbler submerged to 3 m (10 ft) above the pump so the pump turbulence does not affect the transducer (Figure 3.15). Temperature data from thermistors will be recorded both in and out of the six production wells, the cooling tower, and the Student Recreation Building. In the six production wells, six temperature points at 3-m (10-ft) intervals from the bottom will be recorded at 15-min intervals.

Although installation of the computer data acquisition system was completed in 1985, the system is not yet operational. The expansion boards have not worked properly and, as a result, both hardware and software problems still have to be corrected. Data that were to be collected automatically by the computer system were obtained manually during 1985.

Data from the monitoring wells were obtained manually, as planned. Thirteen of the monitoring wells have six temperature data points distributed at 3-m (10-ft) increments from the bottom. The distribution of the data points is shown in Figure 3.16. Thermocouple data from the monitoring wells have been recorded weekly except during critical periods as dictated by data and temperature trends. Two other wells serve as reference points for background data. Water levels have been recorded weekly in six monitoring wells using a chalked surveyor's tape.

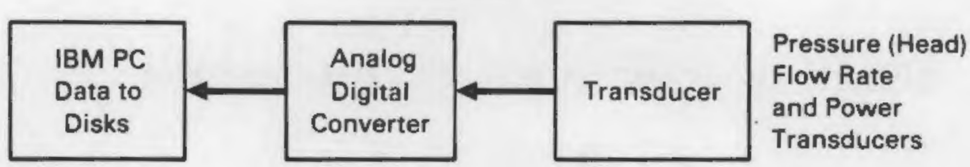



FIGURE 3.14. Planned Computer Data Collection

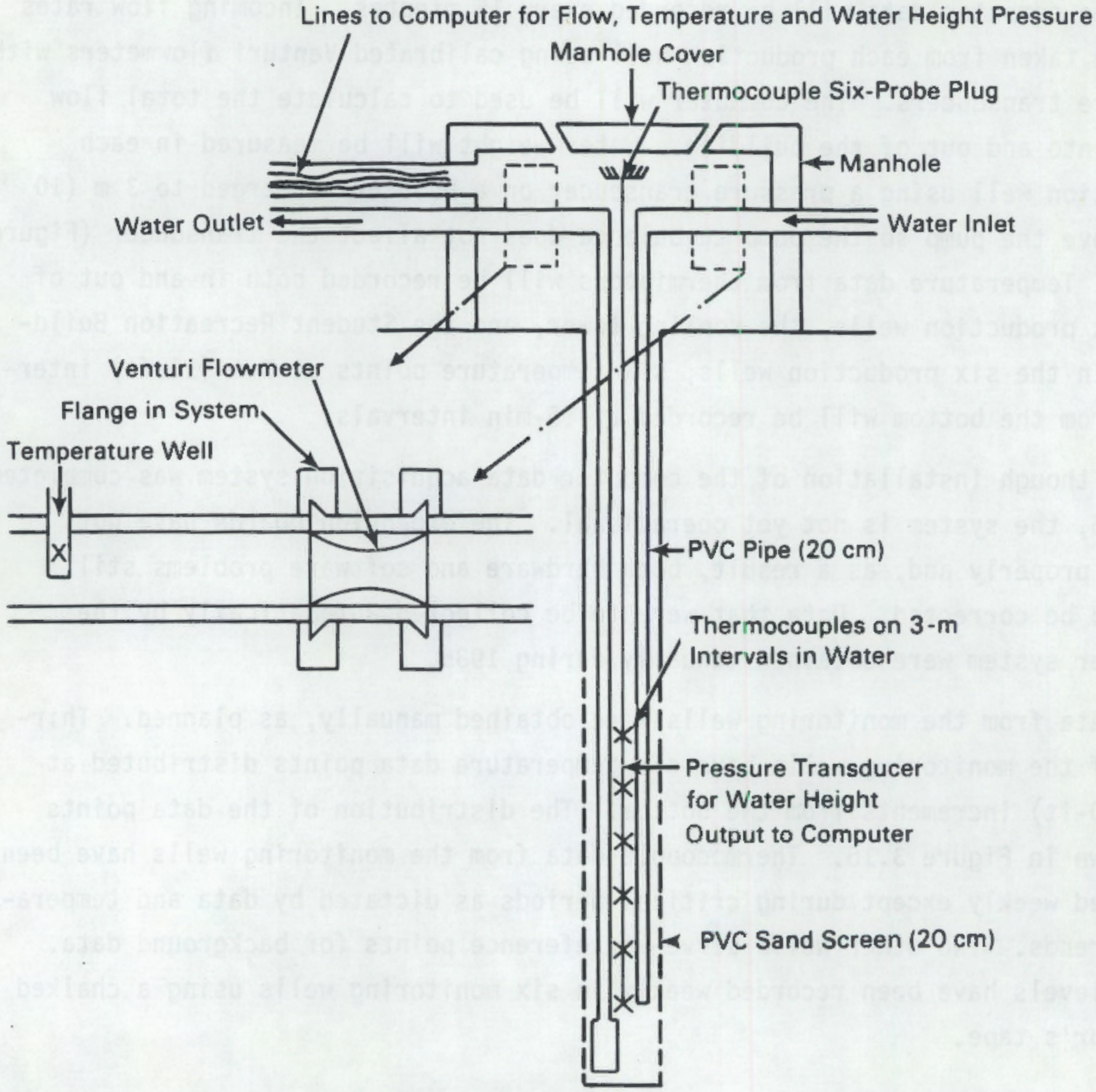



FIGURE 3.15. Production Well with Instrumentation

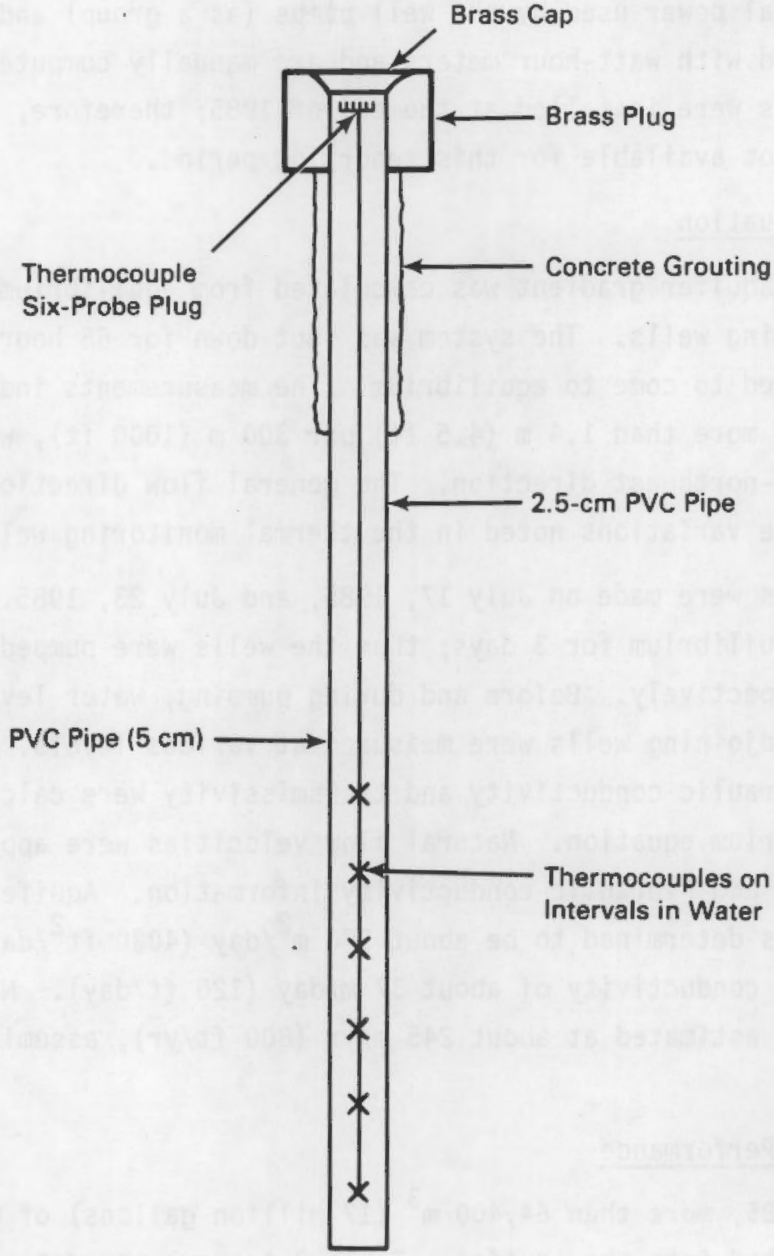



FIGURE 3.16. Temperature Monitoring Well

The electrical power used by the well pumps (as a group) and the cooling tower are recorded with watt-hour meters and are manually computed on a weekly basis. The meters were installed at the end of 1985; therefore, electrical energy data are not available for this reporting period.

Aquifer Evaluation

The natural aquifer gradient was calculated from equilibrium water levels in the six operating wells. The system was shut down for 68 hours, and the aquifer was allowed to come to equilibrium. The measurements indicate a water table gradient of more than 1.4 m (4.5 ft) per 300 m (1000 ft), with the natural flow in the north-northwest direction. The general flow direction is supported by the temperature variations noted in the thermal monitoring wells.

Pumping tests were made on July 17, 1985, and July 23, 1985. The aquifer was brought to equilibrium for 3 days; then the wells were pumped for 9 hours and 20 hours, respectively. Before and during pumping, water levels in the pumped well and adjoining wells were measured at various levels. From these data, aquifer hydraulic conductivity and transmissivity were calculated by use of an equilibrium equation. Natural flow velocities were approximated from the gradient and hydraulic conductivity information. Aquifer transmissivity was determined to be about 370 $m^2$/day (4020 $ft^2$/day), with derived hydraulic conductivity of about 37 m/day (120 ft/day). Natural groundwater velocity is estimated at about 245 m/yr (800 ft/yr), assuming an effective porosity of 25%.

ATES System Performance

During CY 1985, more than 64,400 $m^3$ (17 million gallons) of water were chilled and injected into the aquifer. Table 3.4 shows the data on monthly chilling and injection. More than 75,700 $m^3$ (20 million gallons) of ground water were pumped from the aquifer to air condition the recreation center. Table 3.5 shows the data on monthly usage of the water and thermal parameters.

The aquifer system has shown a general recovery of about 38% (Table 3.6) with some additional losses in the building air-conditioning system. Changes are being made to increase the water temperature differential in the building.

TABLE 3.4. Water Chilled in 1985

| Month | Building Flow ($m^3$) | Tower Temperature (°C) $T_{in}$ | Tower Temperature (°C) $T_{out}$ | Tower Flow Rate (ℓ/min) |
|---|---|---|---|---|
| Jan. | 26,584 | 17.1 | 5.6 | 778 |
| Feb. | 16,543 | 17.2 | 5.8 | 710 |
| Mar. | 801 | 17.2 | 6.6 | 855 |
| Apr. | 297 | 17.2 | 6.7 | 867 |
| May | 0 | - | - | 0 |
| Jun. | 0 | - | - | 0 |
| Jul. | 0 | - | - | 0 |
| Aug. | 0 | - | - | 0 |
| Sep. | 0 | - | - | 0 |
| Oct. | 0 | - | - | 0 |
| Nov. | 830 | 17.8 | 7.2 | 321 |
| Dec. | 20,396 | 18.8 | 5.1 | 763 |
| Annual | 65,450 | 17.4 | 6.3 | 716 |

TABLE 3.5. Water Used for Air-Conditioning in 1985

| Month | Building Flow ($m^3$) | Building Temperature (°C) $T_{in}$ | Building Temperature (°C) $T_{out}$ | Building Flow Rate (ℓ/min) |
|---|---|---|---|---|
| Jan. | 913 | 6.9 | 13.4 | 146 |
| Feb. | 0 | 6.1 | 13.9 | 0 |
| Mar. | 1,209 | 6.3 | 14.3 | 483 |
| Apr. | 3,752 | 8.2 | 14.8 | 302 |
| May | 7,757 | 10.6 | 16.1 | 271 |
| Jun. | 12,178 | 12.7 | 17.6 | 570 |
| Jul. | 6,718 | 13.7 | 17.9 | 560 |
| Aug. | 15,674 | 15.1 | 18.3 | 583 |
| Sep. | 16,293 | 15.8 | 18.7 | 548 |
| Oct. | 6,644 | 13.9 | 17.5 | 396 |
| Nov. | 5,840 | 15.9 | 17.9 | 372 |
| Dec. | 370 | | | 485 |
| Annual | 77,348 | 11.4 | 16.4 | 428 |

TABLE 3.6. Aquifer Energy Injection and Recovery

| Month | Total Injected Energy For Cooling Tower (TJ)[a] | Total Used Energy By Building (TJ) | Total Injected Energy Recovered (TJ) |
|---|---|---|---|
| Jan. | 1.455 | 0.019 | 0.040 |
| Feb. | 0.832 | 0 | 0 |
| Mar. | 0.039 | 0.040 | 0.059 |
| Apr. | 0.013 | 0.102 | 0.134 |
| May | 0 | 0.182 | 0.252 |
| Jun. | 0 | 0.266 | 0.293 |
| Jul. | 0 | 0.118 | 0.112 |
| Aug. | 0 | 0.199 | 0.185 |
| Sep. | 0 | 0.206 | 0.173 |
| Oct. | 0 | 0.073 | 0.058 |
| Nov. | 0.042 | 0.043 | 0.044 |
| Dec. | 1.148 | 0.003 | 0.002 |
| 1985 | 3.529 | 1.250 (35.4%) | 1.353 (38.3%) |

(a) TJ = $10^{12}$ joules

In addition, a large mass of cold ground water moves down gradient and is lost as a result of the natural flow. Methods for correcting this loss are under study.

The ATES system saves energy by eliminating need for the chiller in air conditioning the Student Recreation Center. Because the chiller is the predominant energy utilizer, operating energy is appreciably reduced. A minimum reduction in air conditioning energy (not including blowers) is expected to be 50%. Records for the building show that energy usage for air conditioning is about 117,000 ton-hr per year. If this cooling were provided by an air-cooled mechanical air conditioning system, the power requirement would be 146,250 kWh/yr. Monitoring and measurement of the ATES system indicates that the power requirement to operate the system is approximately 75,000 kWh/yr, which is approximately a 50% savings in power. The savings in dollars is greater because the reduced power usage also reduces the demand charge on the system during summer periods. Dollarwise, the demand charge savings can be greater than energy usage savings. In this system, summer demand is reduced by 140 kW.

### 3.1.3 Laboratory Testing and Field Analyses

During FY 1985, experiments were done to characterize physical and chemical processes at the ATES field test facility located on the University of Minnesota campus at St. Paul, Minnesota. Experimental efforts include field tests at the site to characterize fluid injectability and geochemical studies to investigate chemical reactions resulting from alterations to the aquifer's thermal regime. The results from field tests obtained during the first long-term heat storage cycle are reported here. Heat storage experiments conducted prior to FY 1985 consisted of four short-term cycles from 1981 through 1983.

The long-term heat storage cycle at the St. Paul site began with injection from November 7, 1984, through January 28, 1985, followed by withdrawal from April 2, 1985, through May 31, 1985. This cycle employed a sodium-zeolite ion softening system to replace the gravel-bed precipitator used in earlier cycles. Field studies conducted during injection and withdrawal pumping periods included membrane filter tests to anticipate well impairment by particle plugging. These tests monitored suspended solids content and other injectability parameters of the thermal fluids. Onsite core flooding tests were also conducted to aid in determining response of the aquifer formation to the injected fluid.

Results of membrane filter tests indicate that fluids injected during heat injection and heat recovery had very low suspended solids. Overall, the filter test results indicate that, at temperatures to 115°C (239°F), well impairment due to suspended solids is not a problem. Results of core flooding tests demonstrate that over 20,000 pore volumes of fluid in the 93 to 110°C (199 to 230°F) temperature range can be passed through representative core samples with no significant loss in permeability.

It is concluded from the success of the long-term heat storage experiment that the quality of the water (as treated by the water softening system) was very good for heat injection. The water quality during heat recovery was also good. Any changes in rock fabric that may have been experienced in the aquifer formations did not significantly affect hydrologic performance.

### 3.1.4 Numerical Modeling of ATES

Numerical modeling efforts were continued at a minimum level by PNL in 1985 to support field studies.

The Aquifer Thermal Energy Storage System Simulator (ATESSS) code was modified to allow quantification of the adverse impact of permeability stratification, found in most aquifers, on an ATES system's thermal efficiency. The code now allows a separate hydraulic conductivity for each layer of the aquifer. A suite of simulations has been performed to establish a relationship between various degrees of permeability stratification (using a set of dimensionless parameters) and thermal efficiency.

The ATES facility at the University of Alabama Student Recreation Center was simulated with the Unconfined Aquifer Thermal Energy Storage (UCATES) model to examine the effect of different injection/recovery patterns on the system's thermal performance. This site is subject to a significant regional flow; thermal efficiencies are being decreased due to the drift of the thermal plume away from the recovery area. The UCATES simulation showed that, by using the up-gradient wells to mitigate the regional drift, a significant improvement in thermal efficiency was possible.

The ATES facility being proposed at the General Motors Rochester plant is now being simulated with the UCATES code. Again, mitigating the regional flow at this site is the primary concern. The pumping requirements of several up-gradient wells necessary to control the regional gradient has been established. Additional simulations are being focussed on different well field designs that will not be affected by the regional flow as much as the currently planned well field design.

All of these simulation activities have illustrated the importance of a careful and accurate geohydrological characterization of ATES sites.

## 3.2 STES TECHNOLOGY ASSESSMENT AND DEVELOPMENT

As originally conceived, the STES Technology Assessment and Development (STES-TAD) studies were intended to provide assessment of the economic, institutional, and legal aspects of all STES concepts (including ATES), and to assess and develop nonaquifer STES concepts. This portion of the STES Program has received relatively little funding; further, in 1985-1986, STES-TAD studies received no new funds.

### 3.2.1 STES in Caverns at Ely, Minnesota

In 1983-84, a study of STES using an abandoned mine at Ely, Minnesota, was cofunded with the Minnesota Geological Survey. The positive results of that study led a local entrepreneurial group to begin development of a mine water source heat pump system. The City of Ely received a state grant to study a similar system, which would ultimately lead to STES with solar or waste incineration as the seasonal heat source. Modest funds have been set aside to monitor the operation of either system at this site. Neither system became operational during the reporting period; therefore, there was no DOE-funded activity on this project.

## 3.3 INTERNATIONAL STES ACTIVITIES

Seasonal thermal energy storage is being studied in many European countries, with strong emphasis in Scandinavia, as well as in North America. Several of these nations have major commercial demonstration projects installed, under construction, or under design. Many of these projects are represented in one or the other of two IEA programmes involving STES in which DOE participates.

The U.S. is participating in IEA Task III, "Aquifer Storage Demonstration Plant in Lausanne-Dorigny, and Associated Projects", under the Energy Conservation Through Energy Storage Programme. The U.S. is providing information on the U.S. ATES projects in exchange for data concerning the performance of the Danish Horsholm project and the Swiss SPEOS (Dorigny) project. The Horsholm project is of special interest because it is an ATES system integrated into a district heating system on a commercial basis, and because it uses a five spot well configuration (as opposed to the doublet configuration selected for study in this country). Data exchange from all of these projects enriches the programs of all the countries.

There is considerable international activity in STES. The DOE is a participant in that activity, sharing information on the performance and problems of the various projects and technologies.

# REFERENCES

Kannberg, L. D. 1985. Underground Energy Storage Program 1984 Annual Summary. PNL-5507. Pacific Northwest Laboratory, Richland, Washington.

Kannberg, L. D. 1984. Underground Energy Storage Program 1983 Annual Summary. PNL-5172. Pacific Northwest Laboratory, Richland, Washington.

Kannberg, L. D., et al. 1983. Underground Energy Storage Program 1982 Annual Report. PNL-4735, Pacific Northwest Laboratory, Richland, Washington.

Kannberg, L. D., et al. 1982. Annual Report for 1981 - Compressed Air Technology Program. PNL-4281, Volumes I and II, Pacific Northwest Laboratory, Richland, Washington.

Minor, J. E. 1981. Seasonal Thermal Energy Storage Program Progress Report January 1980 - December 1980. PNL-3746, Pacific Northwest Laboratory, Richland, Washington.

Minor, J. E. 1980. Seasonal Thermal Energy Storage Program Progress Report April 1979 - December 1979. PNL-3322, Pacific Northwest Laboratory, Richland, Washington.

# DISTRIBUTION

No. of
Copies

OFFSITE

US Department of Energy
Attn: K. Klein
Office of Energy Storage & Dist.
Forrestal Bldg, CE-141 5E-052
Washington, DC 20585

US Department of Energy
Attn: E. Reimers
Office of Energy Storage & Dist.
Forrestal Bldg, CE-141 5E-052
Washington, DC 20585

US Department of Energy
Attn: R. Shivers
Forrestal Bldg, CE-141 5E-052
Washington, DC 20585

30 DOE Technical Information
Center
US Department of Energy
P.O. Box 62
Oak Ridge, TN 37830

Argonne National Laboratory
Solar Thermal Storage Program
Attn: A. Gorsky
Building 362
9700 S. Cass Avenue
Argonne, IL 60439

Auburn University
Attn: F. J. Molz
School of Engineering
Auburn, AL 36830

I. Gyuk
1201 Lyndale Drive
Alexandria, VA 22308

H. Haitjema
2323 Rock Creek Drive
Bloomington, IN 47401

Walter Hausz
4520 Via Vistosa
Santa Barbara, CA 93110

No. of
Copies

Illinois State Water Survey
Attn: T. Holm
2204 Griffith Drive
Champaign, IL 61820

Lawrence Livermore Laboratory
Attn: S. Blair
University of California
PO Box 5510
Mail Stop L201
Livermore, CA 94550

Lawrence Berkeley Laboratory
Attn: C. Doughty
University of California
Bldg. 90, Room 1012-H
1 Cyclotron Road
Berkeley, CA 94720

Lawrence Berkeley Laboratory
Attn: C. F. Tsang
University of California
Bldg. 90, Room 1012-H
1 Cyclotron Road
Berkeley, CA 94720

Minnesota Geological Survey
Attn: M. Hoyer
2642 University Avenue
St. Paul, MN 55114-1057

Minnesota Geological Survey
Attn: J. Splettstoesser
2642 University Avenue
St. Paul, MN 55114-1057

Minnesota Geological Survey
Attn: M. Walton
2642 University Avenue
St. Paul, MN 55114-1057

New York State Energy
Research & Development
Agency
Attn: Director
Rockefeller Plaza
Albany, NY 12223

No. of
Copies

New York State Energy
Research & Development
Agency
Attn: G. Walmet
Rockefeller Plaza
Albany, NY 12223

Oak Ridge National Laboratory
Attn: J. F. Martin
PO Box Y
Oak Ridge, TN 37830

Office of Congressman
Sid Morrison
Attn: Kevin Billings,
Legislative Asst.
1330 Longworth Bldg.
Washington, DC 20515

Tennessee Valley Authority
Energy Research Section
1360 Commerce Union Bank Bldg.
Chattanooga, TN 37401

University of Alabama
Attn: E. Brett
School of Mines and Energy
Development
Box 6282
University, AL 35486

University of Alabama
Attn: W. Schaetzle
School of Mines and Energy
Development
Box 6282
University, AL 35486

University of Minnesota
Attn: Director
Physical Plant Operations
University of Minnesota
200 Shops Building
319 15th Avenue S.E.
Minneapolis, MN 55455

US Department of Interior
Attn: Natural Resources
Library
Serials Branch (G/E)
Washington, DC 20240

No. of
Copies

US Geological Survey
Attn: R. T. Miller
US Department of Interior
702 Post Office Bldg.
St. Paul, MN 55101

FOREIGN

Bengt Hidemark Gosta Danielson
Arkitekter SAR
Attn: A. Boysen
Jarntorget 78
S-11 29 Stockholm
Sweden

Commission of European
Communities
Attn: P. Zegers
DG XII, E3
200 Weststraat
Brussels, Belgium

Heidemij Adviesbureau
Attn: A. Snijders
PO Box 264
NL-6800 AG Arnhem
The Netherlands

I.E.N.E.R.
EPF-Ecublens
Attn: B. Saugy
1015 Lausanne
Switzerland

KFA Julich
Projektleitung Energieforschung
Attn: F. J. Friedrich
PO Box 1913
D-5170 Julich
West Germany

KFA Julich, PLE
Attn: V. Lottner
PO Box 1913
D-5170 Julich
West Germany

No. of
Copies

Laboratory for Energetics
Attn: B. Qvale
Technical University of Denmark
DK-2800 Lyngby
Denmark

Management Office for Energy
Research PEO
Attn: K. Joon
P. O. Box 8242
NL-Utrecht
The Netherlands

B. Mathey
Consulting-Engineers Ltd.
2205 Montezillon-Neuchatel
Switzerland

Public Works of Canada
Attn: E. L. Morofsky
C456 Sir Charles Tupper Bldg.
Riverside Dr. and Heron Rd.
Ottawa, Ontario
K1A 0M2 Canada

Riso National Laboratory
Attn: P. L. Christensen
DK-4000 Roskilde
Denmark

Swedish Council for Building
Research
Attn: S-E. Lundin
St. Goransgatan 66
S-112 33 Stockholm
Sweden

Swedish Council for Building
Research
Attn: W. Raldow
St. Goransgatan 66
S-112 33 Stockholm
Sweden

No. of
Copies

Swiss Federal Energy Office
Attn: A. Fehr
CH-3003 Berne
Switzerland

ONSITE

DOE Richland Operations Office

D. Jones/D. R. Segna

34 Pacific Northwest Laboratory

L. D. Kannberg (25)
J. R. Raymond
L. W. Vail
Technical Information (5)
Publishing Coordination (2)