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**DIRECT UTILIZATION OF GEOTHERMAL RESOURCES AT
WARM SPRINGS STATE HOSPITAL, WARM SPRINGS, MONTANA**

Final Report for the Period January 31, 1979—June 30, 1983

June 1983

Work Performed Under Contract No. FC07-79ET27055

**MultiTech, Inc.
Butte, Montana**

**Technical Information Center
Office of Scientific and Technical Information
United States Department of Energy**

GEOTHERMAL

Energy

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DIRECT UTILIZATION
OF GEOTHERMAL RESOURCES AT
WARM SPRINGS STATE HOSPITAL
WARM SPRINGS, MONTANA

FINAL REPORT

PREPARED
JUNE 1983

AMENDED AND PUBLISHED
JANUARY 1984

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P.O. Box 4078
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U. S. Department of Energy
Division of Geothermal and Hydropower Technologies
Washington, D.C. 20585

Under DOE/ID Contract DE-FC07-79ET27055

ABSTRACT

Several decades ago the water from a natural hot spring was piped to the Warm Springs State Hospital barn and greenhouse and eventually into the domestic water supply for showers.

The Montana Department of Natural Resources and Conservation (DNRC) funded a feasibility study on potential development of the geothermal resource from monies originating from coal severance taxes. The program was established to reduce the State's reliance on fossil fuels through increased use of solar, wind, geothermal, small-scale hydro, and biomass alternatives. The results of the feasibility study were subsequently utilized in obtaining a \$721,122 award from the Department of Energy Program Opportunity Notice (PON) program to identify and develop the geothermal resource at Warm Springs.

The study included environmental and legal considerations, geophysical surveys, and the subsequent development of the resource. The well produces 60 to 64 gpm of 154°F geothermal water which is utilized in a heat exchanger to heat domestic water. The system became fully operational on January 13, 1983 and the calculated yearly energy savings represent approximately 17.6 million cubic feet of natural gas which is equivalent to \$77,000, based on current prices.

ACKNOWLEDGEMENTS

MultiTech acknowledges Carroll South, Curt Chisholm, Tom Sellars, Michael Butorovich, Tom McCarthy, and Don Painter of the State of Montana, Department of Institutions; George Nolan of the State of Montana, Architecture and Engineering Division; Frank Childs and Ray Sanders of EG&G, Idaho; and Mike Tucker, Dr. Michael McLatchy, and Kent Hastings of U.S. Department of Energy, Idaho Operations Office, for their assistance and cooperation throughout the duration of the project.

PON FINAL REPORT FORMAT

This report follows a general outline which has been developed for use by all of the PON project final reports. The intent of the outline is to provide general uniformity in reporting, both in format and content, and to assure that the documentation of the project activity is complete. Since the scope of the projects vary, certain sections of the general outline will not be applicable and will be noted as such under the appropriate section heading. This will provide consistent numbering for each subject in each PON project final report.

The 19 PON projects which are expected to use this final report format are shown below.

<u>Contract Number</u>	<u>Project Name</u>	<u>Location</u>	<u>DOE Office</u>
DE-FC07-78ET27054	Monroe	Monroe, Utah	ID
DE-FC07-78ET27080	Haakon School	Philip, South Dakota	ID
DE-FC07-78ET28419	Diamond Ring Ranch	Haakon County, South Dakota	ID
DE-AC07-78ET28424	Ore-Ida Foods	Ontario, Oregon	ID
DE-FC07-78ET28441	St. Mary's Hospital	Pierre, South Dakota	ID
DE-FC07-79ET27027	Utah State Prison	Draper, Utah	ID
DE-FC07-79ET27028	Madison County	Rexburg, Idaho	ID
DE-FC07-79ET27030	Pagosa Springs	Pagosa Springs, Colorado	ID
DE-AC07-79ET27033	Elko Heat Company	Elko, Nevada	ID
DE-FC07-79ET27053	Boise	Boise, Idaho	ID
DE-AC07-79ET27055	Warm Springs State Hospital	W.S.S.H., Montana	ID
DE-AC07-79ET27056	Utah Roses, Inc.	Sandy, Utah	ID
DE-AC03-79ET27154	Klamath Falls	Klamath Falls, Oregon	SAN
DE-AC03-79ET27029	Moana, Reno	Reno, Nevada	SAN
DE-AC03-79ET27040	Susanville	Susanville, California	SAN
DE-AC03-79ET27045	El Centro	El Centro, California	SAN
DE-AC03-79ET27047	Aquafarms	Dos Palmas Area, California	SAN
DE-AC08-78ET27059	T-H-S Hospital	Marlin, Texas	NV
DE-FC08-79ET27058	Navarro College	Corsicana, Texas	NV

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- *Stoker, Roger, C., June 1979, Geothermal Resource Evaluation of the Warm Springs, Montana Area, Energy Services, Inc. and MERDI, Subcontract No. 9-A564-F, Contract No. DE-FC07-79ET27055, Report No. DOE/ET/27055-2.
- Stoker, Roger, C., June 1979, Technical Specifications for Geothermal Well Drilling at Warm Springs, Montana, Energy Services, Inc. and MERDI, Subcontract No. 9-A564-F, Contract No. DE-FC07-79ET27055, Report No. DOE/ET/27055-3.
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- Well Logs, November 1979, Dual Induction - Laterlog, Compensated Neutron-Formation Density, Temperature, Schlumberger and MERDI, Subcontract, Contract No. DE-FC07-79ET27055.
- *Carlson, Jon, R., April 1980, Drilling Report Warm Springs State Hospital Production Well No. 1, Montana Tech Foundation Mineral Research Center and MERDI, Subcontract, Contract No. DE-FC07-79ET27055, Report No. DOE/ET/27055-5.
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- Compendium of Warm Springs Well Water Analysis Reports and Corrosion Analysis, MERDI, 1979-1983, (informal report).

* Available from National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, Virginia 22161.

PROJECT DATA SHEET

1. Project Title: Geothermal Heating of Warm Springs State Hospital, Montana (Warm Springs Hospital) (MultiTech)
2. Contract Number: DE-FC07-79ET27055
3. Former Number: None
4. Period: 01/30/78 to 5/27/83
5. Value: \$756,745
6. DOE Share: \$721,122 -- 95.3%
7. Participant Share:
 - State of Montana \$27,845 -- 3.7%
(excludes \$2,405,458 in kind)
 - Non-Reimbursed MultiTech \$7,778 -- 1.0%
8. Project Application: Original goal was to heat the hospital's domestic hot water, and if the resource was adequate, additionally heat two buildings. Resource anticipated of 300 gpm, 170°F, and 1250 mg/l TDS. Plate heat exchanger application on domestic hot water and installation of direct heat coils in heating/ventilating units. Disposal of water by reinjection.
9. Project Location: Warm Springs State Hospital (25 miles west of Butte, Montana).
10. Well Name/Location: Warm Springs Production No. SE 1/4, SW 1/4, SE 1/4 Section 13, T5N, R10W, Deer Lodge County.
11. Peak Heat Load: 1.8 million Btu/hour
12. Annual Heat Load Displaced: 14.6 billion Btu/year (Load Factor = 50%)
13. Simple Payback: 9.7 years
14. Project Summary: Final well capacity allowed for only the domestic hot water heating system to be developed. Geothermal water (154°F) is pumped at 60 to 64 gpm to a plate heat exchanger where it heats cold water to 140°F for use. The geothermal water, at 85°F, is then disposed of in a waterfowl wetlands.
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PROJECT DATA SHEET

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SECTION 1. INTRODUCTION

This report summarizes the development and use of the geothermal resource at Warm Springs State Hospital, which is located in Deer Lodge County, Montana. The Hospital was partially converted to use this energy source. The major tasks addressed under the project were: 1) preparation of an environmental report; 2) regulatory statute compliance assurance; 3) a geophysical survey of the specific site; 4) well drilling and development; 5) conversion of the hospital's domestic hot water supply system to use geothermal heat; 6) partial conversion of hospital space heating to use geothermal heat which was initially investigated but the geothermal well production was inadequate; and 7) generation of publicity to focus public awareness upon the value of such a renewable energy demonstration project.

The project was funded by the Department of Energy (DOE) under its Project Opportunity Notice (PON) Program and by grants from the State of Montana.

It is noted that the Montana Energy and MHD Research and Development Institute, Inc. (MERDI) was the original program developer under the PON project. In October of 1981, MERDI was restructured into four companies; all are wholly-owned subsidiaries of MERDI, one of which is MultiTech, Inc. All work prior to this diversification was done by future MultiTech personnel. The two firms are discussed separately herein to differentiate between projects; however, for purposes of this report MERDI and MultiTech will be considered as interchangeable entities.

1.1 OBJECTIVES

The first objective of this project was to demonstrate the use of a geothermal resource to reduce energy costs at Warm Springs State Hospital, a Montana facility for the care of the mentally ill. The second objective was to encourage development of geothermal resources similar to the one at Warm Springs by publicizing the benefits derived from using low-grade geothermal energy and to have a demonstrable project to publicize.

Other individual project task objectives included:

- Documentation of methodology, procedures, and results of all exploration and testing performed during the project's duration.
- Retrofit of the current fossil-fueled domestic hot water and space heating systems at the plant to efficiently utilize the available geothermal energy source.
- Definitive design and operation of a geothermal heat transfer system.
- Determine and display costs in a form adaptable to larger or smaller potential industrial users.
- Incorporate expanded geothermal use within present institutional structures.

1.1.1 DOE PON Program

The use of geothermal energy for direct heat purposes by the private sector within the United States has been quite limited to date; yet there is a large potential market for such energy in such areas as industrial processing, agribusiness, and space/water heating of commercial and residential buildings. Technical and economic information is needed to assist in identifying prospective direct heat users and to match their energy needs to the available geothermal reservoirs. Technological uncertainties and associated economic risks have influenced potential user perception of profitability to the point of limiting private investment in geothermal direct heat applications.

In September 1977 and April 1978, the Department of Energy, Division of Geothermal Energy (now the Division of Geothermal and Hydropower Technologies), issued two Program Opportunity Notices (PON's). These solicitations were part of DOE's national geothermal energy program plan, which had as its goal the near-term research and development of hydrothermal resources by the private sector. Encouragement was given to the private sector by DOE offering

to share a portion of the front-end financial risk in a limited number of field experiment projects. After competitive evaluations, 23 PON projects were selected from the two Project Opportunity Notice solicitations. This is the final report for one of those 23 PON projects.

1.1.2 Demonstration Project

The first objective of this project was the field demonstration of the viability of low-grade geothermal energy as a heat source for utilities at Warm Springs State Hospital, a State of Montana facility. Natural gas was the only fuel being used at the hospital.

The second objective was to aggressively publicize the benefits derived from using low-grade geothermal energy at a facility such as Warm Springs State Hospital to reduce consumption of fossil fuels, and to encourage similar geothermal uses by other public facilities and private business.

The project also demonstrated that the socioeconomic and ecological environments received minimal adverse effects from this type of geothermal application (i.e., domestic water and potential space heating).

1.2 PRE-PROJECT BACKGROUND

Warm Springs State Hospital is located in the Deer Lodge Valley of Montana, approximately 26 miles northwest of Butte, Montana (see Figure 1). The hospital adjoins Interstate Highway 90 and is accessible therefrom.

The natural artesian spring at the Warm Springs State Hospital site exhibits a temperature of approximately 172°F, with a flow rate of approximately 60 gallons per minute (gpm). The spring has been flowing continually since before the early 1860's when the first buildings were erected.

Titles to mineral and water rights for essentially the entire site, and all land and buildings, are owned by the State of Montana.

FIGURE 1.--WARM SPRINGS STATE HOSPITAL
LOCATION MAP

MERDI, MultiTech's parent company, is the developer of the geothermal well. The owner/user is the State of Montana, with the Department of Institutions as the operator. The State Department of Natural Resources and Conservation (DNRC) provided funds to MERDI to gather pertinent data on the total energy demand at Warm Springs State Hospital and to examine the feasibility of utilizing the on-site geothermal hot springs to satisfy some portion of this energy demand.

Concurrent with the MERDI study, the Montana College of Mineral Science and Technology (Montana Tech) in Butte, Montana received funding from DNRC to perform a geophysical survey of the area surrounding Warm Springs State Hospital with the objectives of characterizing the geothermal resource and identifying an appropriate well site.

The MERDI study indicated that the geothermal resource was sufficient to support the institution's domestic hot-water system, and could possibly provide enough energy to heat several of the facility buildings. The Montana Tech study concurred with these findings.

It was then decided that MERDI would submit a proposal to the Department of Energy for a PON program to establish a geothermal demonstration facility at the Warm Springs site.

1.3 PROJECT SCOPE

As originally proposed, the Warm Springs State hospital geothermal conversion project was to be a 24-month effort to establish an alternate method for heating domestic water and if the resource were adequate, to convert several buildings to geothermal-supplied space heating.

The assigned tasks under this project were: 1) acquisition of environmental data and preparation of an environmental report; 2) legal assessment of applicable laws and regulations and acquisition of appropriate permits; 3) completion/supplementation of state-funded geophysical survey to identify

a suitable well location; 4) well drilling and development; 5) conversion of the hospital hot water supply system to use geothermal heat; 6) partial conversion of the hospital space heating to use geothermal heat, provided sufficient flow of water were available from the well; and 7) generation of informative publicity to focus the public's awareness on the value of such projects.

Difficulty was encountered during the drilling stage of the project. The well collapsed frequently while drilling due to ground structure irregularities and the first pump installed for pump tests proved to be defective, thus delaying the project.

Routine clean-out procedures were performed on the well, but these proved to be insufficient to improve well flow and utilize the larger geothermal source known to exist in the area.

When drilling was completed the well tests supported a production of 168°F water with a predicted flow of 70 to 90 gpm. This flow was sufficient for domestic hot water heating, but did not allow space heating in the buildings. Therefore, the final scope was changed to provide geothermal heating for only the domestic water.

1.4 GROWTH POTENTIAL

The initial intent of the study and the development project was to provide energy for domestic hot water production and, if possible, space heating of buildings, to provide a comprehensive demonstration of a typical geothermal resource. This was partially accomplished as the resource will only provide 60 to 64 gpm of 154°F water for the domestic hot water heating; also, the ongoing demonstration aspects of the project are available for educational purposes.

It is believed that this project was unsuccessful in attempting to reach a large-scale beneficial geothermal resource which underlies the area. Existing evidence indicates that a potential large-scale resource does exist at a

deeper level, below the 1498 ft depth of the present well. Workover of the well and additional drilling had to be suspended due to contact in the well with a large piece of metal believed to be a length of drilling pipe. Apparently, it was left in the well during initial drilling, thus preventing further drilling.

This project provided proof that geothermal energy can be tapped and used beneficially. It also demonstrated that low-temperature use of geothermal energy is possible and economically feasible.

The growth potential at the site is dependent on drilling additional wells into the deeper resource and then utilizing that resource for additional domestic water heating and space heating for buildings.

SECTION 2. SUMMARY

The environmental portion of the project was completed during the initial onset of the project and the report was submitted in April 1979. It appeared that very little negative environmental impact would be encountered with the development of the resource. It was necessary to ensure that no geothermal water contaminated the fresh water aquifer or nearby stream and that any reinjection or wetlands use adhered to those guidelines.

The investigation of applicable state permitting procedures addressed the areas of water rights, energy planning, wetlands establishment, air and water quality, and archaeological considerations. All of these areas were investigated by legal council and the appropriate permits requested prior to any drilling activities.

The resource assessment was in process prior to the PON project award which comprised an energy demand evaluation, energy audits, and a geothermal utilization. The geophysical investigation conducted under the project continued this assessment and led into the ensuing phases of the project.

After conducting a complete review of data gathered in the Resource Evaluation, the well was sited northwest of the existing hot springs mound, in the area of the facility's main heating plant.

Drilling activities began in mid-October 1979 and were completed in early December 1979 to a total depth of 1,498 ft. (see Figure 2 for diagram of the well completion). Logs run in the well were: 1) Dual Induction - Laterolog; 2) Compensated Neutron Formation Density and caliper; and 3) Temperature log. Also, two water samples were taken to determine R_w (formation water resistivity). Some preliminary pump tests were run by the well driller and then the decision was made to perform matrix acid treatment of the well. Based on an analysis of acid reaction to the well cuttings, hydrochloric acid was chosen for the well stimulation.

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FIGURE 2.--WARM SPRINGS PRODUCTION WELL

MERDI then contracted with a pump company to install a line shaft vertical turbine production pump. The pump test was plagued with vibration problems and binding of the pump shaft. Cause of the vibration problem has been attributed to the failure of the elastomer spider bearings. The line shaft pump was removed from the well and reinstalled with bronze spider bearings and additional short-term pump tests were conducted before the pump again experienced major wearing problems and was subsequently removed allowing the well to flow naturally.

In January 1981, Energy Services, Inc, (ESI) of Idaho Falls, submitted a report to MERDI on their evaluation of the Warm Springs well. The report's conclusions supported recommendations for reworking the well and drilling an additional 50 ft into what was believed to be a zone of hot water. After cleaning the well to the total depth (1498 ft), a solid metal item was struck in the bottom of the hole, probably a length of drill pipe lost during initial well drilling. However, fishing attempts to retrieve the metal were unsuccessful. Since it was not possible to drill through or around the metal, the decision was then made to perforate the bottom 120 ft of casing with two 1/2 in. jet perforations per foot.

A 50 HP Reda G110 submersible pump was installed on April 28, 1981 to a setting depth of 845 ft. The pump was installed to perform pump tests and to then be utilized as the production pump. The pump tests conducted provided some basic well production information, but the flow rates were well below the recommended operating range of the pump. A decision was made to install a smaller submersible pump.

That pump, a 30 HP Reda G75 submersible pump was installed on May 19, 1981 to a setting depth of 987 ft. The pump was test run by a Reda representative for approximately 1/2 hour. On May 23 long-term testing commenced. The well was tested at rates of 50, 75, 95, and 110 gpm, for 100 hours each, and then allowed to recover. After the final recovery of the 110 gpm test, a nine-hour step drawdown of 25, 50, and 75 gpm was run for three hours at each pumping rate. The main purpose of the step drawdown test was not to

determine well efficiency but to gather data on optimum pumping rate of the well. Since this is a developing well, as evidenced by the data obtained, this test cannot give any valid conclusions in regard to well efficiency.

Design of the conversion system proceeded and construction contracts were let to complete the production, disposal, and distribution systems. The utilization of the geothermal resource began on January 11, 1983 with the start-up of the well pump and associated systems. Geothermal water flows ranged from 60 to 64 gpm at 154°F. The system effectively eliminated the steam heating requirement for the domestic water heated in the heating plant. On March 5, 1983 the 30 HP Reda G75 pump failed. That failure has not been documented as to cause. An addendum report is planned after the pump is repaired.

2.1 PROJECT DEVELOPMENT

(For this discussion see Section 2, Summary)

2.2 ECONOMIC RESULT

The total investment to date on the project has been from the State of Montana, and U. S. Department of Energy (DOE) funds, and unreimbursable MultiTech funds. The State has contributed \$27,845, DOE PON project funds are authorized to \$721,122, and additional reimbursable MultiTech costs of \$7,778 total for a project cost of \$756,745.

Calculations have been made on the utilization of the available geothermal energy pumped into the heating plant. The system has been operating at a nominal geothermal flow of 64 gpm and providing an average temperature of 154°F fluid with a net reduction to 104°F. Assigning an arbitrary 60% utilization factor, those flow figures would result in a calculated energy utilization of 959,616 Btuh or 23,030,784 Btu per day.

Using information currently available at the Warm Springs heating plant it was determined that approximately 24,352 gallons of soft water per day is heated from 48°F to 145°F by flowing through the geothermal heat exchanger.

This amount of energy is calculated as 19,676,659 Btu per day, which is reasonably close to the first calculation based on actual geothermal flow. Also, additional recirculation of the stored domestic hot water occurs during periods of off-use times. It is difficult to assign a value to this recirculation, but it is reasonable to round off the calculated energy figure to 20,000,000 Btu per day as a realistic compromise.

The following was then used to calculate the net yearly energy savings that resulted from the geothermal installation.

- 20,000,000 Btu per day, domestic hot water heated.
- 829.5 Btu per cubic ft of natural gas.
- 50% conversion efficiency of natural gas to domestic hot water.
- \$4.682 per 1000 cubic ft of natural gas.

A yearly savings of 17,600,964 cubic ft of natural gas was calculated. This natural gas, equivalent to 14,600 million Btu's per year, is the actual energy value that would be saved at Warm Springs. That savings in natural gas at current incremental pricing is equal to \$82,408 per year.

A simple calculation of dollars expended per million Btu of natural gas saved would be \$756,745 divided by 14,600 million Btu's per year or \$51.83 per million Btu per year saved. A simple payback calculation of dollars expended versus savings per year would be \$756,745 divided by \$82,408, or 9.2 years. This does not take into account the operating and maintenance costs, future increases in usage of the geothermal energy nor the escalating natural gas and electricity prices.

A simple payback including the costs of operation and maintenance costs is shown in Section 33.5.1 and was calculated at 9.72 years. A life cycle analysis of a simple payback was also calculated in Section 33.5.3. That life cycle simple payback was 7.83 years, considering the operation and maintenance costs as well as the inflation rates of energy supplies.

SECTION 3. CONCLUSIONS AND RECOMMENDATIONS

The project proceeded throughout the tasks as outlined in the project scope in a fairly straightforward manner, but several problems occurred which delayed and reduced the scope of the project. The major disappointment in the project was the lower-than-anticipated water volume delivered by the well. Acid treatment and reworking of the well improved the production capability but fell short of the anticipated amounts. Failures of the line shaft pumps were a disappointment; however, they provided an insight into pumping higher temperature fluids laden with particulate material and also identified the problems of that type of pump. Experience with submersible pumps was obtained which resulted in installation of the production pump; however, a failure of that pump occurred on March 5, 1983. This failure has not been documented.

3.1 TECHNICAL

During drilling and completion of the well some difficulties, but no major incidents occurred. As listed below, a number of difficulties were encountered, some of which may be avoided with future wells.

1. Remoteness of well from necessary equipment and supply sources resulted in several delays. Also, plans were frequently altered to accommodate lack of availability of equipment and services.
2. Difficulty was experienced in maintaining good control of mud properties. This was caused by several factors including: delays in delivery of mud chemicals; lack of mud-handling equipment; flow of formation water into the well; and over-night shutdowns.
3. Attempts to log the upper sections of the hole before casing installation was unsuccessful due to mud problems, namely high mud gel strength and lack of hole stability. Both of these are most likely due to formation water flowing into the well.

4. Some of the temperature surveys either were unsuccessful or doubtful for the same reasons as in (3) above. The tendency for the EG&G probe's line to float compounded the problem at depths greater than 500 ft.
5. Confining operation to only 8:00 a.m. to 9:00 p.m. caused major inefficiencies in drilling. Also, non-summertime weather compounded this problem. Drilling time was lost due to shutdown-startup operations. All lines and pumps had to be drained, and the drill pipe had to be tripped out of the hole before shutdown. To startup, the mud pits had to be circulated and conditioned, the drill pipe had to be tripped in the typically tight hole and sloughed material had to be reamed in order to get back to bottom. Consequently, actual drilling time on a typical day was only 8 hours, as compared to 24-hour drilling normally conducted in oil fields.
6. The use of oil field sizes for tubular goods added to the equipment procurement problems, as we are not located in an area where oil field work is common.
7. Labor problems delayed some mud shipments from Butte.
8. Some difficulties were encountered with each of the three pumps used in drilling and production. The duplex mud pumps lacked sufficient pressure and capacity to allow the use of jet nozzles to aid in hole cleaning; high flow rates from the pumps would have allowed operation with lower mud viscosity and gel strength which in turn, would have avoided the cleaning problem. The line shaft pump, as supplied by the well driller, operated well but not enough pipe and bowls were on hand to allow the pump to be set deeper than 250 feet. The electrical submersible pump also supplied by the well driller burned out, terminating the preliminary pumping trials.

9. Other steps to be considered for future geothermal drilling programs include the following:

- a. If at all possible operate on a 24 hour basis.
- b. Assign a project representative to "sit the rig" to observe unusual occurrences which may not show up in the drilling log records.
- c. To avoid possible surface contamination, use steel mud pits and mud solids control equipment such as shaker and cyclone.
- d. Provide blow out prevention equipment so that proper mud weight can be calculated.
- e. Use regular bentonite (Aquagel) vs. high yield bentonite (Quick Gel). Quick Gel does not maintain its viscosity-building properties since it is more sensitive to contaminants.
- f. Use a pull-down unit to spud the wells.
- g. To enhance availability of pipe, use readily available oil field sizes for tubular goods.
- h. Use a cased, cemented, and perforated completion.
- i. Investigate mobile fines problem to determine proper drilling techniques.
- j. Keep mud weight high enough to prevent formation water from inhibiting drilling, but not so high as to damage the formation. This, and the use of standard size oil field casing, would eliminate the need to drill out cement left inside the casing.
- k. Run temperature surveys with Amerada RT-8 gauge, as it was more repetitive.

The following recommendations based on production analysis may be of value to other programs.

1. Wells should be pump tested to determine production potential and to provide information on water source and the geothermal reservoir model.

2. Prior to pump tests, a wash tool, run on the end of drill pipe or tubing can be used to circulate behind slotted casing to ensure that sloughed material is not blocking production.
3. Initial pump testing of a resource should use a pump/control system capable of accurately delivering a wide range of flowrates.
4. To get additional production from similar wells, the following should be considered:
 - a. If pump tests indicate a deep zone of skin damage, the cause is likely from mobile fines. Certain oil field chemicals are available to fix these fines in place and prevent formation damage. Pilot tests should be run to evaluate this possibility.
 - b. Temperature and flow rate surveys should be run to determine the source or sources of present production of geothermal energy. Nonproducing zones lying behind the perforated casing should be isolated, broken down, and acidized.
 - c. The well zones at various levels should be tested for flows.
 - d. Depending on the pressure test results and interpretation, it may be more economical to simply drill additional wells to obtain the required production, rather than either reworking or drilling a single well deeper.
 - e. Some wells do not appear to be good candidates for a conventional fractionation job since the formation may be poorly consolidated. This would make it extremely difficult to maintain a high conductivity fracture. However, porous-permeable cement might work as a fracture-propping agent.

General engineering considerations that could be of value for similar projects are listed below:

1. Recognize site specific problems as they relate to the resources, waste water drainage or reinjection, electrical service, point of use location, and operational and maintenance requirements.

2. Use reputable firms not only for basic site work but also for manufacturer's supplied equipment and engineering design.
3. Use of either corrosion coupon tests or monitoring samples with new electronic corrosion detection equipment will avoid costly material failures and loss of reliability in the operational system.

3.2 INSTITUTIONAL

The project's institutional interfaces tend to be simplified and straightforward because both the owner and user is the same entity; i.e., State of Montana. However, there are some areas that require emphasis or checking to ensure that problems are minimized during similar projects. These include:

1. Coordinate all study and development efforts with land owners and organizations that may be impacted by the project, both initially and throughout the life of the project.
2. Check with regulatory agencies in regard to both the permits required and the applicable review requirements; this avoids unexpected and costly delays.
3. Develop adequate detail for all plans and designs to assure obtaining the most desirable product, or end result, and to satisfy the cognizant agencies in their review and/or bidding.
4. Allow sufficient time for agency review and approval of the various documents required for project finalization.

3.3 ECONOMIC

The amount appropriated for project funding prevented any further exploratory efforts to develop additional geothermal resources; also, the approaching expiration of project funding prevented more extensive use of advanced control technology in the production portion of the final installed system.

The simple payback of 9.2 to 9.72 years seems to be too lengthy and leaves a question as to the cost effectiveness of this project, but allowances have to be made in regard to the additional costs encountered with the well and pump problems. The life cycle analysis simple payback of 7.83 years is encouraging and provides hope that the lessons learned in this project can be used in future projects thereby reducing their payback periods. If the geothermal resource had produced the originally expected amount, the economic results would have changed materially. Development of a demonstration project requires some additional costs of publicity which increase overall costs and directly affect final economic considerations. Finally, the major result of the project was that a geothermal resource was successfully obtained and developed into a functional system, even though at a reduced volume.

SECTION 4. PROJECT DESCRIPTION

The acquisition of environmental data and preparation of an environmental report indicating very little negative impact would be experienced with the development of the resource was completed at the onset of the project. A legal and statutory requirement assessment was performed prior to drilling to assure compliance with all applicable regulations. Preliminary plans included provisions and expectations for enough hot water from the production well to provide energy for the domestic hot water supply and also to heat two of the facility buildings.

A production well was to be drilled at a site chosen after a geophysical survey was performed. After drilling, the well was to be tested and the feasibility of performing both hot water and building heating assessed.

Early in the study, it was apparent that the hospital domestic hot water heating system would have to be modified to accommodate the needed equipment for geothermal heat transfer. Furthermore, it became obvious that the individual heating/ventilating units would require modifications to accept additional heating coils and control instrumentation.

Concurrent with the study, a publicity program was established within the State of Montana to promote the application of geothermal energy.

4.1 TASK BREAKDOWN

The geothermal resource at Warm Springs State Hospital will be utilized directly to heat domestic water for personal hygiene and food preparation. The following tasks were performed under the project:

- Environmental Report and Monitoring;
- Legal Support (Permits, etc.);
- Geophysical Survey Supplement;
- Well Drilling and Development;
- Hot Water System Retrofit;
- Publicity; and
- Project Management.

Each task was arranged into the overall project schedule, as shown in Figure 3. As can be seen in Figure 3 the project was to have been completed by the end of January 1981. The completion date was not met because of problems maintaining well integrity, drilling delays caused by the well drillers test pump, and loss of the first production lineshaft vertical turbine pump.

4.2 ORGANIZATION AND PARTICIPANTS

4.2.1 Key Project Personnel

The project team to carry out these tasks was comprised of: 1) the State of Montana Department of Institutions in Helena, Montana; 2) MultiTech, Inc., in Butte, Montana; and 3) various contractors and subcontractors.

Organizational elements and key project personnel are shown on Figure 4. General management prior to driller selection was handled by M. Eugene McCloud. Just prior to well drilling (by the Dreiling Company), Mr. McCloud left MERDI and Ms. Karen Barclay assumed project management responsibilities. Ms. Barclay administered all phases of the project including, subcontractor selection, publicity, and safety oversight until the end of 1980 when Daniel Stowe assumed the project. Mr. Stowe was responsible for the completion of the pump test and the beginning of the retrofit design.

In June of 1981, Mr. Allan Miller assumed the duties of project manager. He was responsible for the completion of the retrofit design and construction as well as start-up of the system.

Other key personnel and primary responsibilities are shown on the project organization chart (Figure 4).

1 Testing during this period was intermittent with little or no success.
 2 During the time from July 1980 through March 1981, design was intermittent due to unsuccessful pump tests.
 3 Design of the heating system retrofit was stopped when it was determined that production was not going to be adequate.

FIGURE 3.--PROJECT SCHEDULE

FIGURE 4.--PROJECT ORGANIZATION

4.2.2 Decision Points

Several project milestones were established:

- The Need for Geophysical Survey Supplement. After reviewing the information gained during the Montana Tech study conducted in 1978, it was determined that a further geophysical study was necessary to confirm this study and gather other pertinent data.
- Decision to Rework the Well. When it became evident that the integrity of the well had not been maintained due to sloughing and caving within the formation, the decision was made to rework the lower 100 feet of the well and drill an additional 50 feet into what was believed to be a zone of a hotter geothermal resource.
- Decision to Retrofit Heating System. After the unsuccessful attempt to use a vertical shaft pump for the production well, and the lack of success in drilling the hole deeper (due to the lost drill pipe obstruction), it was determined that the well would not produce sufficient flow for both the domestic hot water system and the building heating requirement. Thus, the domestic hot water system was chosen as the final result of the project.

4.3 COST BREAKDOWN

The project was jointly funded by the State of Montana and DOE under its PON program. The total project cost of \$756,745 was comprised of DOE reimbursible costs of \$721,122 (95.3%), State of Montana participation costs of \$27,845 (3.7%), and additional unreimbursed MultiTech costs of \$7,778 (1.0%). The Department of Institutions (DOI) supplied security personnel at no charge to the project. Actual project costs through fiscal 1983 are shown in Table 1.

TABLE 1

COST SUMMARY

WARM SPRINGS STATE HOSPITAL - GEOTHERMAL PROJECT #DE-FC07-79ET27055

TASK	AUTHORIZED DOE FUNDING AVAILABLE	PROJECT COSTS TO DATE	STATE COSTS AND IN-KIND SERVICES TO DATE	TOTAL PROJECT COSTS
Environmental Report	\$ 14,495	\$ 14,495	\$ 9,000	\$ 23,495
Legal Support	2,119	2,119		2,119
Resources Definition	4,180	4,180	13,475	17,655
Well Drilling	438,216	437,885	1,119	439,004
Domestic Hot Water Heating	116,545	117,340	2,736	120,076
Space Heating	2,690	2,690		2,690
Publicity	11,727	11,205	967	12,172
Project Management	131,150	138,986	548	139,534
TOTAL	\$ 721,122	\$ 728,900*	\$ 27,845	\$ 756,745

* Costs include estimates for final printing and wrap-up of final report.

SECTION 5. RESOURCE ASSESSMENT

5.1 PRE-PROJECT ASSESSMENT

MERDI, at the time of PON project proposal, was in the process of evaluating the energy demands of Warm Springs State Hospital and assessing the feasibility of utilizing the hot springs to satisfy this demand. That work completed in 1978 was funded by a grant from the Montana Department of Natural Resources and Conservation.

The evaluation consisted of the following: 1) a review of Montana geothermal laws; 2) a walk-through energy audit of Warm Springs facility buildings; and 3) a Geothermal Utilization study. A brief summary of each of these tasks is given in this Section. It should be noted that the tasks in this assessment are related to both the facility and regulatory statutes and do not concern any geophysical assessment of the property.

5.1.1 Legal Review

A comprehensive review of Montana geothermal laws and a thorough search of the statutes of the State of Montana indicated that many shortcomings exist in the areas of clear definition of terms, regulatory requirements, and state agency jurisdiction over geothermal development.

5.1.2 Energy Audit

Members of the MERDI technical staff conducted a walk-through energy audit of the Warm Springs facility in October 1978. As the buildings did not have individual steam, condensate, or electrical meters it was difficult to accurately determine the individual energy consumption of each building. The central heating plant provided hot water and steam for the complex.

The MERDI staff noted that many windows did not seal properly after closure. Windows also remained opened during periods of cold weather. Entry doors opened to the outside without foyers or air locks, thereby allowing heat loss.

An energy use assessment questionnaire was given to employees at the Institution. Workers responding indicated that opened and poorly sealed windows were widespread at the Institution, as well as the fact that windows were generally single-pane and drapes were often left open at night.

5.1.3 Geothermal Utilization Study

MERDI, under contract to DNRC, performed a technical evaluation on the application of the geothermal resource at Warm Springs State Hospital. The work involved obtaining information and analyzing the components of the energy distribution system at Warm Springs State Hospital to gather pertinent data on the energy demand of the facility. Degree days and ambient temperature calculations were made to determine building heating requirements.

Analysis of the central steam plant loads were made to confirm the building heating needs and to substantiate the domestic hot water demand cycles during the nominal 12-hour day.

Recommendations of this preliminary work were to supply the domestic hot water requirement of 30,000 gallons/day (885,000 Btuh) and peak space heating for the Main Hospital Building and Food Services Building, a space heating total of 2,399,000 Btuh.

5.2 PRE-DRILLING ASSESSMENT

A geophysical investigation of the Warm Springs area was conducted by Dr. Charles Wideman,* of Montana Tech College, plus a geophysical ground and aerial survey by Roger Stoker, MERDI consulting geologist. Mr. Stoker also reviewed a previous aerial and ground survey done by Dr. Hugh Dresser, geologist, Montana Tech College. These studies provided MERDI with necessary data for selection of the well site.

* Geophysical Investigation of the Warm Springs, Montana Area, 1980, by Charles J. Wideman, Montana College of Mineral Science and Technology, DNRC Contract No. RAE-515-WDMN-781.

The composite gravity data indicated a northwest trending linear about 1300 ft northeast of the existing hot springs mound and a gravity high on the south side of this linear just east of the mound. The resistivity data showed a low (<5 ohm-meter) in the area of the mound and the main facility buildings.

The field and aerial study was undertaken to determine the fault structure in the valley. The geophysical data of the valley indicated a north-south fault connecting Warm Springs and Fairmont Hot Springs; surface expressions could not be located.

The aerial surveys indicated some differences in the location of other area faults, but did agree on the geologic structure within and around the valley.

5.3 DRILL SITE SELECTION

The production well could have been located anywhere within the immediate vicinity of the existing travertine mound (hot springs source) and was likely to encounter hot water at shallow depths. The production of the well was dependent upon the permeability of the production zone however, and in order to maximize the production rates and temperatures, the well was located to take advantage of all the inferred fault zones in the area. Considering all previously discussed data, the production well was located in the area of the water tower as marked on Figure 5. This location resulted in the intersection of the wellbore and fault zones beginning at approximately the 500 foot depth provided the faults dipped at $\sim 70^\circ$. Reasonable maximum well production and water temperature would then be encountered from that point deeper to an anticipated maximum depth of 1500 ft.

5.3.1 Site Location

The final drilling location was chosen as a site northeast of the existing hot springs mound within 100 ft of the central heating steam plant in an open field area adjacent to the water tower.

FIGURE 5.--GEOTHERMAL WELL SITE LOCATIONS

5.3.2 Selection Criteria

The well was located to deliver the highest level of benefit from the resource. This location planning placed the well within 100 ft of the central heating steam plant which supplies domestic hot water; thus the linear footage of transmission supply piping was minimized. The heat exchanger also could be located in the central heating plant to materially reduce the footage of distribution piping and eliminate the need for additional building structures.

5.4 POST-DRILLING ASSESSMENT

During the post-drilling assessment, preliminary well tests were run and a decision was made to perform a matrix acid treatment on the well. After this hydrochloric acid treatment, additional well tests were conducted by the well driller, but failures of the pump prevented extensive evaluation. Based on these tests a production line shaft vertical turbine pump was selected and installed for production run-in tests. This pump experienced numerous vibration problems and did not provide adequate operating time to evaluate the well or determine adequate operating history on the pump.

Subsequent to these problems, Energy Services, Inc. submitted their recommendations to rework the well and deepen it an additional 50 ft. This recommendation was followed. Unfortunately the drilling rig encountered the apparent lost drill pipe which prevented deepening the well and a decision was made to do jet perforation on the lower portion of the casing. Following this procedure, a 50 HP Reda G110, series 540, 32-stage submersible pump was installed at a setting depth of 845 ft to perform pump tests and then be utilized as the production pump. The pump tests conducted provided some basic well production figures but those pumping rates were below the recommended operating range of the pump. Another Reda pump was obtained and this 30 HP G75 series 542 22-stage pump was installed at a setting depth of 987 ft.

This pump provided flows in the mid-range of the pump curve and it was determined that a flow between 70 to 90 gpm would be maximum for the well production. This was adequate for domestic hot water heating but was not an adequate resource to provide any space heating to the hospital buildings. At this point in the development, the space heating portion of the project was abandoned.

5.5 OPERATIONAL ASSESSMENT

The utilization of the geothermal resource began on January 11, 1983 with the startup of the well pump and the associated systems. Initial flows from the well were set at approximately 75 gpm. Observation of the vibration in the well head pressure gauges indicated an initial unstable pump operation. After three days of steady operation, the pump and flow conditions stabilized and a steady pressure indication was achieved at the well head; however, during operational adjustment of pressure in the system, flow had drifted down to 60 gpm. Subsequently, geothermal flow values were increased to 64 gpm to bring the pump up to its minimum operating range and prevent pump wearing problems. In an attempt to increase the geothermal flow, the line valves were opened to maximum; but this reduced the back pressure in the system which is not advisable because precipitates could then be formed on the heat exchanger internal surfaces. Therefore, it appears that the geothermal resource will not sustain flows much in excess of 64 gpm.

During the pump tests conducted in the summer of 1981, the well consistently produced geothermal water at 168°F, but on startup the temperature produced was a maximum of 154°F. On March 5, 1983 the 30 HP Reda G75 pump failed. That failure has not been documented as to cause.

SECTION 6. ENVIRONMENTAL ISSUES

6.1 PRE-DRILL

The Environmental Report was undertaken in February 1979 with a study at Warm Springs to determine any adverse environmental or socioeconomic impacts resulting from the demonstration project and to define mitigating measures, where appropriate. The report was submitted to DOE for review in April 1979.

The report indicated that very little negative environmental impact at Warm Springs would result from the development and demonstration of the geothermal resource. It was determined that the possibility either of subsidence or seismic activity associated with utilization and reinjection of geothermal water could be minimized; outflow of used water was directed to an undeveloped wetlands area used by waterfowl that was separate from any existing streams.

A review of historical water data has indicated widespread industrial degradation of water resources in the Warm Springs area; thus, it was critical that the fresh water aquifer and nearby stream be protected from the geothermal resource during the drilling and operational phase of the project. Necessary precautions were to be considered during the drilling to ensure that mud pits did not discharge into the aquifer. In similar projects, water contamination from wells, well heads, piping system, and discharge systems should incorporate design considerations to prevent these types of avoidable contamination.

The air quality in the valley exceeds the primary federal standards for SO_2 ; and, occasionally, this is also true for particulates. It was not anticipated that dust and vehicle emission resulting from the drilling phase would contribute to the area's existing air problems. Hydrogen sulfide was barely detectable at the well site. The surface disposal of spent water to adjacent ponds could result in gaseous releases which could stagnate in the valley during periods of poor ventilation.

Plywood buffers were installed around the drill rig to protect the welfare of the patients and staff at Warm Springs during the drilling and testing phase. Drilling was conducted only during the day to prevent disturbance of hospital routine.

Because of the existing disturbed nature of the site, due to surrounding land uses, the impacts of drilling and operation phases on the terrestrial flora and fauna were negligible.

Long-term effects are not expected to impinge upon the social or economic environments subsequent to and ongoing throughout the life of the demonstration project.

6.2 POST-DRILLING

There were no amendments or changes in the environmental assessment of the project following drilling of the well. Generally, potential impacts identified in the environmental report were found to be accurate and no post-drilling environmental evaluation was performed.

SECTION 7. INSTITUTIONAL ISSUES AND PERMITS

7.1 PRIVATE

Warm Springs State Hospital is the State of Montana's facility for the mentally ill. Title to all mineral and water rights for essentially all of the site is owned by the State of Montana. The State holds title to all land and buildings at the site. There are no private lands involved in the immediate vicinity of the project and there was no necessity for any private agreements.

7.2 CITY

Warm Springs State Hospital does not lie within the boundary of any incorporated city in the State of Montana; therefore, no city regulations were applicable.

7.3 COUNTY

Warm Springs State Hospital is a state-owned institution and within Deer Lodge County and no county regulations apply within the facility boundaries.

7.4 STATE

An investigation of applicable state permitting procedures was performed by legal council prior to drilling activities. The investigation addressed the areas of: 1) water rights permitting; 2) energy planning; 3) wetlands establishment; 4) air and water quality permitting; and 5) archaeological assessment.

The State Departments of Natural Resources and Conservation, Health and Environmental Science, and the State Historical Society were contacted concerning their regulatory jurisdiction over the geothermal project. In brief, the extent of each jurisdiction is summarized in the following pages.

Department of Natural Resources and Conservation (DNRC)

• Water Right Division

The DNRC Water Right Division requires a permit for exploratory and production wells. The exploratory well required an interim permit. The production well required a water use permit. Due to the small size of the well, the cost of these permits is minimal. Under the law, the production well permit application must be for the gross volume withdrawn rather than for consumptive use. Permitting applications for a small-scale geothermal well are as follows:

<u>Permit</u>	<u>Agency</u>	<u>Address</u>	<u>Phone</u>	<u>Fee</u>	<u>Lead Time</u>
Interim Water Use	DNRC Water Rights Div.	32 S. Ewing Helena, MT	(406) 449-3634	\$10.00	Minimal
Water Use	DNRC Water Rights Div.	32 S. Ewing Helena, MT	(406) 449-3634	\$10.00	Within 60 days of beneficial use

Due to the small scale of the Warm Springs well, DNRC did not require an Environmental Impact Statement (EIS). DNRC regulation exempts wells with a capacity of less than 10,000 acre feet/year (15 cfs) from the EIS requirement. The Warm Springs well falls well below this limit.

• Energy Planning Division

The DNRC Energy Planning Division requires no permits for a geothermal well of this size under an amendment to the Major Facility Siting Act passed by the State legislature in 1979. This amendment exempted from certification under the Act those geothermal projects: "designed for or capable of producing less than twenty-five million Btu's per hour of geothermally derived power." The amendment also exempts small geothermal projects from the requirements for exploration reports and long-range planning.

Department of Health and Environmental Sciences (DHES)

DHES has essentially two mechanisms for enforcement of the water quality law: 1) granting permits for the discharge of pollutants into state waters from "point sources", and 2) issuing orders for the prevention or abatement of pollution.

• Discharge Permits

The applicability of the permit requirement for waste water discharge depends on three factors: 1) discharge from a "point source"; 2) discharge into "state waters"; and 3) existence of applicable ambient water quality standards.

1. Point Source: The discharge of waste water from the Warm Springs geothermal project is not a point source discharge, since it flows into a wetlands area.
2. State Waters: State waters include all surface streams and lakes and subsurface reservoirs or streams. Thus, reinjection into the groundwater aquifer would be a discharge into state waters. However, an artificially created impoundment which is not part of an existing surface stream, but which is created by flooding previously dry land, is not "state waters." Therefore, no permit was required for discharge of water into the wetlands which are receiving the well's outflow.
3. Water Quality Standards: In order to grant or deny a discharge permit, the DHES must determine whether the proposed discharge will comply with or violate existing ambient water quality standards applicable to the receiving state waters. This requires, a priori, that water quality standards exist for such waters. At the present time, there are no ambient water quality standards in existence for underground waters and it is not likely that any will be adopted within the next few years. Consequently, there is no functional permit program for discharge into groundwater.

In summary, no water pollutant discharge permit is required for a reinjection well, because of the absence of applicable water quality standards, and no permit is required for discharge into an artificial, offstream wetlands impoundment, because it is not "state waters." However, in the event that any discharge or overflow from the impoundment into nearby Warm Springs Creek occurred, a permit would be required. Even the potential for occasional accidental overflow into the creek would make a permit advisable, if only for information purposes and to specify the obligations of the permittee in case of such accidental discharge. Discharges from the impoundment are the responsibility of Montana's Department of Fish, Wildlife, and Parks (DFWP) as the operator of the wetlands, and DFWP is the appropriate applicant for such a permit.

- Pollution Abatement Orders

In addition to its permit-granting authority, DHES is authorized to issue and enforce pollution prevention or abatement orders to prevent or curtail activities which are likely to cause or are causing degradation of the quality of state waters. There is no requirement for a "point source" of pollution, nor must there be ambient water quality standards in existence. Any significant alteration in the natural quality of surface or subsurface water may justify the prohibition of any activity which contributes to such alteration in water quality. Thus, even though no permit is required for the construction of a wetlands impoundment or for the discharge of water into such impoundment, if the DHES has reason to believe that, for example, seepage from the impoundment will contaminate groundwater, the project could, theoretically, be prevented.

Initially, it was advisable to maintain regular communication with the Water Quality Bureau of the DHES in order to determine what precautions, if any, they might recommend to avoid ongoing adverse water quality impacts. Furthermore, pollution prevention orders by DHES necessarily are based on knowledge of the existing natural water quality in the

affected area, and on the characteristics of the pumped water which may be introduced into the ambient water. They therefore require, and should be provided, any information obtained during exploration, testing, and production regarding the quality of the geothermal fluid and ambient ground and surface water.

Montana State Historical Society

The State Historical Society requests that an archaeological study be conducted in areas of new development. The applicable study was performed as part of the Environmental Impact Report prepared by MERDI for DOE.

7.5 FEDERAL

An Environmental Impact Report (EIR) was prepared to DOE requirements for the Warm Springs Project and properly submitted.

The Soil Conservation Service (SCS) completed tests and feasibility studies, estimated cost and manpower needs, and presented its engineering designs for the wetlands project. These were accepted and the Federal Job Corps (youths from Anaconda) performed all work for the wetlands modifications.

Federal regulations relating to procedures for funding or licensing water diversion or impoundment projects are currently being revised under the Fish and Wildlife Coordination Act and it is unknown whether an amendment would affect this project.

SECTION 8. PRODUCTION DRILLING AND LOGGING

8.1 SUMMARY

The Warm Springs well was spudded at the site on October 12, 1979. The hole was drilled to a total depth of 1498 ft by November 12, 1979.

Preliminary pumping tests indicated that the well was producing considerably less than might be expected from the well log-formation evaluation. A decision was made to perform a hydrochloric matrix acid treatment on the well. Testing and logging activities continued until December 15, 1979 after which time the rig was moved from the site and the well was left flowing to await further pump tests.

Two line shaft vertical turbine production pumps were then installed between April 28 and May 27, 1980 and pump tests resumed. Vibration problems plagued the test and a total running time of only 52 hours was recorded before removing the second pump from the well.

An evaluation was conducted on the well to present significant data and to evaluate the well in terms of the project requirements. The two most promising zones of geothermal productivity were identified at levels of 1,110 ft to 1,180 ft and 1,250 ft to 1,340 ft. The well was identified as having low values of permeability (2.84-5.66 millidarcies) and pump tests seemed to indicate wide variations in the production characteristics of the well. With this information it was recommended that the well be reworked and deepened an additional 50 ft to penetrate what is believed to be another zone of hot geothermal water.

This recommendation was followed and rework started March 12, 1981. The bottom 220 ft of the well was bailed of drilling mud and rock chips. The apparent lost drill pipe was encountered at the bottom of the well and could not be retrieved; thus preventing increasing the hole depth an additional 50 ft. A decision was made to perforate the production liner from 1,391 ft to 1,496 ft with two 1/2 in. perforations per foot. A television camera was

utilized to examine the production liner although the temperatures encountered prevented inspection to the total well depth. A proposal for screening was also abandoned as the well had been so plugged with drilling mud that screening would serve no useful purpose.

A submersible pump was installed on April 28, 1981 and initial testing indicated that the pump sizing was in excess of the producing capacity of the well. Another submersible pump was installed on May 19, 1981 at a setting depth of 987 ft. The well was then tested at rates of 50, 75, 95, and 110 gpm for 100 hours each and nine hours step drawdown tests were run at 25, 50, and 75 gpm. The results of those tests indicate that geothermal water production of 70 to 90 gpm at 168°F can be maintained.

8.2 ORGANIZATION

During the various stages of well planning and development at Warm Springs State Hospital, a number of individuals and companies provided necessary services.

MERDI provided management, engineering, and procurement services. Roger Stoker of Energy Services, Inc. of Idaho Falls, Idaho served as consulting geologist responsible for ground and aerial surveys prior to drilling. He also prepared the drilling specification and pump test plan.

Dreiling, Inc. of Holly, Colorado performed the initial drilling with Dr. Jon Carlson of the Mineral Research Center (MRC) in Butte, Montana as drilling supervisor. Dreiling performed all drilling related functions including excavation of the mud pits.

Under subcontract to Dreiling, Haliburton Service Company cemented portions of the well and Schlumberger ran temperature logs (HRT), dual induction-laterolog (SP-DIL), compensated neutron-formation density logs (CNL-FDC-GR) and caliper log.

Dreiling also contracted B. J. Hughes of Casper, Wyoming to acidize the well for clean out.

Knudsen Irrigation of American Falls, Idaho provided the Worthington shaft pump for production pump testing. When the first pump two tests had to be abandoned due to pump failures, Energy Services, Inc. of Idaho Falls, Idaho was hired as a consultant to review and evaluate all readily available information on the Warm Springs well and to propose a plan for remedial well development. Energy Services also contracted to do the remedial well development which was completed in April 1981.

8.3 DRILLER BIDDING, SELECTION, AND CONTRACT

A Request for Proposal (RFP) was sent to several drilling companies. The RFP outlined the project and qualifications for selection. The first replies to the RFP were rejected due to excessive cost and in one case for failure to comply with the provisions of the RFP.

The RFP was re-issued and replying company's proposals were reviewed and analyzed. Dreiling, Inc. of Holly, Colorado was selected, with DOE approval, as best fitting time constraints and budget limitations. A daily rate contract was entered into between Dreiling and MERDI for drilling services at Warm Springs State Hospital.

8.4 DRILLING SUMMARY

Drilling operations began on October 11, 1979. Two mud pits were excavated (8 ft x 4 ft x 100 ft) and then the drilling and development progressed as follows:

- Spudding began with a 12-1/4 in. bit to depth of 28 ft. The hole was then reamed with a 26 in. bit to 32 ft. The 18 in. conductor pipe was set to a depth of 32 ft and cemented in place. The cement was allowed to set for 24 hours.

- A 12-1/4 in. drill bit was used to drill to a depth of 506 ft and a 17-1/2 in. bit was used to open the hole to 326 ft.
- A 12-3/4 in. drill bit was used to drill to 902 ft and a 17-1/2 in. bit was used to open the diameter of the hole to 909 ft 12-3/4 in. outside diameter; welded casing was set to a depth of 896 ft.
- Haliburton Service Company pumped 1000 sacks of 50-50 pozmix cement plus 2% CaCl_2 into the hole and displaced the cement with 62 barrels of fresh water. The cement was allowed to set for approximately 36 hours (see well profile, Figure 2).
- An 11 in. bit was used to drill the hole to basement granite rock to a total depth of 1498 ft.
- Schlumberger logged Temperature (HRT), Dual Induction - Laterolog (DIL), Compensated Neutron-Formation Density (CNL-FDC-GR) and Caliper.
- After analyzing Schlumberger logs and drill cuttings, an 8-5/8 in. production liner was run from 849 ft to a total depth of 1498 ft.
- A slotted production liner with 16 slots per foot (3/16 in. x 2-3/4 in.) was used from a depth of 1037 ft to 1371 ft.

8.4.1 Wellhead Configuration Drilling

After drilling was completed and the first pump tests by the driller abandoned, 12 in. and 6 in. gate valves were bolted to the casing flange and the well was allowed to flow artesian at 40 to 50 gpm (see Figure 6).

8.4.2 Final Wellhead Configuration

Figure 7 is a schematic of the final wellhead configuration. The major changes that occurred were the removal of the 3 in. 6 in. gate valve, the addition of high pressure gauges, pressure gauge, temperature gauge, a vacuum valve, a solids separator, and flexible bypass hose.

FIGURE 6.--WELL HEAD CONFIGURATION - DRILLING

FIGURE 7.--FINAL WELL HEAD CONFIGURATION

8.4.3 Drill Rig

Dreiling, Inc., the drilling contractor, used a Wilson Super 2800 rig with mast, slush pump, and other components.

The drilling contractor provided 20 5-1/2 in. diameter drilling collars and 2000 ft of 3-1/2 in. drilling pipe.

8.4.4 Drilling Fluid

Quickgel and Cellex were used during drilling. Table 2 is a summary of mud properties. The properties were logged over the time of drilling.

8.4.5 Drill Bit

Standard rotary drill bits were used during drilling.

8.5 COMPLETION METHOD

8.5.1 Casing and Liner

Buttwelded 12-3/4 in. O.D. grade A53B (33.4 lb/ft) casing, consisting of 22 joints, was run to 896 ft and cemented bottom to top. Twenty-three sections of 8-5/8 in. O.D. (22.4 lb/ft.) grade A53B casing were buttwelded and run from 849 ft to 1498 ft. A slotted production liner with 16 slots per foot (3/16 in. x 2-3/4 in.) was used from 1037 to 1371 ft (see Figure 7). Later when the well had to be reworked, the production liner was jet perforated at two 1/2 in. perforations per foot from 1391 ft to 1496 ft.

8.5.2 Cement

After running the welded casing to the bottom (895.68 ft) mud was circulated in the hole 4-1/2 hours for conditioning of the well. This was necessary because the pump truck, which was required for the handling of 1000 sacks of cement, had to come from a relatively long distance. The drilling rig

TABLE 2.--SUMMARY OF MUD PROPERTIES

Date:	10-12	10-15	10-17	10-18	10-19	11-2	11-8	11-10	11-16	11-16
Time Sample Taken	3:00PM	12:00PM	9:15AM	4:00PM	10:00AM	---- AM	11:00AM	1:00PM	6:00PM	8:45PM
Depth (ft)	06	30	029	247	302	630	900	932	1200	1800
Weight (ppg)	8.6	9.2	8.9	8.9	9.0	9.1	8.5	8.7	11.0	11.5
Mud Gradient (psi/ft)	0.447	0.478	0.462	0.462	0.468	-	-	0.452	0.572	0.598
Funnel Viscosity (sec/qt)	41	43	36	38	39	163	28	32	46	49
Plastic Viscosity cp	12	12	17	12	13	-	1	9	17	20
Yield Point (lb/100 sq ft)	12	9	8	11	9	-	0	3	15	19
Gel Strength (lb/100 sq ft)	2/6	6/19	10/14	3/8	3/8	-	0/0	1/2	11/19	12/18
pH Strip	7.2	7.2	12.0	10.0	9.5	7	9.5	11.0	7.4	9.3
Filtrate API (ml/30 min)	8.0	10	46	7.2	6.5	5	NC	6.4	12.8	10.0
API HP-HT Filtrate (ml/30 min)	-	-	-	-	-	-	-	-	-	-
Cake Thickness 32nd in API	1	2	4	1	1	2	-	1	3/32	2/32
Alkalinity, Mud (Pm)	-	-	0.25	0.2	0.01	-	-	-	-	-
Alkalinity, Filtrate (Pf/Mf)	0/.2	0/.25	.4/.65	.6/1.4	.2/.6	-	.09/.18	.7/.8	0/.75	.45/1.2
Chloride (ppm)	350	300	500	400	400	-	500	400	600	550
Calcium (ppm)	32	20	40	k	0	-	16	k	132	68
Sand Content (% by Vol)	k	2	1½	1½	2	-	k	1	2	3½
Solids Content (% by Vol)	2	6	4.2	4	6	-	2	2½	19.4	19
Oil Content (% by Vol)	0	0	-	0	0	-	0	0	0	0
Water Content (% by Vol)	98	94	95.8	96	94	-	98	97.5	80.6	81
Methylene Blue Capacity (me/ml mud)	-	-	-	-	-	-	-	-	-	-

TABLE 2.--SUMMARY OF MUD PROPERTIES (Continued)

	Date:	<u>11-16</u>	<u>11-16</u>	<u>11-16</u>	<u>11-17</u>	<u>11-17</u>	<u>11-18</u>
Time Sample Taken		8:00AM	11:30AM	2:15PM	10:00AM	12:00PM	4:00PM
Depth (ft)		1494	1494	1494	1494	1494	247
Weight (ppg)		10.9	11.8	11.5	11.3	11.7	8.9
Mud Gradient (psi/ft)		0.567	0.615	0.598	0.588	0.610	0.462
Funnel Viscosity (sec/qt)		53	71	47	47	50	38
Plastic Viscosity cp		18	22	16	20	23	12
Yield Point (lb/100 sq ft)		33	42	26	17	21	11
Gel Strength (lb/100 sq ft)		21/33	29/41	17/26	7/12	9/14	3/8
pH Strip		9.5	9.5	9.5	8.8	8.8	10.0
Filtrate API (ml/30 min)		12.0	11.8	13.2	10.6	10.4	7.2
API HP-HT Filtrate (ml/30 min)		-	-	-	-	-	-
Cake Thickness 32nd in API		3/32	3/32	3/32	2/32	2/32	1
Alkalinity, Mud (Pm)		-	-	-	-	-	0.2
Alkalinity, Filtrate (Pf/Mf)		.6/1.4	.45/1.1	.4/1.0	.35/1.0	.32/1.0	.6/1.4
Chloride (ppm)		500	450	550	530	480	400
Calcium (ppm)		80	60	48	64	68	k
Sand Content (% by Vol)	3/4 of 1%	1	1	1½	2½	2½	1½
Solids Content (% by Vol)		18	18	18	21.4	21	4
Oil Content (% by Vol)		0	0	0	0	0	0
Water Content (% by Vol)		82	82	82	78.6	79	96
Methylene Blue Capacity (me/ml mud)		-	-	-	-	-	-

could not safely reciprocate the casing during cement displacement; the casing was tied down at the surface to prevent it from being pumped out of the hole.

The selected cement composition was a 50-50 pozmix (50% class G, 50% flyash by volume) with 2%, by weight, bentonite, and 2%, by weight, calcium chloride.

First, 224 barrels of cement were pumped at 4 barrels per minute with initial surface pressure of 300 psi and final pressure of 500 psi. Next the top (and only) wiper plug was released. After displacing the plug with 50 barrels of fresh water, cement returns were noted. An additional 12.5 barrels of water were pumped, during which good cement returns were obtained.

8.5.3 Perforation Intervals

As was shown in Figure 2, the production lining is slotted at an interval of 16 slots per foot (3/16 in. x 2-3/4 in.) at a depth of 1037 to 1372 ft and is also perforated at two 1/2 in. perforations per foot from a depth of 1391 to 1496 ft.

8.6 STIMULATION METHODS

8.6.1 Method and Equipment

Limited well pumping and clean-out was accomplished while the drill rig was over the hole. Preliminary results indicated that the well was capable of producing less than 135 gpm at 160°F over a sustained period (more than six hours) from a setting depth of 1000 ft. The setting depth operating cost, the poor production (less than 135 gpm), and the short drawdown time (estimated at 6 to 10 hours) were factors which indicated that well stimulation should be considered.

8.6.2 Procedures

The apparent production formations were highly soluble in HCl due to the calcareous material present; thus, a 15% HCl acidizing job was selected for well

stimulation. The acid was pumped down the drill pipe and then displaced by pumping fresh water down the annulus side. The pressure was bled off and the well shut-in for 24 hours. The acidizing job was accomplished on November 30, 1979 using a total of 96 bbls (4000 gallons) of 15% HCl acid. Several days later a pump test was conducted and the well flowed 200 gpm for two hours at 160°F; however, the test was stopped due to the well drillers pump failure.

8.6.3 Results

The return fluids (free-flow) consisted of gas and spent acid indicating that the acid had fully reacted with the formation rock. It is surmized that the zone between 1060 and 1180 ft received the most benefit from the acid treatment.

8.7 WELL LOGGING SUMMARY

8.7.1 Logs Run

Log runs during the drilling of the Warm Springs geothermal well were: 1) Dual Induction - Laterolog in the uncased section from 898 to 1501 ft; 2) Compensated Neutron-Formation Density and caliper from 420 to 1501 ft; and 3) temperature from 50 to 1501 ft. Additionally, two water samples were taken to determine R_w , formation water resistivity.

8.7.2 Lithology

Drill cutting samples were taken every 5 ft and examined for rock type classification and evidence of geothermal alteration. There was no significant mineral alteration found; only varying amounts of calcareous material present in some zones.

Generally, the presence of significant amounts of calcareous (CaCO_3) cementing material was interpreted as evidence of present or past geothermal fluid circulation (see Figure 8 for the lithological log).

MERDI GEOTHERMAL WELL
Warm Springs, Montana

May 2, 1980
Lithology Log

FIGURE 8.--LITHOLOGY LOG

Tertiary valley fill material was expected to be present down to 1500 to 2000 ft. This section was expected to consist primarily of sand, gravel, shale, sandstone, volcanic debris, and limestone. The section contained a lot more sandstone and clay than anticipated and no limestone at all. The large amounts of sandstone encountered caused concern about hole sloughing; and the unusual amounts of clay indicated that productivity may be a problem.

There were no clean cuttings returned from below the 1495 ft level and the presence of granite below 1497 ft is not confirmed. However, the drop in drilling rate (1 ft/35 minutes) and the geophysical logs both indicate a major rock change, most likely of a granite composition.

8.7.3 Porosity

Table 3 lists those intervals whose log characteristics, such as porosity, formation resistivity, and wellbore caliper hole size indicate them to be either sand-like or gravel zones. Neutron versus density log derived porosities have been cross plotted in Figure 9. The extremely high neutron porosity (in excess of 45%) for the interval E indicates bentonite or shale infilling. The same characteristics on intervals A, B, and C also likely indicate extensive infilling by shale material which might be exaggerated by the neutron log response in the cased hole interval caused by the cement and uncertainty regarding the wellbore size behind the casing. The Figure 9 cross plot permits an estimation of corrected total porosity, because of the standardized calibrated response of the neutron and density logs in uncased wellbores, for intervals D and F through I. The position of the points on this crossplot indicates that those intervals consist of primarily carbonate material, which could either be calcarenite or a noncarbonate material bound together with a calcareous cement.

8.7.4 Temperature Logs

Numerous temperature profile logs were taken of the well during the drilling operations. Logging was accomplished in the open hole after the well was left undisturbed overnight. This method allowed the well to recover slightly

TABLE 3.--SUMMARY OF POROSITY DATA

Warm Springs State Hospital Thermal Project

Summary of Data

Interval	From Feet	To Feet	Neutron Porosity %	Density Porosity %	Corr. Porosity %	"F"(a) Humble	Ild ohm-m	Rwa(b) ohm-m	T °F	Pw ohm-m	Rmf ohm-m
A-1	809	814	52	22	—	Probably	Bentonitic	—	—	—	—
A-2	816	827	49	24	—	Probably	Bentonitic	—	—	—	—
B-1	872	876	49	26	—	Probably	Bentonitic	—	—	—	—
C-1	894	898	54	32	—	Probably	Bentonitic	—	—	—	—
D-1	1080	1084	42	33	38	5.0	7.5	1.50	123	5.2	1.9
E-1	1136	1139	47	22	—	Probably	Bentonitic	—	—	—	—
F-1	1151	1154	33	22	28	9.6	28.	2.92	124	5.1	1.8
F-2	1154	1164	37	24	31	7.7	29.	3.77	124	5.1	1.8
G-1	1219	1224	38	25	32	7.2	27.	3.75	126	5.0	1.8
G-2	1226	1228	34	23	29	8.9	33.	3.71	126	5.0	1.8
H-1	1241	1246	33	20	27	10.4	40.	3.85	127	4.9	1.8
H-2	1246	1251	37	24	31	7.7	30.	3.90	127	4.9	1.8
I-1	1326	1330	33	20	27	10.4	32.	3.08	142	4.5	1.6
I-2	1332	1336	31	20	26	11.2	32.	2.86	142	4.5	1.6
I-3	1340	1343	40	22	31	7.7	28.	3.64	123	5.2	1.9

(a) $F = 0.62/\phi^{2.15}$
 where ϕ is
 decimal porosity

(b) $Rwa = Ild/F$

POROSITY AND LITHOLOGY DETERMINATION FROM FORMATION DENSITY LOG AND COMPENSATED NEUTRON LOG (CNL*) FRESH WATER, LIQUID-FILLED HOLES

FIGURE 9. --WARM SPRINGS WELL #1 POROSITY CROSS PLOT

from the cooling effects produced by the drilling fluid. Five of the logs are presented in Figure 10. The temperature reversal noted on October 29 and 30, between the 600- and 700-foot depth, is interpreted as a permeable thief/production zone that took cool drilling fluid. The temperature reversal and isothermal condition shown on the November 17 log below 1080 ft is also interpreted as a thief/production zone and 60 ft of fill.

A temperature survey was run on November 23, 1979 after having pumped the well for two days. The profile is shown in Figure 11.

Two other temperature surveys were conducted by EG&G under contract to Energy Services, Inc. The first was run on April 28, 1980 and the second on September 29, 1980 after the well had been cleaned out. The profiles are shown in Figure 12.

FIGURE 11.--WARM SPRINGS GEOTHERMAL WELL TEMPERATURE PROFILES
November 23, 1979
40 gpm Free Flow
(Well pumped for two days before)

DEPTH (feet)

TEMPERATURE LOG

Warm Springs Hospital well #1

Warm Springs, Montana

100

200

300

400

500

600

700

800

900

1000

1100

1200

1300

1400

1500

LOG TAKEN AND PROVIDED BY
BGGG, IDAHO, INC.

4/28/80

Logged prior to well cleanout

9/29/80

Logged after well cleanout

CASING

FIGURE 12.--WARM SPRINGS GEOTHERMAL WELL TEMPERATURE PROFILE

60

61

62

63

64

65

66

67

68

69

70

71

72

73

74

75

76

77

150°

155°

160°

165°

170°

Temperature (°F)
Temperature (°C)

SECTION 9. RESOURCE TESTING

9.1 APPARATUS

See Section 9.2 below.

9.2 TESTS CONDUCTED

Resource testing conducted during drilling of the Warm Springs production well included geophysical well logs, temperature surveys, flow measurements, water quality measurement, and pump tests. The geophysical tests had their greatest significance in the unencased interval found from 898 to 1500 ft and indicated suitable porosity in the interval from 1084 to 1500 ft.

Some problems were encountered in achieving projected flows from the well during preliminary pump tests by the driller. For this reason, the well was acidized to clean it and improve flow rates. Initial well driller pump tests after acidizing showed that the well flowed at 200 gpm for two hours at 160°F. However, these tests were stopped due to pump failure.

MERDI then contracted with a pump company to install a new Worthington line shaft vertical turbine production pump. This pump was set at 830 ft on May 1, 1980. The pump consisted of 19 stages with spider bearings set on a stainless steel shaft every 10 ft. The pump tests were plagued with vibration problems and binding of the pump shaft which prevented continuous pump use.

Examination revealed that the elastomer spiders within the pump had failed, the bubbler tube had sheared off and the pump intake screen had been lost downhole. Cause of the vibration problem has been attributed to the failure of the elastomer spider bearings. The line shaft pump was reinstalled with bronze spider bearings and additional short-term pump tests were conducted before the pump again experienced major wearing problems and was subsequently removed. One or two hours was the maximum running time of the pump during any single test and although these tests lasted several weeks, a total running time of less than 52 hours was achieved. This series of pump tests was suspended in October 1980.

In January 1981, Energy Services, Inc. of Idaho Falls, Idaho submitted a plan for rework of the Warm Springs well. The plan included drilling an additional 50 ft into what was thought to be a zone of hot water. After cleaning the well to its total depth, a solid metal item was struck in the bottom of the hole; this is probably a length of drilling pipe lost previously. Efforts to recover the pipe failed and attempts to drill around or through the item were unsuccessful; thus, plans for drilling deeper were abandoned.

A 50 HP Reda G110 submersible pump was installed on April 28, 1981 to a setting depth of 815 feet. This pump proved to be too large and a smaller 30 HP pump was then installed. The 30 HP Reda G75 submersible pump was installed on May 19, 1981 to a settling depth of 987 feet. On May 23 long-term testing commenced. The well was tested at rates of 50, 75, 95, and 110 gpm for 100 hours each with required recovery time. Table 4 shows the results of these tests.

Table 4.--Results of Staged Drawdown Tests

<u>Test Rate (gpm)</u>	<u>Test Duration (hours)</u>	<u>Maximum Drawdown (ft)</u>	<u>Recovery Time (hours)</u>
50	100	815	3.4
75	100	900	3.8
95	100	870	2.9
110	100	860	2.5

After the final recovery of the 110 gpm test, a nine-hour step drawdown of 25, 50, and 75 gpm was run for three hours at each gpm rate.

9.3 RESULTS

The main purpose of the step drawdown test was not to determine well efficiency but to gather data on optimum pumping rate of the well. Since this is a developing well, as evidenced by the data obtained, the test cannot give any valid conclusions about well efficiency.

The 30 HP Reda G75 was left in the well as a production pump and production flow rates between 70 and 90 gpm at a temperature of 168°F were predicted for long-range production capacities.

SECTION 10. DISPOSAL DRILLING AND LOGGING

The Montana Department of Fish, Wildlife, and Parks maintain a wetlands for migratory fowl at the Warm Springs facility. The Department expressed a desire to use the waste geothermal discharge to supplement these wetlands. After determining that these waters would have no adverse effect on the environment it was agreed that this was a viable alternative to reinjection as a disposal method. Therefore, no reinjection well drilling was used at the Warm Springs site.

(Sections 10.1 through 10.7 are not applicable to this project.)

SECTION 11. DISPOSAL TESTING

The waste discharge water from the Warm Springs project is being disposed of in a State wetlands for migratory waterfowl so no disposal method testing was necessary.

(Sections 11.1 through 11.3 are not applicable to this project.)

SECTION 12. APPLICATION ANALYSIS

The purpose of this project was to develop and implement the partial conversion of utilities at Warm Springs State Hospital from natural gas to geothermal resource use. The planned system included a production well, heat exchanger, distribution systems, and the final disposal of spent geothermally produced water to a wetlands waterfowl habitat adjacent to the hospital property.

12.1 TECHNICAL

The Geothermal Heat Survey* conducted for domestic water and building heating load requirements in 1978 and finalized in 1979 outlines the following geothermal utilization requirements for the Warm Springs Facility.

The requirement for consumption of domestic hot water at Warm Springs State Hospital is 30,000 gallons per day. The hot water temperature requirement is 140°F, with the average yearly temperature of incoming cold makeup water at 55°F. To heat 30,000 gallons of water each day requires 21,240,000 Btu per day or 885,000 Btu per hour. A 50% overall efficiency establishes the average heat load as 1,770,000 Btu per hour. Inclusion of a hot water storage tank (in the modifications to use geothermal heat) allows adequate provision for peak demands.

Peak space heating requirements for the main hospital building (Warren Building) and the Food Service Building have been estimated at 456,000 and 1,943,000 Btu per hour respectively. Based upon 50% overall efficiency, required peak heat inputs must be 912,000 and 3,886,000 Btu per hour to heat each building.

All space heating in the buildings of interest is accomplished using steam, generated with natural gas-fired boilers. Assuming the same efficiencies as above, and using the May 1978 billing price for natural gas at Warm Springs

* Geothermal Heat Survey for Warm Springs State Hospital, 1979, by Karen L. Barclay, Montana Energy and MHD Research and Development Institute (MERDI), DNRC Contract No. RAE-504-BRCLY-078.

(\$1.77 per MCF), and using an energy content of 887 Btu per cubic foot (as delivered by Montana Power Company), annual natural gas costs are shown below:

<u>Water Heating</u>	\$25,842 per year
<u>Space Heating</u>	
Warren Building	\$ 4,600
Food Service Building	\$19,603
TOTAL	<u>\$50,045 per year</u>

During the past several years the average cost of natural gas, taken from billing data, was:

1974	-	\$0.61 per MCF
1975	-	\$0.95
1976	-	\$1.29
1977	-	\$1.58
1978	-	\$1.77

The price of natural gas is increasing annually at an average compound rate of 30.5 percent, since 1979.

Flow from the natural spring is approximately 60 gpm at 172°F. Assuming a 50°F temperature drop through the heat exchanger, 1,499,000 Btu per hour can be extracted from the natural spring. Therefore, the well must produce the following flow rates to meet energy demands:

Heating Demand	Ratio of: Geothermal Well Flow Natural Spring Flow
Water Heating	0.6*
Space Heating	
Warren Bldg.	0.3*
Food Service Bldg.	1.3*
All of Above	2.2 (135 gpm)*

* As amended to indicate the heat load, eliminating the 50% efficiency factor of natural gas usage. Initial reference values were twice these.

12.2 ECONOMIC

Life cycle cost (as developed in the 1977 Geothermal Heat Survey) of the proposed conversion is shown in the paragraphs that follow to be reasonable when compared to a new construction gasfired system with the same heating performance.

12.2.1 Hypothetical Gas-Fired Systems

Two hypothetical gas-fired heating systems are defined: 1) a central water heating plant; and 2) a space heating and ventilation system to serve two buildings. The systems will need the following components:

Central Water Heating

Gas-fired water heaters
Holding tank
Pumps
Controls

Space Heating & Ventilation

Gas boiler
Pumps
Piping
Heat exchangers
Air ducting
Fans
Controls

Estimated cost of the central water heating system is \$200,000, including installation, for the capacity required at Warm Springs State Hospital. MERDI's architect-engineer team member estimates that HVAC systems cost roughly 13% of total building cost for buildings similar to those proposed for retrofit at Warm Springs. When air conditioning is omitted, reduction to 10% should be conservative.

Construction and renovation cost of the Warren Building and Food Service Building have been adjusted to 1979 prices with the following inflation schedule:

Prior to 1945:	0
1945 to 1970:	5% per year
1970 to 1979:	6% per year

Original and adjusted building costs are:

	<u>Original Cost plus Renovation</u>	<u>1979 Adjusted Cost</u>
Warren Bldg. (1932)	\$134,887 + 787,149	\$4,653,000
Food Service Bldg. (1960)	\$238,741 + 86,981	\$ 675,000
TOTAL BUILDING COST		<u>\$5,328,000</u>

Heating system cost, as estimated by the above method, can be divided into the following segments:

Ducting, fans, and controls	\$ 106,000
Gas boiler, piping, pumps, and heat exchangers	<u>\$ 427,000</u>
TOTAL	<u>\$ 533,000</u>

12.2.2 Comparison of Installed Prices

This retrofit is not a complete stand-alone system because it uses portions of the existing systems. Some costs, such as wells, would be essentially the same for either part of the geothermal installation, or for the two parts combined, as shown in Table 5. Geothermal capital costs compare favorably with gas-fired costs because a shallow well was anticipated.

Environmental analysis costs were a difficult problem. It was assumed that none would be required for the gas-fired system. The lower part of the capital cost breakdown included MERDI's estimated environmental report costs only in the geothermal systems. The possibility of additional costs for an Environmental Impact Analysis (EIA) and Environmental Impact Statement (EIS) was not considered.

TABLE 5.--CAPITAL COST BREAKDOWNS
Geothermal Heat Survey (1979)

	Gas Fired	Included in Retrofit	Geothermal Extras to Complete	Total
Central Water Heating				
Construction		\$ 71,849		
Wells		114,264		
Exploration		13,475		
Legal		3,265		
Management		13,995		
Subtotal	\$200,000	\$216,848	--	\$216,848
Space Heating				
Ducting & Fans			\$106,000	
Other Construction		\$251,796		
Wells		114,264		
Exploration		13,475		
Legal		3,265		
Management		49,044		
Subtotal	\$533,000	\$431,844	\$106,000	\$537,844
Central Water Heating and Space Heating	\$733,000	\$517,688	\$106,000	\$623,688
Added Cost of Environmental Analysis				
Central Water Heating	\$200,000			\$368,250
Space Heating	533,000			689,246
Both	733,000			775,090

12.2.3 Comparison of Operating Costs

Table 6 compares predicted operating costs for the systems as developed in the 1979 Geothermal Heat Survey described in Table 7. Both tables reflect 1979 prices, with fuel costs 30% higher than in 1978.

12.2.4 Life Cycle Cost Comparisons

The following discussion is based on the life cycle cost analysis as developed for the 1979 Geothermal Heat Survey.

Capital costs are straight-line depreciated over a 30-year life with zero salvage value. The cost of money is taken as 9%. Inflation rate is 6% for fuel and other operating costs. All costs are shown in 1979 dollars. Life cycle costs include operating cost; capital cost; and interest on the depreciating capital value.

12.2.5 Economic Analysis

The calculated amount of energy produced by the well after startup is 20,000,000 Btu/day. This is reasonably close to the initial calculated requirement of 21,240,000 Btu per day. The 20×10^6 Btu/day figure is used in the economic calculations.

An economic analysis of the Warm Springs State Hospital geothermal system as installed is presented in Section 2.2, Economic Result; and in Section 33, System Economics.

TABLE 6.--ANNUAL OPERATING COST BREAKDOWNS
Geothermal Heat Survey (1979)

	Gas Fired	Geothermal
Central Water Heating		
Fuel (1979 estimate)	\$33,595	
Operation & Maintenance	600	\$ 600
Water Treatment		240
Total	\$34,195	\$ 840
Space Heating		
Fuel (1979 estimate)	\$31,464	
Operation & Maintenance	1,900	\$ 1,900
Water Treatment		760
Total	\$33,364	\$ 2,660
Total for Both Systems	\$67,559	\$ 3,500

TABLE 7.--LIFE CYCLE COST COMPARISONS - COMBINED SYSTEMS
Geothermal Heat Survey (1979)

	Gas Fired	Geothermal
No Environmental Analysis		
Capital	\$733,000	\$623,688
Annual Operation	67,559	3,500
Life Cycle Cost	\$5.57 x 10 ⁶	\$1.67 x 10 ⁶
Including Environmental Analysis		
Capital	\$733,000	\$775,090
Annual Operation	67,559	3,500
Life Cycle Cost	\$5.57 x 10 ⁶	\$2.02 x 10 ⁶

SECTION 13. OBTAINING USER COMMITMENT

13.1 GENERAL STRATEGY USED

Warm Springs State Hospital is the state-operated facility for the mentally ill located in Deer Lodge County, Montana. At the time of project initiation, MERDI was conducting studies to determine the feasibility of converting the hospital's utilities to use geothermal energy and to define the geothermal resource known to exist at the site of the hospital property. These studies were conducted under a grant from the Montana Department of Natural Resources and Conservation (DNRC).

When the PON program was made available for proposal, MERDI approached Montana's governor at that time, Thomas L. Judge, and the Department of Institutions concerning the possibility of furthering the research and actually utilizing the geothermal resource at Warm Springs. A letter pledging full state cooperation by all state agencies signed by Governor Judge was obtained and proposal writing was initiated by MERDI.

(Sections 13.2 through 13.5 are not applicable to this project.)

SECTION 14. SYSTEM LOADS

During the project assessment funded by the State Department of Natural Resources and Conservation (DNRC), the following heat loads were determined. These loads are for both hot water heating and space heating although the latter was not completed due to insufficient flow from the well.

14.1 PEAK

Warm Springs State Hospital requires 30,000 gallons per day of domestic hot water. The required temperature of this water is 140°F with the average temperature of incoming cold makeup water at 55°F. To heat 30,000 gallons of 55°F water to 140°F requires 21,240,000 Btu per day or 885,000 Btu per hour. Assuming an overall efficiency of 50% established a peak natural gas usage of 1,770,000 Btu per hour. Peak space heating requirements for the main hospital building and Food Services Building have been estimated at 456,000 and 1,943,000 Btu per hour, respectively. Based on a 50% overall efficiency, this establishes peak natural gas heat inputs at 912,000 and 3,886,000 Btu per hour to heat each building.

14.2 ANNUAL

With a daily requirement of 21.2 million Btu, the hot water heating system required 7.75 billion Btu per year. The total annual heat requirement for the building heating is 21.0 billion Btu per year. These figures are calculated without any load factor efficiencies.

14.3 LOAD FACTOR

The load factor used in the above calculations is 50%. This takes into consideration the efficiency of the boilers in converting natural gas Btu's into steam, the heat losses in transmission and final conversion of the steam for end use.

14.4 FUEL REPLACED

Based on the calculations from Section 2.2, Economic Results, a value of 20,000,000 Btu per day was used for domestic hot water heating. The yearly amount of natural gas saved based on 50% conversion efficiencies, would be 17,600,964 cubic feet. Based on current (1983) natural gas costs of \$4.682 per 1000 cubic feet the annual savings would be calculated at \$82,408.

If sufficient geothermal resource had been available for space heating, 57,576,000 Btu per day could have been saved. Based on 50% conversion efficiency, the yearly savings of natural gas would be 50,669,656 cubic feet. Current annual savings could have been \$237,235.

15.0 PRODUCTION SYSTEM DESIGN

The production system consists of the production well, production pump, well house, piping from the well head to the heat exchanger inside the existing heating plant, a solids separator, and related instrumentation.

15.1 SELECTION PROCESS

Selection of the production well site was based on geophysical studies conducted by consulting geologist Roger Stoker on the Warm Springs area. Drilling proceeded, as designed, to a total depth of 1498 ft.

With the failure of the Worthington line shaft pump during pump testing and the subsequent successful use of a Reda submersible pump for these tests it was decided to purchase the Reda pump for use as the production pump. This decision was based upon engineering judgement and standard oil field practice.

15.2 DESIGN

The production well configuration was designed by MultiTech consulting geologist Roger Stoker of Energy Services, Inc. MultiTech engineers provided design specifications for the production pump, well head configuration, well house, and production pumping and instrumentation.

15.2.1 General Description

Figure 13 shows the P&I configuration of the production system. Geothermal water is pumped from the well through the production piping to a plate heat exchanger which is the first component of the distribution system. Pressure and temperature gauges are provided to allow for proper system operation.

The well house is a frame building on a concrete pad which houses the well, pump, and well head components. It was designed by MultiTech engineers and incorporated a generally aesthetic quality to fit in with the existing facility buildings after an initial design for a removable insulated portable

FIGURE 13.--PRODUCTION SYSTEM (PIPING & INSTRUMENTATION)

building was rejected by the Montana Department of Administration, Architecture and Engineering Division. The structure has been designed with a removable roof to facilitate maintenance and repair of the well and piping.

A solids separator has also been installed at the well head to remove any entrained fine materials present in the water. This will aid in preventing solids deposition in the piping and in the heat exchanger.

15.2.2 Controls

The controls for the production system are also indicated within the heavy outlines of Figure 13. The well pump is started by a push button on the well pump control panel. During abnormal operations, temperature and pressure switches in the distribution piping and a flow switch in the production piping can provide a shut-down signal to the control panel; the well pump then stops. The well head globe valve is the primary flow control device for the pump while the globe valve after the heat exchanger is the secondary control device and is used to adjust back pressure on the system.

15.2.3 Major Components

The production system is comprised of the major components detailed below: 1) the production well pump; 2) well house; 3) piping from the well to the heat exchanger; 4) solids separator; and 5) instrumentation.

● Production Pump

The production pump is a REDA G75, 540 series, 22-stage submersible pump with a 30 HP, 440 volt motor. The pump is set at 987 ft total depth and discharges through 3-1/2 in. O.D. tubing to the surface. The pumps recommended operating limits are between 64 and 93 gpm.

A standard Reda model DFH-2 control panel is installed on the power pole located adjacent to the well house. A gas box is installed on the side of the well house where it physically separates the power cable coming from the well; the box serves as a junction and prevents gas from coming up the cable and reaching the control panel.

- Well House

The well house is an 8 ft x 8 ft x 8 ft wood frame structure with an integral one piece asphalt shingle roof which is removable. The building is set on an 8 in. thick reinforced concrete pad which rests on 6 in. of compacted gravel. It has an entrance door and a single operable window. The exterior walls are of redwood plywood finished with a clear red wood stain and the interior walls are treated CDX grade plywood. Wall insulation is foil-faced fiberglass and roof insulation is styrofoam.

- Piping and Fittings

There are both metallic and non-metallic piping materials in the production systems (see Figure 7). The carbon steel piping is ASTM A-106 Schedule 40, threaded. Where needed, carbon steel 150# raised-face flanges are used. All threaded fittings are 2000# ASTM A-105 forged steel. As indicated in Figure 7 the carbon steel piping is used on the well side of the flexible coupling.

Ameron Bondstrand series 2000 fiberglass reinforced epoxy pipe with polyurethane foam insulation as applied by Ricwil is used after the flexible coupling enroute to the heat exchanger. Fittings are filament wound and flanges are molded; all pipe joints have applications of epoxy adhesive.

The geothermal water piping inside the heating plant is Fibercast series OG-2025-IR epoxy resin pipe. That piping has 1" of Owens-Corning fiberglass insulation applied. The insulation has an all service jacket with PVC fitting covers at all elbow and tee connections.

- Solids Separator

A solids separator is included in the system. It is a Lakos Model IL-1123B with 1-1/2 in. inlet and outlet and 3/4 in. drain threaded connections. The unit is sized for a flow of 70 gpm with a maximum pressure drop of 9 psi.

- Instrumentation

The START and STOP controls for the submersible well pump are contained in the pump control panel adjacent to the well house. Mounted on the exterior face of that pump control panel is a wind-up recorder to record pump amperes. The following procedure outlines an operating sequence that incorporates an explanation of the geothermal flow switch and the pressure switch and temperature switch in the distribution piping.

The selector switch at the geothermal well pump control panel has three positions, HAND-OFF-AUTO. The HAND position allows only off and on pump operation. The AUTO position allows OFF and ON pump operation plus automatic overload and underload protection. An overload ampere reading will shut the pump down and will require a manual restart. An underload ampere reading will cause the pump to shut down and the pump will automatically restart after the timer (ATC) completes its time setting.

The Time Delay relay (TD) allows the geothermal well pump starting circuitry to engage and start the pump when the start button is depressed. That Time Delay relay remains engaged until it times out. By that time the water flow has activated the geothermal water flow switch for the normal maintain run circuit. That run circuit also includes the domestic water high temperature switch and high pressure switch contacts.

The loss of geothermal water flow, high temperature in the domestic water flow or high pressure in the domestic water flow will shut down the geothermal well pump. The OFF switch at the pump control panel or the REMOTE STOP located in the heating plant can also shut the pump down. When any of these occur Relay (R) is de-energized and the alarm horn and light located in the heating plant are activated. A silence horn button is also included.

A Foxboro E83W-02SSSP vortex flowmeter is installed in the geothermal supply line to the heat exchanger. A geothermal flow panel located in the heating plant houses the electronics of this flowmeter and has a totalizer to accumulate the total geothermal flow that the production well has pumped.

In addition to the automated instrumentation mentioned above, there is a high pressure gauge at the well head and other pressure and temperature gauges in the system for manual readouts as well as a pressure relief valve for safety considerations.

15.2.4 Energy Monitoring System

There is no direct energy monitoring system, however there is the geothermal flow indicator which has a totalizer to indicate the total flow of geothermal flow that has been pumped. There are temperature gauges at the outlet of the well head and also at the inlet and outlet of the heat exchanger.

15.2.5 Environmental Control and Monitoring

(Not Applicable.)

16.0 DISPOSAL SYSTEM DESIGN

16.1 SELECTION PROCESS

During the initial stage of this project it was proposed that a reinjection well be used as the disposal method. MultiTech approached the Montana Department of Fish, Wildlife, and Parks (DFWP), which operates a migratory bird refuge adjacent to Warm Springs Hospital grounds, with the possibility of using the spent geothermal water to supplement their wetlands. After statutory review and environmental assessment, it was determined that the wetlands would afford an acceptable alternative to reinjection and the decision was made to dispose of the spent geothermal water to the wetlands.

16.2 DESIGN

The disposal system for the spent geothermal water is quite simple. After it exists the heat exchanger at approximately 85°F, the water is piped to an open drainage ditch which flows directly to the waterfowl wetlands. The length of pipe is approximately 140 ft.

The Soil Conservation Service, in conjunction with the DFWP, designed an enlargement of the existing wetlands area. In conjunction with the Anaconda Job Corps - U.S. Forest Service, the expansion of that area was completed.

The wetlands must be maintained in such a manner that no overflow from them contaminates nearby streams. The DFWP monitors these wetlands and it is their responsibility to maintain environmental quality.

16.3 CONTROLS

The wetlands area is sufficiently large to accept the normal quantities of spent geothermal water. There is a system of ditch diversions that are controlled by the DFWP to reroute any excess water and prevent discharge to streams.

16.4 DISPOSAL

The major component of the disposal waste system is the 3 in. pipe which is Ameron Bondstrand series 2000 fiberglass reinforced epoxy pipe without an insulation covering. The filament wound fittings are joined with an epoxy adhesive.

16.5 ENERGY MONITORING SYSTEM

(Not Applicable.)

16.6 ENVIRONMENTAL CONTROL AND MONITORING

It is the responsibility of the DFWP to ensure that there are no discharges to streams in the area.

17.0 TRANSMISSION SYSTEM DESIGN

The pipeline that carries the hot geothermal water from the well to the plate heat exchanger is approximately 70 ft long. This is not considered a significant amount of piping; thus, it has been included in the production system design.

(This section is therefore not applicable.)

18.0 DISTRIBUTION SYSTEM DESIGN

The system consists of a plate type heat exchanger in the domestic hot water system utilizing the geothermal well water as a heat source. All cold water to be heated for domestic use flows through the heat exchanger where it extracts the available heat from the geothermal resource. The heated domestic water will then continue to an existing hot water accumulator for distribution throughout the hospital. The temperature in the accumulator tank is maintained when there is no demand, by circulating water from the accumulator back to the heat exchanger. The geothermal water flows continuously through the heat exchanger and is then disposed of to the waterfowl wetlands.

18.1 SELECTION PROCESS

The configuration of the distribution system was selected after an engineering evaluation of the existing hot water system. Both MultiTech and an A&E firm, Johnson-Graham and Con'Eer Engineering, were involved in the selection and design process.

The plate heat exchanger was selected due to its efficiency and particular adaptation to geothermal uses in similar projects.

18.2 DESIGN

18.2.1 General Description

The distribution system consists of a plate heat exchanger, recirculation pump and associated piping and instrumentation and is totally located within the existing Warm Springs heating plant. The outline around the distribution system shown in Figure 14 presents the relationship of this distribution system to the entire geothermal installation.

Geothermal water continuously passes one side of the exchanger with the cold domestic water passing the other side. The heated domestic water continues to the hot water accumulator which is part of the existing system.

FIGURE 14.--DISTRIBUTION SYSTEM (PIPING & INSTRUMENTATION)

A recirculation pump circulates water from the accumulator tank back into the heat exchanger circuit to maintain and stabilize the temperature in the existing storage system.

18.2.2 Controls

A number of control circuits are incorporated in the distribution system, as shown in Figure 14.

An energy monitoring system consists of a Btu flow meter and thermowell in the 4 in. cold water supply line to the heat exchanger and a thermowell on the 4 in. hot water supply line to the accumulator. This system is used to measure the Btu's extracted from the geothermal water in the heat exchanger and is totaled on the Btu output panel located in the heating plant.

In the 4 in. hot water supply line to the accumulator are high pressure and high temperature switches which are interconnected to the well pump control panel. An excursion of temperature and pressure beyond the setting of the switches will shut the geothermal pump down and activate an alarm horn and light on the alarm panel in the heating plant. A means of silencing the horn is included on the panel.

The control loop for the recirculation pump interlocks with the geothermal flow switch to the heat exchanger and to the aquastat located at the outlet of the hot water accumulator tank. This ensures that domestic water will only be recirculated to the heat exchanger when geothermal water is flowing and the aquastat switch is closed. There are two modes of operation on the recirculation pump selector switch (i.e., auto; and manual). In the auto position, the aquastat measures the temperature of the water leaving the hot water accumulator and when this temperature is below 160°F the geothermal recirculation pump begins operation and circulates domestic water through the heat exchanger. If geothermal flow ceases, an additional set of contacts will shut down the recirculation pump. When the switch is in the manual position, it will operate the pump continuously, bypassing aquastat and flow switch circuits.

18.2.3 Major Components

The major components of the distribution system are: 1) the heat exchanger; 2) recirculation pump; and 3) piping and instrumentation (including Btu flow meter).

- Heat Exchanger

The heat exchanger is an Alfa-Laval type A10-BFG with a total of 188.6 square ft of heat area and an effective heat transfer area of 183.4 square ft, 73 0.6 mm thick 304 SS plates, and resin cured butyl gaskets.

Exchanger working pressure is 150 psi with test pressure of 225 psi and a working temperature of 212°F. The exchanger has a 4 in. inlet and 4 in. outlet with 304 stainless steel lined connections.

The unit is designed to increase the temperature of 37,500 pounds/hour of softened domestic cold water from 55°F to 140°F with a counter-current geothermal water flow of 42,500 pounds/hour and a temperature drop of 160°F to 84.9°F. The total designed pressure drop is 2.0 psi on the domestic and geothermal water sides.

- Recirculation Pump

The recirculation pump is an Amtrol model 22B rated at 20 gpm and 10 ft tdh. A 1/4 HP, 1750 rpm, 120 volt coupling connected motor is included. The pump is of all bronze construction for use in domestic water service.

- Piping

The piping in the distribution system is of type "L" hard copper and joined with 95-5 lead-tin solder. Brass flanges and dielectric unions are used to provide galvanic isolation from the existing galvanized system. One inch of Owens-Corning fiberglass insulation with an all

service jacket was applied to all newly installed domestic piping. In addition, all elbow and tee connections are protected by PVC fitting covers.

- Instrumentation

A Btu flow meter is installed in the domestic water side of the system. The system was supplied by Engineering Measurements Company and consists of two temperature transmitters (model TEM) with temperature ranges of 50° to 180°F, a turbine meter probe (TMP-700) with flowing velocity ranges from 0.5 to 2.7 ft per second, and a turbine meter electronics output board (TME-1170) with an ability to record a maximum input of 8 million Btu per hour.

Pressure and temperature gauges are located on either side of the heat exchanger for manual readouts and a pressure relief valve is also included for safety considerations.

18.2.4 Energy Monitoring System

The energy monitoring system is an Engineering Measurements Company Model 1170 Btu flow meter with the totalizer mounted in a NEMA 4 enclosure. The system has temperature transmitters which are inserted in the pipelines to sense temperatures from 50°F for inlet domestic water up to 180°F for outlet water temperature. A turbine meter provides for flow measurement and provides flow input to the heat flow computer. The entire assembly is installed in the domestic water system on either side of the heat exchanger with the designed flow ranges from 0.5 to 2.7 ft per second in the 4 in. pipeline.

The system uses 120 volt AC power and includes fuses, on-off switch, DC power converter, and associated equipment to convert the input signals to a Btu output signal which is totalized on the panel.

18.2.5 Environmental Control and Monitoring

(Not Applicable.)

19.0 APPLICATION SYSTEM DESIGN

19.1 SELECTION PROCESS

Due to the nature of the modifications to the existing domestic hot water system for accommodation of the geothermal system, minimal retrofit was needed except for two 4 in. pipe interface connections.

19.2 DESIGN

19.2.1 General Description

Figure 15 outlines the application system as it relates to the entire geothermal installation. The application system consists of a hot water heater, hot water accumulator, two recirculation pumps, and associated piping, all of which were existing and in service. The system was previously heated with steam and that steam will now serve as a backup heating system.

The only modification made to this system was the addition of necessary piping to the new distribution system which was described in the Distribution System Design Section.

19.2.2 through 19.2.5

(Items in these sections are not applicable as previous descriptions were addressed in the Distribution System Section.)

20.0 PRODUCTION SYSTEM CONSTRUCTION

20.1 BIDDING, SELECTION, AND CONTRACT

The initial bidding and selection for the drilling of the well and placement of a test pump for preliminary testing of the well was advertised for bid between August 29 and September 14, 1979. Prior to that bid date, drilling specifications were developed and documentation was prepared by Energy Services, Inc. of Idaho Falls, Idaho under subcontract to MultiTech. The successful low bidder was Dreiling, Inc. of Holly, Colorado and they were awarded the subcontract on September 24, 1979. The Mineral Research Center (MRC) of Butte, Montana provided drilling consultation services.

A production pump test plan was developed by Energy Services, Inc. and the specification was developed for that work. A sole source procurement was made to Knudsen's Irrigation Company, Inc. of American Falls, Idaho in March 1980. During this same period of time, March and April 1980, Hiam Electronics of Butte, Montana was also engaged as a sole source subcontractor to install an electrical power feed to the well area.

A subcontract to evaluate the well development up through the completion of Knudsen's Irrigation involvement was then made with Energy Services, Inc. of Idaho Falls. That subcontract was entered into on January 14, 1981. This subcontract was then modified to include the remedial work on February 26, 1981 and that work was then initiated.

The bidding for the completion of the production well head configuration and transmission piping to the heating plant was included in the distribution system invitation for bid package. That package was advertised between April 22 and May 19, 1982. The successful bidder was 4G Plumbing and Heating of Missoula, Montana who were awarded the contract on July 15, 1982.

20.2 AS-BUILT SYSTEM

The initial drilling by Dreiling, Inc. commenced on October 11, 1979 and was completed by December 5, 1979. During that period of time, Energy Services, Inc. and Jon Carlson, a consultant with the Mineral Research Center, provided drilling consulting services. The well configuration as shown on Figure 16 identified the major components of the production well at this stage of the development.

Knudsen's Irrigation Company supplied the Worthington line shaft vertical turbine pump to be used to conduct drawdown and recovery tests. Their work commenced on April 28, 1980 and in the meantime, Hiam Electronics completed the electrical power feed which included transformers, overhead wiring, power distribution panel, and the associated disconnect devices. This pump was set at 830 ft on May 1, 1980. The pump consisted of 19 stages with spider bearings set on a stainless steel shaft every 10 ft. The pump test was plagued with vibration problems and binding of the pump shaft which prevented continuous pump use. The pump completely failed on May 4, 1980 and was subsequently removed and repaired by Knudsen's. Examination revealed that the elastomer spiders had failed, the bubbler tube had sheared off, and the pump intake screen had been lost downhole. Cause of the vibration problem has been attributed to the failure of the elastomer spider bearings.

The line shaft pump was reinstalled on May 27, 1980 with bronze spider bearings and additional short-term tests were run by Knudsen's to satisfy the subcontract and the pump was left in the well at the conclusion of those tests. MERDI then contracted with Knudsen's to allow MERDI to perform some shortterm pump tests with MERDI personnel. The pump again experienced severe vibration problems and was shut down, with a total running time of 52 hours. Subsequent removal and teardown of the pump bowl assembly on September 26, 1980 revealed that the pump bowls and impellers were worn but could be repaired. This concluded the involvement of Knudsen's Irrigation Company, Inc.

FIGURE 16.--PRODUCTION WELL INITIAL DEVELOPMENT

An evaluation of the available information on the well was made by Energy Services, Inc. to suggest a method of well stimulation. In January 1981, an evaluation report was presented recommending remedial action on the well. The report's conclusions supported recommendations for reworking the well and drilling an additional 50 ft into what was believed to be a zone of hot water. ESI's recommendations were approved by DOE and work commenced on March 12, 1981 and was completed by April 7, 1981. It was initially found that the bottom 220 ft was filled with drilling mud and rock chips. In addition, a 12-ft piece of 3/8 in. steel pipe, lost during initial drilling was retrieved. After cleaning the well to the total depth (1498 ft), a solid metal item was struck in the bottom of the hole, probably a length of drill pipe lost during initial well drilling. However, fishing attempts to retrieve the metal were unsuccessful. Since it was not possible to drill through or around the metal, the decision was then made to perforate the bottom 120 ft (from 1391 to 1496 ft) of casing with two 1/2 in. jet perforations per foot. The well was then surged, swabbed, and cleaned with water for several days. The results were that the artesian flow increased from an estimated 20 to 22 gpm to 32 to 35 gpm. This workover prepared the well for the next phase of the well development; i.e., pump testing. The initial development with the additional perforations at the lower end of the well was shown in Figure 2.

Arrangements were made to install a Reda 50 HP G110 submersible pump for initial well evaluation. The pump was installed on April 28, 1981 at a setting depth of 845 feet, but proved to have too great of a pumping capacity and a decision was made to install a smaller pump. The smaller 30 HP Reda G75 submersible pump was installed on May 19, 1981 to a setting depth of 987 ft.

This pump proved to be in the capacity ranges desired and on May 23, 1981 long-term pump tests were started. Those tests indicated that pump flowing rates of 70 to 90 gpm at temperatures of 168°F could be sustained in the well. The final configuration used during pump tests was shown in Figure 6.

Construction of the production well head and the transmission line piping as part of the 4G Plumbing and Heating subcontract was started on September 1, 1982. That subcontract was completed on January 31, 1983 after the startup of the system on January 11.

20.2.1 General Description

The production well was shown in Figure 2 and consists of 12-3/4 in. OD x 12-1/4 in. ID grade A53B pipe welded with two passes to a depth of 896 ft. That casing is cemented in place. A field fabricated pipe reducer used to guide tools to the lower casing is installed at a depth of 850 ft. The lower casing begins immediately below the funnel and consists of 8-5/8 in. OD x 8-1/8 in. ID grade A53B pipe welded with two passes to the total well depth of 1498 ft. The 8-5/8 in. casing is slotted from 1037 to 1371 ft with 16 slots per foot (3/16 in. x 2-3/4 in.). Jet perforations were done from 1391 to 1496 ft with two 1/2 in. perforations per foot. The final well head configuration, as shown in Figure 7, identifies the components of the well head and the production system as it was completed by 4G Plumbing and Heating. The system piping is carbon steel up to the expansion joint in the well house and Ameron Bondstrand series 2000 fiberglass reinforced epoxy with polyurethane foam insulation as applied by Ricwil for the remainder of the piping enroute to the heating plant.

20.2.2 Controls

Controls for the operation of the production system are described in Section 15.2.2.

20.2.3 Major Components

The major components of the production system are the production well pump, well house, piping from the well to the heat exchanger, solids separator, and instrumentation as described in Section 15.2.3.

20.2.4 Energy Monitoring System

There is no direct energy monitoring system installed in the production system; however, a geothermal flow meter is provided for flow indication. That flow meter panel includes a totalizer and is located in the heating plant.

20.2.5 Environmental Control and Monitoring

(Not Applicable.)

21.0 DISPOSAL SYSTEM CONSTRUCTION

21.1 BIDDING SELECTION AND CONTRACT

As the waterfowl wetlands was designed and constructed under the guidelines of the Montana Department of Fish, Wildlife, and Parks, there was no formal bidding procedure for this segment of the work. The only major component of piping in the disposal system was the 3 in. drain line from the heat exchanger. That work was included in the distribution system invitation for bid that 4G Plumbing and Heating was successful in obtaining.

21.2 AS-BUILT SYSTEM

The system remains essentially as originally designed with the outflow of spent geothermal water discharging to open ditches enroute to the designated waterfowl wetlands.

21.2.1 General Description

The 3 in. disposal waste line from the heat exchanger is Ameron Bondstrand series 2000 fiberglass reinforced epoxy pipe without an insulation coating. The approximately 140 ft of pipe is shallow buried as it discharges to an open drainage ditch that runs slightly below ground surface level. Once the spent geothermal water is discharged to the open ditch it is routed to the waterflow wetlands area through a system of ditch diversions.

21.2.2 Controls

All geothermal water is discharged by an open pipe to the discharge ditch. Any flow control of that water has been accomplished manually in the production system operation. The DFWP manually diverts water in the system of drainage ditches.

21.2.3 Major Components

There are only two major components in the disposal system; the 3 in. piping and the waterfowl wetlands.

21.2.4 Energy Monitoring System

(Not applicable.)

21.2.5 Environmental Control and Monitoring

It is the responsibility of the DFWP to control the discharges from the ditches and ensure that there is no discharge to streams in the area. As this system is close to the DFWP game management area, the DFWP, during their normal routine inspections, provides monitoring of the discharge.

22.0 TRANSMISSION SYSTEM CONSTRUCTION

The pipeline that carries the hot geothermal water from the well to the plate heat exchanger is approximately 70 ft long and is not a significant portion of this project and has been included in the production system design.

(This section is therefore not applicable.)

23.0 DISTRIBUTION SYSTEM CONSTRUCTION

23.1 BIDDING, SELECTION, AND CONTRACT

The invitation for bid package that was developed for the distribution system also included portions of the production system, disposal system, and two interface connections to the existing application system. That invitation for bid was advertised between April 22 and May 19, 1982. 4G Plumbing and Heating of Missoula, Montana was the successful bidder and contract award was made on July 15, 1982. 4G used Hiam Electronics of Butte, Montana as an electrical subcontractor.

23.2 AS-BUILT SYSTEM

4G Plumbing and Heating started their actual field work on September 1, 1982. Work continued through startup on January 11, 1983 and to completion on January 31, 1983. The system was essentially constructed as the original design indicated with only one minor modification. That modification was the installation of the Btu flow meter in the 4 in. hot domestic water supply line to the hot water accumulator instead of the 4 in. cold water supply line. The 4 in. hot domestic water line had a longer length of straight pipe available on each side of the Btu flow meter to provide a more stable flow regime.

23.2.1 General Description

In Figure 14, the distribution system is depicted as it is functionally configured and also its interrelation to the entire geothermal and existing application systems is shown. The system consists of a plate heat exchanger, recirculation pump, and the associated piping and instrumentation. All of these are located in the heating plant.

The geothermal water continuously flows through one side of the heat exchanger while the cold domestic water is flowing counter-currently through the other side. The heated domestic water is then routed to the existing hot water

accumulator tank. The recirculation pump circulates accumulator water back through the heat exchanger to maintain temperatures in the system.

23.2.2 Controls

The controls utilized in operation or control of the distribution system are as described in Section 18.2.2.

23.2.3 Major Components

The major components of the distribution system are the heat exchanger, recirculation pump, and piping and instrumentation as described in Section 18.2.3.

23.2.4 Energy Monitoring System

The Btu flow meter with totalizer, as described in Sections 18.2.3 and 18.2.4, is installed in the domestic water side of the system. The sensing temperature transmitters on the cold and hot domestic water lines, in conjunction with the turbine meter, provide an input to the electronic Btu output panel. The Btu output panel provides a totalizer reading which indicates the total amount of heat gained by the domestic water as it flows through the heat exchanger.

23.2.5 Environmental Control and Monitoring

(Not applicable.)

24.0 APPLICATION SYSTEM CONSTRUCTION

24.1 BIDDING, SELECTION, AND CONTRACT

The two interface connections into the existing application system were included in the distribution system invitation for bid that was advertised and awarded to 4G Plumbing and Heating of Missoula, Montana.

24.2 AS-BUILT SYSTEM

Figure 15 depicts the application system as it exists at the Warm Springs State Hospital. The hot water heater, hot water accumulator, two recirculation pumps, and associated piping were in operational use prior to the geothermal modifications. The only modifications involving the application system was the two interface connections and the additional piping as described in the Distribution System Section.

24.2.1 General Description

Items in this section were addressed in Distribution System Sections.

24.2.2 Controls

Items in this section were addressed in Distribution System Sections.

24.2.3 Major Components

Items in this section were addressed in Distribution System Sections.

24.2.4 Energy Monitoring System

Items in this section were addressed in Distribution System Sections.

24.2.5 Environmental Control and Monitoring

Items in this section were addressed in Distribution System Sections.

25.0 SYSTEM MANAGEMENT AND ORGANIZATION

25.1 ORGANIZATION AND PARTICIPANTS

Section 4.2 Organization and Participants, described the key project personnel and Figure 4 depicted the project organization and major tasks of the project.

This section identifies the system of responsibility as it relates to the Department of Institutions. Figure 17 shows the key personnel that were involved in the project at the State level.

25.2 RESPONSIBILITIES

The operating engineers as shown in Figure 17 are the key operators located in the heating plant that are directly responsible for operation of the geothermal system. They receive their direction from the maintenance manager who also can direct other maintenance personnel to assist in repairs or problems in the system.

FIGURE 17.--ORGANIZATION AND PARTICIPANTS - STATE OF MONTANA

26.0 PRODUCTION SYSTEM PERFORMANCE

MultiTech's contract with the Department of Energy did not include any requirement for analysis of system performance and this section is not applicable.

27.0 DISPOSAL SYSTEM PERFORMANCE

MultiTech's contract with the Department of Energy did not include any requirement for analysis of system performance and this section is not applicable.

28.0 TRANSMISSION SYSTEM PERFORMANCE

MultiTech's contract with the Department of Energy did not include any requirement for analysis of system performance and this section is not applicable.

29.0 DISTRIBUTION SYSTEM PERFORMANCE

MultiTech's contract with the Department of Energy did not include any requirement for analysis of system performance and this section is not applicable.

30.0 APPLICATION SYSTEM PERFORMANCE

MultiTech's contract with the Department of Energy did not include any requirement for analysis of system performance and this section is not applicable.

31.0 CONSTRUCTION COSTS

4-G Plumbing and Heating

<u>Item Description</u>	<u>Cost</u>
1. Bond and Move In	\$ 2,000
2. Water Piping	3,800
3. Heating Piping	16,450
4. Equipment	12,800
5. Reclaim Mud Pits	3,000
6. Well House	3,300
7. Electrical	3,000
8. Insulation	<u>1,650</u>
	\$46,000

4-G Plumbing and Heating, a small, minority, and socially and economically disadvantaged business in Missoula, Montana, as low bidder was awarded a subcontract under authority of U.S. Department of Energy Cooperative Agreement Ao. DE-FC07-79ET-27055. Work under this contract included the furnishing of all labor, equipment, materials, and the performance of all mechanical and electrical work required to provide the Warm Springs State Hospital with a retrofitted geothermal water heating system.

32.0 OPERATING AND MAINTENANCE COST

32.1 SUMMARY

The summary of costs given in Table 8, Life Cycle Costs shows the major costs of the project as installed with a total project cost of \$756,745. The system is considered to have a twenty-year life and costs are in 1983 dollars. The following paragraphs clarify the column headings and provide supportive calculations. Annual fuel costs, debt service, and net cash flow are included for clarification of Table 8 and also are required to obtain a net operational cost of the system on a yearly basis.

Column 1 identifies the reference year of the Life Cycle Cost. Column 2 is based on the 20,000,000 Btu per day savings that were developed in Section 2.2. The first year's savings are calculated as follows:

$$\frac{20,000,000 \text{ Btu/day} \times 365 \text{ days/year}}{.50 \text{ conversion efficiency}} = 14.6 \times 10^9 \text{ Btu/year}$$

$$\frac{14.6 \times 10^9 \text{ Btu/year} \times \$4.682/1000 \text{ ft}^3}{829.5 \text{ Btu/ft}^3} = \$82,408/\text{year}$$

A fuel inflation rate of 7% was used to arrive at consecutive yearly costs.

The operation and maintenance costs in Column 3 are based on a fixed percentage of the installed costs of the system. A percentage of 2.5% is a conservative estimate for routine costs as used by industry. That percentage was multiplied times \$73,052 as that is the cost of the production pump (\$27,052) and the distribution system (\$46,000).

$$\$73,052 \text{ installed cost} \times 2.5\% = \$1826/\text{year}$$

An inflation rate of 5% was used to arrive at the continuing yearly costs. Major repair costs can be anticipated on the submersible production pump approximately every six to seven years. Those costs have been estimated at \$17,000 and are also inflated at an annual rate of 5%.

TABLE 8.--LIFE CYCLE COSTS - INSTALLED SYSTEM (1983)

1	2	3	4	5	6	7	8	9
Year	Projected Annual Fuel Costs	Operation and Maintenance Costs	Electrical Pumping Costs	Annual Savings [2-(3+4)]	Debt Service Costs if Project is Financed	Net Cash Flow [6-5]	Accumulated Net Cash Flow	Discounted Cash Flow
(1) 1983	82,408	1,826	2,716	77,866	83,726	- 5,860	- 5,860	71,111
(2) 1984	88,177	1,918	2,906	83,353	83,726	- 373	- 6,233	69,517
(3) 1985	94,349	2,013	3,110	89,226	83,726	5,500	- 733	67,959
(4) 1986	100,953	2,114	3,327	95,512	83,726	11,786	11,053	66,436
(5) 1987	108,020	2,220	3,560	102,240	83,726	18,514	29,567	64,946
(6) 1988	115,581	2,330 + 21,697	3,809	87,745	83,726	4,019	33,586	50,902
(7) 1989	123,672	2,447	4,076	117,149	83,726	33,423	67,009	62,064
(8) 1990	132,329	2,570	4,361	125,398*	83,726	41,672	108,681	60,671
(9) 1991	141,592	2,698	4,667	134,227	83,726	50,501	159,182	59,308
(10) 1992	151,504	2,833	4,993	143,678	83,726	59,952	219,134	57,976
(11) 1993	162,109	2,975	5,343	153,791	83,726	70,065	289,199	56,673
(12) 1994	173,457	3,124	5,717	164,616	83,726	80,890	370,089	55,399
(13) 1995	185,599	3,280 + 30,530	6,117	145,672	83,726	61,946	432,035	44,771**
(14) 1996	198,591	3,444	6,545	188,602	83,726	104,876	536,911	52,936
(15) 1997	212,492	3,616	7,003	201,873	83,726	118,147	655,058	51,745
(16) 1998	227,366	3,797	7,494	216,075	83,726	132,349	787,407	50,580
(17) 1999	243,282	3,987	8,018	231,277	83,726	147,551	934,958	49,442
(18) 2000	260,312	4,186	8,579	247,547	83,726	163,821	1,098,779	48,329
(19) 2001	278,533	4,395	9,190	264,958	83,726	181,232	1,280,011	47,240
(20) 2002	298,031	4,615 + 42,958	9,822	240,636	83,726	156,910	1,436,921	39,181
TOTAL				3,111,441			1,436,921	1,127,186

* Simple payback point 7.83 years.

** Discounted payback point 12.31 years.

The electrical pumping costs shown in Column 4 were calculated from operating data that indicated a total of 21 kWh of electricity was used for both the production pump and the domestic water circulation pump. That figure multiplied by 8760 hours per year and an incremental power cost of \$0.014762 per kWh results in an annual cost of \$2716. Again, a fuel inflation rate of 7% was used to arrive at costs for the continuing years.

The annual savings in Column 5 is the result of subtracting the operation and maintenance costs plus the electrical costs (Columns 3 + 4) from the projected annual fuel costs of Column 2.

Column 6 is a calculation based on a straight loan repayment schedule if the total project costs of \$756,745 were financed at 9-1/2% (government/municipal bonds) for a period of 20 years.

The net cash flow shown in Column 7 is the difference between the debt service (Column 6) and the annual savings (Column 5) if the accounts were all credited to one uniform account.

Column 8 is an accumulated total of the net cash flow as developed in Column 7.

32.2 OPERATING COSTS

(This item was discussed in Section 32.1.)

32.3 MAINTENANCE COSTS

(This item was discussed in Section 32.1.)

33.0 SYSTEM ECONOMICS

33.1 CAPITAL COSTS

The project was funded jointly by the State Department of Natural Resources and Conservation (DNRC), the State Department of Institutions (DOI), and the U.S. Department of Energy (DOE). The total project cost of \$756,745 was comprised of DOE reimbursible costs of \$721,122, State of Montana participation costs of \$27,845, and additional unreimbursed MultiTech costs of \$7,778.

33.2 OPERATING AND MAINTENANCE COSTS

The operating and maintenance costs were calculated on a percentage of the installed costs of the production pump and distribution system as shown in Section 32.1 Table 8 shows those costs in Column 3 over the twenty year project life. In addition to the routine costs an additional major repair cost for the submersible production pump is also included in Column 3 for years 6, 13, and 20.

Electrical pumping costs were also calculated to obtain a basis for operating costs. Those costs were based on the incremented electrical costs of \$0.014762 per kWh. Column 4 of Table 8 shows those costs. The total calculated 1983 operational and maintenance costs from Columns 3 and 4 are \$4542.

33.3 FUEL SAVINGS

Sections 2.2 and 32.1 outline the basis for the natural gas fuel savings. The 20,000,000 Btu per day savings is converted into yearly natural gas savings as follows:

$$\frac{20,000,000 \text{ Btu/day} \times 365 \text{ days/year}}{.50 \text{ conversion efficiency} \times 829.5 \text{ Btu/ft}^3} = 17,600,964 \text{ ft}^3/\text{year}$$

The 1983 cost basis for this quantity of natural gas is based on the incremental price of \$4.682 per 1000 ft³. The calculation $17,600,964 \text{ ft}^3/\text{year} \times \frac{\$4.682}{1000 \text{ ft}^3}$ yields an annual savings of \$82,408.

33.4 CUSTOMER BILLING

As the Warm Springs State Hospital is the operator and beneficial user of the geothermal resource there is no customer billing procedure and this section is not applicable.

33.5 ANALYSIS

The analysis utilizes the information as presented in Sections 2.2, 32.1, and 33.0 to further evaluate the project on an economic basis in 1983 dollars.

33.5.1 Simple Payback

The following information that was previously developed is used in calculating the simple payback.

Total Project Cost	\$756,745
Yearly Fuel Savings	\$ 82,408
Yearly Operation and Maintenance Costs	\$ 4,542

$$\text{Simple Payback} = \frac{\$756,745}{\$82,408 - \$4,542} = 9.72 \text{ years}$$

This simple payback of 9.72 years does not address the possibility of additional usage of the spent geothermal water nor any treatment for escalation of natural gas prices.

33.5.2 PON R&D Analysis

(Not applicable.)

33.5.3 Other Analysis

The life cycle costs are shown in Table 8. Explanation of the specific columns is included in Section 32.1.

A simple payback comparison of the life cycle table would require a summation of the annual savings (Column 5) until it equals the projects costs of \$756,745. This simple payback would be in 7.83 years. This value differs from the 9.72 years presented in Section 33.5.1 as that calculation was based only on the first year and did not consider inflation rates and major equipment repair costs.

Column 9 was added to Table 8 to provide an analysis of discounted cash flow based on the 9-1/2% interest rate. This column can be used for various analysis. One method is that the total present value of the discounted cash flow is \$1,127,186. This can be interpreted to mean that \$1,127,186 could be financed at 9-1/2% on the project and still would break even at the end of the project, in 20 years, considering the net cash flow. A second method would be to add the values in Column 9 until they equal the project cost of \$756,745. This yields a discounted payback of 12.31 years. This payback period is higher than the others presented because savings occurring in future years have less value than savings in the current year.