Geothermal Resources Council TRANSACTIONS, Vol. 17, October 1993

GEOGRAPHICAL VIABILITY OF GROUND WATER GEOTHERMAL HEAT PUMPS IN THE UNITED STATES

Kevin M. Freeman(1)
Leland Roy Mink(2)

(1) University of Idaho, College of Mines and Earth Resources, Moscow ID
(2) Idaho Water Resources Research Institute, Moscow ID

Abstract

Ground-source heat pumps can provide a cost-efficient alternative to standard air-source heat pumps. However, for the earth-coupled and ground water heat pump systems, developmental factors such as ground water availability and installation costs tend to weigh against using these systems. To promote the feasibility of the ground water heat pump, it must be demonstrated to manufactures and consumers that there is a ready and constant supply of economically obtainable ground water in many areas of the United States. A set of four plates, depicting areas of shallow ground water and its average temperature, demonstrates that well over one-half of the United States, particularly the central and southeast, possess the hydrogeologic characteristics necessary to make the ground water heat pump a viable option. Further linking these plates with demographic studies would provide additional value to the economic viability of ground water heat pumps.

Introduction

The Idaho Water Resources Research Institute (IWRRI) at the University of Idaho is currently engaged in a cooperative program with the University of Utah Research Institute (UURI) and the Oregon Institute of Technology (OIT) to develop and promote the use of ground-source, or geothermal heat pumps. At the Idaho Water Resources Research Institute research addressing the feasibility and application of geothermal heat pumps has focused primarily on both the earth-coupled and the ground water heat pump systems. To promote the further use of ground water geothermal heat pumps, IWRRI has produced a set of three plates of the United States, describing potential favorable near-surface ground water supplies which may be used for ground water heat pumps.

Background

Ground-source heat pumps are manufactured in three varieties: the earth-coupled, the groundwater, and the lake-source heat pump. All three operate using the same general process, a fluid is circulated by a heat pump (exchanger) through tubing, where it releases heat or absorbs heat, depending on if the unit is cooling or heating. Earth-coupled heat pumps achieve this goal by pumping the fluid through tubes buried in the ground. Lake-source heat pumps circulate fluid through tubing submerged in a standing body of water. Ground water heat pumps can use ground water pumped directly from an aquifer as their fluid, or they may circulate a fluid through tubing placed within wells drilled into the ground water system. This fluid is then passed through the heat pump where heat is either absorbed from or released to the building or home. If ground water has been extracted and used for fluid it is then returned to the aquifer through an injection well. Today, the two most widely used geothermal heat pump systems are the earth-coupled and ground water systems.

Purpose

According to Dr. Steve Kavanaugh of the University of Alabama, ground-source (geothermal) heat pumps are receiving increasing attention as a higher-efficiency, lower-cost alternative to traditional air-source heat pumps. Of the three types of ground-source heat pumps, the ground water heat pump is less costly to construct than the earth-coupled heat pump, owing to the fact that the earth-coupled type requires burying pipes below ground. However, since ground water conditions necessary for the optimum functioning of a ground water heat pump are not usually obvious to the eye, these are often shunned in favor of a more traditional heating/cooling system. Even when a ground water source does exist, prohibitive economics can be a factor against using ground water heat pumps. One of the more restrictive elements of a ground water heat pump is the initial construction cost of the system. Drilling costs for a ground-source system can vary widely in price, depending on physical conditions at the site, the nature of the subsurface geology, and more importantly the depth of the hole required by the selected system. However, these costs can be offset by utilizing a suitable, pre-existing source. The drill hole depth and static water level are of special concern in developing a ground water heat pump system. One must reach a sustainable source of ground water which provides a reasonable pumping rate. Ground water heat pumps require between 1 to 1.5 gpm per ton of heating or cooling capacity (K. Denbraven, written commun., 1993). In addition, the return temperature from the heat pump must be kept above approximately 37°F to prevent freezing of the water, and at 1 gpm/ton a drop of 15-20°F can be expected across the heat pump from inlet to outlet. The purpose behind these plates is to provide a preliminary assessment of areas in which use of ground water geothermal heat pumps may be feasible.

Methods

The package produced by IWRRI includes four plates and one base map. The four plates consist of: (1) aquifers associated with shallow alluvial valleys (Figure 1), (2) aquifers associated with unconsolidated and semi-consolidated sedimentary deposits (Figure 2), (3) ground water temperatures in wells at depths of 100 to 200 feet (Figure 3), and (4) interpreted shallow ground water regions of the United States (Figure 4). The base map used (not presented in this paper) is the USGS publication, *Physical Divisions of the United States*, by Nevin M. Fenneman (1949), a polyconic projection at a scale of 1:7,000,000. This map was chosen for its excellent depiction of river drainages, as well as its manageable scale.

These plates depict those aquifers which are known to produce water within a relatively shallow depth (within approximately 100 to 200 feet of land surface is the intended range). The alluvial valley plate (Figure 1) depicts those aquifers of thick sand and gravel deposits beneath floodplains and stream terraces associated with existing streams or rivers. The hydrogeologic properties of these types of sediments in combination with the river or stream acting as a constant recharge source, gives the alluvial valley strong potential for providing shallow ground water.

The unconsolidated and semi-consolidated sedimentary deposits (Figure 2) display areas of water-bearing sands and gravels and sandstones of the Cenozoic and Mesozoic ages. These unconsolidated sediments are often found as alluvial valleys, alluvial basins, thick alluvial deposits, glacial deposits, or as interbeded sands and silts. These unconsolidated or semi-consolidated deposits are often found near-surface, and many contain shallow unconfined, or water table aquifers. Further, the hydrogeologic properties of the sands and gravels that form these types of unconsolidated and semi-consolidated sediments allow for sustainable quantities of ground water at relatively shallow depth, assuming there is a dependable source of recharge to the aquifer.

The ground water temperature plate (Figure 3) is included as a general reference to determine the possible ground water temperatures encountered for use in a ground water geothermal heat pump. Although existing ground water temperature may show much greater detail (Hart, 1986) for some areas, and should be referred to if available, this map provides an adequate representation of temperature on a national scale and are designed to be used with the other plates. It should be noted that ground water temperature is higher and more seasonally consistent than ambient air temperature, resulting in more efficient heat transfer. When examining the combination of the alluvial valley plate, the unconsolidated and semi-consolidated sediment plate, and the temperature plate shows the ground water geothermal heat pumps (as well as earth-coupled geothermal heat pumps) may be a viable option for a large portion of the United States.

Interpretation

Combining the ground water potential delineated by the alluvial valley plate and the unconsolidated and semi-consolidated plate (Figure 4), it can be estimated that a large portion of the continental United States has the possibility of producing shallow ground water. Using the 10 ground water regions of Thomas (1952) (Figure 5) as a physiographic classification system, an estimation of the ground water heat pump viability for each region can be made. Along the Atlantic and Gulf Costal Plain, much of this region would be supplied through water from unconsolidated or semi-consolidated aquifers with ground water temperatures ranging from 54 to 72°F. In the Glaciated Central Region, sand and gravel aquifers offer some potential production, but alluvial valley aquifers would provide most of the possible shallow ground water, ranging in temperature from 44 to 58°F. The Glaciated Appalachians, Unglaciated Appalachians, and Unglaciated Central Region show sparse areas of shallow ground water, which appears to be confined to particular river valleys at temperatures from 44 to 70°F. The High Plains show excellent potential for both unconsolidated and semi-consolidated aquifers and alluvial valley aquifers, with ground water temperatures from 54 to 68°F. The Colorado Plateau, as well as the Columbia Lava Plateau, are two regions which both show sparse shallow ground water potential. Finally, although the Western Mountain Ranges and the Alluvial Basins appear to have an inconsistent distribution of shallow ground water sources, most of which are of the unconsolidated and semi-consolidated variety, many of these sources are consistent with the more populated regions of the west. Ground water temperatures in these two regions average between 48 and 74°F.

Recommendations and Conclusions

As stated above, the next step in the feasibility process is to correlate these maps with demographic analysis, in order to determine favorable populated areas for heat pump development. At IWRRI, we feel that this process would best be accomplished through the utilization of a GIS ARC-INFO base, and to incorporate these plates into a GIS system. This task will be conducted in conjunction with activities performed at OIT and IWRRI.

Ground water and earth-coupled heat pumps have the potential to become a highly-efficient, low-cost method of providing heating and cooling to private and commercial interests in the United States. To make this technology available to consumers on a large scale, it first must be demonstrated to the interested parties, utilities, manufactures, and possible manufactures of ground-source heat pumps, that the natural geothermal resource exists on a broad enough scale and that the technology is economically viable and attractive.

REFERENCES USED

Hart, D.P., 1986, *Earth-Coupled Heat Transfer*, National Water Well Association, Dublin, Ohio.

Heath, R.C., 1983, *Ground water Regions of the United States:* U.S. Geological Survey Water-Supply Paper 2242, 76p.

Kavanaugh, S. *Ground-Coupling With Water Source Heat Pumps*. The University of Alabama, Tuscaloosa, Alabama.

Thomas, H.E., 1952, *Ground water regions of the United States - their storage facilities* in The physical and economic foundation of natural resources: U.S. 83d Congress House Committee on Interior and Insular Affairs, Washington D.C., v. 3, p.3-78.

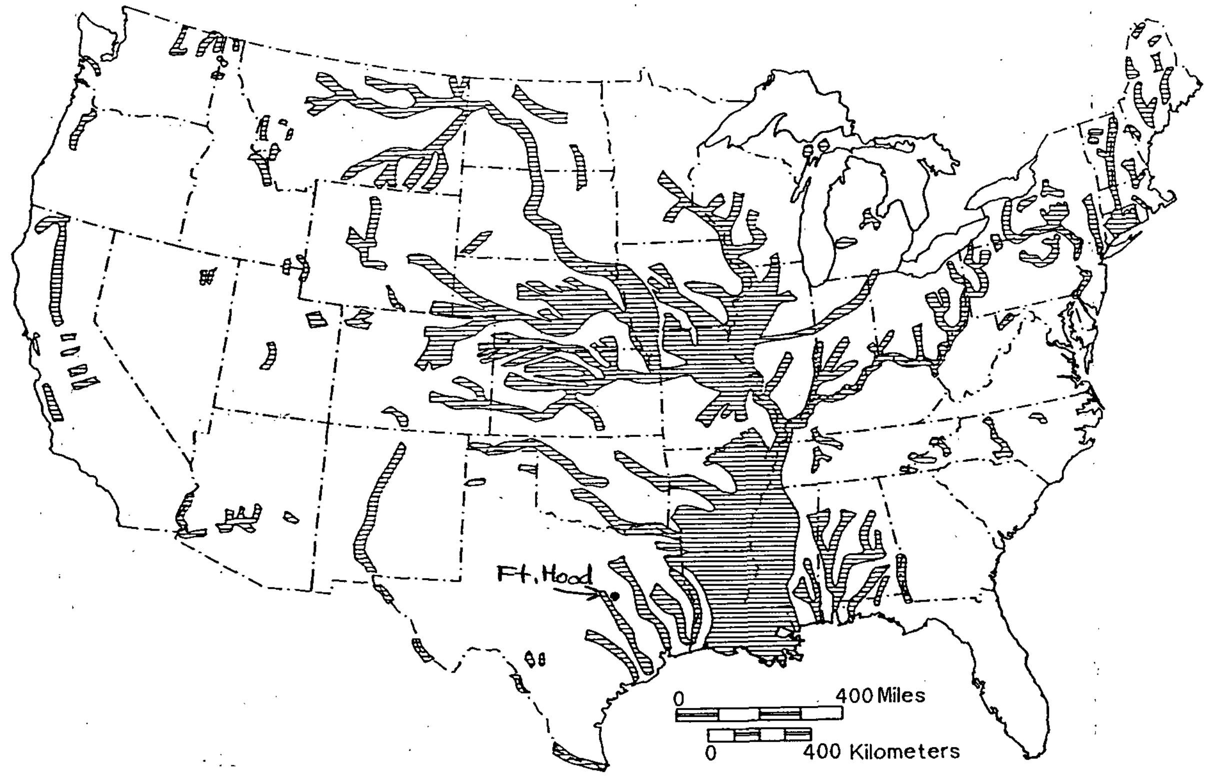


Figure 1. Shallow aquifers associated with alluvial valleys. (Modified from Heath, 1984.)

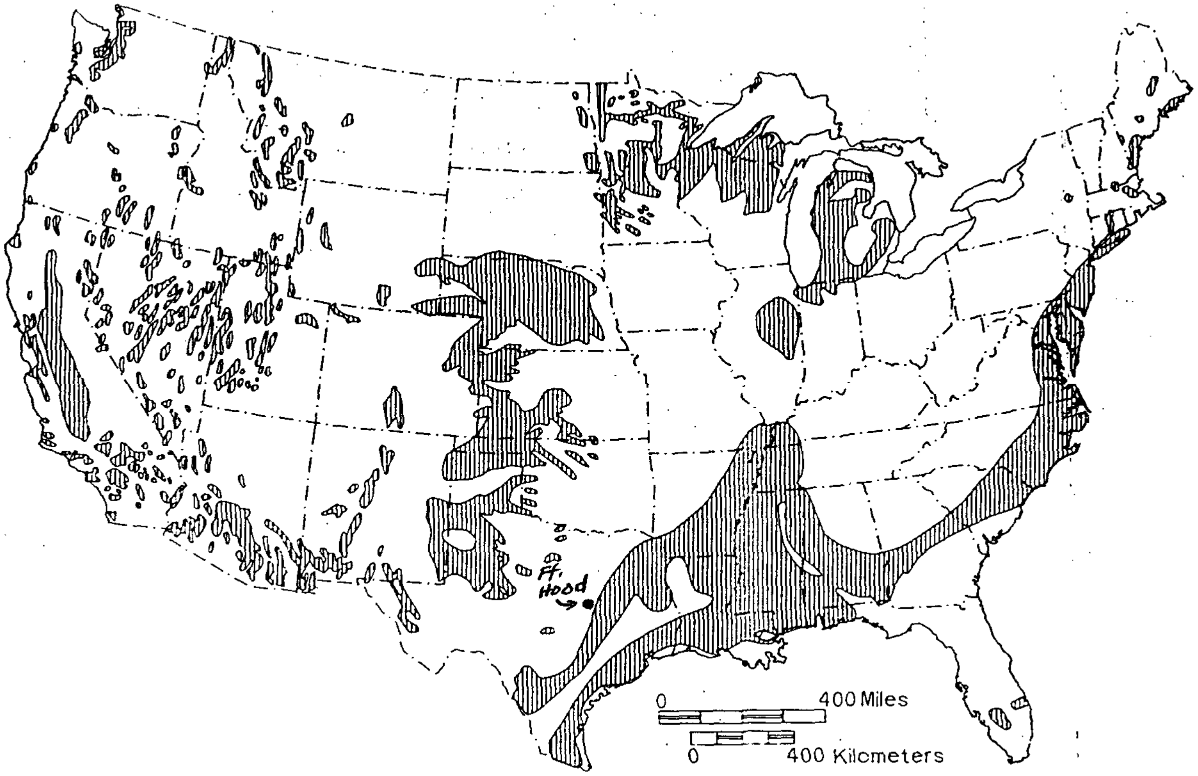


Figure 2. Unconsolidated and semi-consolidated sedimentary deposits of the United States. (Modified from Heath, 1984.)

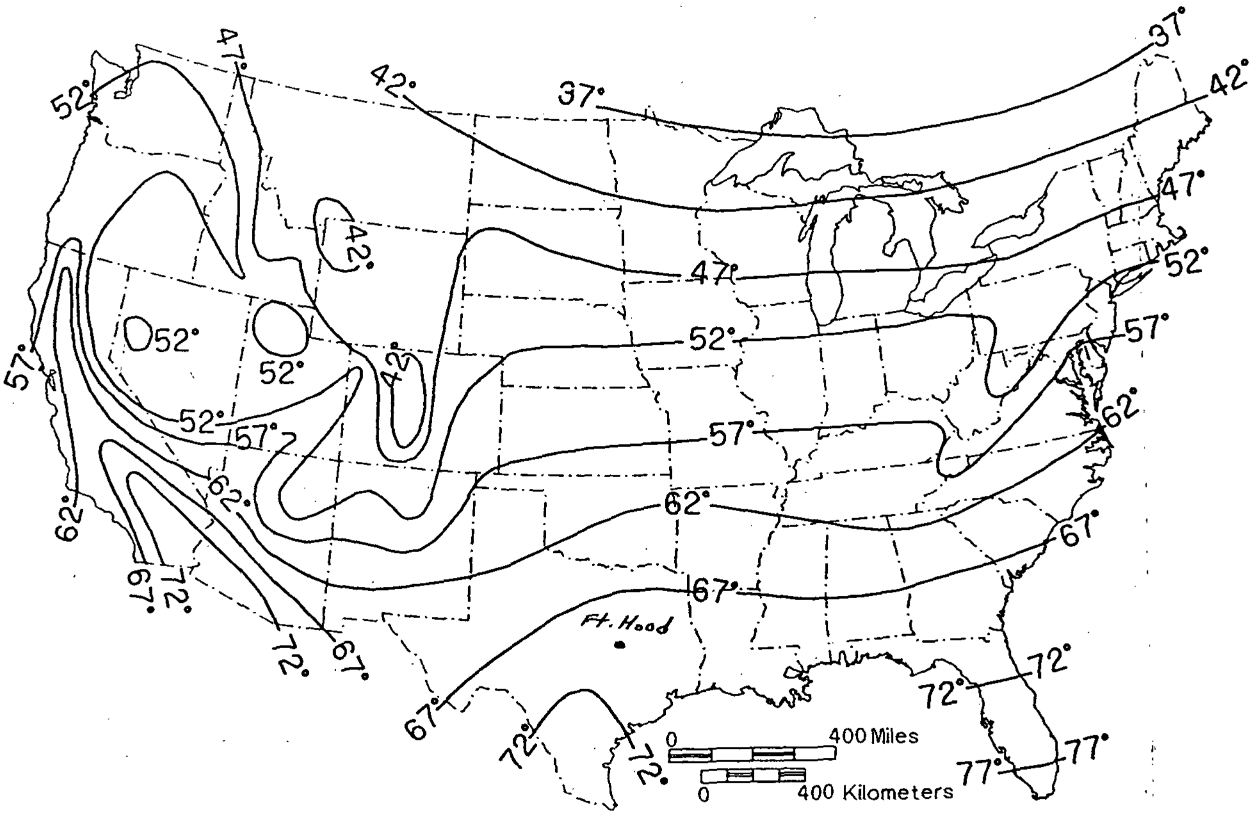


Figure 3. Ground water temperatures from depths of 50 ft to 150 ft. (Modified from Hart, 1986.)

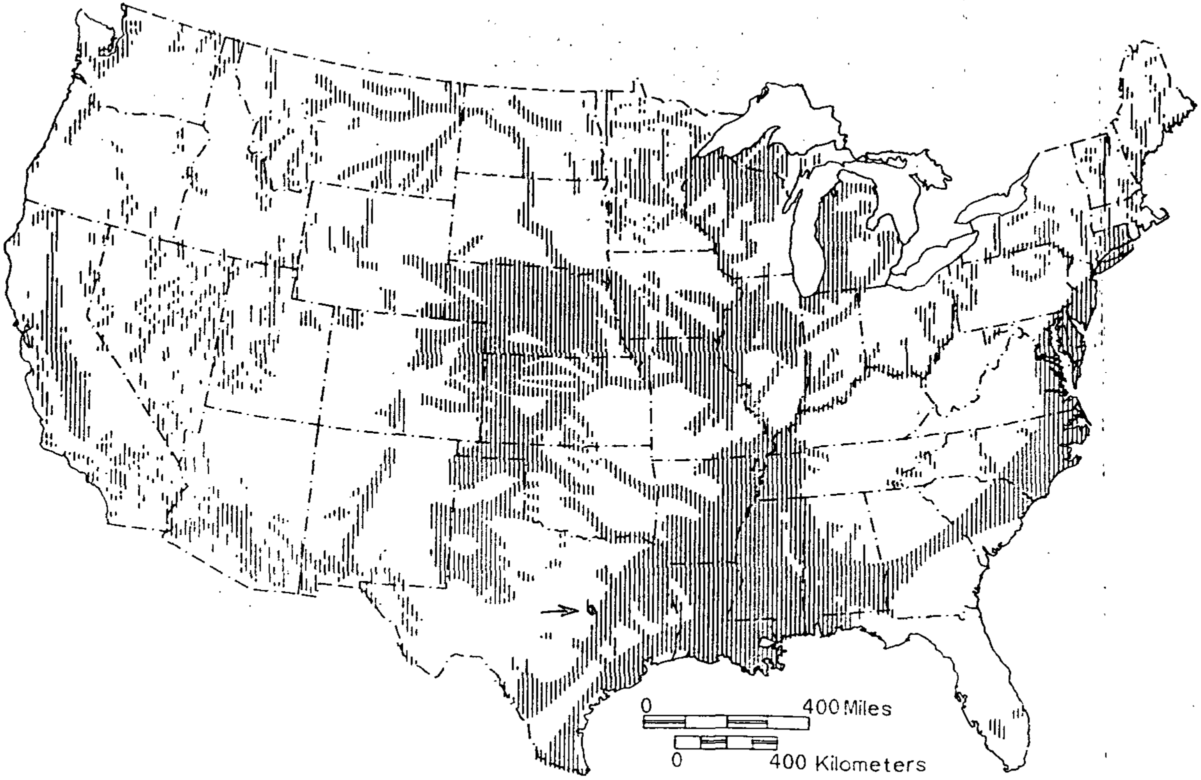


Figure 4. Inferred shallow (100 ft to 200 ft) ground water areas of the United States.

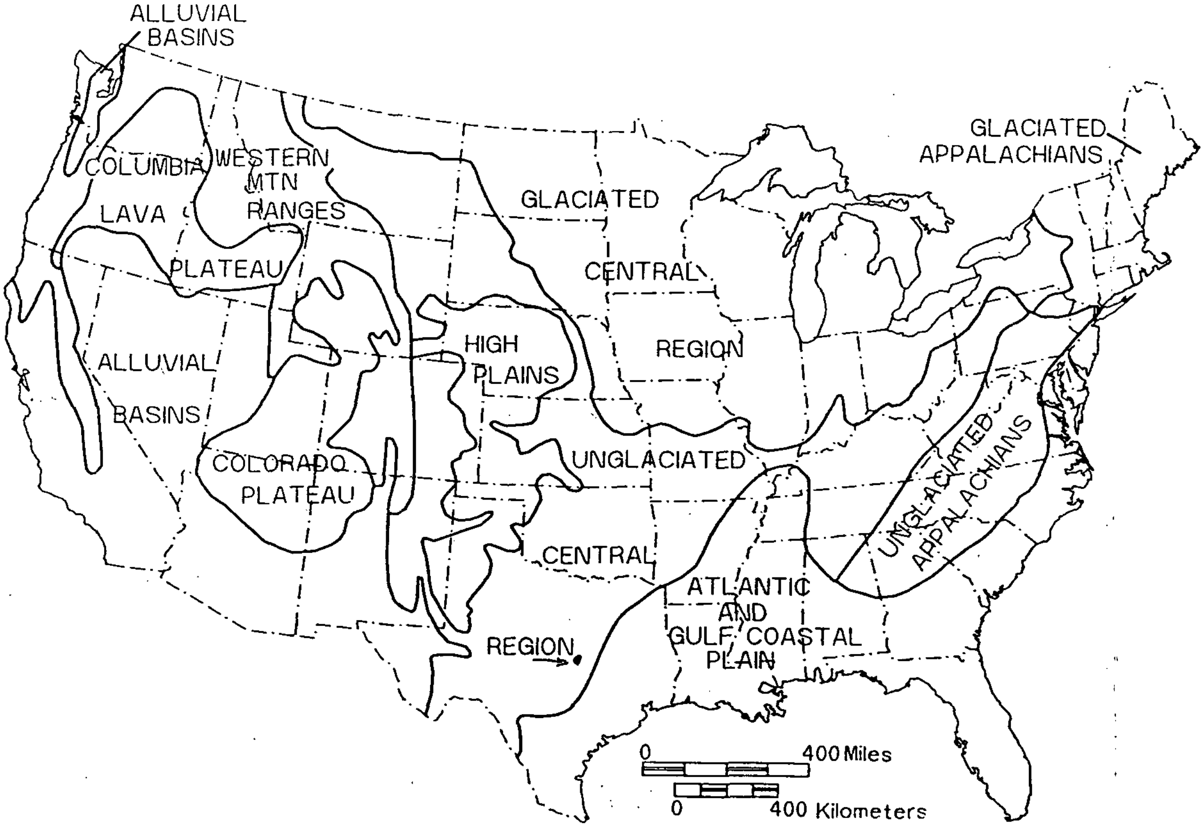


Figure 5. Ground water regions of the United States. (From Thomas, 1952, figure 1.)

IWRRI

Proposal

LOW TEMPERATURE GEOTHERMAL ENERGY ASSESSMENT

A Cooperative Proposal

Idaho Water Resources Research Institute
Utah Earth Science Laboratory
Oregon Institute of Technology Geo-Heat Center

March, 1991

Goal 1: Low Temperature Geothermal Energy Assessment

Introduction

Low temperature geothermal energy has taken a back seat to other alternative energy programs in past years. The last major effort in assessing the national potential of low temperature geothermal occurred in the late 1970s. Since that time there has been no coordinated effort ~~made~~ to compile information on the potential of using low temperature geothermal energy to satisfy some of the energy needs of the nation. A heightened awareness of our nation's energy dependency compels us to determine the viability of this alternative energy source. Due to limited data it is essential that effort is invested in establishing a baseline for potential use of this renewable energy resource.

Background

Low temperature geothermal energy is best used in direct heat applications. The applications typically involve small users, such as home space heating, greenhouse heating, and light industrial applications. Larger applications may involve district heating systems or large building complexes. It is the larger applications that offer the most benefit and result in the greatest energy savings. In all cases, whether it is the individual home space heating project or the larger district heating system there is a lack of understanding of the heat source and information as to its reliability. This information is essential to the success of this project and often is the critical factor in securing initial financing. This information is also very expensive to obtain and only the large developers can afford to acquire adequate information to be used in development plans. Other potential users are often discouraged before they ~~their~~ get the project "off the ground."

Project Description

The program will be conducted jointly by the Idaho Water Resources Research Institute (IWRRI), the University of Utah Earth Science Laboratory (UURI), and the Oregon Institute of Technology Geo-Heat Center (OIT). State geothermal teams will be involved in collecting geothermal resource information and assisting in information dissemination within their state. The Idaho Water Resources Research Institute will focus on two thrusts: 1) updating the geothermal data base for Idaho, and 2) performing geothermal reservoir evaluations for selected reservoirs throughout the western United States. Specific activities are as follows:

1. Collect, update and compile Idaho's available geothermal resource data.

2. Assist in the prioritization of low temperature reservoirs, using information from OIT, UURI, and the state teams which are located near ~~a~~ potential users.

3. Define geologic controls of the geothermal system, using information from UURI and the state teams, and establish a conceptual model of the geothermal reservoir.

4. Collect hydrologic or reservoir data on the geothermal system, with the help of the state teams, and evaluate this data to initiate a data base for reservoir evaluation. New data may be necessary to fill in data gaps.

5. Determine the best estimate of reservoir capabilities, using the compiled data. Reservoir testing or modeling will be recommended where appropriate. The reservoir estimates will be made on a site-by-site basis depending on the priorities established in Activity 1.

Work Statement

Task 1. Collect Hydrothermal Resource Data for Idaho

Collect, update and compile the available geothermal resource data which has been generated in Idaho. The emphasis will be on data which has been generated since the last state assessment. The information is expected to include temperature gradient measurements, geochemical data, geological mapping, geophysical studies (heat flow, gravity, and electrical), reservoir testing and analysis, well identification, thermal spring investigations, and quantitative reservoir estimations. Emphasis will also be placed on those potential resources which are located in close proximity to population centers and are of higher temperature or high flow rates.

Task 2. Prioritization of Low Temperature Geothermal Systems

With information from UURI, OIT, and the individual state teams assist in the prioritization of low temperature geothermal systems which are located in close proximity of potential use. Factors to be considered include: the distance to prospective users, such as a population center, temperature, size, producibility of the geothermal resource, and the near-term potential of a development occurring. IWRRI will assist in the development of a matrix which incorporates the factors of the resource, potential uses, heat loads, and economic/social factors for use in establishing priorities for development strategies.

Task 3. Development of a Conceptual Reservoir Model

A conceptual model will be generated for selected reservoirs using data from UURI and the state team most familiar with the geologic and hydrologic setting of the system. The conceptual model will describe the geologic, geochemical and hydrologic controls affecting the system. The conceptual model will be the basis for determining any data gaps. This information is necessary for a detailed evaluation and for setting the stage for potential numerical modeling.

Task 4. Conduct a Reservoir Assessment of Selected Systems

Perform a reservoir assessment of selected systems to determine reservoir capability for anticipated development. The assessment will address production capability with respect to flow, temperature, and chemistry of the fluids. Flow testing data for selected reservoir parameters will be critical for this analysis, especially if modeling of the system is conducted. It is hoped this information will be available for the prioritizing systems. If not, the state teams and IWRRI will work with the potential developers to gather the necessary information.

Goal 2: Geothermal Heat Pumps

Introduction

Geothermal heat pump systems can be grouped into two general categories: (1) ground water heat pumps which extract energy from the water beneath the surface of the earth, and (2) earth energy heat pumps which extract energy from the soils beneath the surface of the earth. Both systems rely on the constant temperature found beneath the surface of the earth as the energy source. Presently, the efficiency of the ground water based heat pump is greater because ground water is a more efficient method of transporting the heat compared to conductive heat movement within dry soils.

Geothermal heat pump systems have a much greater potential for utilization across the nation because of the following:

1. The system relies on natural temperatures beneath the surface rather than outside air temperatures, therefore has potential throughout the United States where space heating is a concern.
2. The system is capable of both heating and cooling, therefore it can be used throughout the year for most applications. The cooling cycle would be of greatest use in the southern tier states of the United States.

The expanded use of the geothermal heat pump systems will result in a net savings of conventional energy sources, such as coal, oil, natural gas, and electrical energy, for heating and cooling . The wider use of geothermal heat pump systems would also result in an environmentally safe energy source as compared to fossil fuel systems.

Project Description

The geothermal heat pump portion of the project will be a cooperative program with OIT, UURI, and IWRRI. OIT will be primarily responsible for developing marketing and incentive programs, determining potential national energy savings, performing suitability and market studies. UURI will perform studies in ground transfer, drilling techniques, and integrated resource planning. IWRRI will conduct resource studies to update existing generalized maps on shallow ground water occurrences and temperatures, soil and geologic conditions, and potential drilling conditions. All three collaborators will be involved in outreach and public education programs. Involvement of water or energy institutes from several eastern states is expected. In addition, some assistance from the western states geothermal teams will be provided in gathering the necessary technical data and assisting in outreach and public education.

Work Statement

Task 1. <u>Contract Negotiation</u>

IWRRI will negotiate contracts, supported by OIT and UURI, with the state teams or water/energy institutes involved in the data collection.

Task 2. <u>Review State Resource Inventory--Begin Update</u>

Conduct an assessment of ground water conditions for geothermal heat pump use. This would involve the update of the national map prepared by the National Water Well Association. This would be done by IWRRI with support from the other state Water Resource Centers or geothermal resource teams. The assessment would involve the gathering of existing data on the water table, bedrock, soil conditions, and subsurface temperature in a general overview.

Task 3. Review Demographics

The geothermal heat pump concept is expected to involve the entire United States. Initially, Phase 1, would include several eastern states in the assessment. Demographic studies will be coordinated with the state teams by IWRRI and OIT.

Task 4. Outreach and Public Education

IWRRI, OIT and UURI will work cooperatively with the Geothermal Resource Council, the Geothermal Education Office, and other energy conservation groups in information transfer. Geothermal energy information, including the use of geothermal heat pump systems, will be disseminated to potential developers and the public. In addition, contacts will be established with builders, construction companies, groundwater professionals, and other trade and energy focused groups.

Budget

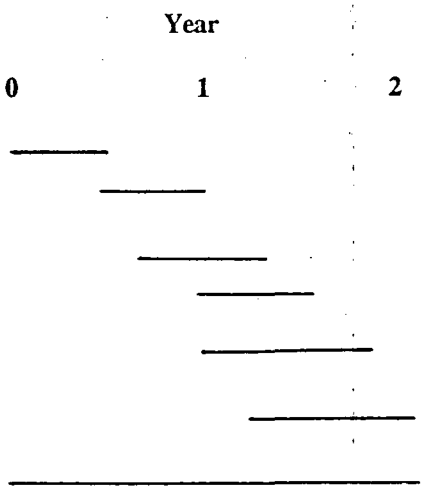
Manpower Requirement	Geothermal Reservoir Assessment Program	Heat Pump Program
Program Management and Technical Support	10%	10%
Research Associate	50%	50%
Graduate Student (M.S.)	1 @ 100%	1 @ 100%
Secretarial	25%	25%
Data Management	75%	75%
Technical Support	50%	50%

Per Year	Year 1	Year 2	Total
Director - L. Mink (2mm)	$12,137	$12,137	$24,274
Research Associate (12 mm)	25,000	25,000	50,000
Fringe Benefits (24.5%)	9,099	9,099	18,198
Secretarial Support (6 mm)	4,472	4,472	8,944
Fringe Benefits (12.5%)	559	559	1,118
1 Grad Student (6 mm)	10,000	10,000	20,000
Fringe Benefits (12.5%)	1,250	1,250	2,500
Travel (domestic)	10,000	10,000	20,000
Computer	5,000	5,000	10,000
Field supplies	5,000	5,000	10,000
Telephone/postage/xeroxing/supplies	6,017	6,017	12,034
Printing/publishing	7,441	7,441	14,882
Conference support	10,000	10,000	20,000
Subtotal	$105,975	$105,975	$211,950
Indirect Cost 43.6%	44,025	44,025	88,050
Total	$150,000	$150,000	$300,000

Geothermal Reservoir Assessment
Task Performance Schedule

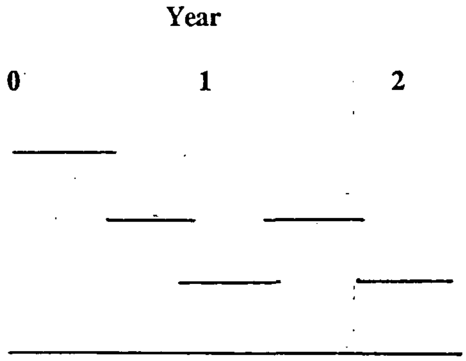
Geothermal Reservoir Assessment

Task	Description
1	Collect hydrothermal data for Idaho Develop Idaho database
2	Assist in systems prioritization Develop systems matrix
3	Develop conceptual models
4	Perform reservoir assessments
5	Outreach and public education



Geothermal Heat Pumps

Task	Description
1	Assist in contract negotiations
2	Review resource inventory
3	Review demographics (w/OIT)
4	Outreach and public education



Geothermal Resources Council TRANSACTIONS, Vol. 17, October 1993

GEOGRAPHICAL VIABILITY OF GROUND WATER GEOTHERMAL HEAT PUMPS IN THE UNITED STATES

Kevin M. Freeman(1)
Leland Roy Mink(2)

(1) University of Idaho, College of Mines and Earth Resources, Moscow ID
(2) Idaho Water Resources Research Institute, Moscow ID

Abstract

Ground-source heat pumps can provide a cost-efficient alternative to standard air-source heat pumps. However, for the earth-coupled and ground water heat pump systems, developmental factors such as ground water availability and installation costs tend to weigh against using these systems. To promote the feasibility of the ground water heat pump, it must be demonstrated to manufactures and consumers that there is a ready and constant supply of economically obtainable ground water in many areas of the United States. A set of four plates, depicting areas of shallow ground water and its average temperature, demonstrates that well over one-half of the United States, particularly the central and southeast, possess the hydrogeologic characteristics necessary to make the ground water heat pump a viable option. Further linking these plates with demographic studies would provide additional value to the economic viability of ground water heat pumps.

Introduction

The Idaho Water Resources Research Institute (IWRRI) at the University of Idaho is currently engaged in a cooperative program with the University of Utah Research Institute (UURI) and the Oregon Institute of Technology (OIT) to develop and promote the use of ground-source, or geothermal heat pumps. At the Idaho Water Resources Research Institute research addressing the feasibility and application of geothermal heat pumps has focused primarily on both the earth-coupled and the ground water heat pump systems. To promote the further use of ground water geothermal heat pumps, IWRRI has produced a set of three plates of the United States, describing potential favorable near-surface ground water supplies which may be used for ground water heat pumps.

Background

Ground-source heat pumps are manufactured in three varieties: the earth-coupled, the groundwater, and the lake-source heat pump. All three operate using the same general process, a fluid is circulated by a heat pump (exchanger) through tubing, where it releases heat or absorbs heat, depending on if the unit is cooling or heating. Earth-coupled heat pumps achieve this goal by pumping the fluid through tubes buried in the ground. Lake-source heat pumps circulate fluid through tubing submerged in a standing body of water. Ground water heat pumps can use ground water pumped directly from an aquifer as their fluid, or they may circulate a fluid through tubing placed within wells drilled into the ground water system. This fluid is then passed through the heat pump where heat is either absorbed from or released to the building or home. If ground water has been extracted and used for fluid it is then returned to the aquifer through an injection well. Today, the two most widely used geothermal heat pump systems are the earth-coupled and ground water systems.

Purpose

According to Dr. Steve Kavanaugh of the University of Alabama, ground-source (geothermal) heat pumps are receiving increasing attention as a higher-efficiency, lower-cost alternative to traditional air-source heat pumps. Of the three types of ground-source heat pumps, the ground water heat pump is less costly to construct than the earth-coupled heat pump, owing to the fact that the earth-coupled type requires burying pipes below ground. However, since ground water conditions necessary for the optimum functioning of a ground water heat pump are not usually obvious to the eye, these are often shunned in favor of a more traditional heating/cooling system. Even when a ground water source does exist, prohibitive economics can be a factor against using ground water heat pumps. One of the more restrictive elements of a ground water heat pump is the initial construction cost of the system. Drilling costs for a ground-source system can vary widely in price, depending on physical conditions at the site, the nature of the subsurface geology, and more importantly the depth of the hole required by the selected system. However, these costs can be offset by utilizing a suitable, pre-existing source. The drill hole depth and static water level are of special concern in developing a ground water heat pump system. One must reach a sustainable source of ground water which provides a reasonable pumping rate. Ground water heat pumps require between 1 to 1.5 gpm per ton of heating or cooling capacity (K. Denbraven, written commun., 1993). In addition, the return temperature from the heat pump must be kept above approximately 37°F to prevent freezing of the water, and at 1 gpm/ton a drop of 15-20°F can be expected across the heat pump from inlet to outlet. The purpose behind these plates is to provide a preliminary assessment of areas in which use of ground water geothermal heat pumps may be feasible.

Methods

The package produced by IWRRI includes four plates and one base map. The four plates consist of: (1) aquifers associated with shallow alluvial valleys (Figure 1), (2) aquifers associated with unconsolidated and semi-consolidated sedimentary deposits (Figure 2), (3) ground water temperatures in wells at depths of 100 to 200 feet (Figure 3), and (4) interpreted shallow ground water regions of the United States (Figure 4). The base map used (not presented in this paper) is the USGS publication, *Physical Divisions of the United States*, by Nevin M. Fenneman (1949), a polyconic projection at a scale of 1:7,000,000. This map was chosen for its excellent depiction of river drainages, as well as its manageable scale.

These plates depict those aquifers which are known to produce water within a relatively shallow depth (within approximately 100 to 200 feet of land surface is the intended range). The alluvial valley plate (Figure 1) depicts those aquifers of thick sand and gravel deposits beneath floodplains and stream terraces associated with existing streams or rivers. The hydrogeologic properties of these types of sediments in combination with the river or stream acting as a constant recharge source, gives the alluvial valley strong potential for providing shallow ground water.

The unconsolidated and semi-consolidated sedimentary deposits (Figure 2) display areas of water-bearing sands and gravels and sandstones of the Cenozoic and Mesozoic ages. These unconsolidated sediments are often found as alluvial valleys, alluvial basins, thick alluvial deposits, glacial deposits, or as interbedded sands and silts. These unconsolidated or semi-consolidated deposits are often found near-surface, and many contain shallow unconfined, or water table aquifers. Further, the hydrogeologic properties of the sands and gravels that form these types of unconsolidated and semi-consolidated sediments allow for sustainable quantities of ground water at relatively shallow depth, assuming there is a dependable source of recharge to the aquifer.

The ground water temperature plate (Figure 3) is included as a general reference to determine the possible ground water temperatures encountered for use in a ground water geothermal heat pump. Although existing ground water temperature may show much greater detail (Hart, 1986) for some areas, and should be referred to if available, this map provides an adequate representation of temperature on a national scale and are designed to be used with the other plates. It should be noted that ground water temperature is higher and more seasonally consistent than ambient air temperature, resulting in more efficient heat transfer. When examining the combination of the alluvial valley plate, the unconsolidated and semi-consolidated sediment plate, and the temperature plate shows the ground water geothermal heat pumps (as well as earth-coupled geothermal heat pumps) may be a viable option for a large portion of the United States.

Interpretation

Combining the ground water potential delineated by the alluvial valley plate and the unconsolidated and semi-consolidated plate (Figure 4), it can be estimated that a large portion of the continental United States has the possibility of producing shallow ground water. Using the 10 ground water regions of Thomas (1952) (Figure 5) as a physiographic classification system, an estimation of the ground water heat pump viability for each region can be made. Along the Atlantic and Gulf Costal Plain, much of this region would be supplied through water from unconsolidated or semi-consolidated aquifers with ground water temperatures ranging from 54 to 72°F. In the Glaciated Central Region, sand and gravel aquifers offer some potential production, but alluvial valley aquifers would provide most of the possible shallow ground water, ranging in temperature from 44 to 58°F. The Glaciated Appalachians, Unglaciated Appalachians, and Unglaciated Central Region show sparse areas of shallow ground water, which appears to be confined to particular river valleys at temperatures from 44 to 70°F. The High Plains show excellent potential for both unconsolidated and semi-consolidated aquifers and alluvial valley aquifers, with ground water temperatures from 54 to 68°F. The Colorado Plateau, as well as the Columbia Lava Plateau, are two regions which both show sparse shallow ground water potential. Finally, although the Western Mountain Ranges and the Alluvial Basins appear to have an inconsistent distribution of shallow ground water sources, most of which are of the unconsolidated and semi-consolidated variety, many of these sources are consistent with the more populated regions of the west. Ground water temperatures in these two regions average between 48 and 74°F.

Recommendations and Conclusions

As stated above, the next step in the feasibility process is to correlate these maps with demographic analysis, in order to determine favorable populated areas for heat pump development. At IWRRI, we feel that this process would best be accomplished through the utilization of a GIS ARC-INFO base, and to incorporate these plates into a GIS system. This task will be conducted in conjunction with activities performed at OIT and IWRRI.

Ground water and earth-coupled heat pumps have the potential to become a highly-efficient, low-cost method of providing heating and cooling to private and commercial interests in the United States. To make this technology available to consumers on a large scale, it first must be demonstrated to the interested parties, utilities, manufactures, and possible manufactures of ground-source heat pumps, that the natural geothermal resource exists on a broad enough scale and that the technology is economically viable and attractive.

REFERENCES USED

Hart, D.P., 1986, *Earth-Coupled Heat Transfer*, National Water Well Association, Dublin, Ohio.

Heath, R.C., 1983, *Ground water Regions of the United States:* U.S. Geological Survey Water-Supply Paper 2242, 76p.

Kavanaugh, S. *Ground-Coupling With Water Source Heat Pumps*. The University of Alabama, Tuscaloosa, Alabama.

Thomas, H.E., 1952, *Ground water regions of the United States - their storage facilities* in The physical and economic foundation of natural resources: U.S. 83d Congress House Committee on Interior and Insular Affairs, Washington D.C., v. 3, p.3-78.

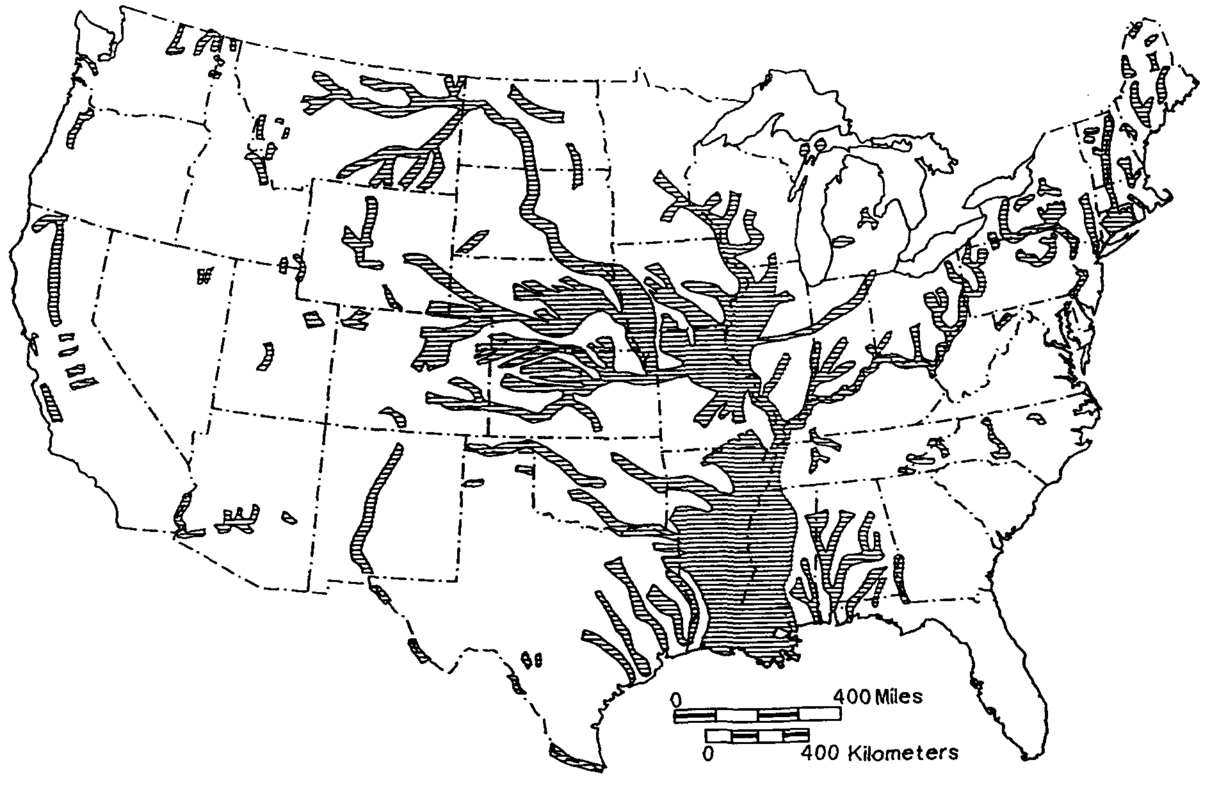


Figure 1. Shallow aquifers associated with alluvial valleys. (Modified from Heath, 1984.)

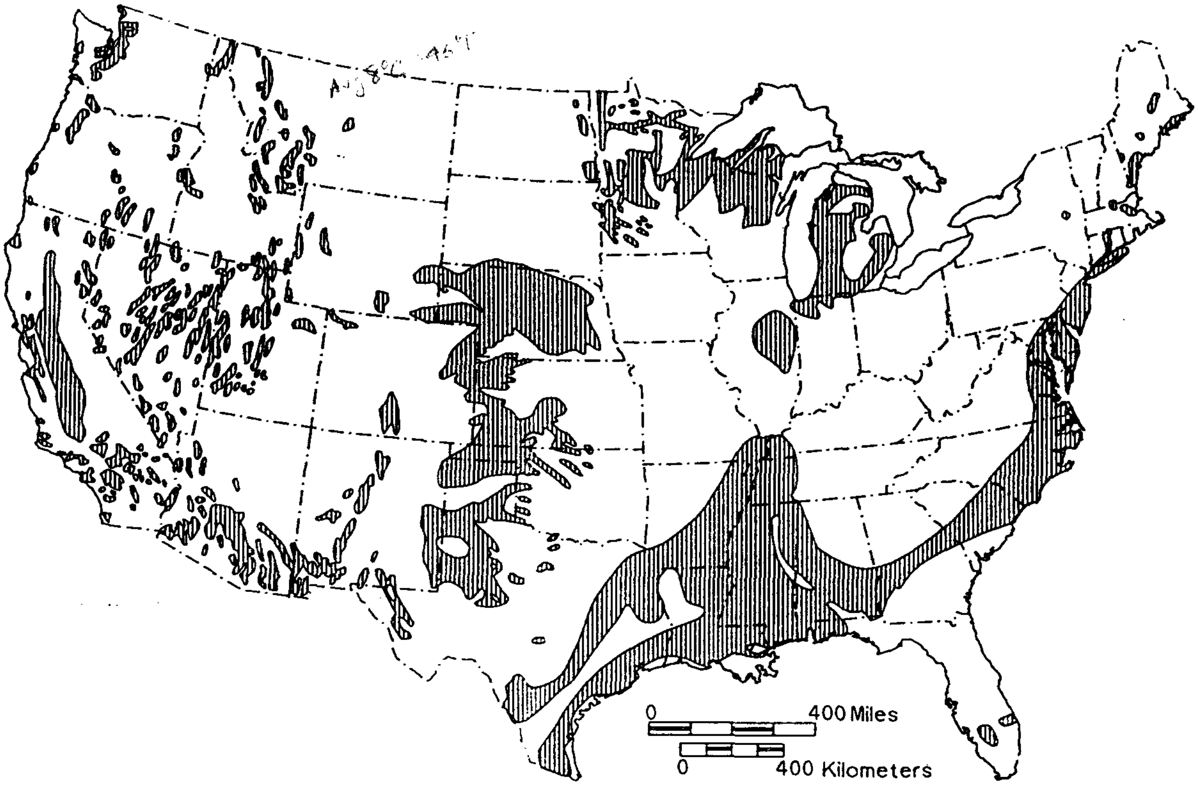


Figure 2. Unconsolidated and semi-consolidated sedimentary deposits of the United States. (Modified from Heath, 1984.)

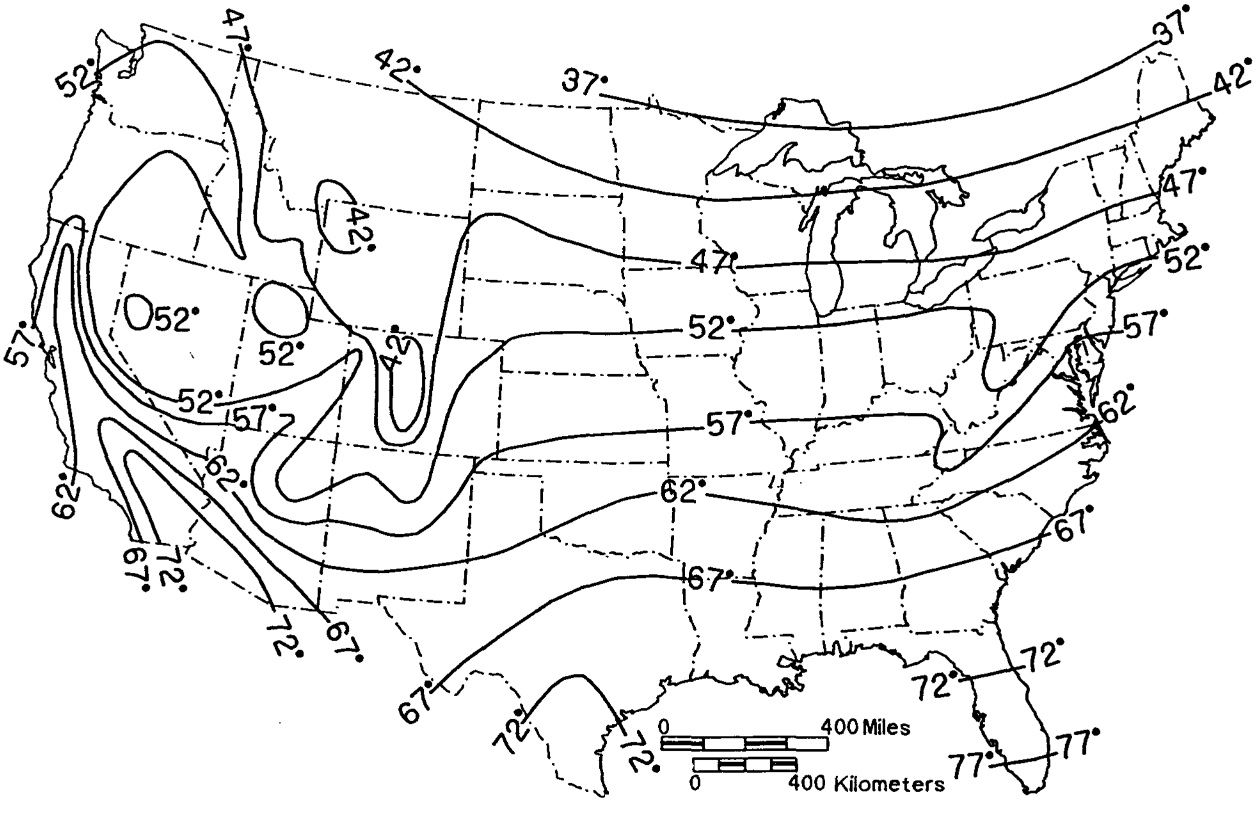


Figure 3. Ground water temperatures from depths of 50 ft to 150 ft. (Modified from Hart, 1986.)

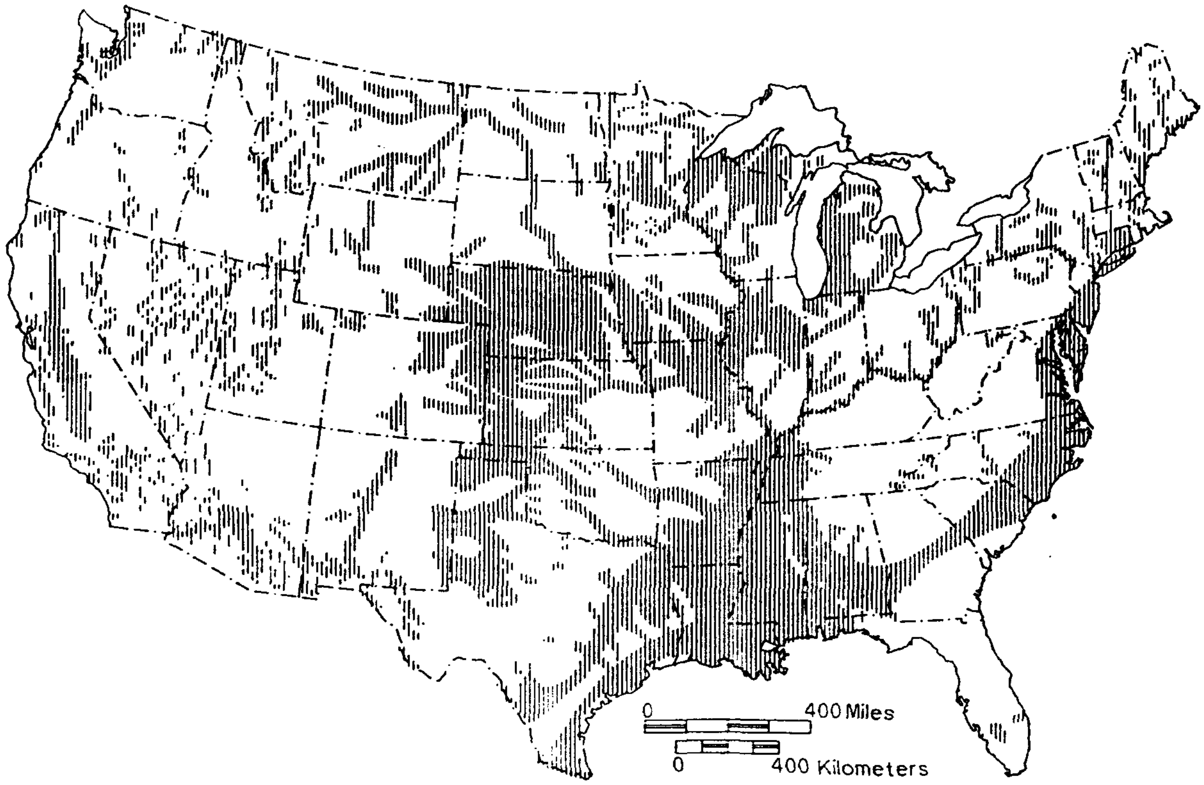


Figure 4. Inferred shallow (100 ft to 200 ft) ground water areas of the United States.

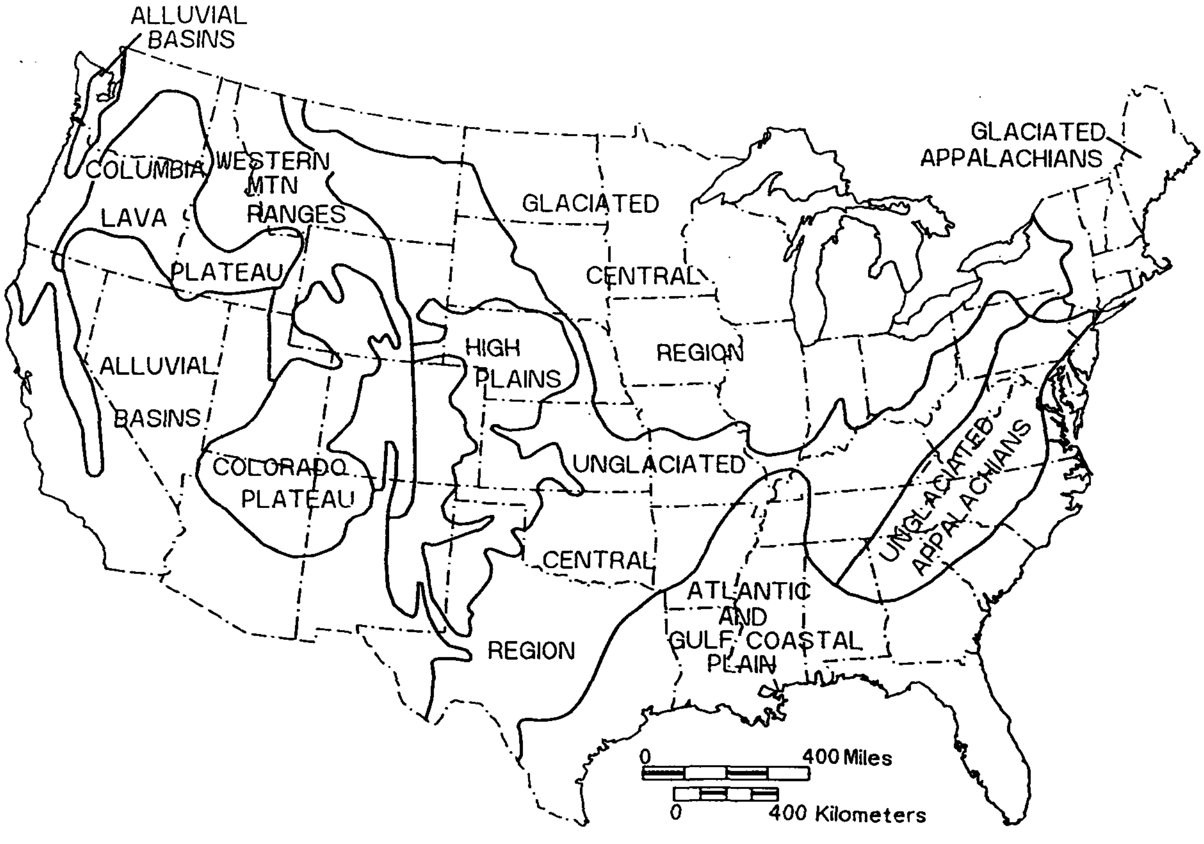


Figure 5. Ground water regions of the United States. (From Thomas, 1952, figure 1.)

IDAHO WATER RESOURCES RESEARCH INSTITUTE

Leland L. Mink
Director
Morrill Hall 106
University of Idaho
Moscow, Idaho
83844-3011

Phone: (208) 885-6429
FAX: (208) 885-6431

February 21, 1995

Mr. Joel Renner, Geothermal Program Manager
Lockheed Idaho Technologies Company
765 Lindsay Blvd.
Idaho Falls, ID 83415

Dear Joel:

Enclosed is the final report for the goethermal assessment for Idaho. The report consists of four items:

1. The report text "Overview of Geothermal Investigations in Idaho, 1980 to 1993" in hard copy.

2. Geothermal database in DBASE III Plus, on diskette, file GEOTHERM.dbf.

3. "Bibliography of Idaho Geothermal Resources" in WordPerfect for Windows 5.2, also on diskette, file GEOTHERM.bib.

4. "Geothermal Resources of Idaho" map at a scale of 1:1,000,000, in pocket of report.

The diskette is in an envelope attached to the map pocket of the report. I am sending separately additional unfolded copies of the map for your use. Please let me know if I can be of further assistance.

According to our contract all obligations have now been met. Please contact me if your records do not agree.

Sincerely,

John Kauffman

John Kauffman

Enclosures

xc: Roy Mink
Howard Ross, UURI
Paul Lienau/Gene Culver, OIT
Marshall Reed, DOE
Paul Castelin/Ken Neely, IDWR

UNIVERSITY OF UTAH RESEARCH INSTITUTE
UURI
391 CHIPETA WAY, SUITE C
SALT LAKE CITY, UTAH 84108-1295
TELEPHONE 801-524-3422

March 11, 1994

Leland Roy Mink
Director
Idaho Water Resources Research Institute
Morrill Hall, Rm. 106
University of Idaho
Moscow, Idaho 83843

Dear Roy:

Enclosed are 50 copies of the Low-Temperature and GHP fact sheet, and two copies of the completed Colorado Low-Temperature Resources Map. The map can be used as one example of the State Teams' deliverables which are available to developers and the general public. We had 1,000 copies of the fact sheet printed, so use these freely and let me know when you need more.

I was pleased to hear that you trip to Washington went so well. I am sorry that the fact sheet was not available at the time. Mike Wright will be out most of the week of March 14, but I asked him to call you to coordinate scheduling.

Sincerely,

Howard

Howard Ross
Section Head/Applied Geophysics

encl.

Hi Roy:

I have been making inquiries about the availability of spinner flowmeters for borehole logging tools. There seem to be several options for size and type of tool, temperature limits, electronics and cable compatibility, and of course, cost. At this point I had best forward the information I have to you so you can follow up with more detailed discussions. Here is the information from the more useful phone calls.

Century Geophysical Corp. tel. (918) 838-9811
* Jack Freeman (?)
7517 East Pine
Tulsa, Oklahoma 74115

Century is mainly a logging service, with U.S. operations offices in Elko, and Las Vegas, NV and in Tulsa. They will also sell instruments.

Specs. for their 9710 logging tool are attached. Note the temperature limitation of 75 degrees C. They indicated that they may be able to modify the tool for higher temperature, but would have to look into this. Century has a FAX-Back information service- index and instructions are attached.

Mt. Sopris Instrument Co. tel. (303) 279-3211
17301 W. Colfax, Ste. 255
Golden, CO 80401

* James Koerlin, Engineering Manager.

Mt. Sopris also makes a spinner flowmeter, but the standard instrument has a 65 degree C temperature limit. They may also be willing to look into the cost, etc. for a somewhat higher temperature tool. They said they would FAX more info but it hasn't arived here yet.

Hot Hole Instruments tel. (505) 672-3000
* Larry Handy
Los Alamos, NM

Hot Hole Instruments have taken tool developments made under the DOE Geothermal Program (at Sandia or Los Alamos?) and have developed their own high-temperature (to 600 C) tool. Their PATS (pressure, temperature, spinner) tool sounds like a Cadillac - high sensitivity, high temperature, electronics for standard log-type printouts, etc. They need to know the details of your requirements for a logging tool. They may also market, or use, the Pruitt flowmeter tools, which are also used in geothermal holes.

Gerald Nimi, Thermasource, Santa Rosa, CA tel. (707) 523-2960 is a consulting reservoir engineer who seems to know alot about geothermal flowmeter tools and services. He may be of some help.

ESRI

Earth Sciences and Resources Institute
(Formerly UURI)
391 Chipeta Way, Suite C
Salt Lake City, UT 84108-1295
USA

Phone: 801-584-4422 FAX: 801-584-4453

Facsimile (FAX) Cover Page

From: HOWARD ROSS

Date: Sept. 1, 1995

To: LELAND ROY MINK, Director
IDAHO WATER RESOURCES RESEARCH INST.

FAX: (208) 885-6431

Number of pages including this one: 7

Message or Comments:

Hi Roy:

Attached is some info, which is all I know, about who sells / uses borehole flowmeters. I recommed that you talk to Larry Handy of Hot Hole Instuments to get more information.

Good to see you last week, Roy. Thanks for the great trip on the Snake River.

Regards,
Howard

Hi Roy:

I have been making inquiries about the availability of spinner flowmeters for borehole logging tools. There seem to be several options for size and type of tool, temperature limits, electronics and cable compatibility, and of course, cost. At this point I had best forward the information I have to you so you can follow up with more detailed discussions. Here is the information from the more useful phone calls.

Century Geophysical Corp. tel. (918) 838-9811
* Jack Freeman (?)
7517 East Pine
Tulsa, Oklahoma 74115

Century is mainly a logging service, with U.S. operations offices in Elko, and Las Vegas, NV and in Tulsa. They will also sell instruments.

Specs. for their 9710 logging tool are attached. Note the temperature limitation of 75 degrees C. They indicated that they may be able to modify the tool for higher temperature, but would have to look into this. Century has a FAX-Back information service- index and instructions are attached.

Mt. Sopris Instrument Co. tel. (303) 279-3211
17301 W. Colfax, Ste. 255
Golden, CO 80401

* James Koerlin, Engineering Manager.

Mt. Sopris also makes a spinner flowmeter, but the standard instrument has a 65 degree C temperature limit. They may also be willing to look into the cost, etc. for a somewhat higher temperature tool. They said they would FAX more info but it hasn't arived here yet.

Hot Hole Instruments tel. (505) 672-3000
* Larry Handy
Los Alamos, NM

Hot Hole Instruments have taken tool developments made under the DOE Geothermal Program (at Sandia or Los Alamos?) and have developed their own high-temperature (to 600 C) tool. Their PATS (pressure, temperature, spinner) tool sounds like a Cadillac - high sensitivity, high temperature, electronics for standard log-type printouts, etc. They need to know the details of your requirements for a logging tool. They may also market, or use, the Pruitt flowmeter tools, which are also used in geothermal holes.

Gerald Nimi, Thermasource, Santa Rosa, CA tel. (707) 523-2960 is a consulting reservoir engineer who seems to know alot about geothermal flowmeter tools and services. He may be of some help.

HRRoss

Century
GEOPHYSICAL CORP.

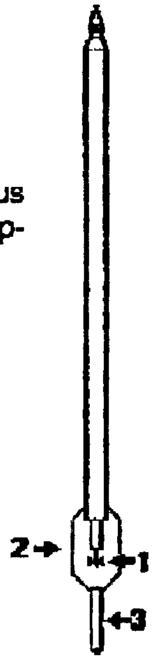
9710 Logging Tool

Measurements:

Flow
Delta Flow

Applications:

Oilless operation; High Resolution
Used primarily in determining locations of fluid flow through the annulus and formation. By logging in the up and downward directions, assumptions of both the amount and direction of flow may be made.



Specifications:

Length:	70 inches *(177.8 cm)*
Diameter:	Standard Cage 4.5 inches *(11.4 cm)* (Small cage optional)
Weight:	18 pounds *(8 kg)*
Temperature:	167 degrees F *(75 degrees C)*
Pressure:	2500 psi *(175.7 kg/cm2)*
Logging Speed:	2 - 60 fpm *(.15 - 18 meters/minute)*

Features:

1. Flow propeller
2. Propeller guard cage
3. Lower end weight, 5 lbs. *(2.3 kg)*

7517 EAST PINE • TULSA, OKLAHOMA 74115 USA • (918) 838-9811 • FAX (918) 838-1532

[illegible]-BACK SERVICE

These documents were sent using Century Geophysical's FAX-BACK system. You may access this system 24 hours per day, 7 days per week. Once you call this number, you may retrieve other technical or promotional information at your convenience.

If you do not have the Fax Document Index, your first call to the system should be to retrieve this document. The Fax Index lists all available documents, and their corresponding three digit code. THE THREE DIGIT CODE FOR THE INDEX IS 101.

How to use the system:

1. Call 918-838-0652 using your FAX MACHINE to place the call.
2. At the main greeting message, press 2.
3. Enter appropriate three digit code to select the desired document.
4. If you desire to retrieve additional documents, you may enter their corresponding three digit code when prompted. Up to three documents may be selected during one call session.
5. Follow the additional instructions, and the document(s) will be sent to you immediately during the same call.

Please note that the FAX-BACK service is periodically being updated with new documents. The last update was:

July 5, 1995

Please check the date on your Fax Index to see if you have the most current version available. We recommend that you keep a copy of the Fax Index for future reference.

BULLETIN BOARD

Please also note that Century has a computer bulletin board. The number is 918-838-0649. The BBS is running at 14,400 baud, and you may access the BBS using at least a 2400 baud modem.

The BBS system contains up-to-date software, bug fixes, and other useful digital files.

The most current software is:

ACL Version 1.24
PCL Version 8.34
Compu-Dip Version 1.10

If you are a registered owner of any of the above software, check your version number. If your number is not the same, you should download the most current version.

You may also use the BBS system to upload data files to us. The allows you to send questionable log data files, or other files to us so that we can take a look at them.

Century strives to provide the best available service to our customers, representatives, and employees. We look forward to your comments and suggestions.

Century Geophysical Corporation

Fax-Back Service

FAX Document Index

5-Jul-95 last update

Using Century's Fax-Back Service is simple and fast!

1) ***You must use your fax machine to place your call.***
2) **Call 918-838-0652.**
3) **At the main greeting message - press 2.**
4) **Enter the three digit code for the desired document.**
5) **Follow the instructions, and your document will be sent to your fax machine during your call. Up to three documents may be selected during one call.**

Description	Code	Pages	Last Update
1000 Meter ILS Drawworks Description Sheet	185	1	16-May-95
300 Meter ILS Drawworks Description Sheet	192	2	31-May-95
9033 Standard Operating Procedures	300	5	9-Jan-95
9033 Tool Description Sheet	202	1	5-Jan-95
9035 Standard Operating Procedures	301	4	9-Jan-95
9035 Tool Description Sheet	204	1	5-Jan-95
9036 Standard Operating Procedures	302	4	9-Jan-95
9036 Tool Description Sheet	206	1	5-Jan-95
9041 Standard Operating Procedures	303	4	9-Jan-95
9041 Tool Description Sheet	208	1	5-Jan-95
9042 Standard Operating Procedures	304	3	9-Jan-95
9042 Tool Description Sheet	210	1	5-Jan-95
9045 Tool Description Sheet	212	1	5-Jan-95
9050 Tool Description Sheet	141	1	10-Feb-95
9051 Standard Operating Procedures	305	4	9-Jan-95
9055 Standard Operating Procedures	306	5	9-Jan-95
9055 Tool Description Sheet	214	1	5-Jan-95
9060 Standard Operating Procedures	307	4	9-Jan-95
9060 Tool Description Sheet	216	1	5-Jan-95
9065 Standard Operating Procedures	308	3	9-Jan-95
9065 Tool Description Sheet	218	1	5-Jan-95
9067 Standard Operating Procedures	309	5	9-Jan-95
9067 Tool Description Sheet	220	1	5-Jan-95
9068 Standard Operating Procedures	310	4	9-Jan-95
9068 Tool Description Sheet	222	1	5-Jan-95
9071 Tool Description Sheet	224	1	5-Jan-95
9072 Standard Operating Procedures	311	4	9-Jan-95
9072 Tool Description Sheet	226	1	5-Jan-95
9080 Standard Operating Procedures	143	7	10-Feb-95
9080 Tool Description Sheet	142	1	10-Feb-95
9085 Tool Description Sheet	228	1	5-Jan-95

	9095 - Field Application Report	130	11	24-Jan-95
	9095 Standard Operating Procedures	312	8	9-Jan-95
	9095 Tool Description Sheet	132	1	24-Jan-95
	9310 Standard Operating Procedures	313	6	9-Jan-95
	9310 Tool Description Sheet	230	1	10-Feb-95
	9400 Standard Operating Procedures	314	5	9-Jan-95
	9410 Standard Operating Procedures	315	8	9-Jan-95
	9410 Tool Description Sheet	232	1	5-Jan-95
	9510 / 9511 Standard Operating Procedures	317	10	9-Jan-95
→	9511 Tool Description Sheet	133	1	24-Jan-95
	9520 Standard Operating Procedures	318	5	9-Jan-95
	9620 Standard Operating Procedures	319	5	9-Jan-95
	9620 Tool Description Sheet	236	1	5-Jan-95
	9710 Standard Operating Procedures	320	5	9-Jan-95
	9710 Tool Description Sheet	238	1	5-Jan-95
	9750 Tool Description Sheet	240	1	5-Jan-95
	Acoustic Televiewer Tool Description Sheet	186	1	16-May-95
	Bearing Replacement, 9710 Flow Probe	193	2	16-Jun-95
	Brochure, ACL	117	4	12-Jan-95
	Brochure, Century General Information	120	4	5-Jan-95
	Brochure, Compu-Log System	121	4	9-Jan-95
	Brochure, Compu-View	131	4	24-Jan-95
	Cable Resistance/Temperature Change Chart	110	1	10-Jan-95
	Cablehead Illustration and Parts List	108	1	10-Jan-95
	Cableheading Instructions - Hytrel Cable	146	5	10-Feb-95
	Cableheading Instructions - Steel Cable	145	10	10-Feb-95
	Calibration Basics, Century Probes	191	15	16-May-95
	COMPU-LOG Desktop Description Sheet	170	1	17-Apr-95
	COMPU-LOG II Training Notes	165	6	17-Apr-95
	COMPU-LOG Ultra Lite Description Sheet	171	1	17-Apr-95
	Demo Logs	400	5	5-Jan-95
	Depth Encoder Testing Procedures	166	1	17-Apr-95
	DHPS to Ultralite cable schematic (29017C)	113	1	11-Jan-95
	Dipmeter Quality Control Report	316	11	9-Jan-95
	Drawworks Bypass Cable Schematic (27050A)	118	1	17-Apr-95
	Drawworks Bypass Cable Schematic, ILS (33428)	172	1	17-Apr-95
	Drawworks Bypass Cable Schematic, Ultra Lite (31014)	175	1	17-Apr-95
	Drawworks Interconnect Cable Schematic (29553F)	119	1	13-Jan-95
	Drawworks Interconnect Cable Schematic, F-250 (29016B)	176	1	17-Apr-95
	Drawworks Interconnect Cable Schematic, ILS (33429)	173	1	17-Apr-95
	Drawworks Interconnect Cable Schematic, ILS w/strain (33430)	174	1	17-Apr-95
	Drawworks Interconnect Cable Schematic, UL to ILS (32514)	181	1	21-Apr-95
	Flyer, Visual Compu-Log	122	1	5-Jan-95
	Geophysical Tools, Selected List	200	4	17-Apr-95
	Index	101	4	5-Jul-95
	Instructions - Return of equipment (International only)	169	1	17-Apr-95
	Instructions - Using FAX-BACK with computer fax board	125	1	18-Jan-95
	Instructions for Letter of Credit	105	1	5-Jan-95
	Manual, ACL (PART 1)	177	10	17-Apr-95
	Manual, ACL (PART 2)	178	10	17-Apr-95
	Manual, ACL (PART 3)	179	9	17-Apr-95
	Manual, ACL Update, Reranging a curve	184	1	21-Apr-95
	Manual, Compu-Dip	112	14	11-Jan-95

	Manual, Ultra-Lite Operation (PART 1)	126	9	20-Jan-95
	Manual, Ultra-Lite Operation (PART 2)	127	7	20-Jan-95
	Manual, Ultra-Lite Operation (PART 3)	128	9	20-Jan-95
	Map to Tulsa Office	129	1	24-Jan-95
	MPTC (C-25) Tool Card Diagnostics	149	5	10-Feb-95
	MPTC (C-25) Tool Card, Diagram (PCB)	198	1	16-Jun-95
	MPTC (C-25) Tool Card, setup procedures	168	1	17-Apr-95
	Price Schedule Quick Compute, Retail	180	1	6-Jun-95
	Problem Identification Form (PIF)	183	1	21-Apr-95
	Rental Price Schedule Quick Compute, Rental	182	1	6-Jun-95
	Rental Terms & Conditions Contract, (Domestic)	106	2	17-Apr-95
	Repair Authorization Form, 1000 meter Drawworks	163	3	16-May-95
	Repair Authorization Form, 150 meter Drawworks	162	3	16-May-95
	Repair Authorization Form, 300 Meter ILS Drawworks	187	3	16-May-95
	Repair Authorization Form, 9030/33 Probe	154	3	16-May-95
	Repair Authorization Form, 9041 Probe	150	3	16-May-95
	Repair Authorization Form, 9042 Probe	151	3	16-May-95
	Repair Authorization Form, 9050 Probe	155	3	16-May-95
	Repair Authorization Form, 9055 Probe	156	3	16-Jun-95
	Repair Authorization Form, 9060 Probe	157	3	16-May-95
	Repair Authorization Form, 9065 Probe	152	3	16-May-95
	Repair Authorization Form, 9067 Probe	190	3	16-May-95
	Repair Authorization Form, 9069 Probe	189	3	16-May-95
	Repair Authorization Form, 9400 Probe	195	3	16-Jun-95
	Repair Authorization Form, 9410 Probe	194	3	16-Jun-95
	Repair Authorization Form, 9510/9511 Probe	153	3	16-May-95
	Repair Authorization Form, 9620 Probe	196	3	16-Jun-95
	Repair Authorization Form, 99095 Probe	197	3	16-Jun-95
	Repair Authorization Form, COMPU-LOG II	161	3	16-May-95
	Repair Authorization Form, COMPU-LOG III/IV	160	3	16-May-95
	Repair Authorization Form, COMPU-LOG Ultra Lite	158	3	16-May-95
	Repair Authorization Form, COMPU-LOG Ultra Lite-2	159	3	16-May-95
	Repair Authorization Form, Generic	107	3	16-May-95
	Repair Authorization Form, RDHPS	164	3	16-May-95
	Repair Authorization Form, S-2000 Pickup Logging Unit	188	3	16-May-95
	S-2000 Hour meter replacement instructions	123	1	13-Jan-95
	S-2000 Hydraulic Flow Schematic	114	1	11-Jan-95
	S-2000 Strain Bolt Wiring Schematic	116	1	11-Jan-95
	S-2000 Wiring Diagrams	115	3	11-Jan-95
	Sales Terms and Conditions	102	2	5-Jan-95
	Service Terms and Conditions	103	2	5-Jan-95
	Software License and Warranty	104	1	5-Jan-95
	Tech Note - Flowmeter analysis in cased and open wells	137	2	24-Jan-95
	Tech Note - Full-wave acoustic report	147	11	10-Feb-95
	Tech Note - Geophysical logging of monitor wells	138	2	24-Jan-95
	Tech Note - Graphical applications for log analysis	135	2	24-Jan-95
	Tech Note - Logging parameters for coal exploration	140	2	24-Jan-95
	Tech Note - True depth and thickness using logs	139	2	24-Jan-95
	Tech Note - Using logs to determine well integrity	134	8	24-Jan-95
	Tech Note - Using logs to evaluate cased monitor wells	136	2	24-Jan-95
	Test Pits, Maps to sites	111	4	11-Jan-95
	TR 174 - Spectral Gamma Ray Logging	144	12	10-Feb-95
	Troubleshooting Tips (Version 1)	124	4	13-Jan-95

	Uranium Logging, Calibration, K-Factor, Deadtime	199	3	16-Jun-95
	Wire Wrap Tool Card Fuse Location	109	1	10-Jan-95
	Wire Wrapped Tool Card, setup procedures	167	1	17-Apr-95

TO: Howard Ross, UURI

FROM: Bill Dansart, IWWRI

SUBJECT: Idaho Geothermal Database Compilation Status

DATE: April 22, 1993

The Idaho Water Resources Research Institute (IWRRI) is compiling available geothermal resource data generated for the state of Idaho. Results of the compilation focus on data generated since the last published state assessment (Mitchell, Johnson, and Anderson, 1980). Sources of information include state and federal agencies, organizations under contract to the Department of Energy, and individual authors. The report outlines the characteristics, occurences, and uses of thermal waters in the state of Idaho documented by resource investigations conducted since 1980. Copies of the report, with data set on computer disk will be available through the Idaho Water Resources Research Institute; an Idaho geothermal bibliography (about 700 references) will also be available in hardcopy or disk format.

In addition to well data from other reports, the (IWRRI) report includes data from over 200 water wells, up to 3030 feet in depth, drilled in Idaho from 1980 to 1992, for which drillers logs have been filed with the Idaho Department of Water Resources (IDWR). Temperatures in these wells range from 70^0 F to 180^0F. Approximately 50% of these wells were drilled for geothermal applications(municipal and domestic heating, greenhouses, fish farming, bathing resort facilities) . Geographically most drilling has occurred in Twin Falls(62), Boise(39), Owyhee (37), and Ada (20) counties; approximately 80% of warm-water wells drilled in Idaho are located in these four counties.

Water Information Bulletin No. 30, part 9 (Mitchell, Johnson, and Anderson, 1980) is a compilation of Idaho geothermal resource data available at the time. The publication contains information on the properties, characteristics, and origins of 899 thermal water occurrences with surface temperatures of 20^0 C or higher within the state. Included with this study was a statewide geothermal resource map (NOAA, 1980). The report lists chemical analyses of 357 sites. Previous published reports on statewide geothermal potential included: Stearns and others (1937); Waring (1965); Ross (1971); Nichols and others, (1972); Warner (1972) and (1975); Young and Mitchell (1973).

Since publication of Water Information Bulletin No. 30, part 9, in excess of 350 papers have been written addressing Idaho geothermal resources. This information has been reviewed and summary findings of these investigations will be presented according to geographical area; point data from these reports is presently being tabulated. Several significant geothermal investigations conducted since the IDWR state compilation are listed below.

Geothermal studies since 1980

A compilation of data from Idaho thermal water sample analyses (1,319) performed at USGS laboratories between 1921 and 1991, Open-File Report 92-175 (Parliman and Young, 1992), has recently been released.

Blackwell and others (1992) heat flow modelling of the Snake River Plain presents previously unpublished geothermal data collected after 1980 from 68 wells of which 42 holes were drilled for the expressed purpose of geothermal evaluation. In addition, geothermal evaluation of 31 hydrocarbon test wells is included. A bottom-hole temperature of 197°C is reported at a depth of 5.7 km in a well in Clark County, near the Idaho-Montana border.

Other regional studies include : Smith (1980), Snake River Plain; Lewis and Young (1980), Payette River Basin; Lewis and Young (1982), Boise River Basin; Young and Lewis (1982), Salmon River Basin; Young (1985), Idaho Batholith; Batdorf and others(1980), SE Idaho; Ralston and others (1981), SE Idaho; Souder (1985), SE Idaho; Young and Lewis (1982), SW Idaho; McClain (1980), SW Idaho.

Environmental assessments of seven Snake River Plain Known Geothermal Resource Areas (KGRA's) were conducted by EG&G, Idaho (Spencer, Russell, and Sullivan, editors, 1979). Areas evaluated are: Vulcan Hot Springs, Crane Creek, Castle Creek, Bruneau, Mountain Home, Raft River, and Island Park/Yellowstone.

Other reports are of more local coverage. A few examples are listed by county.

Ada County

The city of Boise has been utilizing geothermal resources since the 1890's for heat and hot water. The first commercial use of water was a small domestic heating system,supplied by two 400-foot wells drilled in 1890; this venture eventually became the Boise Warm Springs Hot Water district. Use of geothermal heat began to decline in the 1930's, when low cost gas and electricity became available. Major expansion of Boise's geothermal resource use began with successful retrofit of the State Health Laboratory , as a pilot project, in 1977. In 1980, the State of Idaho drilled two wells to service the Capitol Mall heating system. The 160° F water heats 800,000 square feet of office space (Austin, 1984), flowing at a maximum rate of 800 gpm during peak heating system (Berkley Group, 1990). In 1981, Boise Geothermal , a agency created to coordinate activities between the City of Boise and the Boise Warm Springs Water District, drilled three production wells to service a 4.5 mile heat distribution system through downtown Boise. The Boise City District Heating sytem became operational in 1983, and is capable of delivering 4000 gpm or 2.2 million therms to the heating system (Mickelson, 1985).

An extensive review of data and evaluation of the Boise Geothermal Aquifer was conducted by the Berkely Group (1990). The report concluded that geothermal production wells along the Boise Front Fault communicate readily; interference occurs between production wells and effects water levels along the fault in general.

Boise County

Several greenhouses, resort facilities, and numerous homes use geothermal resources to provide hot water and space heating needs in Boise County, particularly in the Garden Valley -Crouch area. Logs were filed with the Idaho Department of Water Resources for 39 warm water wells for the period 1980 to 1992. Water temperatures recorded ranged from 79° to 184° F; 24 of the wells showed temperatures greater than 130°F.

Lewis and Young (1980) characterized 31 thermal springs in the Payette River basin. Water temperatures ranged from 34° to 86° C, with estimated reservoir temperatures of 53° to 143° C.

Six hot spring areas along the South Fork of the Payette River were examined in detail by two Washington State University graduate students, Reed (1986) and Dingee (1987). Geothermometers give estimated reservoir temperatures of 68^0 to 150^0 C. Reservoir volume and temperature appear sufficient to support localized direct-use applications.

Cassia County

The Raft River Geothermal site in southern Idaho has been the subject of more evaluation than any other area in Idaho. Work on the Raft River Geothermal project began in 1973 with startup of a 5MW(e) pilot geothermal plant in the fall of 1981; final shutdown occurred during June, 1982 (Bliem, 1983). The plant , built by the Idaho National Engineering Laboratory, successfully demonstrated the technical feasibility of using a moderate temperature (275 to 300^0F) to generate electrical power in an environmentally acceptable manner. The plant used a dual-boiling binary cycle with isobutane as the working fluid. Seven deep geothermal wells were drilled to support the project (five production, two injection) in addition to several geothermal gradient and monitor holes. A vast amount of knowledge was obtained on the characteristics of a fracture-controlled geothermal system with respect to production and injection. Successful non-electric experiments included agriculture, aquaculture, biomass production, wetland studies, and space conditioning (Mink, 1982). Reports generated are too numerous to list.

Elmore County

A 4403-foot test hole was drilled by the Air Force on the Mountain Home Air Force Base for geothermal exploration. The purpose was to determine the availability of water from geothermal aquifers to supply energy for space heating of military housing and other base facilities. Maximum temperature recorded during temperature logging was 93^0 C (Lewis and Stone, 1988).

Evaluation of an area near Mountain Home as a hot dry rock prospect was performed by Arney, Beyer, Simon, Tonani,and Weiss (1980). A favorable target was identified. Temperatures of 200^0C were projected at 3 km depth, with granitic rocks to be intersected 2 to 3 km deep.

Idaho County

Kuhns (1980) outlined the structural and chemical aspects of the Lochsa geothermal system near the northern margin of the Idaho Batholith. Maximum source temperatures of 170^0 to 200^0 C were predicted by geothermometers; heat flow data suggested a geothermal gradient of 50^0 C/km with circulation depth estimated at 3 to 4 km.. Kuhns suggested a potential geothermal reservoir 300 to 400 cubic kilometers in size exists along the Lochsa River.

Lemhi County

An evaluation of Big Springs Hot Springs as a source of electrical power for the Blackbird Cobalt Mine was conducted (Struhsacker, 1981). Big Creek Hot Springs is one of the hottest known geothermal systems in Idaho, with a surface temperature of 93^0 C (199^0F). Geothermometer estimates of reservoir temperature range from 137^0C (279^0F) to 179^0 C (354^0 F). It was concluded that Big Creek Hot Springs is an excellent geothermal prospect; a suggested exploration program, engineering and economic analyses, and appraisal of institutional factors was outlined.

UNIVERSITY OF UTAH RESEARCH INSTITUTE
UURI
391 CHIPETA WAY, SUITE C
SALT LAKE CITY, UTAH 84108-1295
TELEPHONE 801-524-3422

November 25, 1992

Bill Dansart
Idaho Water Resources Research Institute
106 Morrill Hall
University of Idaho
Moscow, ID 83843

Dear Bill:

Enclosed are five of the UURI reports dealing with Idaho geothermal resources requested in your FAX of November 5. A variety of activities and problems have delayed our response to your request - I apologize for the delay. We will have to hunt up and copy the remaining publications as time permits.

Also enclosed is a copy of a paper regarding evaluation of geothermal water samples which you may find of interest. We are asking the state teams to include a charge balance column in their data tabulations.

Regards,

Howard

Howard Ross
Project Manager

HR/mt
Enclosures

NTIS® Alert

Customized for
UNIV OF UTAH RESEARCH INST
EARTH SCIENCE LAB SUITE C
391 CHIPETA WAY
SALT LAKE CITY, UT 84108

October 15, 1992
Volume 92, Number 26
ORDERING INFORMATION ON BACK COVER

ENERGY: Geothermal Energy

Aquifer test at Comore Loma No. 4, Idaho Falls, Idaho

J. M. Hubbell.

EG and G Idaho, Inc., Idaho Falls. Dec 91, 35p, EGG-GEO-9987. Sponsored by Department of Energy, Washington, DC.

Order number **DE92011699WAL** Price code: PC A03/MF A01

An aquifer test was conducted at Comore Loma Well (number sign)4 to determine the aquifer hydraulic characteristics at this location on July 11 and 12, 1991. Water was withdrawn from Comore Loma Well (number sign)4 at approximately 850 gallons per minute for 8 hours while monitoring the water level in the plumping well and an observation well 930 ft away. The pumped well showed over 12 ft of drawdown with no discernable drawdown in the observation well. The drawdown in the pumped well was nearly instantaneous, showing little additional drawdown after 1 minute. The transmissivity was calculated to be approximately 140,000 ft(sup 2)/day using the Jacob solution. This gives a hydraulic conductivity of 1300 ft/day for the 110 ft interval tested. The high transmissivity and geologic setting suggest the aquifer may in part produce water from the Snake River Plain aquifer. However, the warm water temperature (71(degrees)F) indicates the presence of a geothermal source typical of the foothills aquifer. The storage coefficient could not be calculated since no water level decline was detected in the observation well.

—Proceedings, Symposia, Etc.—

HDR opportunities and challenges beyond the long-term flow test

D. V. Duchane.

Los Alamos National Lab., NM. 1992, 8p, LA-UR-92-978, CONF-920378-1. Geothermal energy program review: geothermal energy and the utility market--the opportunities and challenges for expanding geothermal energy in a competitive supply market, San Francisco, CA (United States), 24-26 Mar 1992. Sponsored by Department of Energy, Washington, DC.

Order number **DE92011234WAL** Price code: PC A02/MF A01

The long term flow test (LTFT) of the world's largest, deepest, and hottest hot dry rock (HDR) reservoir currently underway at Fenton Hill, NM, is expected to demonstrate that thermal energy can be mined from hot rock within the earth on a sustainable basis with minimal water consumption. This test will simulate the operations of a commercial facility in some ways, but it will not show that energy from HDR can be produced at a variety of locations with different geological settings. Since the Fenton Hill system was designed as a research facility rather than strictly for production purposes, it will also not demonstrate economic viability, although it may well give indications of system modifications needed for economic HDR operations. A second production site must be constructed, ideally under the direction of the private geothermal community, to begin the process of proving that the vast HDR resources can be accessed on a worldwide scale. Finally, research and development work in areas such as reservoir interrogation, and system modeling must be accelerated to increase the competitiveness and geographical applications of HDR and the geothermal industry in general. This paper addresses the above issues in detail and outlines possible paths to future prosperity for the commercial geothermal industry.

Tensor controlled-source audiomagnetotelluric survey over the Sulphur Springs thermal area, Valles Caldera. Annual report

P. E. Wannamaker.

Utah Univ. Research Inst., Salt Lake City. Earth Science Lab. Oct 91, 36p, DOE/ER/14083-1, ESL-91023-TR. Sponsored by Department of Energy, Washington, DC.

Order number **DE92010950WAL** Price code: PC A03/MF A01

The extensive tensor CSAMT survey of the Sulphur Springs geothermal area, Valles Caldera, New Mexico, consists of 45 high-quality soundings acquired in continuous-profiling mode and has been funded in support of CSDP drillholes VC-2A and VC-2B. Two independent transmitter bipoles were energized for tensor measurements using a 30 KW generator placed approximately 13 km south of the VC-2B wellhead. These current bipoles gave source fields over the receiver sites which were substantially independent in polarization and provided well-resolved tensor elements. The surroundings in the Sulphur Springs area were arranged in four profiles to cross major structural features. At each receiver, two orthogonal electric and three orthogonal magnetic field components were acquired in accordance with tensor principles. Derivation of model resistivity cross sections from our data and their correlation with structure and geochemistry are principal components of the OBES award. However, Sulphur Springs also can serve as a natural testbed of traditional assumptions and methods of CSAMT with quantification through rigorous model analysis. Issues here include stability and accuracy of scalar versus tensor estimates, theoretical versus observed field patterns over the survey area, and controls on near-field effects using CSAMT and natural field data both inside and outside the caldera.

WATER
for
IDAHO

Idaho Water Resources
Research Institute

Leland L. Mink
Director
Morrill Hall 106
University of Idaho
Moscow, Idaho
83844-3011
Phone: (208) 885-6429
FAX: (208) 885-6431

Al E. Murrey
Associate Director
2110 Ironwood Parkway
Coeur d'Alene, Idaho
83814
Phone: (208) 765-0590
FAX: (208) 667-4869

Paul Jehn
Associate Director
UI Boise Center
800 Park Boulevard
Suite 200
Boise, Idaho
83712
Phone: (208) 334-2999
FAX: (208) 364-4035

November 23, 1993

Mike Wright
University of Utah Research Institute
391 Chipeta Way
Salt Lake City, Utah 84108

Dear Mike:

I enjoyed talking to you last week and again express a desire to work with you on the 1994 annual meeting. I would be delighted to put together a session on Yellowstone for the meeting.

On another issue, I feel the map UURI put together on the U.S. Geothermal Provinces could be enhanced using the heat pump data generated by us under the low temperature program. I have included these plates describing the areas of high potential for geothermal heat pump use either for cooling or heating cycles. The first plate (A) is a map of surface unconsolidated and semi-consolidated sediments which allow easier installation of systems and generally are either saturated or have high moisture content for more efficient systems. The second plate (B) is areas of shallow aquifers where ground water/geothermal heat pumps would be most efficient. The third plate (C) is a composite of the first two and shows where geothermal heat pumps could be used most effectively. It is the third plate I feel would be the most effective on the base map of U.S. Geothermal Provinces. The "Area Suitable for Geothermal Heat Pumps" could be divided into two categories: 1) areas of high potential for geothermal heat pump use and 2) other areas suitable for geothermal heat pumps. The first category would include the area outlined by plate (C).

I have these maps digitized and they can be computer generated if it would be of help in generating an overlay. Also, Kevin Freeman and I have the backup information on file here at the Idaho Water Resources Research Institute if you need it.

Sincerely,

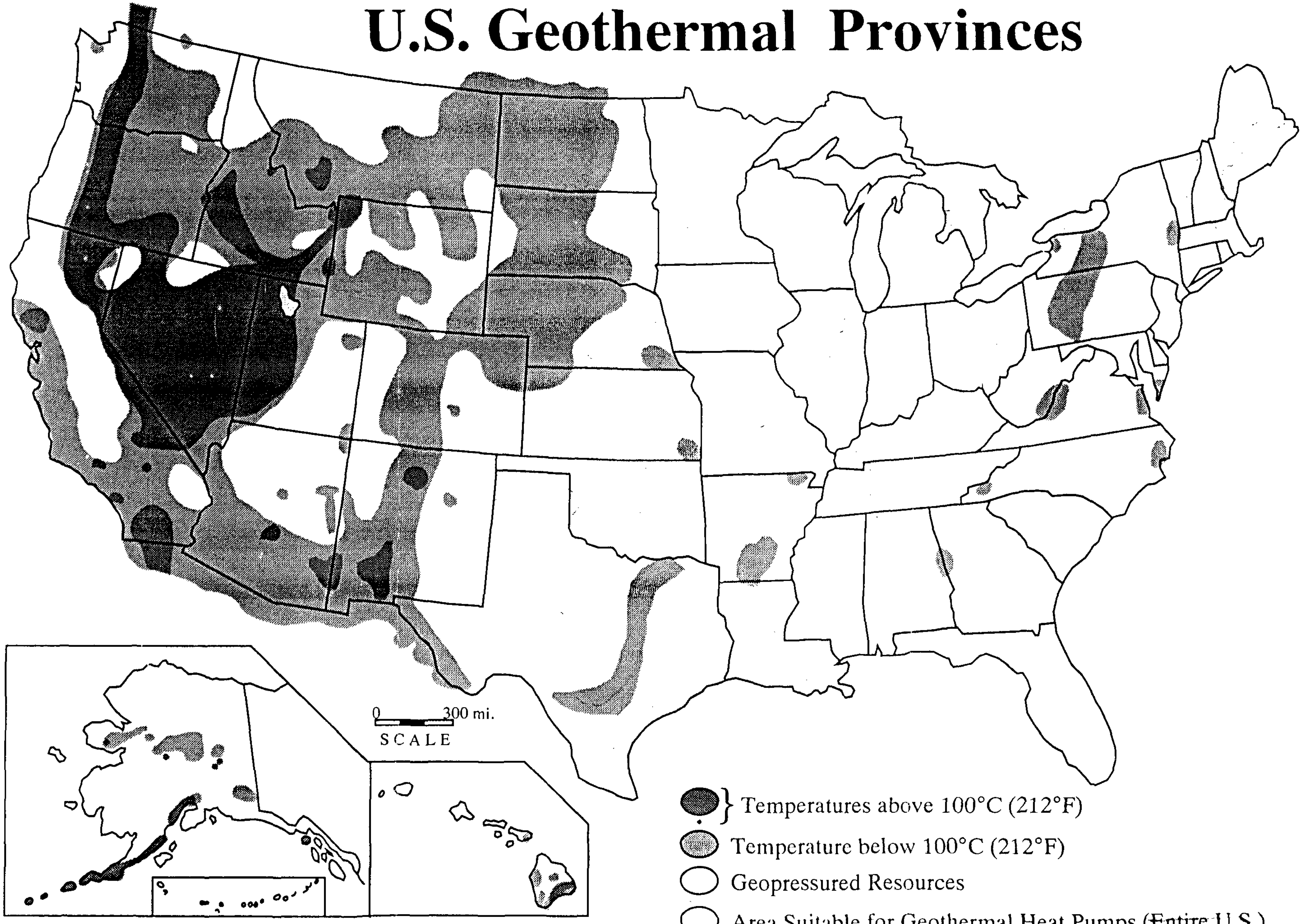
Leland L. Mink

Leland L. Mink
Director

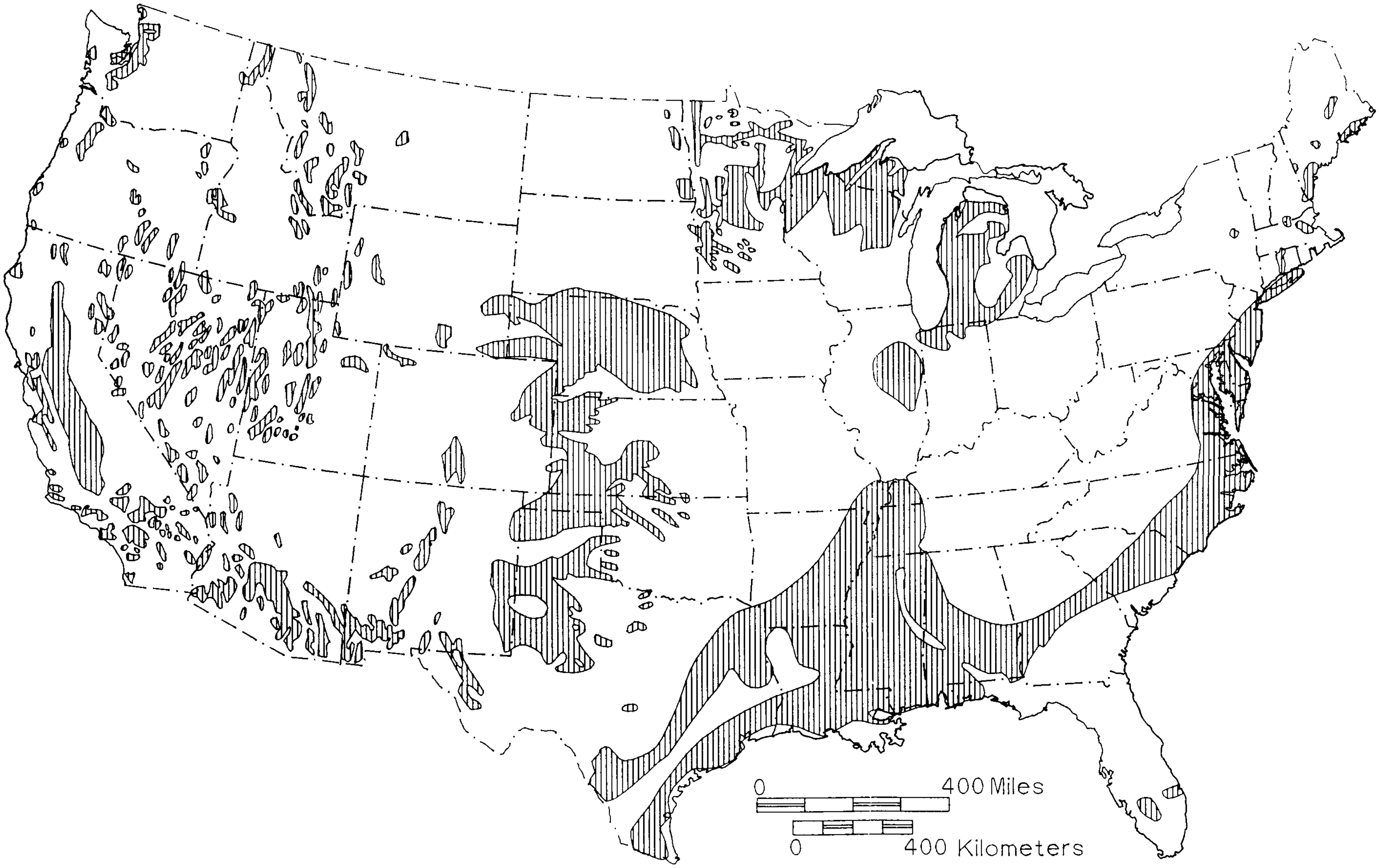
C:\WP51\Letter\Wright.Let

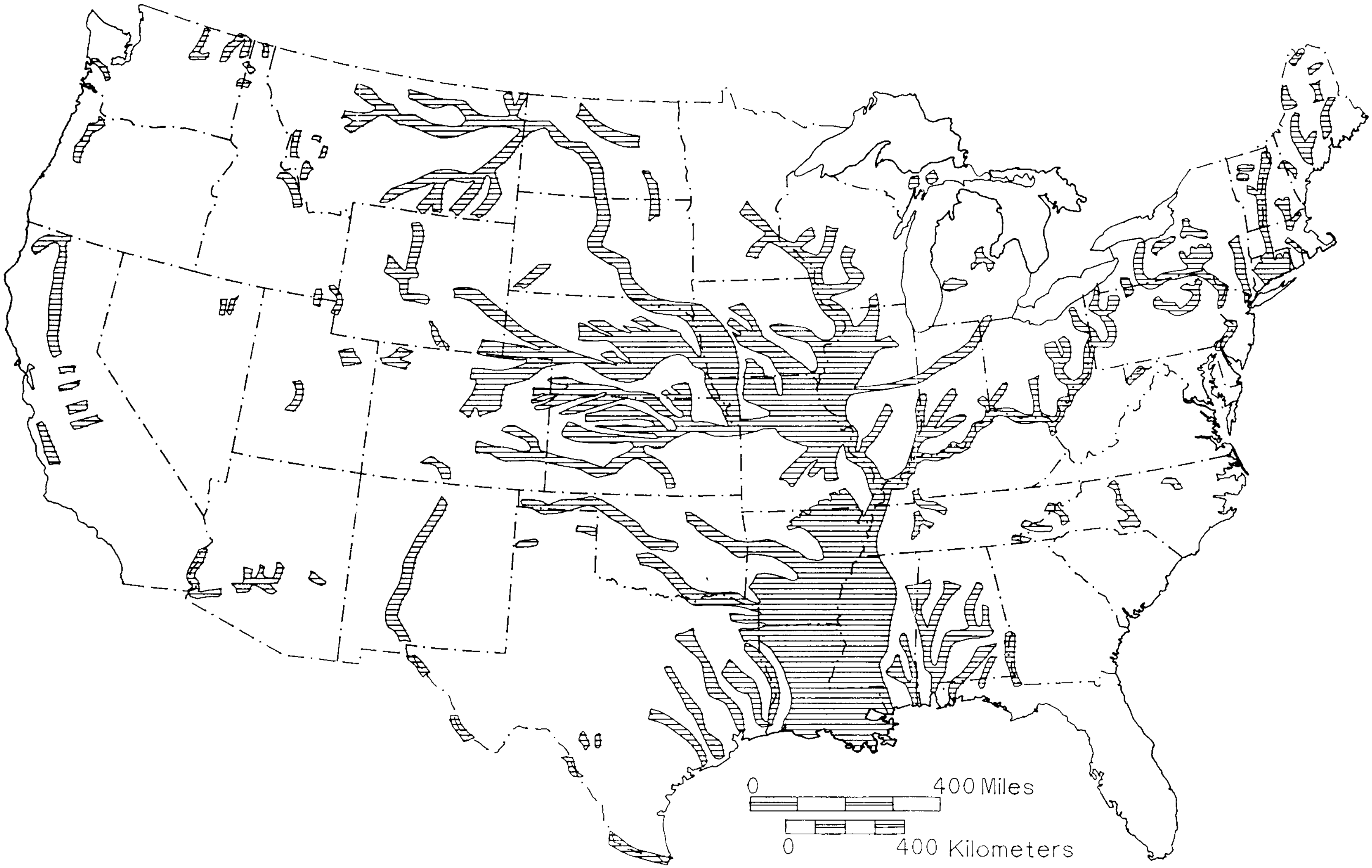
AA/EOE

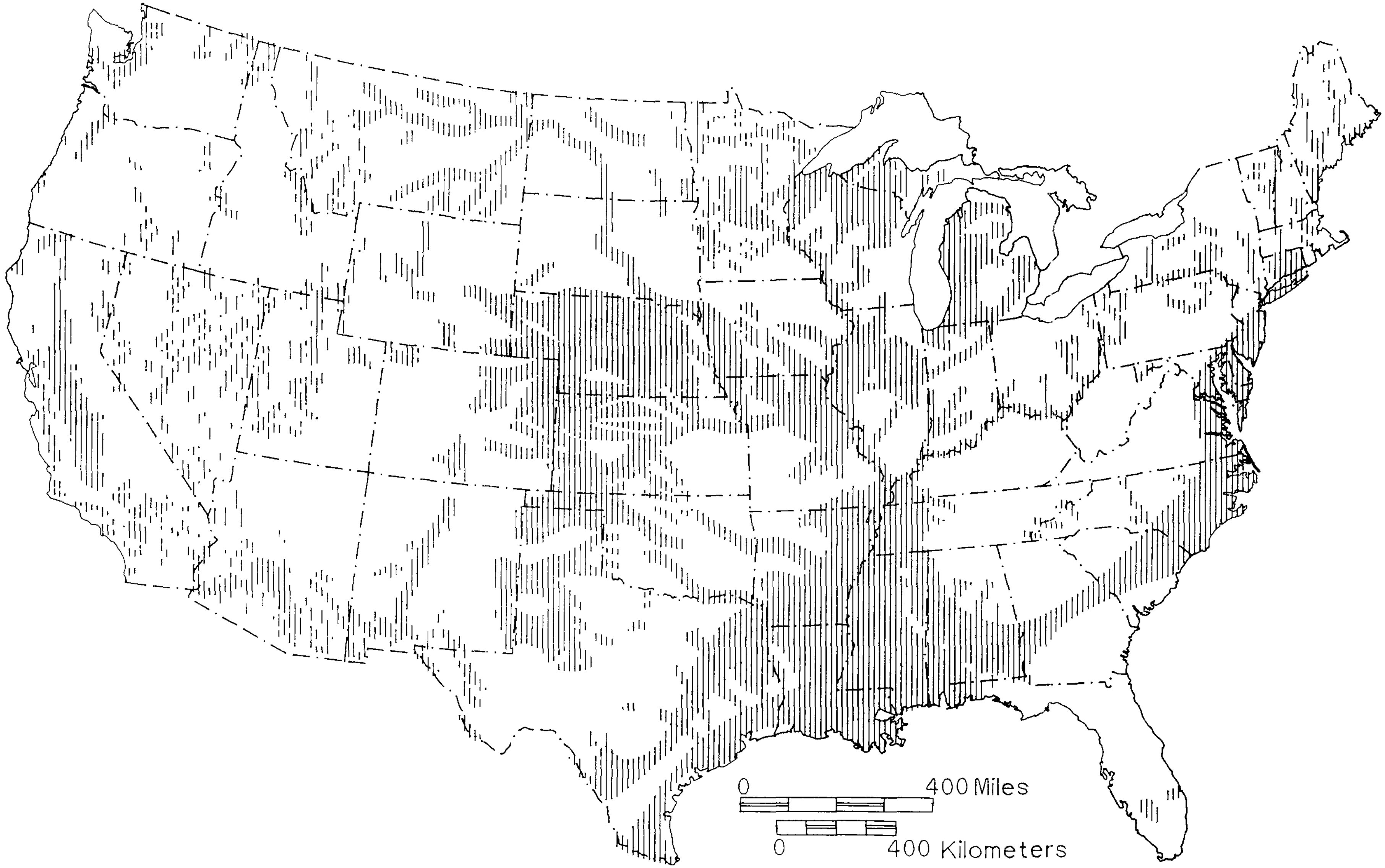
U.S. Geothermal Provinces



Source: UURI


0
400 Miles
0
400 Kilometers


0
400 Miles
0
400 Kilometers


0
400 Miles
0
400 Kilometers

#12

Research Technical Completion Report

OVERVIEW OF GEOTHERMAL INVESTIGATIONS IN IDAHO, 1980 TO 1993

by

William J. Dansart
John D. Kauffman
Leland L. Mink

Idaho Water Resources Research Institute
University of Idaho
Moscow, Idaho 83844

December, 1994

Table 2. County codes used in DBase files (after Parliman and Young, 1992, Table 2, p. 10).

County	Numeric code
Ada	01
Adams	03
Bannock	05
Bear Lake	07
Bingham	11
Blaine	13
Boise	15
Bonneville	19
Butte	23
Camas	25
Canyon	27
Caribou	29
Cassia	31
Clark	33
Custer	37
Elmore	39
Franklin	41
Fremont	43
Gem	45
Gooding	47
Idaho	49
Jefferson	51
Jerome	53
Latah	57
Lemhi	59
Lincoln	63
Madison	65
Minidoka	67
Nez Perce	69
Oneida	71
Owyhee	73
Payette	75
Power	77
Teton	81
Twin Falls	83
Valley	85
Washington	87

Research Technical Completion Report

OVERVIEW OF GEOTHERMAL INVESTIGATIONS IN IDAHO, 1980 TO 1993

by

William J. Dansart
John D. Kauffman
Leland L. Mink

Idaho Water Resources Research Institute
University of Idaho
Moscow, Idaho

submitted to
U.S. Department of Energy
Geothermal Division

December, 1994

TABLE OF CONTENTS

FIGURES AND TABLES

ACKNOWLEDGEMENTS

This low temperature geothermal assessment program was funded by the U.S. Department of Energy, Geothermal Division. The Idaho Water Resources Research Institute serves as the subcontractor to EG&G Idaho, Inc., for the purpose of fulfilling the terms of the contract within the State of Idaho.

We would like to thank Howard Ross of UURI, Paul Lienau and Gene Culver of OIT, and Joel Renner of EG&G Idaho, Inc. for reviewing and for providing comments and suggestions for improving the products of this project.

We also would like to express our appreciation to Ken Neely, Idaho Department of Water Resources, Boise, for providing additional references for the bibliography and for obtaining information in the USGS geothermal data base.

Loudon Stanford, Idaho Geological Survey, produced the camera-ready separates of the geothermal resources map and provided suggestions which greatly enhanced the final product. Roy Breckenridge, also with the Idaho Geological Survey, reviewed portions of the manuscript and provided helpful comments.

Finally, we would like to thank Janet Hohle for her considerable assistance with information compilation and data entry.

DISCLAIMER

ABSTRACT

The Idaho Water Resources Research Institute has compiled available geothermal resource data for the State of Idaho generated since the last state assessment published in 1980 by the Idaho Department of Water Resources. Data sources include state and federal agency reports, organizations under contract with the U. S. Department of Energy, company reports, research theses, and Idaho Department of Water Resources Well Driller's Report forms. This report summarizes the characteristics, occurrences and uses of thermal waters in Idaho which are documented by resource investigations conducted since 1980. Recommended areas for further investigation are briefly discussed.

Additional products of this compilation include a *DBase III Plus* data set, a bibliography of Idaho geothermal resources, and a 1:1,000,000-scale geothermal resource map of Idaho. The data set includes 1554 entries for 1537 individual wells and springs; this information was derived from a variety of reports on geothermal investigations, from previous compilations and from well drillers' reports filed with the state between 1979 and 1993. The bibliography lists over 750 references on Idaho geothermal resources. The map presents the distribution of geothermal wells and springs included in the data set of this report.

OVERVIEW OF GEOTHERMAL INVESTIGATIONS IN IDAHO, 1980 TO 1993

INTRODUCTION

The Idaho Water Resources Research Institute (IWRRI) has compiled available geothermal resource data for the State of Idaho focusing on data generated since the last state assessment published by the Idaho Department of Water Resources (IDWR)(Mitchell and others, 1980). Sources of information include state and federal agencies, organizations under contract to the Department of Energy, and individual authors. The report outlines the characteristics, occurrences and uses of thermal waters in Idaho which are documented by resource investigations conducted since 1980.

In addition to well data from other reports, the DBase files include data from nearly 200 water wells as much as 924 meters (3030 feet) in depth, drilled in Idaho from 1979 to 1993, for which drillers logs have been filed with the Idaho Department of Water Resources (IDWR). Temperatures in these wells range from 20°C to 82°C (68°F to 180°F). Approximately 50% of these wells were drilled for geothermal applications including municipal and domestic heating, greenhouses, fish farming, and bathing resort facilities; the remainder were domestic and irrigation wells that encountered warm water. Seventy-five percent of the warm-water wells drilled in Idaho since 1979 are located in Twin Falls, Boise, Owyhee, and Ada counties.

Funding for this project was provided by the United States Department of Energy, Geothermal Division under subcontract with EG&G Idaho, Inc., Task Order No. 77, Subcontract C85-110544.

Report Scope and Format

The scope of this report is to present a summarization of geothermal data in Idaho compiled by various individuals, companies and organizations since publication of the IDWR report (Mitchell and others, 1980); the reader is referred to the cited references for detailed information. Attached to the report is a diskette containing data on 1537 thermal wells and springs (GEOTHERM.dbf) and a bibliography of over 750 references compiled on Idaho geothermal investigations (GEOTHERM.bib). Also attached is a geothermal map of Idaho (in pocket), compiled at a scale of 1:1,000,000, that presents locations for thermal wells and springs. Identifier numbers for each site on the map correspond to the county (CO) and identifier (ID) fields in the DBase file.

In this report, geothermal resources are discussed by county in alphabetical order. Named wells or springs are listed by name and/or township, range, section and subsection; their county and DBase identifiers (field 2, CO; and field 3, ID, respectively) in **bold** parentheses. Unnamed wells and springs are given location identifiers following the format used by the U. S. Geological Survey and IDWR (see

Figure 1) and also identified with the DBase ID. Units of measurement are presented as metric units with English Standard units in parentheses.

Compiled geothermal data have been entered in *DBase III Plus* in the data set GEOTHERM.dbf (attached diskette). This file contains information for wells and springs from published reports or unpublished documents. The focus of this compilation is on information developed since 1980; however, basic information on name, location, type, and temperature has been included for all thermal wells and springs in Idaho. Reference sources (field 25) for data are designated by an asterisk (*) in the *References Cited* section of this report. Fifty-seven data fields are contained in file GEOTHERM.dbf; these fields are listed in Table 1. Counties (field 2) are listed by a two-digit numeric code corresponding to their alphabetical order as shown in Table 2. Subsections (field 7) for some wells or springs may differ slightly from some published locations in other reports. Generally this is the result of different subsection listings for the same well or spring described in different publications. Whenever possible, the discrepancy was resolved by locating the thermal occurrence on a 7.5-minute quadrangle topographic map and determining the subsection position. Published latitude-longitude positions were used when available. When published positions were not available or when errors were apparent in published locations, the geothermal occurrence was located on a 1:100,000-scale topographic map and its position was measured manually. A list of the geothermal sites, locations and temperatures included in the DBase III file is printed on the reverse side of the accompanying map (in pocket).

This report and the accompanying *Bibliography of Idaho Geothermal Resources* (Dansart and others, 1994) have been composed in WordPerfect for Windows 5.2. The report and bibliography are available in either hard copy or diskette format; the DBase file is available only on diskette. The map accompanying the report is also available separately. Requests for all these items may be made through the Idaho Water Resources Research Institute, University of Idaho, Moscow, Idaho 83844-3011, (208) 885-6429.

Record Checking

Some duplication of geothermal sites in the DBase file is inevitable when dealing with different reference sources and sometimes incomplete location information. We have attempted to minimize duplication by sorting routines designed to identify sites with identical locations, and by cross-checking names/locations from different sources. However, unnamed sites, particularly from Parliman and Young (1992), may duplicate some named sites from earlier reports which have slightly different subsection and/or latitude-longitude designations; this is especially true in the Boise area. When sites with slightly different locations were determined to be the same, they were given the same identifier (ID field) number in the DBase file; otherwise

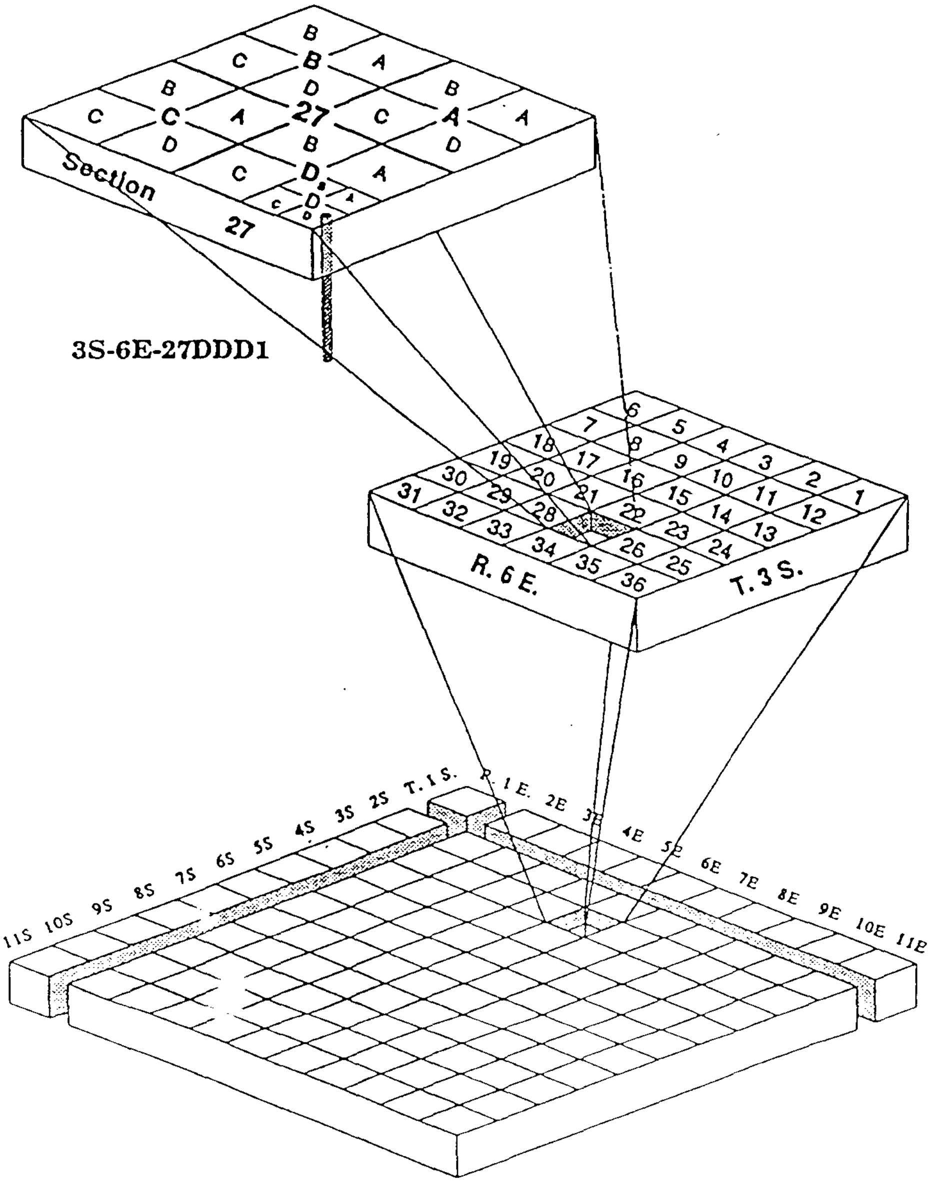


Figure 1. Well and spring location and numbering system (after Parliman and Young, 1992, Figure 1, p. 2).

Table 1. DBase file GEOTHERM.dbf data fields.

Field #	Name	Description
1	NAME	well/spring name or location code
2	CO	county code #; see Table 2
3	ID	site identifier
4	TWN	township
5	RNG	range
6	SEC	section
7	SUB	subsection(s); see Figure 1
8	LAT	latitude, in decimal degrees
9	LONG	longitude, in decimal degrees
10	DATE	date of information source or sample
11	TYPE	well (W) or spring (S)
12	TEMP_C	temperature in °C
13	TEMP_F	temperature in °F
14	SAMPLE_C	water sample temperature in °C
15	TEMP_TYPE	surface or downwell water
16	FLOW_GPM	flow rate in gallons per minute
17	FLOW_LPM	flow rate in liters per minute
18	FLOW_LPS	flow rate in liters per second
19	DEPTH_FT	well depth in feet
20	DEPTH_M	well depth in meters
21	DEPTH_OF_C	depth of circulation in meters
22	M_TO_H2O	depth to water in meters
23	ELEV_FT	elevation in feet
24	ELEV_M	elevation in meters
25	REFERENCE	source of information
26	PH	pH
27	SPCOND	specific conductance in micromhos (μmhos)
28	TDS_MGL	total dissolved solids in milligrams per liter (mg/l)
29	NA	sodium (mg/l)
30	K	potassium (mg/l)
31	CA	calcium (mg/l)
32	CACO3	calcium carbonate (mg/l) (hardness)
33	MG	magnesium (mg/l)
34	FE	iron (mg/l)
35	FE_MICRO	iron in micrograms per liter (μg/l)
36	AL	aluminum (mg/l)
37	SIO2	silicon dioxide (mg/l)
38	B	boron (mg/l)
39	B_MICRO	boron (μg/l)
40	LI	lithium (mg/l)

Table 1. (continued)

Field #	Name	Description
41	LI_MICRO	lithium (μg/l)
42	HCO3	bicarbonate (mg/l)
43	SO4	sulfate (mg/l)
44	NO2_NO3	nitrite plus nitrate (mg/l)
45	CL	chloride (mg/l)
46	F	fluoride (mg/l)
47	AS_MICRO	arsenic (μg/l)
48	RESTEMP	reservoir temperature in °C
49	RS_NA_K_CA	reservoir temperature with Na/K/Ca geothermometer in °C
50	LOG_ARAG	log saturation index - aragonite
51	LOG_CALC	log saturation index - calcite
52	LOG_DOLO	log saturation index - dolomite
53	LOG_TALC	log saturation index - talc
54	LOG_TREMOL	log saturation index - tremolite
55	CL_TO_NA	Cl:Na molar ratio
56	SILICA_DEG	silica geothermometer temperature in °C
57	PCO2	partial pressure of CO_2 gas (atmospheres)

Table 2. County codes used in DBase files (after Parliman and Young, 1992, Table 2, p. 10).

County	Numeric code
Ada	01
Adams	03
Bannock	05
Bear Lake	07
Bingham	11
Blaine	13
Boise	15
Bonneville	19
Butte	23
Camas	25
Canyon	27
Caribou	29
Cassia	31
Clark	33
Custer	37
Elmore	39
Franklin	41
Fremont	43
Gem	45
Gooding	47
Idaho	49
Jefferson	51
Jerome	53
Latah	57
Lemhi	59
Lincoln	63
Madison	65
Minidoka	67
Nez Perce	69
Oneida	71
Owyhee	73
Payette	75
Power	77
Teton	81
Twin Falls	83
Valley	85
Washington	87

they were entered as separate sites with different identifier numbers. When duplicate sites are suspected or when the name is uncertain, the name field (NAME) is queried.

Previous Compilations

Water Information Bulletin No. 30, Part 9 (Mitchell and others, 1980) is a compilation of Idaho geothermal resource data available at that time. The publication contains information on the properties, characteristics, and origins of 899 thermal water occurrences with surface temperatures of 20°C (68°F) or higher within the state. Included with this study is a state geothermal resource map (NOAA, 1980). The report lists chemical analyses of 357 sites. Other reports on statewide geothermal potential include: Stearns and others (1937); Waring (1965); Ross (1971); Nichols and others (1972); Warner (1972; 1975); and Young and Mitchell (1973).

Since publication of Water Information Bulletin No. 30, Part 9, in excess of 350 papers have been written addressing Idaho geothermal resources. Notable assessments which encompass areas hosting most geothermal occurrences in Idaho include those by Blackwell (1988) and Mabey (1983). In addition, a compilation of data from Idaho thermal water [sample] analyses performed at USGS laboratories between 1921 and 1991 is presently available (Parliman and Young, 1992); this reference was used extensively to compile data for our study.

Regional studies include: Blackwell and others (1992) and Smith (1980), Snake River Plain; Lewis and Young (1980b), Payette River Basin; Lewis and Young (1982b), Boise River Basin; Young and Lewis (1982b), Salmon River Basin; Young (1985), Idaho batholith; Batdorf and others (1980), Ralston and others (1981) and Souder (1985), southeast Idaho; Young and Lewis (1982a) and McClain (1980), southwest Idaho.

Environmental assessments of seven Known Geothermal Resource Areas (KGRA's) were conducted by EG&G, Idaho (Spencer and Russell, 1979a-e; Spencer and others, 1979a-b). Areas evaluated are: Vulcan Hot Springs, Crane Creek, Castle Creek, Bruneau, Mountain Home, Raft River, and Island Park/Yellowstone KGRA's.

SUMMARY OF GEOTHERMAL STUDIES SINCE 1980

Geothermal resources are discussed below by county whenever practical. The scope of some reports extends across several counties; in these instances, the reports are discussed under the county in which the geothermal resource dominates. Associated geothermal sites that occur in adjacent counties are noted by their ID code. Portions of some reports are excerpted in their entirety for summary purposes; these have been referenced for proper credit.

Ada County (01)

Boise Area

Hot springs on the north side of Boise near the base of the foothills were the earliest indicators of a geothermal resource in the Boise area. The City of Boise has been utilizing geothermal resources since the 1890's for heat and hot water. The first commercial district heating system was built in Boise in the 1890's and supplied the state penitentiary facilities with geothermal water for space heating, showers, and a laundry complex for over 80 years. Warm water was supplied by two 122 m (400 ft) wells drilled in 1890 **(1-90, 1-91)**; this venture eventually became the Boise Warm Springs Hot Water district. In the 1930's hot water was provided to approximately 400 residences, small commercial businesses, and a well-known natatorium (swimming and health facility). Use of geothermal heat from the system began to decline in the late 1930's when low cost natural gas and electricity became readily available. In 1974 the State of Idaho initiated a study of heating ten State office buildings in downtown Boise. Shortly thereafter, the City of Boise, in cooperation with the United States Department of Energy, formed the City Energy Office and began developing feasibility studies for a major downtown district heating system. Major expansion of Boise's geothermal resource use began with a successful retrofit of the State Health Laboratory, as a pilot project, in 1977. In 1979, a new agency was created called Boise Geothermal to coordinate activities between the City of Boise and Boise Warm Springs Water District. In 1980 and 1981, the State of Idaho drilled two wells to service the Capitol Mall heating system. One of these became the production well **(1-76)**; the other became the injection well. The 71°C (160°F) water heated over 74,320 m^2 (800,000 ft^2) of office space (Austin and others, 1984), flowing at a maximum rate of 3028 l/min (800 gpm) during peak heating system (Berkeley Group, 1990). In 1981, Boise Geothermal drilled three production wells (BGL-2, BGL-3, and BGL-4)**(1-80, 1-82, and 1-83)** to service a 7.2 km (4.5 mi) heat distribution system in downtown Boise. Through the cooperative efforts of the City of Boise, the Boise Warm Springs Water District, the Department of Energy, and the Economic Development Administration, a major refurbishing of the Warm Springs pipeline system was completed and a new district heating system was built in order to serve downtown Boise (Mickelson, 1985). The Boise City District Heating system became operational in 1983, and in 1985 was capable of delivering 15,140 l/min (4000 gpm) or 2.2 million therms to the heating system (Mickelson, 1985). Twenty-one buildings were connected by March, 1985. These buildings represent 77,107 m^2 (830,000 ft^2). The 21 buildings include private offices, a library, a hospital, several public buildings, a veteran's home, and a commercial laundry. The system has the capacity to service four to five times the connected area (Mickelson, 1985).

In addition to space-heating, the geothermal system is used to treat tree root infestation within the sewer system. Geothermal water is also used by the local highway district to clear inlets and drains; and to melt ice at stream undercrossings (Mickelson, 1985).

The Boise project is a technical success having completed several heating seasons. Buildings formerly heated with oil, natural gas and electricity have been converted to geothermal heat. The resource appears to have a bright future in Boise.

An extensive review of data and evaluation of the Boise Geothermal Aquifer was conducted by the Berkeley Group (1990) under contract to the Idaho Department of Water Resources. The Berkeley Group evaluated an area extending from approximately 2.4 km (1.5 mi) southeast of the State Capitol building to 0.8 km (0.5 mi) northwest along the Boise Front. Pressure and temperature response modeling was conducted. The report concluded that: 1) geothermal production wells along the Boise Front fault communicate readily and 2) interference occurs between production wells and affects water levels along the fault in general. The effects of development on the geothermal aquifer and aquifer longevity cannot be predicted without further hydrologic, geophysical and geochemical investigation. The report outlined needed monitoring and recommended methods for further investigation.

Locations of slim hole observation wells were proposed, along with identification of existing wells for temperature and water level monitoring. Recommendation of a long-term flow test was also made, along with installation of accurate total flow devices on selected production wells. Regular geochemical sampling of major pumping wells and tracer testing of injection wells was also suggested (Berkeley Group, 1990).

Geologic mapping and data from geothermal water wells have provided information to delineate late Cenozoic geologic units and structures important to understanding the geothermal system of Boise as it is currently being developed (Wood and Burnham, 1983). The main geothermal aquifer is a sequence of rhyolite layers and minor arkosic and tuffaceous sediments of the Miocene Idavada Group. The aquifer is confined by a unit of impermeable basaltic tuffs. The aquifer has sufficient fracture permeability to yield 65-77°C (150-170°F) hot water at a rate of 2271 to 4542 l/min (600 to 1200 gpm) from wells drilled in the metropolitan area north of the Boise River. In this area the rhyolite lies at a depth of 274 to 610 m (900 to 2000 ft). A conceptual model of recharge assumes percolation to a depth of 2.13± km (7000± ft) beneath the granitic highlands northeast of the city driven by topographic head. Heated water convects upward through the northwest-trending range-front faults.

Underlying the Idavada Group, granitic rocks of the Idaho batholith have been intersected by at least two deep wells; one of these wells has the highest flowing temperature, at 82°C (180°F)**(1-98)**, of any well in the Boise area. The granite is not usually a drilling target because of assumed low permeability. However, along the Boise Front fault zone, the granite can be relatively shallow and exhibit a high degree of fracture permeability. An unconformity separates the Idavada Group from the overlying sediments and basalts of the Idaho Group. Wells completed within the Idaho Group provide domestic water for Boise residents; water temperatures and chemistry from the lower portions of the Idaho Group indicate that some leakage from the underlying geothermal aquifer is occurring (Berkeley Group, 1990).

An analysis of drawdown and production data by Waag and Wood (1987) suggests that the Boise Geothermal Aquifer system was at or near equilibrium prior to 1983. A decline in water levels was recognized in the vicinity of production wells. The rate of decline appeared to be increasing without a coincident increase in production. The main unreinjected production comes from wells owned by Boise Warm Springs Water District and Boise Geothermal Limited. These two well fields are completed within fractures of the Boise foothills fault zone (Bffz) along the boundary between the Boise foothills and the SRP. Capitol Mall, owned by the State of Idaho, produces from and reinjects fluid into fractured rhyolites and interbedded sediments beneath the SRP approximately 914 m (3,000 ft) southwest of the Bffz. Water levels within the system are cyclical and fluctuate between a low in late February and a high in early September. Although other factors may play a minor role, the principal cause of the cyclicity is withdrawals from the aquifer in response to demand for hot water. In the late 1890s the artesian head in the Warm Springs area was at approximately 858 m (2815 ft) elevation (Lindgren and Drake, 1904). By 1983, maximum recovery declined to approximately 843 m (2,765 ft) and in 1987 to 832 m (2,730 ft). Prior to 1982-83 the system seems to have been at or near equilibrium. However, in 1983-84 unreinjected production peaked at approximately 1722 million liters (455 million gallons) and equilibrium was disturbed. Although withdrawals by the two major producers which do not reinject have decreased to an average of 1514 million l/yr (400 million gal/yr) recovery levels in the Boise vicinity have declined at rates increasing from 0.4 to 3.65 m/yr (3 to 12 ft/yr). The evidence suggests interconnection and interference between the wells of the major producers (Waag and Wood, 1987).

In addition to investigations previously cited, other evaluations of the Boise Geothermal Aquifer include those by Wood and Burnham (1983), Mayo and others (1984), Young and others (1988), and Mariner and others (1989).

Other areas in Ada County

A study was conducted for Boyd Anderson near Mora, Idaho to assess the technical and economic feasibility of integrating a geothermally heated anaerobic digester with a fuel alcohol plant and cattle feedlot. It was determined that sufficient quantities of biogas can be produced through the anaerobic digestion of tillage and manure collected from a cattle feedlot to provide approximately 14,000 of the 30,000 Btu required to produce each gallon of alcohol (Austin, 1981).

The geothermal potential of the Mora area is probably similar to that of the Nampa-Boise area. Information on the temperature potential at depths greater than 610 m (2000 feet) was obtained by an analysis of the well logs from the J.N. James No. 1 well **(1-111)** (T4N, R1W, section 27), a 4.27 km (14,000 ft) oil test well drilled about 24 km (15 mi) northwest of Mora. The bottom hole temperature in this well (recorded 11.5 hours after circulation) was 177°C (350°F), yielding a gradient of about 40°C/km (2.5°F/100 ft). Whether or not sufficient quantities of water are available at these greater depths is questionable.

Bannock County (05)

Tyhee Area

According to Corbett and others (1980) it appears that warm water suitable for space heating may be available in the Tyhee area if structures controlling thermal water movement can be identified at depth. Highest estimate of subsurface temperature at drillable depth is 80°C (176°F); a low of 41°C (106°F) is represented by surface discharge in the area.

The area studied by Corbett and others (1980) includes approximately 72 km^2 (28 mi^2) of the Tyhee portion of Bannock County,immediately northwest of Pocatello, Idaho. The Tyhee area is marginal to the SRP and located at the main boundary separating the SRP from the adjacent Bannock Range block. Gravity and magnetic studies, geochemical surveys, temperature gradient measurements, well log compilation, geologic mapping and Landsat imagery interpretation was conducted. These data were used to create a model for the Tyhee area.

Temperature gradient measurements were made in seven unused wells in the Tyhee and adjacent areas. These wells ranged in depth from 30 to 230 m (98 to 754 ft). The temperature gradients measured were inconsistent and variable; reliable overall temperature gradients for the Tyhee area could not be determined. The gradients range from nearly isothermal to a maximum of 190°C/km (11.4°F/100 ft). Most gradients were above normal (33°C/km [2.8°F/100 ft]). Four of the wells from which gradients were obtained exhibited a lower gradient in the upper section of the well and a steeper gradient in the deeper parts of the well bores. Possible causes include thermal conductivity changes in underlying sediments and rock, vertical or lateral groundwater movement, topographic effects, seasonal fluctuations and/or irrigation practices.

Hot waters of the area appear to be both spatially and genetically related to the major faults present, primarily at fault intersections. Recurrent fault movement probably created permeable zones for water circulation; these zones most likely control hot water occurrence. The quartz chemical geothermometer and a mixing model indicate that thermal water equilibrated last at a temperature of between 63°C and 80°C (145°F and 176°F). Geothermal gradient measurements indicate a gradient of 60°C/km (4.3°F/100 ft) and speculative thermal conductivity values indicate heat flow of from 1.2 to 3.0 HFU with a probable value of about 3 HFU for the area.

Pocatello

Trans Energy Systems (1981) studied the potential application of low temperature geothermal heat to a barley malting process. The study focused on the Great Western Malting Company facility at Pocatello, Idaho; the plant utilized natural gas. Trans Energy Systems estimated the presence of a geothermal resource yielding 3785 to 5678 l/min (1000 to 1500 gpm) at 65.5°C to 121°C (150°F to 250°F) in the area. Based on this estimate, the viability of seven different processing systems utilizing geothermal heat was evaluated. Preliminary analysis indicated payback on the installation of a system to utilize the resource would occur in under 2 years.

Bear Lake County (07)

A hydrogeologic investigation of geothermal systems in the vicinity of the Bear River Range was conducted by Baglio (1983). This was a reconnaissance level examination of regional geologic controls and hydrochemical characteristics of thermal and nonthermal groundwater systems in the area. Fifty three selected springs and shallow wells were characterized. These sites are located in Bear Lake, Caribou and Franklin counties but are discussed here because the majority of the area examined is in Bear Lake County.

Thermal springs in the vicinity of the Bear River Range occur in the Bear Lake, Gem, and Cache valleys and the Blackfoot Lava Field. Limited, small scale use of the geothermal resources has occurred; development has been primarily at discharge sites.

Baglio's (1983) research was conducted within the region bordered by the Blackfoot River to the north, Gem and Cache valleys to the west, and the Idaho state line to the south. The eastern boundary extends from the Blackfoot River Reservoir to the southeastern corner of the state. This 4,700 km^2 (1815 mi^2) area of southeastern Idaho is characterized by north- and northwest-trending mountain ranges and valleys. Linear ranges of predominantly Paleozoic and Mesozoic marine carbonate strata are separated by wide intermontane basins filled with thick deposits of continental ash, conglomerate, and limestone. The surfaces of the basins are covered by Quaternary basalt, alluvium, colluvium, and lacustrine sediments.

Three regional hydrochemical groups were identified: two groups represent thermal ground water systems and the other includes the nonthermal ground water systems of the area. The following description of the geothermal systems is excerpted from Baglio's report (1983).

Geographical and geological similarities of the springs and wells sampled were examined to understand physical conditions that control the ground water discharges. The hydrochemical data were examined statistically to group the springs and wells by chemical characteristics. The resulting hydrochemical groups were then compared with physical settings to identify and conceptualize regional ground water flow systems, specifically geothermal flow systems.

The sites selected for analyses represent thermal and selected nonthermal hydrogeologic regimes in the area. Temperatures measured ranged from 5°C (41°F) at Trout Creek Spring in Caribou County to 75°C (167°F) at Maple Grove Hot Spring **(41-6)** in Franklin County.

Conclusions drawn by Baglio (1983) are:

1. The locations of nonthermal ground water discharges, particularly in the Bear River Range, appear to be controlled chiefly by stratigraphic relationships; the locations of thermal discharges throughout the area appear to be controlled by predominantly major normal or tear faults.

2. Thermal spring and well discharges with surface temperatures contribute a negligible volume of water to the overall hydrologic budget of the area.

3. The ground water flow systems emanating at the surface as both nonthermal and thermal discharges are probably meteoric in origin.

4. The thermal systems probably derive heat by thermal conduction from rock at depth; the depths of ground water circulation are estimated from 300 m to 3,000 m.

5. Two end-members of hydrochemical types present within the study area are: a) water with calcium or magnesium and bicarbonate as dominant ions; and b) water with sodium and chloride as the dominant ions.

6. Three hydrochemical groups of ground waters delineated by the chemical characteristics represent: a) nonthermal ground water systems throughout the area; b) thermal systems in the Soda Springs/Blackfoot Lava Field area; and c) thermal systems in the lower Gem Valley area.

7. Nonthermal ground water systems throughout the area have cold surface temperatures, low dissolved solids concentrations, and are chemically uniform with calcium and bicarbonate as the dominant ions. Nonthermal systems specifically within the Bear River

Range are controlled by predominantly karstic conditions and discharge from carbonate formations located stratigraphically above the Brigham Quartzite.

8. Thermal systems in the Soda Springs area have warm surface temperatures, high dissolved solids concentrations, and have primarily calcium and bicarbonate as dominant ions. The unique chemical characteristics of these discharges appear, in part, to be the result of external inputs of CO_2 into the flow systems at some depth. The variations in temperature and dissolved solids concentrations appear to be related to differences in the structural controls of the discharges.

9. Thermal systems in lower Gem Valley have warm to hot surface temperatures, moderate dissolved solids concentrations, and evolve hydrochemically from having calcium and bicarbonate as dominant ions to having sodium and chloride as dominant ions. This evolution occurs from north to south along the trace of the West Gem Valley fault. The cause of the hydrochemical evolution is suspected to be the dissolution of halite.

Blaine County (13)

The geology of several hot spring sites has been mapped in varying detail by Anderson and others (1985); Blackett (1981b); Struhsacker and others (1983) and Leeman (1982). Individual systems that have been investigated are Magic Hot Springs **(13-3)**(Struhsacker and others, 1983; 1984) and Guyer Hot Springs **(13-17)**(Blackett, 1981b; Burkett and Litke, 1989). Assessments that include the geothermal resources of Blaine County have been made by personnel from the U.S. Geological Survey (Sammel, 1978; Mariner and others, 1983).

Geochemical studies of thermal springs in Blaine County were conducted by Zeisloft and others (1983) and Foley and others (1983). Foley and Street (1985a-b; 1986; 1988) discussed the nature and occurrence of the thermal resources and associated elevated fluoride levels and have prepared a field guide addressing individual spring sites and regional geothermal potential.

Zeisloft and others (1983) integrated the results of previous geological and geochemical studies with the results of their study to develop a target model for hydrothermal resources on the margin of the Idaho batholith. Samples of thermal and non-thermal water were collected from selected springs and wells during this study, and analyzed for major and trace element constituents.

Several studies have described the individual hot spring or well sites in detail (Anderson and others, 1985; Blackett, 1981b; Mitchell, 1976; Mitchell and others, 1980; Struhsacker and others, 1983; and Foley and Street, 1988).

Wood River Drainage

The Idaho Department of Water Resources studied hydrothermal systems in the Wood River drainage (Anderson and others, 1985; Street, 1990). Anderson and others (1985) concluded that geothermal resource potential in the Wood River Drainage is limited to isolated thermal water reservoirs in the vicinity of fault controlled hot springs. None of the rock units in the area have the necessary permeability and transmissivity to serve as thermal water aquifers. Water temperatures indicate suitability for direct uses like space heating, bathing and fish culture, but elevated fluoride concentrations will complicate commercialization of the resource.

A geochemical investigation of both thermal and nonthermal springs in the Wood River area by Street (1990) was conducted to determine possible flowpaths, ages of the waters, and environmental implications of development. Seven thermal springs and five cold springs were sampled for major cations and anions along with arsenic, lithium, boron, deuterium and oxygen-18. Eight rocks, representative of outcrops at or near the thermal occurrences were sampled and analyzed for major and trace elements. Street (1990) reported that Wood River area hydrothermal springs are dilute $Na\text{-}HC0_3\text{-}SiO_2$ type waters. Calculated reservoir temperatures do not exceed 100°C (212°F), except for Magic Hot Springs Landing well **(13-2)**(108°C [226°F] with Mg correction). The isotope data suggest that the thermal water is not derived from present-day precipitation, but from precipitation when the climate was much colder and wetter.

Anderson and others (1985) studied a 3626 km^2 (1400 mi^2) area within the Wood River Drainage with emphasis on seven different sites with thermal springs. In addition to the surface and subsurface geologic surveys, a limited geochemical and isotope survey was conducted in order to obtain more information on thermal history. Shallow subsurface geologic and hydrologic data were obtained from existing well logs to determine aquifer potential and shallow geologic structure. Temperature gradient profiles were obtained from measurements taken in existing unused drill holes to assist in determining potential aquifer temperatures.

Anderson and others (1985) discuss the geology and related geothermal systems for each hot spring area proceeded by geographic location from south to north within the study area as follows:

<u>Magic Hot Springs</u> **(13-3)**

The Magic Hot Springs area is located in the southern portion of the study area on the north edge of Magic Reservoir in TlS, R17E, section 23aab. The geothermal development at this location presently consists of a 79 m (259 ft) well **(13-2)** that has an artesian flow of 57 l/min (15 gpm) of 74°C (165°F) water. This well was drilled near the former site of Magic Hot Springs, which had a surface discharge of 492 l/min (130 gpm) at a temperature of 36°C (97°F) (Ross, 1971). As a result of the drilled well, the springs ceased flowing.

Another well located approximately 400 m (1312 ft) due east of the Magic well, in T1S, R17E, section 23aaa **(13-1)**, was drilled to a depth of 117 m (384 ft). This well, penetrated granite from 96 m (315 ft) to total depth, does not flow, and has a temperature of 37°C (98.6°F).

The rocks exposed at or near the surface in the immediate area of the Magic Hot Springs are mostly basalt, rhyolite, and rhyolitic ash-flow tuff that are in places covered by Quaternary sediments. The youngest rocks in the area are Quaternary-age basalt flows. Leeman (1982) suggests rhyolite is the "basement" rock for much of the Magic Reservoir area. Quaternary sediments are locally exposed in the area, and may have a combined thickness of nearly 80 m (262 ft) as indicated by water well data at the hot springs site.

The area is cut by numerous, normal faults that trend northeast, northwest, and west. The northwest- and west-trending faults appear to be the dominant structures, forming a horst block in the hot springs area. Data from water well logs in the area and temperature gradient profiles suggest the resource is fault controlled. Those wells not intersecting major structural features or related permeable zones have isothermal temperature gradients and yield little water. Those wells drilled on or near major structural features have higher temperature gradients and higher water yields.

The geothermal resource at Magic Hot Springs is probably controlled by deep, convective circulation of waters along major faults, being heated by an unknown heat source at depth, eventually migrating upward and discharging at the surface at or near the intersection of these major structures.

Hailey Hot Springs **(13-10)**

Hailey Hot Springs is located about three kilometers west of Hailey on the north side of Croy Creek in Democrat Gulch, T2N, R18E, section 18dbb. The geothermal resource at this location consists of several tightly grouped spring discharges, with a cumulative flow of 265 l/m (68 gpm) at 59°C (138°F). Prior to their development, these springs discharged through the alluvial material of Democrat Gulch. Just a few feet west of the springs is an exposure of highly jointed Milligen Formation carbonate rocks which presumably is an outcrop of the thermal water conduit.

Much of the area of spring discharge has been enclosed by a concrete headbox with the hot water funneled into a buried pipe distribution system for swimming pool and space heating use in Hailey at the Hiawatha Hotel. The hotel burned leaving the subsequent use of the resource questionable.

The rocks exposed in the area of Hailey Hot Springs are carbonate and argillite of the Milligen and Wood River Formations overlain on the west by Challis Volcanics. The alluvium-covered valley floor is nearly 210 meters wide at the springs and is flanked on the east by a narrow deposit of elevated terrace gravels. The subsurface geology in the area of the hot springs is relatively unknown as only limited well drilling has been done in the area. This resource appears to be structurally controlled because rock permeabilities are generally low.

McLain and Eastlake (1979) conducted a site specific analysis of Hailey for the Idaho Office of Energy in order to characterize its suitability for space heating systems. They identified three practical space heating applications: 1) spaceheating of greenhouses at the hot springs location; 2) spaceheating a new subdivision development somewhere between the hot springs and the city of Hailey; and 3) spaceheating residential and commercial buildings in Hailey. They concluded a city owned district heating system had the highest potential for economic success, with start up capital being the biggest obstacle.

Clarendon Hot Springs **(13-13)**

Clarendon Hot Springs is located in T3N, R17E, section 27dcb. The spring is located on the west side of Deer Creek, just above the Clarendon Hot Springs Resort. The geothermal resource at this location consists of a spring discharging 378 l/m (100 gpm) at 47°C (116.6°F) (Mitchell and others, 1980). This spring is currently utilized at the adjoining ranch which includes swimming facilities. It was proposed to use these waters for space heating at an adjoining recreation area under development.

Rocks exposed in the Clarendon Hot Springs area are Cretaceous granitic intrusives, sandstone and quartzite of the Wood River Formation, and argillite of the Milligen Formation. Alluvium covers the narrow valley floor. The subsurface information and surface geology indicate rock and formation permeabilities are low with the thermal occurrence most likely structurally controlled.

Limited shallow well drilling in the area has met with varied success. Producing wells are used to support the resort facilities.

Guyer Hot Springs **(13-17)**

Guyer Hot Springs are located on the south side of Warm Springs Creek near the western city limits of Ketchum in T4N, R17E, section 15aac. The geothermal resource at this location is privately owned, and consists of several springs with a cumulative discharge of about 3,780 l/m (1,000 gpm). Temperatures vary from one discharge point to another ranging from 55°C to 70°C (131°F to 158°F). Much of the spring area has been capped by enclosed concrete headboxes. The thermal water is funneled into a single distribution system for local space heating and swimming pool use in Ketchum. Sifford

(1984) reported approximately 60 homes and businesses utilizing this warm water distribution system.

About 640 m (2100 ft) east of Guyer Hot Springs is Grayhawk Hot Springs **(13-16)** which discharges at nearly 8 l/min (2 gpm) through the alluvium-covered valley floor at 55°C (131°F).

Rocks exposed at Guyer Hot Springs are folded, faulted, and locally highly jointed Paleozoic sediments of the Wood River Formation. Just east of the hot springs, the narrow valley floor broadens significantly, forming wide alluvial flats flanked by terrace gravels. Faulting appears to control the migrating thermal waters. Secondary mineralization found along a northwest-trending fault system just east of the intersection with a north-south-trending fault system suggests previous migration of thermal waters. The subsurface geology in the area of the hot springs is relatively unknown as only limited drilling has been done in the area.

This resource seems to be structurally controlled because formation permeabilities are generally low. Water chemistry data suggest Guyer and Greyhawk Hot Springs may originate from the same source.

Warfield Hot Springs **(13-15, 13-19)**

Warfield Hot Springs, also known locally as Frenchman's Bend Hot Springs, is located west of Ketchum about 17.5 km (10.9 mi) up Warm Springs Creek. The geothermal resource at this location consists of two main spring discharges and several minor discharges. One spring **(13-15)** located in T4N, R16E, section 36aac, discharges from locally highly jointed granitic rock at about 378 l/min (100 gpm) at 65°C (149°F). This spring, like the others, discharges below the high water mark of Warm Springs Creek and flows directly into it. The other spring **(13-19)**, located in T4N, R17E, section 31bbc, is a major seep. This seep discharges through highly fractured carbonate rocks at 62°C (143.6°F) and is approximately 305 m (100 ft) downstream from the spring. Other smaller seeps, discharging through a thin veneer of alluvium covering the carbonate rocks, are visible for a short distance (90 m [295 ft]) south of the main seep along Warm Springs Creek. The area is easily accessible from Ketchum by an improved gravel road. Facilities at the site consist of several hand-dug bathing pools and a small change house. A few summer recreation cabins are located nearby.

Rocks exposed in the Warfield Hot Springs area consist of a moderately weathered and jointed Cretaceous granite and highly jointed carbonate rocks of the Wood River Formation. A veneer of alluvium covers the narrow valley floor. The thermal surface discharges of the area appear controlled by the major jointing found in the granite and dolomite. Discharges appear to occur along northwest- and northeast-trending joint sets which create enough permeability to allow migration of thermal waters. Major faulting in the area is not well defined. As no wells have been drilled in this area, the subsurface geology is unknown. Rock permeabilities appear to be low. The thermal occurrences seem to be structurally controlled and confined to avenues of fracture permeability.

Easley Hot Springs **(13-22)**

Easley Hot Springs is located in the northern portion of the study area in T5N, R16E, section 10dbc (Mitchell and others, 1980). The spring occurs on the south side of the Big Wood River valley floor very near the southern boundary of the Sawtooth National Recreation Area.

The geothermal resource at this location consists of a spring with a discharge rate of approximately 68 l/min (18 gpm) at 37°C (98.6°F). The spring is located just a few feet above the valley floor, discharging from a highly jointed exposure of Tertiary Challis Volcanics. Just below the spring, within the alluvium-covered valley floor, a shallow marshy pond is fed by thermal water migrating upward through what appears to be the same joint system. Presently, the spring is almost fully diverted for use.

Facilities at Easley Hot Springs consist of a large camping area including a modern outdoor swimming pool fed by the spring. This area, along with newly constructed support facilities, is managed by the First Baptist Church of Idaho.

The rocks exposed in the Easley Hot Springs area are primarily Challis Volcanics and Quaternary alluvium. Angular volcanic float and remnant terrace gravels cover much of the steep slopes flanking the valley floor.

The surrounding area has not been drilled, and subsurface geology is relatively unknown. Easley Hot Springs is likely structurally controlled as rock permeabilities are low.

Russian John Hot Springs **(13-23)**

Russian John Hot Springs lies within the Sawtooth National Recreational Area. The specific location is unsurveyed, but has been reported as T6N, R16E, section 33cca (Mitchell and others, 1980). The area is just west of State Highway 75 and Russian John Guard Station.

The geothermal occurrence at this location consists of a seep of about 4 l/min (1 gpm) with a surface temperature of 35°C (95°F). This spring discharges from Quaternary alluvial material; there are hand-dug shallow bathing pools constructed at the site. About 245 m (804 ft) to the east, in the valley plain, there are some shallow marsh-like ponds that have a surface temperature of 18-20°C (64.4-68°F). The ponds appear to be connected to the system as they rarely freeze during winter.

The main rocks exposed in the immediate area of Russian John Hot Springs are Quaternary alluvium and terrace gravels. Many of the stream valleys in the area have fragmental gravel terraces at different elevations along their flanks with extensive floodplain deposits in the bottom. These deposits primarily consist of quartzite, sandstone, and volcanic rocks with minor fragments of porphyritic volcanic units. The gravels are generally well rounded and contain some boulders up to three feet in diameter.

Little is known about the subsurface geology; no wells have been drilled in the area. Surface geology indicates that rock permeabilities are low. The thermal occurrence found here is most likely controlled by the convective circulation of water, heated at depth, migrating upward along structurally controlled avenues of higher permeability.

Anderson and others (1985) concluded that the chemistry and temperature of thermal water occurrences in the Big Wood River drainage generally are typical of other thermal waters found in or near rocks associated with the Idaho batholith. These waters likely originated as precipitation 11,000 to 22,000 years ago. The narrow range for oxygen-18 depletion shown by the thermal waters suggests very similar thermal histories. Meteoric water likely occurred during a cooler period and was elevated to similar temperatures at depth. Variations in deuterium may indicate separate recharge areas and flow systems for the thermal springs in the area. Other published data indicating specific water chemistry and thermal histories for individual hot springs associated with the Idaho batholith support this theory.

The standard geothermal model for the area and similar thermal water occurrences along the northern edge of the SRP suggests recharge in the upland with downward migration of water along deep faults to depths of 2 to 3 km (6560 to 9840 ft). The heat source at these depths is generally considered to be related to the granitic rocks of the Idaho batholith. The water is probably heated by simple conductance prior to its return to the land surface through fault generated permeable zones. The upward rate of flow is controlled by thermal gradients and hydrostatic pressure as well as the transmissivity of the permeable zone. The limited data in the Wood River drainage area suggest a geothermal gradient of approximately 30°C/km (2.6°F/100 ft).

It is likely that the resource consists of relatively small isolated thermal water reservoirs with limited development potential. None of the hot springs in the area have large discharges.

None of the rock units in the area, except the recent alluvium and Quaternary glacial deposits, have the necessary permeability and transmissivity to serve as thermal water aquifers. Production wells in the Wood River drainage have to intersect the fault that controls the upward movement of thermal water. Mapping fault traces at the surface is the logical first exploration step. Infrared aerial photography may be useful in identifying fault traces associated with thermal water. Resistivity profiles taken at right angles to fault traces may be an appropriate geophysical tool. Correlation testing should be conducted along faults known to be associated with hot water (Anderson and others, 1985). Published geochemical thermometer data for the region (Mitchell and others, 1980) indicate water of moderate temperature suitable for direct uses such as space heating, bathing, and fish culture. The elevated fluoride concentrations (> 12 mg/l) in the thermal water will complicate commercialization of the resource. These waters do not meet state or federal standards for drinking water, so regulatory agencies are unlikely to approve surface discharge of spent thermal water in amounts greater than the existing spring flows.

Ketchum

A site-specific analysis of Ketchum was initiated by the Oregon Institute of Technology (OIT) Geo Heat Center (Dellinger and others, 1982). It was later determined that the analysis could not contribute to further geothermal development due to several physical, legal, and institutional factors that included limited resource quantity, ownership considerations, and environmental concerns. Sifford (1984) reported approximately 60 homes and businesses utilizing a warm water distribution system originating at Guyer Hot Spring, a 70.5°C (159°F), 3785 l/min (1000 gpm) resource.

Warm Springs Creek

During 1987, ground water and surface water studies were conducted in the Warm Springs Creek area by Burkett and Litke (1989) for the Idaho Department of Health and Welfare. The ground water research was designed to characterize the valley aquifer and ground water flows, to assess background fluoride levels and sources of fluoride to the aquifer, and to determine the effect of pipeline leaks on the ground water and domestic well contamination. Surface water research was designed to assess water quality impacts due to existing geothermal discharges as well as to evaluate potential impacts from proposed geothermal developments. Warm Springs Creek, Trail Creek, and the Big Wood River were included in this research. Ground water monitoring documented fluoride levels in excess of the current state Maximum Contaminant Level (MCL) of 2.4 mg/l at several public and private wells. The research indicated that leakage from the pipeline does enter the Warm Springs Creek valley aquifer, and that it has a demonstrated effect on fluoride levels in several public community drinking water systems. Removal of the leakage was projected to reduce fluoride levels in these wells by 1-2 mg/l on average, and possibly as much as 5 mg/l during periods when the pipeline is pressurized. The report recommended that this leakage be eliminated to protect public health from fluoride impacts. The report also made recommendations for surface and ground water quality protection of the Warm Springs Creek area relative to future geothermal development.

Boise County (15)

According to Blackwell and others (1992), in the southern part of the Idaho batholith there are major effects on the heat flow regime associated with deeply circulating ground water. Hot springs are common in the southern part of the Idaho batholith and occur along major topographic lows, spaced a few kilometers apart. Estimates of heat loss from the hot springs within this area correspond to 10 to 20% of the regional heat flow, significantly affecting the conductive transport pattern. The average "background" values for gradient and heat flow are about 26°C/km (2.4°F/100 ft) and 75mWm^{-2}, respectively; this is due to heat generation in the granitic rocks in the batholith. High heat-flow values (greater than 85mWm^{-2}) coincide with hot spring locations, lineations, or the margin of the SRP. These hot springs have been described by Ross (1971), Mitchell and others (1980), and Lewis and Young (1980b, 1982b). Heat-flow losses from these hot springs have a major effect on the conductive transport pattern of regional heat flow.

Garden Valley Area

Several greenhouses, resort facilities, and numerous homes use geothermal resources to provide hot water and space heating needs in Boise County, particularly in the Garden Valley-Crouch area. Logs for 31 warm water wells **(15-17, 15-21, 15-23, 15-24, 15-26 through 15-44, and 15-46 through 15-53)** were filed with the Idaho Department of Water Resources for the period 1980 to 1992. Water temperatures recorded ranged from 27°C to 84°C (81°F to 183°F); 24 of the wells showed temperatures greater than 55°C (131°F).

According to Blackwell (1988), the area with the most well documented geothermal gradient and heat-flow data is just west of Garden Valley along the South Fork of the Payette River. The hot springs all exit along the banks of, or in, the South Fork of the Payette River at elevations of about 1000 m (3280 ft). Measured spring temperatures range from 41-61°C (105.8-141.8°F)(Mitchell and others, 1980). Detailed geochemical information for the springs have been discussed by Lewis and Young (1980b). High heat flow values are found 3-4 km (1.9-2.5 mi) from the Payette River near Grimes Creek (T8N, R6E) in mineral exploration holes at elevations of over 1800 m (5900 ft). Even higher heat flow is found at Reservoir Creek (reported as T8N, R5E, section 16bcc but shown in section 21 on Figure 8 [Blackwell, 1988]) about 1.5 km (0.9 mi) from the river and its topographic lineament. Blackwell (1988) also reports that four holes were drilled along Wash Creek (T8N, R4E) approximately perpendicular to, and south of, the Payette River to explore the size of the thermal anomaly [no temperature information could be located for the these wells or the well on Reservoir Creek and therefore they are not included in the accompanying data base]. Results clearly indicated an area of several tens of square kilometers in size that has anomalous temperature gradients and heat flow. Estimated reservoir temperatures of the hot springs sampled range from a low of 56°C (132.8°F) to a high of 122°C (251.6°F). The existence of high heat flow values over such a broad area rules out the theory of very local circulation systems around hot springs or lineaments. Lewis and Young (1980b) found no simple geochemical correlation between thermal and nonthermal water. The nature of the geothermal system is still unknown and further studies are needed. There may be significant potential for development of some of these systems for space and/or process heating where nearby developments exist (Blackwell, 1989).

Payette River Basin

Lewis and Young (1980b) characterized 31 thermal springs in the Payette River basin. Water temperatures ranged from 34°C to 86°C (93.2°F to 186.8°F), with estimated reservoir temperatures of 53°C to 143°C (127.4°F to 289.4°F). Tritium analysis indicated that sampled geothermal waters are at least 100 years and possibly more than 1000 years old.

Six hot spring areas along the South Fork of the Payette River were examined in detail by two Washington State University graduate students, Reed (1986) and Dingee (1987). Geothermometers give estimated reservoir temperatures of 68°C to 150°C (154.4°F to 302°F). Reservoir volume and temperature appear sufficient to support localized direct-use applications.

Much of the study area(s) is underlain by plutonic rocks of the Cretaceous Idaho batholith. Tertiary dike swarms and granitic plutons transect the areas. Northeast- and northwest-trending major fault zones cut this lithology and control the course of the South Fork of the Payette River.

West of Lowman

Reed (1986) studied four hot spring areas located along the South Fork of the Payette River, between the towns of Lowman and Banks. The purpose of this investigation was to determine the detailed geologic, geochemical, and hydrologic setting of the thermal springs.

According to Reed (1986) the four thermal spring areas are located along major fault zones and were divided into two types. The Goller **(15-6)**, Corder **(15-7)**, and Pine Flat **(15-14)** Hot Spring areas are associated with Tertiary dike swarms related to the Idaho porphyry belt. Hot spring vent locations are controlled by the dikes having the highest hydraulic conductivity. SiO_2 and Na:K:Ca geothermometry yielded source temperatures of 71°C (159.8°F) which, combined with a measured geothermal gradient of 80°C/km (5.4°F/100 ft), suggests a 1 km (3280 ft) circulation depth. The Deer Creek Hot Spring **(15-15)** area is distinct geologically and geochemically from the other three areas. Situated in an area lacking dikes, the hot water rises 2 km (6560 ft) along the intersection of two major faults from a thermal aquifer at 142°C (287.6°F). The two types of geothermal systems share several common features. Recharge, with cold meteoric water, occurs along the major fault zones with long (9,000-28,800 years) residence times for waters in the system. Little or no mixing of thermal and nonthermal waters occurs during ascent. Recurrent fault movement has maintained open conduits otherwise plugged by the gradual precipitation of minerals by the rising thermal water.

Reed states that residents of the study area use the hot spring water for bathing, space heating of homes and greenhouses, and for medicinal purposes. The few wells drilled for hot water in the study area have been shallow (<75 m [<246 ft]) and flowrates (up to 240 l/min [62.4 gpm]) of water at temperatures similar to nearby springs have been obtained. It appears that sufficient hot water is present in this sparsely populated area to accommodate increased development of this resource for most direct use applications. In addition, the scenic setting of the hot spring areas and their proximity to a major population center (Boise) suggests that careful development of these areas for tourism and recreation may ultimately yield the greatest economic returns from this resource.

East of Lowman

Dingee (1987) investigated three hot spring areas--Kirkham **(15-22)**, Bonneville **(15-54)** and Sacajawea **(15-55)** hot springs--located east of Lowman, Boise County, Idaho along the South Fork of the Payette River. The objectives were to determine the detailed geologic, hydrologic and geochemical setting of these hot spring areas. A summary of Dingee's report follows.

The SiO_2, Na/K and Na:K:Ca geothermometers were applied to hot spring waters from each of the areas. Estimated aquifer temperatures for Bonneville and Sacajawea hot springs are 130-150°C (266-302°F), while those of Kirkham Hot Springs are 70-90°C (158-194°F). Using the silica heat flow method, an average geothermal gradient of 50°C/km (3.7°F/100 ft)was calculated. The Bonneville and Sacajawea hot springs areas have an estimated aquifer source about 2-3 km (6560-9840 ft) below the surface while the Kirkham Hot Springs reservoir is about 1-2 km (3280-6560 ft) deep.

Hot spring vents in all areas are located along faults and fault zones and discharge from fractures in granite/granodiorite; they are frequently associated with dikes. On a regional basis, each geothermal area occurs where northwest-trending Basin-Range style faults terminate against the trans-Challis fault system. Recharge is thought to occur along Basin-Range faults; thermal waters migrate in a northerly direction along these faults and ascend to the surface when the trans-Challis fault system is encountered.

Hot spring waters from the area of investigation are moderately alkaline (pH 9.2 to 9.4); temperatures range from a low of 50°C (122°F)(Kirkham Hot Springs) to a high of 85°C (185°F)(Bonneville Hot Springs). Temperatures are uniform for the larger discharge vents at each hot springs area. Discharges are variable at each hot spring; vents with larger discharges usually have the highest temperatures for each hot springs complex.

The geothermal systems examined in Dingee's (1987) study produce waters suited for direct use applications. The geothermal system may be quite large and possess quantities of hot water able to sustain direct use development. The hot springs areas are located on U.S. Forest Service land, precluding commercial development, in sparsely populated areas with relatively low energy requirements. The hot springs of the area are presently used for recreational bathing and swimming. They will remain a recreational resource unless there is a change in local energy demands and U.S. Forest Service policies.

Bonneville County (19), Caribou County (29), Jefferson County (51), and Madison County (65)

Unlike the SRP ground water system, there has been relatively little study of the hydrology of the southeastern Idaho Basin and Range province. Ralston and Mayo (1983) summarized geothermal gradients from temperature logs and bottom hole temperature (BHT)measurements in oil wells. The BHT data is of questionable quality but gives some idea of geothermal gradients. Blackwell and others (1992) collected BHT data from wells drilled since 1983. Well sites are both north and south of the SRP and estimated BHT values range from just over 100°C (212°F)at 4 km (13,120 ft) to almost 180°C (356°F) at 5 km (16,400 ft) depth. One well studied, the Gentile Valley #29-1 **(19-18)**(shown as GENVA1-9 in Table 3b, Blackwell and others, 1992), was drilled by CONOCO in 1979 and was later taken over by Phillips Geothermal. The well has an average gradient of 60°C/km (4.3°F/100 ft) to a depth of 3 km (9840 ft) with a bottom hole temperature of 190°C (374°F). This BHT is best fit by a heat flow of 127 mWm^{-2} for the whole well. The heat flow is significantly above the expected Basin and Range background in this area 50 km (31 mi) from the edge of the SRP.

Based on sketchy data, there may not be significantly elevated heat flow in the area north of the South Fork of the Snake River. Two unidentified wells south and east of the South Fork of the Snake River have apparent average geothermal gradients of over 50°C/km (3.7°F/100 ft) to depths of 3-4 km (9840-13,120 ft); these values are considered anomalous for this area. Available information suggests highly variable heat flow in southeast Idaho. There is a very large area of elevated geothermal gradient in the vicinity of Grey's Lake and Blackfoot Reservoir. The Gray's Lake/Soda Lake area heat flow in deep wells ranges from 50 to 120 mWm^{-2}. The area has been thought to have significant geothermal potential based on the geologic setting. Gradients in this area are distinctly anomalous with respect to those elsewhere in the southeastern Idaho Basin and Range province (Blackwell and others, 1992).

The Hubbard #25-1 (SUNHUB 25) well **(29-18)**(T7S, R41E, section 25) is near Blackfoot Reservoir. Numerous Quaternary rhyolite and basalt volcanoes are found in this vicinity. Geochemistry of ground water shows no evidence of high temperature geothermal systems. Maximum temperature recorded on a poor quality temperature log is 68°C (154.4°F) at 2300 m (7544 ft). Based on a typical limestone thermal conductivity of 2.7 $Wm^{-1}K^{-1}$ an upper limit for the heat flow is 82 mWm^{-2} (Blackwell and others, 1992).

Caribou Range Area

Hubbell (1981) described geothermal flow systems in the vicinity of the Caribou Range in southeastern Idaho. He characterized 23 springs and two wells in addition to describing area geology. The study analyzed thermal and nonthermal flow systems based upon hydrogeologic and chemical data collected at selected spring and well sites.

The springs inventoried in the study area are divided into three groups for discussion purposes: 1) thermal springs that discharge highly mineralized water; 2) thermal springs or wells that discharge water with relatively low concentrations of dissolved solids; and 3) nonthermal springs. Descriptions of thermal occurrences by Hubbell (1981) follow.

Heise Hot Spring **(51-1, 51-2)**

This 48°C (118.4°F) spring is located at the foot of a 300 m (984 ft) escarpment. It has deposited a 10-m (33-ft) high travertine mound which is being eroded at its base by the Snake River. Heise Hot Springs resort, located 0.2 km (0.1 mi) northeast of the springs, has used water from this spring since the late 1800's for recreational purposes.

Heise Hot Spring is located in a structurally complex area. This spring is associated with two faults. The Heise fault, a major northwest-trending normal fault, runs through the spring site, and a smaller fault intersects the Heise fault less than 100 m (328 ft) to the east of the spring. The area south of the Heise fault is covered by alluvial sediments deposited by the Snake River. The smaller northeast-trending fault north of the Heise fault separates Tertiary rhyolitic tuff to the northwest and undifferentiated Mesozoic and Paleozoic rocks to the southeast. The spring flows from the Tertiary rhyolite covered at this site by a mantle of travertine and colluvium (Proskta and Embree, 1978). The spring site is located near older sedimentary rocks as indicated by a 100-m (328-ft) deep well drilled about 100 m north of the springs in limestone (Stearns and others, 1937).

Heise Hot Spring deposits travertine, gypsum, and free sulfur and has a hydrogen sulfide odor. The mineralized water has a specific conductance of 6500 mhos/cm and a pH of 6.7 (Young and Mitchell, 1973). Sodium and chloride are the dominant ions in this water. A subsurface temperature of 79°C (174.2°F) was estimated using a silica geothermometer (Mitchell and others, 1980).

Fall Creek Mineral Springs **(19-2, 19-3)**

Several springs and seeps discharge water along a 1.2 km (0.75 mi) reach of Fall Creek. The warmest spring is 24°C (75.2°F) and flows from a travertine deposit located next to the creek. Travertine deposits fill the valley floor along the entire length of the springs. The springs discharge from the Mission Canyon Limestone and are associated with the northwest-trending Snake River fault.

The springs deposit free sulfur and travertine and give off a strong hydrogen sulfide odor. Two other large deposits of travertine are located at a higher elevation on a ridge 0.5 and 1.6 km (0.3 and 1.0 mi) west of the springs. There are no springs associated with these deposits and their surface elevation ranges from 1680 to 1840 m (5510 to 6035 ft). The waters from Fall Creek Mineral Springs have specific conductance values of 7800 and 6800 mhos/cm and a pH of 6.2. The dominant ions are sodium and chloride. The subsurface temperature may be as high as 40°C (104°F) as indicated by the quartz geothermometer (Mitchell and others, 1980).

Alpine Hot Springs **(19-13)**

These springs were located on both sides of the former channel of the river but are presently submerged in Palisades Reservoir. The data presented are based upon an investigation of the site prior to the creation of the reservoir and during a visit when the water level was low in the reservoir. The springs flow from Quaternary alluvium and are associated with the Snake River fault (Gardner, 1961).

Six springs on the west side of the river had temperatures ranging from 31°C to 62°C (87.8°F to 143.6°F). This cluster of warm springs formed calcareous, sulphurous, and saline deposits. Many small springs escaped along the bank for a distance of 90 m (295 ft) or more; the deposits varied in color. The highest temperature observed here was 62.2°C (144°F); low temperature was 31.1°C (88°F). On the east side of the river there were two main springs and several smaller ones with temperatures ranging from 49°C to 66°C (120.2°F to 150.8°F)(Stearns and others, 1937). The wide range of temperatures in these springs indicate that warm and cold ground water is mixing before reaching the surface.

Unnamed Springs, TIN, R40E, section 4abc **(19-4)**

These springs are located in the bottom of a canyon formed by Willow Creek. The springs discharge water at a temperature of 21°C (69.8°F) from rocks of the Gannett Group. They flow from fractures in an outcrop of chert pebble conglomerate at the base of the Ephriam Conglomerate. A northeast-trending fault intersects this site from the north displacing the Peterson Limestone, placing Bechler Conglomerate against the Ephriam conglomerate. The geology is complicated by rhyolite tuff, basalt, and Salt Lake Formation units, which together conceal most of the older sedimentary rocks except where they have been exposed by erosion along Willow Creek.

Travertine deposits are located in rocks of the Bechler Formation west of the present springs. Saline deposits surround the springs. These springs have a high specific electrical conductance of 11,000 mhos/cm and a pH of 6.6. The dominant ions are sodium and sulfate.

Brockman Hot Springs **(19-10, 19-11)**

These springs flow from several small seeps and a 1.2-m (4-ft) diameter pool into Brockman Creek. The springs have a temperature of 35°C (95°F). Travertine deposits surround the springs and an inactive travertine mound is located a short distance to the south.

The area around the springs is folded and faulted. The springs flow out of Quaternary alluvium overlying Bechler Conglomerate or Peterson Limestone. Several minor faults cross the area, the nearest of which is 200 m (656 ft) to the north (Gardner, 1961). A major northwest-trending fault is located 1.7 km (1.1 mi) northeast of the spring.

The major spring has a specific electrical conductance of 8,800 mhos/cm and a pH of 6.6. The dominant ions in this water are sodium and sulfate. The subsurface temperature may be as high as 38°C (100.4°F) as indicated by the chalcedony geothermometer (Mitchell and others, 1980).

Elkhorn Warm Spring **(65-1)**

Elkhorn Warm Spring is located 2.8 km (1.7 mi) northwest of Heise Hot Springs **(51-1, 51-2)**. This spring is located on the escarpment formed by the Heise fault at an elevation of 40 to 70 m (131 to 230 ft) above Heise Hot Springs. The intrusive body suggested by Mabey (1978) to be under Heise Hot Springs is also believed to underlie Elkhorn Warm Spring. The spring emerges from relatively flat-lying rhyolite tuff on the southern edge of the Rexburg Caldera Complex (Proskta and Embree, 1978). The spring does not have associated travertine deposits and does not give off any gaseous odors.

Elkhorn Warm Spring has a specific conductance of 390 mhos/cm, a temperature of 20°C (68°F), and a pH measurement of 6.6. The dominant ions are calcium and bicarbonate.

Unnamed Spring, T3N, R41E, section 32bbd **(19-15)**

This 23°C (73.4°F) spring discharges from a densely welded ash-flow tuff. This tuff may only form a thin covering overlying older Mesozoic and Paleozoic rocks. A 9.3-km (5.8 mi) long, northeast-trending fault is located 0.2 km (0.1 mi) to the south of this spring site (Protska and Embree, 1978). This spring has a specific electrical conductance of 650 mhos/cm and a pH of 7.2. The dominant ions in the water are calcium and bicarbonate.

Dyer and Anderson Wells **(19-5 and 19-6)**

These two wells are representatives of a group of warm water wells located in a subdivision called Rim Rock Estates on the bench east of Idaho Falls. The wells are located 1.6 km (1.0 mi) apart with the Dyer well located northeast of the Anderson well. They have temperatures of 21°C and 20°C (69.8°F and 68°F), respectively. Tertiary Salt Lake Formation is mapped at the well sites with outcrops of rhyolite welded tuff and associated ash nearby (Mansfield, 1952). The Salt Lake Formation mapped in this area appears to be a thin covering overlying the welded tuff. The drill log for the Dyer well indicates that the water is obtained from fractured rhyolite. There is a northwest-trending fault mapped 0.2 km (0.1 mi) west of this well. In the Anderson well, the driller's log reports that the water is coming from sandstone or rhyolite.

The chemistries of these wells are similar. The specific electrical conductivity values are 520-530 mhos/cm and the pH is 7.7. The dominant ions present are calcium and bicarbonate.

Conclusions

The major thermal discharges within Hubbell's (1981) study area are located along structural features with the hottest water associated with deep normal faults along the Swan, Grand, and Star valleys. The combination of their locations relative to major faults, elevated temperatures, and high total dissolved solids lead to the following hypotheses for ground water flow:

1) Recharge occurs in the mountain ranges and moves vertically downward facilitated by the intense structural deformation in these areas. The ground water moves laterally along bedding planes to the faults bordering the Swan, Grand, and Star valleys. The faults allow upward migration of the thermal ground water to the surface.

2) Recharge occurs along some portions of the fault systems along the Swan, Grand, and Star valleys that allow deep migration of the ground water. The thermal ground water then moves upward along the fault zones to the surface some distance from the recharge site.

3) Thermal springs with high total dissolved solids are located in the Willow Creek Hills. Their high temperatures, high total dissolved solids, and location relative to minor faults suggest that the ground water supplying these springs circulates to depths where they are heated, then move upward to the surface following minor faults.

4) Thermal flow systems associated with caldera structures in this area have temperatures less than 24°C (75.2°F) and low specific electrical conductivities indicating shallow ground water flow systems. Recharge in surrounding areas moves to shallow depths where it is heated. The ground water then moves to the surface following minor faults. Nonthermal springs in the area probably represent relatively shallow ground water flow systems controlled by the complex lithology and structure in the area.

5) The chemistry and physical setting of Heise Hot Springs relative to Elkhorn Warm Spring indicates that the ground water flow system represented by Heise Hot Springs is unrelated to Elkhorn Warm Spring. Heise Hot Springs appear to be closely related to the springs controlled by normal faults in the sedimentary system and not to the rhyolite caldera system to the north and west.

6) The small total discharge of springs with temperatures above 39°C (102.2°F) indicates there is very little deep movement of ground water.

7) Temperature data in three of the four oil exploration wells drilled in this area indicate a higher than normal geothermal gradient. The maximum depths of circulation for thermal springs with high specific electrical conductivities are estimated to be from 600 to 2400 m (1968 to 7872 ft). The maximum depths of circulation for thermal springs with low specific electrical conductivities are estimated to be 200 to 300 m (656 to 984 ft).

Camas County (25)

The Camas Prarie/Mt. Bennett Hills area is not clearly part of the Idaho batholith or the SRP terrains. Walton (1962) calculated an average gradient for the area of 92°C/km (6.4°F/100 ft). Holes sampled are in low thermal conductivity clays, but estimated heat flow values (100-123 mWm^{-2}) are significantly above those in the adjacent Idaho batholith. Faulting of Quaternary basalt in the province demonstrates active volcanism and tectonism within the last few million years. Mitchell (1976) reports geochemical data from a 79 m (259 ft) well with a flowing temperature of 74°C (165.2°F) near Magic Reservoir; he suggests a possible subsurface temperature as high as 200°C (392°F). Gradients of over 125°C/km (7.8°F/100 ft) occur along the west side of Magic Reservoir over a 7 km (4.35 mi) stretch; the area may contain a major geothermal system at depth. Unfortunately all holes examined by various investigators are relatively shallow; little is known about deep thermal conditions. The heat source appears to be either deep ground water circulation in the typical SRP margin thermal setting, remnant heat associated with the young basaltic volcanism, unusually deep circulation associated with the most recent faults, a very young silicic intrusion with no surface manifestations, or some combination of these possibilities (Blackwell and others, 1992).

The Camas Prairie, especially the Magic Reservoir area, has above average geothermal potential. Temperatures are certainly in the range of 30-40°C (86-104°F) at depths of 300± m (984± ft) and may be high enough for commercial electric power production in the most favorable case. High gradients are also indicated along the north and south edges of the Mount Bennett Hills (Blackwell, 1989).

An evaluation of the Magic Reservoir area was conducted by University of Utah Research Institute (Struhsacker and others, 1983). The authors attempted to place the Magic Reservoir volcanic rocks in the regional stratigraphic framework and heat flow regime of the SRP and identify the structures that control geothermal fluid circulation. The Magic Reservoir area straddles the Camas-Blaine county line in south-central Idaho and is described under the Blaine County section of this report.

Fairfield

The Fairfield area was selected for a site development analysis by the Idaho Office of Energy (McClain and others, 1979) regarding potential for spaceheating public buildings and industrial applications. Three locales with good geothermal potential were identified; recommendations for exploration and potential applications were made. Five sites on the Camas Prairie were selected by the Idaho Office of Energy for the purpose of estimating cost of geothermal development. A summary of the report follows.

Fairfield, Idaho, is a small agricultural community located on the Camas Prairie in central Idaho. The community is located at an elevation of 1544 m (5,065 ft) in an east-west-trending intermountain basin which is surrounded by mountains of the Idaho batholith and Mt. Bennett Hills. The area is a transition zone between the granitic rocks of the batholith and the volcanic rocks of the SRP. The Camas Prairie area has been classified by the Idaho Department of Water Resources as a Geothermal Resource Area. Hot springs located in the area vary in temperature from 32.2°C to 71°C (90°F to 160°F).

The Camas Prairie consists of poorly sorted sediments of Pliocene to Holocene age derived from the mountains to the north and ranging in size from clay to boulder. A bedrock of Cretaceous granite exists at a depth of 152 to 167 m (500 to 550 ft) near the center of the prairie. The Soldier Mountains to the north and part of Mt. Bennett Hills to the southwest are made up of Cretaceous granitic rocks of the Idaho batholith whose main body lies further to the north. Part of the Soldier Mountains consists of Challis Volcanics which crop out along the north-central part of the basin. These volcanic flows and lower Pliocene volcanic rocks are also found along southern portions of Camas Prairie. Other basalt flows are found along the southeastern and western edges. The structural control of the Camas Prairie Basin is to a large extent unknown.

The movement of ground water in the Camas Prairie generally parallels Camas Creek and its tributaries. The major source of ground water is the Soldier Mountains to the north with minimal input from the Mt. Bennett Hills to the south. Two major aquifers composed of fine-grained sand and gravel exist in the valley fill at depths of approximately 61 to 121 m (200 to 400 ft).

Geothermal Potential

There are several hot springs in and around the Camas Prairie. Barron's Hot Springs **(25-16, 25-18)** are located approximately 12 km (7 mi) southwest of Fairfield. A surface temperature has been recorded of 72°C (163°F) with a predicted reservoir temperature of 125°C (257°F). The springs issue from the valley fill material. Two other hot springs in the area show strong evidence of a moderate temperature geothermal resource existing below the valley fill. Hot Springs Ranch (Wardrop Hot Springs)**(25-1 through 25-4)** and Elk Creek Hot Springs **(25-5 through 25-7)** both have discharge temperatures above 54°C (130°F).

Most of the irrigation wells in the area have higher than normal water temperatures. Two areas stand out as geothermal anomalies. One is the area southwest of Fairfield, just north of Barron's Hot Springs. Wells with temperatures near 21.1°C (70°F) are common in this area and Barron's Hot Spring is the high point at 71.1°C (160±°F). A temperature gradient of 146°C/km (8°F/100 ft) has been calculated for the area to the southwest of Fairfield around Barron's Hot Springs. The second anomalous area is centered approximately 3.2 km (2 mi) south of Fairfield. Temperatures at 91.4 m (300 ft) below ground level above 21.1°C (70°F) occur in an area 9.6 km (6 mi) long (E-W) and 1.6 km (1 mi) wide (N-S).

McLain and others (1979) concluded geothermal resources of Fairfield and the Camas Prairie area can be developed economically if the specific development site can be located reasonably close (3.2 to 4.8 km [2 to 3 mi]) to a large user facility. Camas Prairie appears to be a shallow depression, but the shallow geothermal fluids appear to be dependent upon faults for their upward migration. There is likely lateral movement of the geothermal water whenever permeable beds are encountered by the zones. However, for maximum production and highest temperature, the area faults zones should be explored by drilling.

There are three areas around Fairfield that appear to offer excellent geothermal exploration targets. The area around Barron's Hot Springs, on the downdip (east) side of the fault, appears an excellent target for both shallow and deep exploration. This includes the area between Barron's Hot Springs and Hot Springs Ranch. A second area, also rated excellent for shallow exploration is located south of Fairfield and enclosed by the 21.1°C (70°F) contour shown on Figure 3.4 of McClain and others (1979). The third area rated as a very good locality for deep exploration is along the downdip (east) side of the north-south-trending inferred fault passing just to the east of Fairfield. Fairly deep (244-610 m [800 to 2000 ft]) geothermal exploration wells must be drilled into fault zones in order to encounter permeable zones that will result in maximum production and temperature. Geophysical (electromagnetic VLF radio and earth magnetic) surveys should be conducted to pinpoint the existence and attitude of faults in the valley that extend into the granitic basement (McLain and others, 1979).

Canyon County (27)

Numerous warm water wells and favorable geologic conditions indicate that the Nampa area has good potential for using geothermal energy in direct applications. Many existing warm water wells are in the 24-38°C (75-100°F) temperature range. Nampa is an agricultural service center 28.8 km (18 mi) west of Boise with a population of about 25,000 people. There are numerous warm water wells in the town and the surrounding areas. The combination of a thermal water resource matched with a community of considerable size spurred an investigation of the geothermal energy potential.

The rock units in the Nampa area are composed of basalt of Miocene to early Pliocene age. Several widespread sandstone aquifers overlie the basalt. These sandstone aquifers are projected to yield good flows of 30°C (86°F) to 60°C (140°F) water from depths of 305 to 670 m (1,000 to 2,200 ft). The sandstone aquifers are better targets than the basalt because of greater anticipated permeability (Dellinger and others, 1982).

Two analyses of potential direct resource use in the Nampa area were performed by OIT Geo Heat Center (Dellinger and others, 1982). One evaluation dealt with retrofitting of Parkview and Lakeview schools to use an existing hot water source of 32°C (90°F) for heat pump conversions; in this particular instance, the conversions were not economically practical relative to cheap coal prices. The second evaluation examined a geothermal conversion for Mercy Medical Center; the economic feasibility looked favorable.

The Idaho Department of Water Resources (IDWR) conducted an integrated geological, hydrological, geochemical and geophysical survey for the purpose of evaluating the geothermal potential of the Nampa-Caldwell area (Mitchell, 1981a-b). Recommendations for resource definition and development were outlined. A summary of the report follows.

The area studied by the IDWR included approximately 925 km^2 (357 mi^2) of the Nampa-Caldwell portion of Canyon County, an area within the central portion of the western SRP immediately west of Boise, Idaho. Geologic mapping, hydrologic, geochemical, and geophysical surveys were run. In addition, existing magnetotelluric and reflection seismic data were purchased and incorporated into the investigation.

Shallow subsurface geologic and hydrologic data were obtained from existing water well logs to determine the number and extent of shallow aquifers and shallow subsurface structural configuration. Enhanced Landsat false-color infrared imagery was also studied to detect evidence of major structural features which could control thermal water in the area and provide possible migration paths for recharge to thermal and nonthermal water. Temperature gradients and heat flow data were obtained from existing unused drill holes.

Within the graben-like basin known as the western SRP geophysical studies have revealed complex basin structures. A large basin exists in the Nampa-Caldwell area, and another in the Meridian-northwest Boise area. These basins are separated by a structural high.

Idaho Group and Snake River Group rocks of Pliocene-Pleistocene age are exposed within the Nampa-Caldwell area. These rocks consist of terrace gravels of the Boise River drainage, basalt of the Pleistocene Snake River Group and basalt, sand, silt, and claystone of the Pliocene Glenns Ferry Formation.

The Glenns Ferry Formation is underlain by the lower Idaho Group in the subsurface beneath the western SRP in the Nampa-Caldwell area. Beneath the Idaho Group is a thick section of basalt and sediments. Silicic volcanic rocks of the Idavada Group are notably absent to a depth of 4.3 km (2.7 mi) in a deep well just east of Nampa. Three geologic units have been identified as important cold water aquifers within the middle to upper Glenns Ferry and overlying formations. Within the middle Glenns Ferry Formation, a "blue clay" unit acts as an aquitard that separates the three upper cold water aquifers from lower aquifers containing warm water (>20°C [>68°F]). Unconformities within the upper Glenns Ferry Formation may mean this formation is thin, or absent in the Boise front area.

Six permeable zones which may contain hot water are suspected to exist at depths of approximately 91-213 m (300-700 ft), 457 m (1,500 ft), 640 m (2,100 ft), 1037 m (3,400 ft), 1311 m (4,300 ft) and 1677 m (5,500 ft). Oil company logs for many of the oil and gas wells in the area indicate subsurface temperatures for the six suspected permeable zones to be 30°C, 43°C, 49°C, 58°C, 66°C and 75°C (86°F, 109.4°F, 120.2°F, 136.4°F, 150.8°F and 167°F), respectively. These temperatures are thought to be minimum due to cooling effects of drilling fluids circulated within boreholes during drilling operations. Thicknesses of the permeable zones probably vary but estimates are, respectively, about 15 m (50 ft), 40 m (131 ft), 31 m (100 ft), 100 m (330 ft), 61 m (200 ft) and 75 m (245 ft).

Geochemical studies using stable isotopes of hydrogen and oxygen show that thermal water in the Nampa-Caldwell area is depleted in deuterium and in oxygen-18 relative to cold water. Indications are the water may be either rain or snow water that fell more than 11,000 years ago or evaporated river water which has undergone isotopic exchange of oxygen with aquifer minerals. The geothermal parent water in the Nampa-Caldwell area appears, from isotope data, to be identical to parent geothermal water in the Bruneau-Grand View and Boise areas of the western SRP, or to have a similar source(s) and/or age. Little is known about present day recharge. Chemical data and mixing models, which correlate well with isotope data, indicate geothermal waters may be migrating upward from deeper permeable zones with 75°C to 95°C (167°F to 203°F) temperatures.

A detailed heat-flow contour map of the western SRP was produced from 65 temperature gradients measured in the region. The western SRP is a region of recognized convectively induced high heat flow outlined by a 3.0 HFU contour. Thermal conductivities of 247 samples, selected from well cuttings, drill cores and rock outcrops, were determined to calculate heat-flow values. In addition, 60 previously measured temperature gradients and 85 previously determined thermal conductivities from surrounding areas and from within the area were used. Measurement sites were relatively evenly dispersed, averaging one per 43 km (17 mi).

The average thermal conductivities determined for the major rock units were: granite = 6.01 ± 0.50 TCU; sand and clay = 3.49 ± 0.90 TCU; clay = 2.79 ± 0.51 TCU; silicic volcanics = 4.54 ± 0.24 TCU; basalt = 3.62 ± 0.85 TCU. The average temperature gradient for the area was 78°C/km (4.29°F/100 ft) and the average heat-flow value was 2.55 HFU.

The oil well survey in the Nampa-Caldwell area shows that high temperatures can exist near the surface where there are no visible structures and in areas of low heat flow. This area's low heat flow is caused by infiltration of irrigation water which masks shallow (to 91 m [300 ft]) temperature gradient measurements.

Geothermal gradients in the Nampa-Caldwell area are consistently in excess of 30°C/km (2.6°F/100 ft)down to a depth of at least 3 km (10,000 ft). At a depth of 1,000 m (3,300 ft), temperatures in excess of 45°C (113°F) are expected over most of the area. Development of commercial amounts of geothermal water will be limited by the presence of good intergranular or fracture permeability at depth. Subsurface geological and geophysical data suggest two situations which might yield good flows to wells: 1) Youthful major fault zones which cut the uppermost part of the stratigraphic section and have the largest displacements should retain good fracture permeability, particularly where they cut hard brittle formations at depth. These fault zones are known as the "Eagle-West Boise fault zone, the Middleton fault zone, and the Lake Lowell fault zone." 2) Deep sand aquifers within the lower Idaho Group, and possibly within the older basalt section, may also be good producers of hot water. None of these confined sand aquifers have been tapped by wells for water, but it is likely they would yield hot artesian waters. Sand aquifers of the lower Idaho Group were encountered in two deep wildcat wells in the Meridian area, but have not been encountered in more recently drilled geothermal wells in the Boise area, nor do they occur in the deep wells between Meridian and Middleton. These sand aquifers are probably best developed in the area northwest of Nampa, but their extent is not known. Electrical log interpretation suggest good permeability in these deep sand units.

In summary, geothermal waters of moderate temperature suitable for space heating can be expected at depths of 450 to 1200 m (1,500 to 4,000 ft) over most of the Nampa-Caldwell area. Oil and gas wildcat wells have explored the subsurface, but the deep water-bearing units have not been tested to assess their water producing capacity. The most favorable drilling targets are along the major youthful faults detected by a seismic reflection survey. Areas of proven warm water wells at shallower depths, 200 to 300 m (600 to 1,000 ft), generally lie in the area around Lake Lowell and south to the Snake River. North of this area few warm water wells have been drilled, and locations of warm water wells are spotty. These anomalously warm wells are probably located near fault zones with fracture permeability that serve as conduits for ascending warm waters.

Cassia County (31)

The Raft River Known Geothermal Area (KGRA) in southern Idaho has been the subject of more evaluation than any other area in Idaho. A geothermal exploration program was begun during 1973 by the U.S. Geological Survey in cooperation with the U.S. Department of Energy. Results of these early programs were summarized by Williams and others (1975). Covington (1980) later described the subsurface geology and factors contributing to the convective hot water system based upon drilling data from deep exploration and production wells. A report presenting and interpreting the geological, geophysical, geochemical, and hydrologic data was subsequently compiled by Dolenc and others (1981). Startup of a 5MW(e) pilot geothermal plant occurred in the fall of 1981; final shutdown occurred during June 1982 (Bliem and Walrath, 1983). The plant, built by the Idaho National Engineering Laboratory, successfully demonstrated the technical feasibility of using a moderate temperature (135-149°C [275-300°F]) to generate electrical power in an environmentally acceptable manner. The plant used a dual-boiling binary cycle with isobutane as the working fluid. Seven deep geothermal wells were drilled to support the project, including five production and two injection wells **(31-91, -94, -97, -98, -106, -107 and -108)** in addition to several geothermal gradient and monitor holes. A vast amount of information was obtained on the characteristics of a fracture-controlled geothermal system with respect to production and injection. Fracture-flow analysis was conducted by Rashrash and Ralston (1988) utilizing borehole televiewer logs to identify fractures. Blackett and Kolesar (1983) described geological and mineralogical data from the Raft River geothermal system. The purpose of the study was to characterize the subsurface stratigraphy and geothermal mineral assemblages present in the Raft River system that could ultimately affect the results of injection research studies. Successful non-electric experiments included agriculture, aquaculture, biomass production, wetland studies, and space conditioning (Mink and others, 1982). Reports generated are too numerous to list, but are included in the Idaho geothermal bibliography available through IWWRI (Dansart and others, 1994).

The Raft River KGRA lies in south-central Idaho, near the Utah border, in a valley bounded by mountains on three sides and opening northward to the SRP. The KGRA is located near the south end of the valley. The Raft River Valley is a down-dropped sedimentary basin composed primarily of Tertiary-age siltstone, tuffaceous sandstone, and conglomerate units of the Salt Lake Formation. The overlying Pleistocene Raft River Formation consists of several hundred meters of alluvium and lacustrine sediments. The Bridge fault, trending northward along the west side of the valley, is believed to control upward migration of thermal fluids. The Bridge fault, which dips 60° to 70°, is cut off to the north by the younger Narrows fault zone.

The geothermal reservoir is fracture dominated; hydraulic conductivity is greatest parallel to the Bridge fault zone. Tritium data indicate very young (60 to 70 years old) thermal fluids. Water chemistry indicates the deep geothermal system is hydraulically connected with the shallow aquifer system.

Experiments related to direct and secondary geothermal fluid utilization were conducted at Raft River. The effects of using expended geothermal water for irrigation on selected crops was studied; these crops showed growth rates, yields, and nutritional values comparable to those irrigated with non-geothermal waters (Stanley and Schmitt, 1980). Fluidized bed potato waste drying experiments demonstrated the feasibility of using low-temperature (< 145°C [< 293°F]) geothermal water as a heat source to dry slurry-like industrial products; the system could also be modified to dry solid vegetable products

(Cole and Schmitt, 1980). Biomass production and chemical cycling were studied in a man-made wetland utilizing geothermal water (Breckenridge and others, 1983). Successful experiments raising catfish, carp, and shrimp in geothermal waters were also completed (Mink and others, 1982). Wells RRGP-4 **(31-98)** and RRGP-5 **(31-91)** were selected for hydraulic fracture stimulation experiments, but the desired results were not achieved.

Custer County (37)

Stanley

The Idaho Energy Office completed a site specific development report for Stanley in 1979. The results of this study were favorable for development of a district heating system. The OIT Geo Heat Center (Dellinger and others, 1982) conducted a site specific development analysis of the Stanley area. It was concluded that a geothermal district heating system for Stanley was technically feasible and economically attractive. The reservoir area has significant potential for production of large amounts of thermal water; silica geothermometer estimated temperature is 75°C (167°F). A synopsis of this study follows.

Stanley is situated in a valley surrounded by the Sawtooth and White Cloud mountains in central Idaho. Elevations range from 1865 to 3000 m (6,120 to 9,840 ft). The community is contained within the Sawtooth National Recreation Area which is managed by the U.S. Forest Service. Summers are cool and winters are cold with heavy snowfall (239 cm [94 in] average annual). The temperature falls below 0°C (32°F) more than 300 days a year. This climate necessitates space heating year round. A geothermal district heating system in Stanley would displace some use of electricity, propane, and wood.

The Stanley Basin is a structurally controlled intermountain valley which trends northwest and contains the upper watershed of the Salmon River. The White Cloud Range to the east of Stanley is composed primarily of Cretaceous granite of the Idaho batholith. Younger granite of the Sawtooth batholith is found along the western margin of the valley. The contact between these two batholiths strongly controls the structure of the valley.

A major structure that influences the location of a series of thermal springs known as the Sunbeam Hot Springs district has been named the Mormon Bend fault. The fault lies along the northern boundary of the Stanley Basin and is east-west trending. The fault also controls the course of the Salmon River east of Stanley. Several thermal springs that occur along the Salmon River Canyon, including Sunbeam Hot Springs **(37-17)**, Slate Creek Hot Springs **(37-10)**, Sullivan Hot Springs **(37-21)**, Mormon Bend Hot Springs **(37-16)**, and USFS Campground Hot Springs **(37-15)**, all discharge along the Mormon Bend fault. Many of these springs occur near drainage confluences or ridge points that protrude into a stream.

Stanley Hot Springs **(37-9)** is just north of town at the confluence of Valley Creek and the Salmon River. The spring discharges about 150 gpm of water ranging in temperature from 31°C to 41°C (88°F to 106°F). The water quality of Stanley Hot Springs is good. The spring water is low in total dissolved solids, but relatively high in fluoride (14 mg/l). The drinking water standard for fluoride is 2 mg/l. This fluoride level may limit the available disposal options for a geothermal application. The potassium level at Stanley Hot Springs is significantly lower than most other thermal springs in the area. The low potassium level affects some geochemical measurements which are used to predict reservoir temperatures. The most reliable geothermometer under these conditions is the silica geothermometer which predicts a reservoir temperature of 75°C (167°F). The reservoir area appears to have significant potential for production of large amounts of thermal water.

Based on Stanley's character and the nature of the geothermal resource, potential applications include a spa complex to complement other tourist facilities, greenhouses for local produce, and space heating for homes and businesses. Private interests have discussed developing a spa near Stanley Hot Springs. The community has expressed strong support for the development of a district heating system, and an interest in greenhouses.

Stanley offers the opportunity to develop an existing geothermal resource for the benefit of a community and to serve as an educational tool for the thousands of people who visit the city each year. Numerous other communities in the Northwest have geothermal district heating potential, but few are as advanced in planning as Stanley. Financing is the key to implementing the development of Stanley's geothermal district heating system (Dellinger and others, 1982).

Mackay

Water samples from springs in the Mackay, Idaho area were collected by the University of Utah Research Institute (UURI) to investigate potential of a direct-heat geothermal resource. Geothermometry results suggested that subsurface temperatures for spring waters is not significantly above the measured surface temperatures. The potential for finding a shallow geothermal reservoir with temperatures much above 22°C (71.6°F) appears slight (Sibbett and Capuano, 1984).

Other Sites

The Challis subsection of the southern Idaho batholith appears to have 10-20% higher heat flow than the main portion of the Idaho batholith. Gradients are also significantly higher because the volcanic rocks in the Challis subsection have lower thermal conductivity than the main batholith granite. Significant high heat-flow anomalies occur in the Bayhorse Mining District and along the Salmon River. This part of the Salmon River flows along a major hot springs lineament. Geothermal heat-flow and gradient data of the Bayhorse Mining District suggest the presence of a blind geothermal system (Blackwell and others, 1992).

Elmore County (39)

Mountain Home

The 37 km^2 (14.3 m^2) Mountain Home Known Geothermal Resource Area (KGRA) is located in Elmore County in south-central Idaho about 80 km (50 mi) southeast of Boise and about 16 km (10 mi) east of Mountain Home (Spencer and Russell, 1979d). The KGRA is located between Tertiary and Cretaceous granitic rocks to the east, and the Tertiary and Quaternary rocks of the SRP to the west. Mountain Home lies on the northwest-southeast-trending fault that marks the relatively abrupt transition zone northwest of the KGRA. The major hot springs in the area are controlled by faulting.

Although there are many permanent streams in the area, almost all of them have been diverted for agricultural use. Thermal water is abundant in the area. Temperatures range from 57-68°C (134.6-154.4°F) in springs and in irrigation wells 150-300 meters (492-984 ft) deep. The water is fresh with a TDS content of about 300 ppm.

The OIT Geo Heat Center (Dellinger and others, 1982) conducted a site specific analysis of the Mountain Home Air Force Base. The study was an investigation of the engineering and economic feasibility of developing a heating system to service 1500 housing units on the base. The report concluded more resource assessment was needed to define the limits of resource capability. A summary of the OIT (Dellinger and others, 1982) study follows.

Mountain Home Air Force Base is about fifty miles south and east of Boise, in Elmore County. The base is bordered to the northeast by the Mountain Home KGRA and on the southwest by the Bruneau-Grand View KGRA. The City of Mountain Home had a 1981 population of 7,000; approximately 10,000 people lived on the Air Force Base.

The geologic setting in the area of Mountain Home Air Force Base is favorable for the existence of geothermal resources. This potential has yet to be proven. The geology in the area of the base consists of Pliocene and Pleistocene sediments, Pleistocene basalt and Tertiary rhyolite. These units overlie Cretaceous granite. The rhyolite and granite may have significance in the search for geothermal resources, but their suitability as thermal water reservoirs is unknown. The rock units mentioned above are underlain by the Idavada Volcanics, about 914 m (3,000 ft) thick in the area, which may be a source of hot water.

There are numerous thermal wells and a few hot springs near Mountain Home Air Force Base. Several warm wells are situated just to the west and several miles to the east of the base. Surface temperature of the wells range from 20-25°C (68-77°F). The deepest known well in the area is the Bostick 1-A **(39-71)**. The well was drilled by Union Oil to almost 2743 m (9,000 ft) before casing problems halted further work. It produced 3785 l/min (1,000 gpm) of flowing 132°C (270°F) water. Geothermal gradients indicate that temperatures suitable for space heating could be obtained at depths between 914 and 1219 m (3,000 and 4,000 ft).

Water quality analysis from thermal wells in the area show low levels of total dissolved solids, but somewhat high levels of fluoride. The fluoride may restrict a geothermal project from surface disposal of waste water.

A 1342 m (4403 ft) test hole **(39-52)** was subsequently drilled by the Air Force on the Mountain Home Air Force Base for geothermal exploration. The purpose was to determine the availability of water from geothermal aquifers to supply energy for space heating of military housing and other base facilities. A temperature of 45°C was recorded during sampling; maximum temperature recorded during temperature logging was 93°C (199.4°F) at a depth of 1207 m (3960 ft)(Lewis and Stone, 1988).

Evaluation of an area near Mountain Home as a hot dry rock prospect was performed by Arney and others (1980). A favorable target was identified. Temperatures of 200°C (392°F) were projected at 3 km (9840 ft) depth, with granitic rocks to be intersected at a depth of 2 to 3 km (6560 to 9840 ft). Geothermometry data from nearby shallow wells give predicted reservoir temperatures of 127°C (260°F); this indicates that the water sampled had not been in contact with the higher temperature rocks reported in the Bostic 1-A well (195°C [383°F] BHT). Wells along fracture systems in the area flow at rates up to 18,925 l/min (5000 gpm) with temperatures to 60°C (140°F), indicating a highly productive and permeable zone in the upper portion of the reservoir.

Franklin County (41)

The geology and hydrology of the southeastern Idaho Basin and Range province is complicated. Relatively little study of the ground water system has occurred. It is an area of high topography and extensively faulted, predominantly carbonate rocks. There are several hot springs in Franklin County, most notably Cleveland **(41-4)**, Maple Grove **(41-6)**, Squaw **(41-15)**, and Battle Creek (Wayland)**(41-13)** hot springs (Mitchell and others, 1980). Geochemistry of the thermal water suggests reservoir temperatures of 150-200°C (302-392°F) for some of the hot springs; however, the chemistry of the water is not the most suitable for applications of chemical geothermometers and these estimates are likely high. There have been several geothermal test wells drilled in this province. Well 15S-39E-6ca (SUN-1001)**(41-11)** is about 2 km (1.2 mi) from Battle Creek Hot Springs and about 3.5 km (2.2 mi) from Squaw Hot Springs. The temperatures in this well are dominated by shallow lateral flow of hot water (almost 110°C [230°F] at this location) in the shallow ground water aquifer recharged by upflow of hot water (Blackwell and others, 1992).

Fremont County (43)

Hoover and others (1985) postulated that the Island Park area is underlain by a solidified but still hot pluton that represents a significant hot dry rock resource. Exploration and development activities have been retarded by a lack of surface thermal features, evidence of hydrothermal systems, and environmental concerns. Deep drilling is necessary to substantiate the interpretation and provide heat-flow data.

The Island Park-Yellowstone National Park region comprises a complex caldera system which has formed over the last 2 million years. The caldera system has been estimated to contain 50% of the total thermal energy remaining in all young igneous systems in the United States. The Island Park system contributes 32% of the total thermal energy remaining in the complex and contains twice as much energy as the next largest system, the Valles caldera in New Mexico. These considerations make the Island Park region an excellent site for geothermal exploration, yet there is essentially no activity in the region today. Although development is not permitted within Yellowstone National Park, neither exploration nor development is progressing in the caldera complex outside the park. Environmental concerns have in part caused this, but the lack of surface thermal manifestations and the lack of evidence for hydrothermal systems within the Island Park part of the caldera complex is also responsible. As the result of a reexamination of the data and recent electrical work in the area, Hoover and others (1985) postulate that much of the area where the first- and second-stage calderas developed is underlain by a solidified but still hot pluton. That pluton represents a significant hot dry rock resource for the United States.

Thermal manifestations are notably absent within the Island Park region. Only a few minor warm springs are known; the nearest flowing warm spring is at Ashton Hot Spring **(43-21)**, 20 km (12.5 mi) south of Henrys Fork caldera. Ashton Hot Spring has been measured at 41°C (105.8°F), and is the only spring where geochemical thermometers indicate reservoir temperatures over 90°C (194°F)(Hoover and others, 1985). A 300 m (984 ft) test hole, HFT-19 (OXY-19)**(43-25)**, was drilled near the center of the caldera, reported to be in T12N, R42E, section 36ccb (Blackwell, 1988). In this hole the gradient increases systematically from 27°C/km to 66°C/km (2.5°F/100 ft to 4.6°F/100 ft) with increasing depth; heat flow of the lower half of the hole is 109 mWm^{-2}. These data suggest areas of high heat flow in the caldera. A significant geothermal anomaly may be located at the northwestern edge of the caldera in T13N, R42E, sections 24 and 25. Two 38 m (125 ft) holes near the shores of Island Park Reservoir show uniform and high gradients. Hole WW-IPB2 in section 24 has an average gradient of 189°C/km (11.3°F/100 ft), while hole WW-IPB1 in section 25 has an average gradient of 102°C/km (6.6°F/100 ft). These gradients imply heat-flow values of about 310 and 200 mWm^{-2}, which are distinctly anomalous with respect to regional values and document the presence of a geothermal anomaly in the area. The wells were so shallow that the area had not been recognized to have anomalous temperatures; bottom hole temperatures were below 13°C (55.4°F). A high gradient was encountered just south of the caldera rim in hole

OXY-8, T9N, R43E, section 11bda; a gradient of 155°C/km (9.5°F/100 ft) was measured between depths of 60 and 135 m (197 and 640 ft); bottom hole temperature was below 11°C (52°F)(Blackwell, 1988, 1989; Blackwell and others, 1992).

The absence of surface thermal features at Island Park has been cited as evidence for lack of a hot dry rock resource. According to Hoover and others (1985), this has little significance relative to the presence or absence of a geothermal resource at depth. Large volumes of ground water flow occur in the Island Park area. In the porous upper volcanic units the ground water flow would mask any thermal anomaly associated with conductive cooling of an unfractured pluton. The lack of seismicity of the region also indicates that no major brittle fracturing is occurring by which hydrothermal systems might gain access to the central and hottest part of the pluton.

Active volcanic systems similar to Island Park and in which no thermal manifestations are present within the calderas have been recognized. The existence of systems with no surface expression has been documented at Magic Reservoir, Butte City, and in the vicinity of the Champagne Mine. Data support mostly high heat-flow values (many over 120 mWm^{-2}) on the margins and low values (mostly in the range of 30 to 20 mWm^{-2}) in the SRP aquifer. Low heat-flow areas result from crustal thermal conductivity contrasts as well as from regional aquifer motion. Geothermal and ground water aquifer systems have a major effect on the distribution of surface heat flow along the margins of the SRP aquifer. Based on evidence, geothermal systems appear to be as common along the northern edge of the SRP as along the southern margin (Hoover and others, 1985).

The size (500 km^2 [193 mi^2]) of the possible hot dry rock system present at Island Park implies a significant geothermal heat source. If the heat source is present in Island Park then development of the resource should pose little risk to Yellowstone National Park because of the lack of permeability in the Island Park pluton, the presence of an apparent structural boundary along the Madison fault zone, and a ground water flow direction toward the south and west away from the park.

Idaho County (49)

Kuhns (1980) and Youngs (1981) studied geothermal areas in the Bitteroot lobe of the Idaho batholith and integrated geologic and hydrologic investigations.

Lochsa Geothermal System

Kuhns (1980) outlined the structural and chemical aspects of the Lochsa geothermal system near the northern margin of the Idaho batholith. Heat-flow data suggest a geothermal gradient of 50°C/km (3.7°F/100 ft)with circulation depth estimated at 3 to 4 km (9840 to 13,120 ft). Kuhns postulated a potential geothermal reservoir 300 to 400 km^3 (72 to 96 mi^3) in size exists along the Lochsa River.

The geothermal system investigated is located near the northern margin of the Idaho batholith (Bitterroot Lobe), north of the Selway-Bitterroot Wilderness Area about 32 km (20 mi) west of Lolo Pass, Idaho. U.S. Highway 12 and the Lochsa River traverse the area.

Hot spring vents are found where a northeast-trending dike intersects north- or northwest-trending shear zones. This suggests that circulating thermal fluids moving along the shear zone intersect an impermeable barrier (dike) and ascend along this barrier. All hot spring vents in the study area follow this pattern. Main hot spring vents are located along Weir Creek at Colgate Licks **(49-14)**, and on Warm Springs Creek at Jerry Johnson Hot Springs **(49-16)**. The springs are currently used for recreation and bathing by people traveling along U.S. Highway 12. Eight water samples were collected at vent sites.

According to Kuhns (1980), maximum source temperatures of 170°C to 200°C (338°F to 392°F) are predicted from the chemistry of thermal waters using cation ratios (Cl, Mg, Fe, Mn, Mg/Ca, Na/Ca, Na/Li, Cl/F, Cl/B) and geochemical thermometers (SiO_2, Na/K and Na:K:Ca). Heat-flow data suggest a gradient of 50°C/km (3.7°F/100 ft) exists in the Lochsa area. Geothermometer and heat-flow data combined indicate a reservoir depth for circulating thermal fluids of three to four kilometers. The depths, temperatures, and the low chloride concentrations suggest that a wet steam geothermal field exists under the Lochsa River area. Presently the remoteness and ruggedness of the study area, coupled with the low population density make the area a low priority geothermal resource. Space heating and domestic uses are certainly possible and could benefit local residents along the Lochsa and Clearwater Rivers.

Running Springs Geothermal System

Youngs (1981) characterized the geology and geochemistry of the Running Springs geothermal area. The maximum temperatures indicated by geothermometry are in the 80-90°C (176-194°F) range. Given the low temperature, small probable size and relative isolation of the system, there is little immediate economic potential. A summary of Youngs'(1981) report follows.

The Running Springs geothermal system consists of two major vents (discharge above 100 l/min [25 gpm]) and three minor vents (discharge below 20 l/min [5 gpm]) in the drainages of Warm Springs Creek and Running Creek. Youngs' (1981) investigation encompasses the petrologic, structural, and geochemical aspects of these springs and the 30 km^2 (11.6 mi^2) surrounding area. The study area is located within the central portion of the Bitterroot Lobe of the Idaho batholith, on the eastern margin of the Selway-Bitterroot Wilderness Area. The major thermal springs examined are located approximately 40 km (25 mi) east of the town of Elk City, Idaho, in section 14, T29N R12E, **(49-8)** along the drainage of Warm Springs Creek. One additional thermal spring vent is located in the same section.

The most widespread rocks in the study area are Cretaceous quartz monzonite and Tertiary granite of the Idaho batholith; some Precambrian gneiss is also exposed. Three varieties of rhyodacite dikes and two varieties of rhyolite dikes have intruded the granitic rocks. One of the minor and both of the major thermal spring vents were located in rhyodacite dikes.

The geochemical survey of the Running Springs area consisted of sampling the water at each of the five recognized thermal springs at the same time discharge measurements were made. One nonthermal spring was also sampled.

Application of SiO_2, Na:K, and Na:K:Ca geothermometers indicate maximum source temperatures of 40°C to 80°C (104°F to 176°F). This, combined with a geothermal gradient of 40°C/km (3.2°F/100 ft)(calculated from the heat generation traits of local rocks), suggests a depth of circulation of 1 to 2 km (3280 to 6560 ft). The low source temperatures and geographic isolation of the Running Springs geothermal system suggest little economic development potential.

Jefferson County (51)

Heise Hot Springs (51-1, 51-2)

See discussion under **Bonneville County.**

Lemhi County (59)

Big Creek Hot Springs (59-15)

An evaluation of Big Creek Hot Springs as a source of electrical power for the Blackbird Cobalt Mine was conducted by Struhsacker (1981a-c). Big Creek Hot Springs is one of the hottest known geothermal systems in Idaho, with a surface temperature of 93°C (199°F). Geothermometer estimates of reservoir temperature range from 137°C to 179°C (279°F to 354°F). It was concluded that Big Creek Hot Springs is an excellent geothermal prospect. A suggested exploration program, engineering and economic analyses, and appraisal of institutional factors was outlined.

Big Creek Hot Springs is located approximately 13 miles north of the Blackbird Mine. Reservoir rocks are likely competent Precambrian metamorphic and metasedimentary rocks, with fractures serving as hot water conduits. The system consists of a linear set of spring vents trending N40-45W that intersect Hot Springs fault. The heat source is probably deep circulation of meteoric water. There may be potential for buried thermal anomalies along the entire length of Hot Springs fault.

Several institutional factors complicate the development potential of Big Creek Hot Springs; it lies on U. S. Forest Service land and is close to the River of No Return

Wilderness Area. The distance from population centers precludes development at present of electrical generation potential.

The engineering feasibility study modeled an 11 MWe binary power plant, utilizing propane (95%) and hexane (5%) as the mixed working fluid. It was determined a power plant could be located along Panther Creek; power would be transmitted 20.8 km (13 mi) to where it would tie into the Idaho power grid that services the town of Cobalt (Struhsacker, 1981a-c).

Shoup Geothermal Area

The geology and geochemistry of three hot springs systems in the Shoup geothermal area was investigated by Vance (1986). The study area is located in the region adjacent to the southeastern border zone of the Bitterroot Lobe of the Idaho batholith and west of Shoup, Idaho. Big Creek Hot Springs **(59-15)** is 9.6 km (6 mi) southwest of Shoup, at latitude 45°18'37"N and longitude 114°20'17"W, along Hot Springs Creek. Owl Creek Hot Springs **(59-14)** is 16.1 km (10 mi) west-southwest of Shoup, at latitude 45°20'40"N and longitude 114°27'44"W, along Owl Creek. Horse Creek Hot Springs **(59-16)** is 20.9 km (13 mi) northwest of Shoup, at latitude 45°30'12"N and longitude 114°27'46"W, along Horse Creek.

In addition to structural and petrologic analysis, Vance's study determined physical and chemical conditions for waters from the thermal vent systems and for local and regional nonthermal spring sites. The data obtained from the thermal waters were used to compute temperature of equilibration using various geothermometers.

The geothermal convection systems are contained in permeable fracture zones within impermeable crystalline country rocks. Big Creek Hot Springs and Owl Creek Hot Springs are located in Precambrian rocks. Horse Creek Hot Springs is located in the Tertiary Painted Rocks Lake pluton.

The use of various chemical geothermometers give reasonable agreement and indicate temperatures of equilibration for the three systems studied as follows: Big Creek Hot Springs, 181°C (357.8°F); Owl Creek Hot Springs, 127°C (260.6°F); and Horse Creek Hot Springs, 40°C (104°F) for the vents on Horse Creek and 70°C (158°F) for the vents on Lindgren Creek. The estimated geothermal gradients at Hot Springs Creek, Owl Creek, and Horse Creek of 51°C/km (3.8°F/100 ft), 44°C/km (3.4°F/100 ft), and 51°C/km (3.8°F/100 ft), respectively, give depths of circulation for the thermal waters of 3.4 and 2.4 km (11,152 and 7872 ft) at Hot Springs Creek and Owl Creek, respectively. The shallow high-flow portion of Horse Creek extends to a depth of 0.5 km (1640 ft) and the low-flow portion along Lindgren Creek to a depth of 1 km (3280 ft)(Vance, 1986).

Due to the isolation of the area and the location in National Forest ladn adjacent to primitive areas, economic development of the existing hot spring systems does not appear to be practical.

Lemhi Range

The central Idaho Basin and Range province differs geologically and tectonically from the remainder of the provinces north of the SRP. Heat-flow values in the bedrock of the Lemhi Range are 55-59 mWm^{-2}, significantly below average values elsewhere in the greater Northern Rocky Mountain province. On the other hand the gradient in a deep hole in the adjacent Lemhi River valley is 84°C/km (5.6°F/100 ft) and the estimated heat flow is greater than 105 mWm^{-2}. As is the case with the southeastern Idaho Basin and Range province, deep drill holes are needed to evaluate the intrinsic thermal characteristics of this province. The only deep thermal data are bottom-hole temperature measurements from several hydrocarbon exploration wells drilled near the Idaho/Montana border in the vicinity of the Lima Anticline and two wells drilled in Birch Creek and Lemhi valleys. Unlike some of the wells described in the southeastern Idaho Basin and Range province, none of these wells appear to have gradients in excess of 40°C/km (3.2°F/100 ft). The deepest well, the EXXON Meyers Federal Unit #1 **(33-8)**, located in adjacent Clark County, reaches an uncorrected bottom-hole temperature of 197°C (386.6°F) at 5.7 km (18,696 ft)(Blackwell and others, 1992).

Madison County (65)

Madison County has an agricultural environment in the upper Snake River valley of eastern Idaho. Rexburg, the county seat, has a population of approximately 11,000, plus 6,000 students that attend Ricks College (Kunze and Stoker, 1979).

In the summer of 1980, a 1202 m (3943 ft) well **(65-10)** was drilled at the edge of Rexburg in a region that had been tested by shallower holes. The goal of the project was to identify a geothermal resource suitable for heating several large buildings in the Rexburg area (Kunze and Marlor, 1982) as well as supply industrial food processing energy for a large potato granule plant. Temperatures measured near the bottom of the hole were far below what was predicted or needed and drilling was halted.

The area investigated is within a 30 km (19 mi) radius of Rexburg roughly outlined by a complex of about eight Pliocene calderas known as the Rexburg Caldera Complex (Prostka and Embree, 1978). The complex straddles the northeast-trending boundary between the eastern SRP and the Basin-Range province. The calderas were the source of several major rhyolitic volcanic deposits along the southeast margin of the eastern SRP. Rhyolite flows of the Rexburg Caldera Complex unconformably overlie highly deformed miogeosynclinal sedimentary rocks of Paleozoic and Mesozoic age that are well exposed in the Snake River Range, the Caribou Range, and in the Big Hole Mountains. The rocks apparently do not play an important role in the geothermal system of the area. The rhyolite flows are unconformably overlain by tuffaceous clastic sediments, basalt lava flows, pyroclastic deposits, and rhyolitic ash flow tuff. The various rock types (mainly basalt, rhyolite, and interbed zones) which lie beneath Rexburg act as a common aquifer, although individual well performance varies considerably in different rock types.

No surface manifestations of a geothermal resource exist in the local Rexburg area. A higher than normal geothermal gradient is suggested on the Rexburg Bench, a structural and topographic feature. Thermal springs and anomalies are located along the eastern edge of the SRP. Several geologic features of the Rexburg area constitute evidence for geothermal potential (Prostka and Embree, 1978). High precipitation in the mountains recharges the ground water system which eventually discharges into the Snake River aquifer. The Rexburg Caldera Complex is ideally situated to intercept ground water flow and channel it downward along fault zones. Water may then be heated and stored in closed-basin reservoirs related to caldera subsidence and/or faults of the Basin and Range type. Secondly, continuing tectonic extension may reactivate faults, many of which constitute channels for circulating geothermal water. Finally, the high regional heat flow of the SRP and Basin and Range provinces (Sass and others, 1976) is augmented by Pliocene and Pleistocene rhyolitic volcanism and continuing Quaternary basaltic volcanism, and has facilitated transfer of mantle heat to high crustal levels.

The distribution of hot wells and springs in the Rexburg area is concentrated along major late Cenozoic linear and arcuate fault zones, and especially at the intersections of these zones.

Estimated aquifer temperatures were calculated by using the silica and Na-K-Ca geothermometers of well water samples. The water chemistry and temperature data indicate the existence of a reservoir with a probable temperature in the range of 100-200°C (212-392°F)(Stoker and Kunze, 1980).

Relatively high thermal gradients are to be expected in the Rexburg area at depths where the movement of ground water is not affecting the temperatures. Reported gradients range from 47.8°C/km to 86°C/km (3.6°F/100 ft to 5.7°F/100 ft)(Blackwell and others, 1992).

Elkhorn Warm Spring **(65-1)**

See **Bonneville County** discussion.

Owyhee County (73)

According to Blackwell and others (1992), thermal data collected within the western SRP generally fall into two categories. These categories correspond to areas of relatively high gradient and heat flow (approximately 100°C/km [6.4°F/100 ft] and 120 to 150 mWm^{-2}), and areas of moderate gradient (about 40°C/km [3.2°F/100 ft]) and average heat flow values (60-80 mWm^{-2}). Most of the gradients range between 45°C/km and 85°C/km (3.4°F/100 ft and 5.6°F/100 ft). Heat-flow values range from 50-150 mWm^{-2} with a 100±10 mWm^{-2} average. Areas of high heat flow are distributed in two bands along the northern and southern margins of the western SRP. Lower gradients and heat flow are found along the axis of the SRP between Caldwell and Mountain Home. Deep drilling in the Boise area and in the Bruneau-Grand View region has demonstrated that the high heat-flow values there are related to intermediate temperature (40-80°C [104-176°F]) geothermal systems and relatively local geothermal anomalies. Typical temperature-depth curves in the Boise front geothermal system and in the Bruneau-Grand View geothermal system show isothermal or low gradient sections starting between 80 and 280 m (262 and 918 ft) with temperatures of 40°C to 80°C (104°F to 176°F). Geochemistry suggests that maximum temperatures in the geothermal systems are 70-100°C (158-212°F). This accounts for the high gradients and heat flow that are measured in holes 50-200 m (164-656 ft) deep and range up to 80°C (176°F). This pattern of heat flow and gradient is due to systematic regional flow of ground water toward the edges of the SRP from the higher elevation margins. Very low heat flow that may represent part of the recharge system occurs south of the Bruneau-Grand View area. At the edge of the SRP hydraulic boundaries cause upflow, which gives rise to the geothermal systems at the various locations. Average heat-flow values are on the order of 50-100% above regional background values. Outside the areas of most active fluid flow, temperature-depth curves are linear to depths of at least 400-500 m 1312-1640 ft).

High gradients and heat flows are also found in holes drilled in granitic rocks on both margins of the SRP. The high heat flows are related to crustal deformations along the SRP margins. Heat flow is 25% to 50% higher along the margins of the SRP than at the center. The regional heat flow south of the SRP is about 100 mWm^{-2}, about 75 mWm^{-2} north of the SRP and approximately 60 to 75 mWm^{-2} in the central SRP (Blackwell and others, 1992).

Large areas of the western SRP have temperatures of over 50°C (122°F) at depths of 500 m (1640 ft) or less. Within the lowest gradient areas of the western SRP a temperature of 40°C (104°F) can be expected at a depth of 500 m (1640 ft). Fluids and temperatures suitable for many low temperature geothermal resource applications exist in most places.

The Owyhee Uplands province is south of the SRP. It is a low relief volcanic plateau built on a largely unknown basement. Its boundary with the SRP is marked by subsurface faults, but is not abrupt at the surface. Gradients range from 16°C/km (1.8°F/100 ft) to over 75°C/km (5.1°F/100 ft); average geothermal gradient is 51±4°C/km (3.8±1.2°F) and the average heat flow is 98±7 mWm^{-2}. These values are significantly above those in central and northern Idaho; the low values may be due to regional downflow. The gradient average for the Owyhee Plateau is less than the western SRP, but the difference in heat flow is not significant. The rocks encountered in the drill holes are mostly silicic volcanic rocks with higher average thermal conductivity values than the sedimentary rocks in the western SRP, thus lower gradients for a similar heat flow (Blackwell and others, 1992).

Bruneau-Grand View Area

According to Mabey (1983), the largest hydrothermal system in Idaho is in the Bruneau-Grand View area of the western SRP with a calculated reservoir temperature of 107°C (225°F). More information is needed to define the extent of the system and source of hot water; no evidence in the existing data indicates that large volumes of water hotter than that indicated by geothermometers will be found within 3 km (9840 ft) of the surface.

The Bruneau-Grand View area occupies about 2850 km^2 (1,100 mi^2) on the southern margin of the SRP in northern Owyhee county. The area has a rural population dependent on ground water for irrigation. Temperature of the ground water ranges from 15°C (59°F) to more than 80°C (176°F). Ground water for irrigation is obtained from flowing and pumped wells. Discharge of thermal ground water from 104 irrigation wells and 5 hot springs in 1978 was about 62,266,500 m^3 (50,500 acre-ft)(Young and others, 1979).

Young and others (1979) divided the Bruneau-Grand View area into four geographic units: Castle Creek, Grand View, Little Valley, and Bruneau Valley. The investigators inventoried 104 irrigation wells and 5 hot springs, made measurements or estimates of their discharges and pumping levels, and measured or reported water temperatures throughout the 1978 irrigation season.

According to Young and others (1979), heat from the Bruneau-Grand View system is discharged convectively by hot water which discharges naturally from hot springs or artificially through pumped or flowing wells. Prior to any development in the area, all convective heat flux was by hot spring discharge. Presently, almost all convective heat flux is by hot water discharge from irrigation wells.

Historic data from Stearns and others (1937, p. 148) show 11 hot springs or groups of hot springs within the boundaries of the four geographic units included in the Young and others (1979) study. Temperatures of the springs ranged from about 38°C to 49°C (100.4°F to 120.2°F), and discharges ranged from about 95 to 6814 l/min (25 to 1,800 gpm). From these data, the natural convective heat flux from the Bruneau-Grand View area was estimated to be about $9\text{x}10^6$ cal/s. Total convective heat flux from the Bruneau-Grand View area was about $4.97\text{x}10^7$ cal/s in 1978. Only about 1 percent of this total was natural discharge from the hot springs in the Bruneau Valley unit; 99 percent was contained in water pumped or flowing from wells (Young and others, 1979).

Bruneau Known Geothermal Resource Area (KGRA)

According to Spencer and Russell (1979a), the Bruneau KGRA is located in eastern Owyhee County on the Bruneau River. This KGRA is part of the large thermal anomaly that includes the Castle Creek KGRA. Fluoride levels are high in thermal waters, even in waters of low total dissolved solids.

Bruneau lies just north of the fault zone forming the southern edge of the Snake River graben. Miocene silicic volcanic rocks form the Owyhee Plateau and underlie the KGRA. These may be related to the Idavada Volcanics exposed north of the Snake River graben. Surface geology consists of interbedded lava flows, lacustrine and fluvial sedimentary deposits of the Idaho Group dating from early Pliocene time. Upper Pleistocene terrace gravels are exposed along the margins of the Bruneau Valley, and alluvial deposits form the valley flood plain.

Castle Creek KGRA

The Castle Creek KGRA, as described in Spencer and Russell (1979b), is part of the Bruneau-Grandview thermal anomaly. The area may have potential for greenhouse operations and other low-temperature, direct-heat applications, utilizing warm water from shallow depths. Water from sedimentary aquifers is generally higher in total dissolved solids and has low fluoride levels, while that water produced from the volcanic aquifers has significantly higher levels of fluoride but lower total dissolved solids.

The Castle Creek KGRA lies on the downthrown side of the southern margin of the western SRP graben. The KGRA is associated with the western Idaho fault zone which is suspected to have been recurrently active since middle Miocene. Miocene silicic volcanic rocks occupy the region of the fault zone south of the KGRA in the foothills of the Owyhee Mountains. Idaho Group formations, dating from the Pliocene, constitute most of the rocks exposed at the surface and form badland topography over much of the area. Rock units include basalt lava flows and consolidated lacustrine and fluvial facies. Faults in these formations apparently serve as conduits for the geothermal anomaly (Spencer and Russell, 1979b).

Grand View

OIT Geo Heat Center (Dellinger and others, 1982) conducted an analysis of the Grand View area. A number of thermal wells, ranging from 25°C to 83°C (77°F to 181°F), are situated within a 4.8-km (3-mi) radius of the town. Several buildings were already heated by warm water. The study concluded that Grand View has good geothermal energy potential, but the economics of a district heating system were not very attractive.

Grand View is a small community along the Snake River, located in Owyhee County at the junction of State Highways 67 and 78 in the Bruneau-Grand View KGRA. The climate is classified as semi-arid, having warm summers and cold to moderate winters. The area around Grand View has been designated as a Known Geothermal Resource Area (KGRA) by the U.S. Geological Survey.

The geology of the Grand View area has been analyzed by a number of authors. The youngest lithologic unit in the area is the Idaho Group. It consists of poorly to well-stratified deposits of unconsolidated to semi-consolidated gravel, sand, silt and clay with numerous layers of ash, basaltic tuff, and thin basalt flows. In the Grand View area, the unit is about 518 m (1,700 ft) thick. The oldest formation within the Idaho Group is the Banbury basalt, 91 to 152 m (300 to 500 ft) thick in the Grand View area. Another important unit is described as consisting of Tertiary silicic volcanic rocks and silicic latite; it underlies the Banbury basalt. The unit has been jointed and fractured near the contact zone with the Banbury basalt.

The consolidated volcanic units are the targets for obtaining thermal waters. Wells in the Grand View area that penetrate the Banbury basalt and the Tertiary silicic volcanics commonly have high artesian pressures. The upper portion of the Idaho Group acts as a cap rock on the ground water system that occurs in the two consolidated lower volcanic units. Wells in the area commonly produce 60°C (140°F) water from depths of 762-915 m (2,500-3,000 ft). Artesian shut-in pressures in some wells are as high as 94 psi at the surface.

Many geologists believe that recharge to the thermal ground water system occurs as precipitation on the plateau and mountains to the south and southwest.

Dellinger and others (1982) report that water quality analyses were performed for six thermal wells in the Grand View area that range in depth from 396 to 732 m (1,300 to 2,400 ft). However, only five wells are listed with depths from 494 m to 905 m (1620 ft to 2970 ft) (Dellinger and others, 1982, p. 135, Table 1)**(73-89, -91, -95, -97, and -98)**. Overall, the water quality is good. The only constituent which exceeds drinking water standards is fluoride.

Indian Bathtub Area

The Indian Bathtub area is about 96 km (60 mi) southeast of Boise in southwestern Idaho. Young and Parliman (1989) presented physical, chemical and isotopic data collected from 86 thermal water wells and 5 springs in the Indian Bathtub area. These data were collected as part of a study to determine the cause of decreased discharge at Indian Bathtub Hot Springs **(73-273, 73-277)** and other thermal springs along Hot Creek. The data include well and spring locations, well construction and water level information, hydrographs of water levels in 9 wells, hydrographs of discharges in 4 springs, and chemical and isotopic analyses of water from 33 thermal water wells and 5 springs. In addition, Young and others (1990) presented results of test drilling and hydrologic monitoring of the Indian Bathtub area.

More recently, interest in the decline of thermal spring flow and its impact on the threatened Bruneau Hot Springs snail has resulted in studies of the thermal system. Berenbrock (1993) studied the effects of well discharges on hydraulic head and thermal spring discharge in the Indian Bathtub area and determined that a hydraulic head/spring discharge relation exists for two sites at Indian Bathtub Spring and a nearby test hole **(73-273)**.

Twin Falls County (83)

Twin Falls County is located in south-central Idaho between the Snake River and the Nevada border. Surface geothermal manifestations near Twin Falls are limited to three hot springs issuing from faults: Miracle Hot Springs **(83-21)** and Banbury Hot Springs **(83-33)** in western Twin Falls County near the Snake River, and Nat-Soo-Pah Warm Spring **(83-153)** south of Twin Falls. Magic Hot Springs **(83-181, 83-182)** occur in the southeastern corner of the county near the Idaho-Nevada border. Except for development of the Banbury Hot Springs spa around 1910, little use was made of the thermal resource until the 1970's. During the mid-1970's, western Twin Falls County began using the resource, tapped by relatively shallow wells, for aquaculture and space heating. In the late 1970's an increasing number of residents installed wells to utilize the thermal water (Lewis and Young, 1989).

Banbury Hot Springs Area

Lewis and Young (1982a) characterized geothermal resources in the Banbury Hot Springs area. An inventory of wells and 2 thermal springs in the area was completed. Water levels and discharge rates were measured, and chemical analyses were conducted. Estimated age of geothermal water is at least 100 years and possibly more than 1000 years. Reservoir temperature is estimated between 70°C and 100°C (158°F and 212°F). A summary of the Lewis and Young (1982a) report follows.

The Banbury Hot Springs area is located immediately south of the Snake River between Salmon Falls Creek and Deep Creek in Twin Falls County, south-central Idaho. In the early 1970's, several wells that produce thermal water were drilled. Successful use of these wells led to increased development of the resource. In 1982, 26 wells that produce thermal water had been completed. Many residents were concerned that continued development could limit geothermal water available to current users. If continued development reduces flow or causes heads to drop below land surface, the economic advantage of using the resource will be impaired.

Thermal water in the Banbury area is used for residence heating, catfish and tropical fish production, greenhouse operation, swimming pools, and therapeutic baths. In 1979, 12,699,900 m^3 (10,300 acre-ft) of thermal water was utilized. The thermal waters sampled are sodium carbonate or bicarbonate in character and slightly alkaline. Mixing of hot (72°C [161.6°F]) water with local cooler ground water can be shown from various relations among stable isotopes, chloride, and enthalpy.

Lewis and Young's (1982a) study included: 1) inventory of 50 thermal and nonthermal wells and 2 thermal springs in the Banbury Hot Springs area; 2) collection of water level or pressure information and discharge measurements, where possible, at the time of inventory; 3) collection of water samples from 21 thermal wells and 2 thermal springs for chemical analyses, including common ions, silica, and the minor elements of arsenic, boron, lithium, and mercury; and 4) collection of water samples from nine wells and two springs for deuterium and oxygen-18 analyses, four wells and one spring for tritium analysis, and two wells and one spring for sulfate-water isotope analysis. Water level measurements were used to compile a generalized potentiometric map. Discharge measurements and water temperatures at land surface were used to determine the present quantity of thermal water being utilized and the associated convective heat flux. Reservoir temperatures were estimated for all sampled thermal water in the Banbury Hot Springs area and for selected thermal water in the nearby areas using the silica and Na-K-Ca geothermometers. Reservoir temperatures for two wells and one spring were estimated by using the sulfate-water isotope geothermometer. Relations of selected chemical constituents to deuterium and oxygen-18 isotopes and concentrations of tritium were used to distinguish and define the approximate areal extent of the Banbury Hot Springs geothermal reservoir.

Rocks underlying the Banbury Hot Springs area are volcanic and sedimentary in origin and range in age from late Miocene to Holocene. They are divided into: 1) Tertiary silicic volcanics; 2) Tertiary basalt; 3) Quaternary and Tertiary sedimentary rocks; and 4) Quaternary basalt and sedimentary rocks. A large number of the springs in the canyon walls at Thousand Springs occur at the contact between the Tertiary and Quaternary basalt units. Permeability appears to decrease drastically at the contact betweeen the older and younger basalt.

Tertiary silicic volcanics consist chiefly of welded tuff of the Idavada Volcanics of late Miocene age and are exposed locally in the canyon of Salmon Falls Creek and in the uplands southwest of the Banbury Hot Springs area. Total thickness of the Idavada Volcanics in the vicinity of Banbury Hot Springs exceeds 610 m (2,000 ft)(Malde and Powers, 1962). Tertiary basalt, consisting chiefly of olivine basalt flows of the Banbury Basalt of late Miocene age, is the predominant rock unit in the area. This unit is reported to be about 198 m (650 ft) thick. Quaternary and Tertiary sedimentary rocks, consisting chiefly of detrital basin fill deposits of the Glenns Ferry Formation of late Pliocene and early Pleistocene age, are also exposed throughout the area.

Several northwest-trending normal faults have been mapped in the area studied. Most faults have their downthrown side on the northeast. Some graben and horst structures occur southwest of the study area. Most of the faulting probably occurred in late Miocene time, although some faulting continued through Pleistocene time.

Most wells are located in a narrow belt centered along the extension of a northwest-trending fault. Other northwest-trending faults southwest of the study area act as barriers to ground water movement from the southwest. Artesian heads in wells at the time of the study were as much as 110 m (360 ft) above land surface. The hottest water (temperature near 72°C [161.6°F]) occurs in the vicinity of Salmon Falls Creek **(83-12)**. On the basis of available heat-flow data, depth of circulation in the system required to attain water temperatures near 70°C (158°F) is about 1341 m (4,400) feet. Because these temperatures occur in water from wells 128 to 213 m (420 to 700 ft) deep, some convective transport of heat, probably upward along faults, is indicated.

A general increase in concentrations of chloride, fluoride, and boron occurs with an increase in temperature. Indications are that of a mixing of hot water from a single deep source with shallow cooler local ground water to give the range of temperature and chemical makeup evident in the Banbury thermal waters. Concentrations of tritium in samples indicate that most thermal water contains little or no post-1954 water and is probably at least 100 years old and perhaps more than 1,000 years old (Lewis and Young, 1982a).

The Earth Science Lab Division of the University of Utah Research Institute (UURI) provided geologic assistance to Fishbreeders of Idaho, Inc. to locate a thermal well for operation expansion. The study area was located near Banbury Hot Springs in the Hagerman Valley, about 32 km (20 mi) west of Twin Falls (Blackett, 1981a).

Hagerman Valley is the site for much of Idaho's commercial fish industry. Cold water fish species are raised from numerous cold springs that discharge from the canyon wall on the northeast side of the Snake River. Warm water fish species are raised in thermal water produced from wells located southwest of the Snake River. No thermal wells or springs are known to occur on the northeast side of the Snake River and therefore the general course of the river has been considered as the approximate boundary to the geothermal system (Lewis and Young, 1980a).

Goldman (1982) documented the development of the Leo Ray fish farming operation near Buhl, which utilizes geothermal energy **(83-53, 83-54)**. History of development is described and recommendations for future resource evaluation are presented.

UURI conducted an evaluation of exploration methods useful for low-temperature geothermal systems in the Artesian City area (Struhsacker and others, 1983). Each technique was critiqued and an exploration strategy outlined.

Central Twin Falls County

Lewis and Young (1989) characterized the hydrothermal system in central Twin Falls County. The report described the areal extent and thickness of the hydrothermal reservoir and proposed a conceptual model of the system. They concluded the reservoir is approximately 1000 km^3 (240 mi^3), with aquifers contained primarily in the Idavada Volcanics. Aquifer thickness ranges from 213 to 610 m (700 to 2000 feet). Estimated reservoir temperature is 70°C to 80°C (158°F to 176 °F); carbon-14 age dates place samples from 1000 to 10,000 years old. Net heat flux is about 2.2 HFU.

An investigation of the thermal resource in central Twin Falls County was conducted by the Idaho Department of Water Resources. The initial part of the study, completed by Street and DeTar (1987), provided baseline data on geology, historic pressure and temperature fluctuations in the system, and thermal water geochemistry. The second part of the study included continued monitoring of system temperatures and pressures, additional water chemistry and rock geochemistry. This portion of IDWR's investigation was completed by Baker and Castelin (1990); a conceptual model was proposed.

According to Baker and Castelin (1990), the Idavada Volcanics and Paleozoic sedimentary rocks east of Hollister act as part of the geothermal aquifer. A north to northwest flow pattern is implied. Although water level decline is apparent in developed areas, discharge due to pumping does not exceed natural recharge.

Mariner and others (1991) investigated the chemical, isotopic, and dissolved gas compositions of the hydrothermal system in Twin Falls and Jerome counties. It appears thermal waters range in age from 2000 to 26,000 years. Westward-flowing older water, north of the Snake River, may join younger northward-flowing water; main direction of flow in the hydrothermal system seems to parallel surface drainage.

According to Lewis and Young (1989), the artesian pressure of the geothermal system in Twin Falls county has been used to generate electricity for sale to power companies. Low hydraulic head hydrogenerators have been installed on some flowing warm water wells. Discharge from these wells is generally sufficient to produce some electricity, but the heat content of the resource is not efficiently used. Increased utilization of the thermal water has caused aquifer pressures to decline in recent years. Near the city of Twin Falls, pressure declines of up to 15 pounds per square inch since 1984 have been documented, and water levels in some formerly flowing thermal wells have declined to below land surface.

Lewis and Young (1989) state that the thermal water occurs primarily in the silicic volcanic rocks of the Idavada Volcanics. Electrical resistivity soundings indicate that the Idavada Volcanics are continuous beneath most of the area; thickness ranges from about 213 to 915 m (700 to 3,000 ft) and averages about 610 m (2,000 ft). Reservoir volume is about 1000 km^3 (240 mi^3). Temperatures of water sampled range from 26°C (78.8°F) to nearly 50°C (122°F) in wells completed in the upper part of the reservoir; the warmest temperatures occur near Twin Falls.

Most of the thermal water is a sodium bicarbonate type. Carbon-14 concentrations in selected thermal water samples indicate ages of 1,000 to 15,000 years. The water becomes progressively older northward along proposed ground water flowpaths. According to Baker and Castelin (1990), the chemistry of the thermal water appears to be strongly governed by the chemical composition of and exposure time to the rocks that it comes in contact with. The shorter flow paths to the south appear to occur entirely within the Paleozoic rocks, as indicated by the calcium bicarbonate chemistry of the thermal water. As the flow paths become progressively longer towards the north, the thermal waters apparently encounter the silicic volcanics during their ascent. The chemistries of the thermal waters gradually equilibrate to the new host rock conditions and lose their Paleozoic signatures as exposure time increases. Ultimately, the chemistry of the thermal water changes to a sodium bicarbonate type.

The net heat flow for the area is between 2.2 and 3.7 HFU's, depending on variables assigned. The 3.7 HFU is an anomalously high heat flow for south-central Idaho and would be more representative for heat flow in an active geothermal area. The 2.2 HFU is more compatible with values for margins of the SRP published by Sass and others (1971) and Brott and others (1976, 1978) and probably is a better estimate for the Twin Falls area. The more credible lower value requires a system older than 5,000 years and recharge rates considerably less than 0.31 m^3/sec (11 ft^3/sec)(Lewis and Young, 1989).

The mountainous terrain to the south and southeast of the study area is thought to be the recharge area for the geothermal system. Natural discharge from the system occurs primarily through upward leakage to the overlying cold-water system. Where topographic and geologic conditions are favorable, thermal water flows at land surface as springs and seeps. Based on the relative positions of the presumed recharge and discharge areas of the system, a north to northwest direction of flow is implied.

Significant declines have been observed in the potentiometric surface in areas where development of the thermal resource has been most concentrated. Based on observed water-level trends, it appears total discharge does not exceed recharge. Apparently, the amount of upward leakage that naturally took place in these areas has been reduced by approximately the amount of discharge from wells (Baker and Castelin, 1990).

A monitoring network of five wells in the Banbury Hot Springs area was established in the fall of 1983. A similar network of four wells was established for the Twin Falls area in the spring of 1984. It is Street and DeTar's (1987) opinion, based on well testing, similarity of monitoring results, responses to changes in discharge and water chemistry, that there seem to be no barriers to thermal water movement within or between the Twin Falls and Banbury portions of the system. While the Twin Falls and Banbury portions of the system appear hydrologically connected, the source of the heat component at Twin Falls is not clear.

Monitoring of the aquifer has shown that temperatures have remained constant while water levels are still declining and have not reached equilibrium. The seasonal fluctuations indicate response to the decrease in discharge, not necessarily to recharge.

The monitoring also demonstrated that the aquifer responds rapidly to the development and usage of new wells or to the repair and shut-in of existing wells; this indicates good hydraulic interconnection between the Banbury and Twin Falls portions of the system (Street and DeTar, 1987).

Valley County (85)

An environmental analysis of the Vulcan Hot Springs KGRA was completed by EG&G, Idaho (Spencer and Russell, 1979e) as part of a preplanning environmental program related to Known Geothermal Resource Areas in the Snake River Basin. A second report, USGS Open-file Report 80-518, consists of a telluric profile and location map for Vulcan Hot Springs KGRA (Christopherson and others, 1980).

The Vulcan Hot Springs KGRA is one of the more remote KGRA's in Idaho. Vulcan Hot Springs **(85-21)** are composed of 13 vents with a combined discharge of 32 l/sec (507 gpm) and a surface temperature of 84°C (183.2°F). The chemistry of Vulcan Hot Springs indicates a subsurface resource temperature of 147°C (296.6°F). The resource may be a candidate for power generation. Geologically, the Vulcan Hot Springs KGRA is located a few kilometers east of the western margin of the Idaho batholith. The KGRA follows a north-trending lineament which probably controls the presence of the hot springs (Spencer and Russell, 1979e).

Washington County (87)

Washington County has attracted geothermal exploration activity due to the presence of Weiser **(87-18)** and Crane Creek **(87-7)** hot springs. The thermal values from shallow holes are quite scattered with gradients and heat flow values ranging from 20.4°C/km (2.1°F/100 ft) and 32 mWm^{-2} to 84°C/km (5.6°F/100 ft) and 102 mWm^{-2}. The average heat flow value is 57 mWm^{-2} and the average gradient is 45°C/km (3.4°F/100 ft). A nonequilibrium bottom hole temperature for the Christiansen #A-1 well **(87-10)** is 130°C (266°F), resulting in an estimated gradient of greater than 48°C/km (3.6°F/100 ft), and an estimated heat flow of 76 mWm^{-2}. Heat flow and gradient are significantly lower than those found in the western SRP (Blackwell, 1989).

Crane Creek KGRA

The Crane Creek KGRA is located in Washington County in southwestern Idaho. Estimated resource temperature is 166°C (330.8°F)(Na-K-Ca) to 176°C (348.8°F)(quartz). The KGRA is situated along the west side of the north-south-trending Idaho fault zone. An environmental assessment of the area was performed by EG&G, Idaho (Spencer and Russell, 1979c).

Cretaceous Idaho batholith rocks are exposed approximately 20 km (12.5 mi) east of the Crane Creek KGRA. Older Mesozoic and Paleozoic metavolcanic and metasedimentary rocks are exposed approximately 11 km northwest of the KGRA. These rocks are believed to form the basement complex under the Crane Creek KGRA.

The dominant structures in the Crane Creek KGRA are a series of north-northwest-trending high-angle faults that form a narrow structural zone that trends across lower Crane Creek and parallel to the Weiser River. This fault zone coincides with a steep gravity gradient that is suggestive of a major structure in basement rocks at depth. Hot springs along Crane Creek are located on the east side of the fault zone and may be related to hot water rising along a deep-seated basement fault and into younger faults in the overlying lavas. The overlying sandstone units are fractured and displaced by minor faults. Small faults in the sediments may have resulted from continued movement on older faults in the underlying lavas or from subsidence related to hot spring activity. The hot springs in the Crane Creek area are located along the margin of a siliceous sinter terrace or in adjacent sediments covering part of a sinter apron (Spencer and Russell, 1979c).

Weiser and Little Salmon River Drainages

Fifteen thermal springs, two thermal wells, and eight cold springs in the Weiser River and Little Salmon River drainages were sampled for deuterium and oxygen-18 analysis during the fall of 1981 by the Idaho Department of Water Resources (Mitchell and others, 1984). The analysis suggests that thermal waters might be Pleistocene age. Isotopic data indicate little evidence for mixing of thermal and nonthermal waters. A summary of the IDWR study follows.

A high-angle fault east of the hot springs area is a possible source for the thermal water. The high-angle faults associated with a graben structure believed to exist near the western margin of the study area may also provide conduits for the movement of thermal water.

Most thermal water occurrences in west-central Idaho are confined to arcuate zones defined by the general courses of the South Fork of the Salmon and the Weiser rivers. Springs that do not lie on this arcuate trend are generally found east of this zone and include Cove Creek Hot Springs **(87-1)** and Crane Creek Hot Springs **(87-7)** in Washington County, and White Licks Hot Springs **(3-6)** in adjacent Adams County.

Samples were taken along the length of two of the arcuate zones defined in the Weiser River and Little Salmon River drainage basins to determine isotopic compositions of thermal water along their lengths. Sites for isotopic sampling along the arcuate trends were chosen on the basis of surface temperature and geographic location. All springs were sampled during the fall of 1981 to insure sampling of perennial discharge. A total of 24 samples were collected.

Many of the thermal springs and wells are found on or near major mapped faults or near contacts of different rock units. Thermal wells generally have been drilled into Miocene stream or lake deposits or Quaternary alluvial deposits close to their contact with basalt rocks or with each other.

Only a few deep wells have been drilled in the Weiser Hot Springs-West Weiser Flat area. These include: a 244 m (800 ft) deep well **(87-22)**(11N-6W-10cca2) drilled near Weiser Hot Springs **(87-18)**, from which thermal water flows, that was formerly used for greenhouse space heat and for a natatorium; Weiser Strat No. 2 well (11N-6W-15aal), drilled by Phillips and then plugged, was 209 m (658 ft) deep and encountered 64°C (147°F) water near the bottom; Weiser Strat No. 3 well, drilled to 437 m (1550 ft) again by Phillips, that bottomed in basalt and had no water reported in the well; and well 11N-5W-33bcl, drilled by the City of Weiser for municipal use [no temperature is given for this well and therefore it is not included in the data base]. An interesting aspect of the logs from these wells is the association of thermal water (<100°C [<212°F]) with a lithologic unit identified by a water well drillers' term "blue clay". "Blue clay" is associated with thermal water in the Crane Creek, Parma, Nampa-Caldwell, and Boise areas of the western SRP and has been noted in drillers' logs in thermal wells as far east as Bannock County. In the Nampa-Caldwell area a "blue clay" acts as an aquitard or cap rock, separating nonthermal water from thermal water found below the "blue clay" [(Anderson and Wood, 1981)](Mitchell and others, 1984).

In the Weiser Hot Springs area, based on geologic data, there is no obvious reason for the hot springs occurrence. Therefore, it is assumed that the hydrothermal water is generated elsewhere and brought to the surface through some minor structure.

The isotope data gathered indicate that recharge to the thermal systems is from ancient (Pleistocene) precipitation which fell in proximity to the thermal discharges on adjacent slopes or in adjacent mountain ranges. Thermal waters issuing from Weiser, Crane Creek, Cove Creek, and White Licks hot springs have been enriched in oxygen-18, indicating that these waters have been at higher temperatures than other thermal waters sampled from the study area. There is little or no evidence in the isotope data to indicate that sampled thermal waters are mixtures of thermal and nonthermal waters. Possible exceptions might be water issuing from Stinky (also spelled *Stinkey*) Warm Springs **(3-19)** in Adams County, and the Glen Hill well **(87-16)**(Mitchell and others, 1984).

RECOMMENDED FUTURE STUDY AREAS

Introduction

Site specific studies of the economic potential for geothermal development were conducted during the period from 1978 to 1982 for several Idaho communities. Most of these investigations show the need for further exploration of the geothermal resources for many areas in Idaho. Areas that should be further investigated are discussed below by county. The Twin Falls area is considered the highest priority for immediate study due to the heavy use of the resource that has caused a significant local water level decline, as well as underutilization of the resource that is withdrawn from the aquifer. Other areas of interest have not been prioritized.

Ada County (Boise area)

An extensive review of data and evaluation of the Boise Geothermal Aquifer was conducted by the Berkeley Group (1990) under contract to the Idaho Department of Water Resources. The Berkeley Group evaluated an area extending from approximately 2.4 km (1.5 mi) southeast of the State Capitol building to 0.8 km (0.5 mi) northwest along the Boise Front. Pressure and temperature response modeling was conducted. The report concluded that: 1) geothermal production wells along the Boise Front Fault communicate readily and 2) interference occurs between production wells and affects water levels along the fault in general. Further hydrologic, geophysical and geochemical investigations are needed to predict the effects of development on the geothermal aquifer and its longevity.

The report outlined needed monitoring and recommended methods for further investigation. Locations of slim hole observation wells were proposed, along with identification of existing wells for temperature and water level monitoring. Recommendation of a long-term flow test was also made, along with installation of accurate total flow devices on selected production wells. Regular geochemical sampling of major pumping wells and tracer testing of injection wells was also suggested. Details of the proposed follow-up studies are contained in the report (Berkeley Group, 1990).

Bannock County (Pocatello-Tyhee and Lava Hot Springs areas)

Corbett and others (1980) believed that warm water suitable for space heating may be available in the Tyhee area if structures controlling thermal water movement can be identified at depth. Highest estimate of subsurface temperature at drillable depth is 80°C (176°F); a low of 41°C (105.8°F) is represented by surface discharge in the area.

Additional data collection is necessary before a realistic assessment of the geothermal resource can be made. Corbett and others (1980) recommended the following additional studies:

1) Flow tests on the known warm water wells to determine sustainable yield and well interference potential.

2) Seismic and electrical prospecting to delineate locations of controlling geologic structures.

3) Monitoring holes drilled and aquifer tests conducted to determine aquifer characteristics and well interference potential. Monitoring holes would help better determine structural and stratigraphic controls on thermal and nonthermal water in the area.

4) Hydrogen-deuterium and oxygen 18-oxygen 16 isotope ratios should be determined for both thermal and nonthermal water in the Tyhee area to indicate origin of the thermal waters.

In the Lava Hot Springs area, McClain (1978) described investigations undertaken to determine the feasability of designing a district heating project. Flow potential, temperatures, and low likelihood for interference with existing wells appeared to favor the project. A follow-up investigation in the near future may be warranted.

Boise County (Garden Valley area)

Several greenhouses, resort facilities, and numerous homes use geothermal resources to provide hot water and space heating needs in Boise County, particularly in the Garden Valley-Crouch area, a major developing area for space heating. The combination of relatively high temperatures at shallow depth, moderately productive domestic wells, nearby developments, and a user base make this an attractive area for further investigation. The geothermal reservoir is a fracture-controlled granitic aquifer.

According to Blackwell (1988), the area with the most documented geothermal gradient and heat flow data is just west of Garden Valley along the South Fork of the Payette River. The nature of the geothermal system is still unknown and further studies are needed. There may be significant potential for development of some of these systems for space and/or process heating where nearby developments exist (Blackwell, 1989).

Further detailed study of the geothermal reservoir should be conducted. Well inventory, current water level measurement, and determination of historic water level decline patterns should be carried out. Aquifer tests and heat hole drilling should be conducted to determine potential size of geothermal aquifer and temperature expected. Other aquifer characteristics such as recharge and discharge areas, hydrologic boundaries, and structural controls should be investigated.

Camas County (Camas Prairie area)

The Camas Prairie, especially the Magic Reservoir area, has above average geothermal potential. Temperatures are certainly in the range of 30-40°C (86-104°F) at depths of 300± m (984±) and may be high enough for commercial electric power production in the most favorable case. High gradients are also indicated along the north and south edges of the Mount Bennett Hills (Blackwell, 1989).

The three areas around Fairfield discussed by McClain and others (1979) that appear to offer excellent geothermal exploration targets should be considered for future study. These include: the area around Barron's Hot Springs, on the downdip (east) side of the fault, which appears to be an excellent area for both shallow and deep exploration; the area south of Fairfield, also rated excellent for shallow exploration; and the area along the downdip (east) side of the N-S trending inferred fault passing just to the east of Fairfield, rated very good for deep exploration. Fairly deep geothermal exploration wells must be drilled into fault zones in order to encounter permeable zones that will result in maximum production and temperature. Geophysical (electromagnetic VLF radio and earth magnetic) surveys recommended by McClain and others (1979) should be conducted to pinpoint the existence and attitude of faults in the valley that extend down into the granitic basement. Based on funding available, some follow-up characterization of the geothermal resource in the area is likely warranted.

Canyon County (Nampa-Caldwell area)

Numerous warm water wells and favorable geologic conditions indicate that the Nampa area has good potential for using geothermal energy in direct applications. Many existing warm water wells are in the 24°C to 38°C (75°F to 100°F) temperature range.

Nampa is an agricultural service center 28.8 km (18 mi) west of Boise with a population of about 25,000 people. The combination of a thermal water resource matched with a community of considerable size makes this an attractive area for geothermal energy development in the future.

The rock units in the Nampa area are composed of basalt of Miocene to early Pliocene age. Several widespread sandstone aquifers overlie the basalt units. These sandstone aquifers are projected to yield good flows of 30°C (86°F) to 60°C (140°F) water from depths of 305 to 670 m (1,000 to 2,200 ft). The sandstone aquifers are better targets than the basalt because of greater anticipated permeability (Dellinger and others, 1982).

The Idaho Department of Water Resources (IDWR) conducted an integrated geological, hydrological, geochemical and geophysical survey for the purpose of evaluating the geothermal potential of the Nampa-Caldwell area (Mitchell, 1981). The area studied by the IDWR included approximately 925 km^2 (357 mi^2) of the Nampa-Caldwell portion of Canyon County. Geologic mapping, hydrologic, geochemical, and geophysical surveys were run. In addition, existing magnetotelluric and reflection seismic data were purchased and incorporated into the investigation. Their recommendations for resource definition and development are outlined below.

1) Investigations of effects of widespread artificial aquifer communication by well drilling on the thermal permeable zones and their use as a heat source should be conducted.

2) Should large scale development take place, it would be advisable to establish a geochemical sampling program whereby quarterly or even monthly samples are obtained from production zones. Such information has been utilized in high temperature fields for early detection of impending production changes (volume, temperature, fluid characteristics) in geothermal wells.

3) Thief sampling of water from permeable zones, isolated by packers to prevent mixing within the well bore of the Richardson No. 1 well should be made to determine deep water isotope and geochemical characteristics.

4) Investigations to delineate possible recharge of the thermal aquifers should be undertaken to determine if recharge is presently occurring. These could include further stable isotope work in suspected recharge areas in the mountains on both sides of the SRP, tritium age dating, dating using 12C, 13C, and 14C and inert gas methods to determine absolute age of thermal water from various thermal aquifers.

5) More work is needed to determine clay layer semi-permeable membrane effects on the stable isotope ratios in the Nampa-Caldwell area.

6) Monitoring of potentiometric surfaces to detect stress effects in the aquifers and permeable zones would provide early warning of water level declines should these take place due to increased pumpage from geothermal development.

7) Stable isotope data should be incorporated as standard water quality data in other areal investigations where deemed appropriate. Stable isotope studies should be integrated in any groundwater study of the Boise front geothermal system.

8) Seismic risks associated with possible large scale dewatering of the geothermal system should be assessed. A seismic net (3 stations) should be set up in the Nampa-Caldwell area and another along the Boise front area to obtain background data before large scale withdrawal of geothermal water begins, and should be continued after production begins.

9) Detailed petrographic and geochemical studies of well cuttings from deep wells with comparisons to outcrops in and around the western SRP should be made for correlation purposes.

10) More geophysical data within the western SRP should be purchased and interpreted to help determine the boundaries of the geothermal system(s).

11) More detailed geologic mapping, particularly on the northern margin of the western SRP is needed to unravel the stratigraphy and correlate units. A better understanding of the geology, hydrology and geochemistry of groundwaters in and near the plain will greatly expand geologists' ability to locate and evaluate areas of geothermal potential in this region.

Caribou County (Greys Lake and Blackfoot Reservoir area)

According to Blackwell and others (1992), there is a very large area of elevated geothermal gradient in the vicinity of Grey's Lake and Blackfoot Reservoir. The Gray's Lake/Soda Lake area heat flow in deep wells ranges from 50 to 120 mWm^{-2}. The area has been thought to have significant geothermal potential from the geologic setting alone (Leeman, 1985). Gradients in this area are distinctly anomalous with respect to those elsewhere in the southeastern Idaho Basin and Range province. This vicinity is sparsely populated, but temperatures reported in oil wells suggest this area may have temperatures sufficient for electricity generation at depth. Extremely young rhyolitic rocks and structures exist in the vicinity and the geologic framework favors the possibility of a high-temperature reservoir at depths greater than 2 km (1.25 mi); exploration for this resource will be expensive. However, Caribou County presents a unique opportunity for low temperature resource prospecting by drilling into fault zones associated with travertine deposits (Mitchell, 1976). Detailed delineation of these fault zones combined with limited shallow test drilling should be conducted to evaluate this resource.

Fremont County (Island Park area)

The Island Park geothermal reservoir is at present off-limits to drilling activities due to an unsubstantiated fear that development of the aquifer will endanger geothermal features at Yellowstone Park. However, deep drilling is necessary to substantiate the interpretation postulated by Hoover and others (1985) that the Island Park area is underlain by a solidified but still hot pluton that represents a significant hot dry rock resource. Deep drilling would also provide needed heat-flow data.

The Island Park-Yellowstone National Park region comprises a complex caldera system which has formed over the last 2 million years. The caldera system has been estimated to contain 50% of the total thermal energy remaining in all young igneous systems in the United States. The Island Park System contributes 32% of the total thermal energy remaining in the complex. The Island Park system, alone, contains twice as much energy as the next largest system, the Valles caldera in New Mexico. These considerations make the Island Park region an excellent site for geothermal exploration, yet there is essentially no activity in the region today. Although development is not permitted within Yellowstone National Park, neither exploration nor development is progressing in the caldera complex outside the park. Environmental concerns have in part caused this, but the lack of surface thermal manifestations and the lack of evidence for hydrothermal systems within the Island Park part of the caldera complex are also responsible.

Lemhi County (Big Creek Hot Springs)

An evaluation of Big Creek Hot Springs as a source of electrical power for the Blackbird Cobalt Mine was conducted (Struhsacker, 1981). Big Creek Hot Springs is one of the hottest known geothermal systems in Idaho, with a surface temperature of 93°C (199°F). Geothermometer estimates of reservoir temperature range from 137°C to 179°C (279°F to 354°F). It was concluded that Big Creek Hot Springs is an excellent geothermal prospect. A suggested exploration program, engineering and economic analyses, and appraisal of institutional factors was outlined.

Big Creek Hot Springs is located approximately 20.8 km (13 mi) north of the Blackbird Mine. Reservoir rocks are likely competent Precambrian metamorphic and metasedimentary rocks, with fractures serving as hot water conduits. The system consists of a linear set of spring vents trending N40-45W that intersect Hot Springs fault. The heat source is probably deep circulation of meteoric water. There may be potential for buried thermal anomalies along the entire length of Hot Springs fault.

Several institutional factors complicate the development potential of Big Creek Hot Springs; it lies on Forest Service land and is near the River of No Return Wilderness Area. The distance from population centers precludes development at present of electrical generation potential.

The engineering feasibility study modeled an 11 MWe binary power plant, utilizing propane (95%) and hexane (5%) as the mixed working fluid. It was determined a power plant could be located along Panther Creek; power would be transmitted 20.8 km (13 mi) to where it would tie into the Idaho power grid that services the town of Cobalt (Struhsacker, 1981).

Follow-up studies suggested by Struhsacker (1981) include:

1) Thermal gradient measurements in existing accessible water or exploration wells and mineral exploration holes; local gradient is unknown.

2) Mapping to define the nature of the Hot Springs Fault and to determine the role the fault plays in controlling the geothermal system.

3) Shallow (49 to 160 m [160 to 525 ft]) temperature gradient hole drilling.

4) Resistivity survey to identify buried structures and low resistivity zones that may correspond with the presence of warm water and hydrothermal alteration.

5) After completion of work listed above, target modeling would indicate if further, more detailed work was merited. Work would include detailed prospect mapping, deeper drilling, and flow testing.

Twin Falls County (Twin Falls area)

The Twin Falls area should be given the highest priority for additional geothermal assessment, exploration and development because of the potential size and temperature of the geothermal reservoir, the close proximity to the population center of Twin Falls, and the recent decline of water levels in several wells being used for space heating, including the geothermal space heating system of the College of Southern Idaho. Recently the college had to install pumps in their wells to maintain adequate flow for their system. Other users have also expressed concern about pressure decline in the thermal system.

Although several investigations have focused on the Twin Falls area, the source of the heat component of the Twin Falls system is not clear and the relationship of the Twin Falls and Banbury systems is poorly understood. Lewis and Young (1989) estimated that the reservoir is approximately 1000 km^3 (240 mi^3) with temperatures of 70-80°C (158-176°F). Additional studies should be conducted to assess the Twin Falls geothermal system. These studies should be conducted to: 1) compile existing geologic, hydrologic and geothermal information from local, state and federal sources; 2) develop a conceptual model of the reservoir which could be used as the basis for future numerical modeling; and 3) provide information for resource management decisions.

SUMMARY

This report summarizes investigations of geothermal resources of Idaho that have been conducted since the compilation by the Idaho Department of Water Resources in 1980 (Mitchell and others, 1980). The DBase file accompanying this report contains data for all geothermal wells and springs we have been able to identify in Idaho with temperatures above 20°C (68°F). Data sources include past compilations along with more recently published reports and unpublished documents.

With over 1500 individual thermal wells and springs, Idaho has a significant potential for further geothermal resource development. Because most thermal sites are relatively low temperature, development of the resource for additional space heating and other low-temperature uses appears promising. Several areas are recommended for further study, including the Boise, Nampa-Caldwell, Twin Falls, Pocatello, Garden Valley and Camas Prairie areas. Of these, the Twin Falls area should be given the highest priority.

REFERENCES CITED

* indicates references cited in *DBase III Plus* file GEOTHERM.dbf accompanying this report; most are also cited in the report text.

*Anderson, J.E., Bideganeta, K., and Mitchell, J.C., 1985, Geothermal investigations in Idaho: Preliminary geologic reconnaissance of the geothermal occurrences of the Wood River Drainage area: Idaho Department of Water Resources Water Information Bulletin 30, Part 13, 54 p.

Anderson, J.E. and Wood, S.J., 1981, Geothermal investigations in Idaho: Geological, hydrological, geochemical and geophysical investigations in the Nampa-Caldwell and adjacent areas, western Snake River Plain, Idaho <in> J.C. Mitchell, ed., Geothermal investigations in Idaho: Idaho Department of Water Resources Water Information Bulletin 30, Part 11, Chapter 3, p. 183.

Arney, B.H., Beyer, J.H., Simon, D.B., Tonani, F.B., and Weiss, R.B., 1980, Hot dry rock geothermal site evaluation, western Snake River Plain, Idaho, <in> Geothermal: Energy for the eighties: Geothermal Resouces Council Transactions, v. 4, p. 197-200.

Austin, J.C., 1981, Geothermal source potential and utilization for methane generation and alcohol production: EG&G Idaho, Inc. Report EGG-2137.

Austin, J.C., Fettkether, L.M., and Chase, B.J., 1984, Idaho capitalizes on its geothermal resources, <in> Geothermal energy: Bet on it!: Geothermal Resources Council Transactions, v. 8, p. 135-138.

Baglio, J.V., 1983, Hydrogeologic investigations of geothermal systems in the vicinity of the Bear River Range, southeastern Idaho: M.S. thesis, University of Idaho, 83 p.

*Baker, S.J. and Castelin, P.M., 1990, Geothermal resource analysis in Twin Falls County, Idaho, Part 2: Idaho Department of Water Resources Water Information Bulletin 30, Part 16, 50 p.

Batdorf, J.A., McClain, D.W., Gross, M., and Simmons, G.M., 1980, Industrial application of geothermal energy in southeast Idaho: Idaho Office of Energy Report DOE/ID-12010-4, 80 p.

Berenbrock, Charles, 1993, Effects of well discharges on hydraulic heads in and spring discharges from the geothermal aquifer system in the Bruneau area, Owyhee County, southwestern Idaho: U.S. Geological Survey Water-Resources Investigations Report 93-4001, 58 p.

*Berkeley Group, 1990, Boise geothermal aquifer study: final report for IDWR contract #DWR-89-03-46-102-54, Report DOE/ID/12748-3, 216 p.

Blackett, R.E., 1981a, A geothermal resource site evaluation near Banbury Hot Springs - Twin Falls county, Idaho: University of Utah Research Institute, Earth Science Laboratory Report ID/BHS/ESL-1, (with maps), 14 p.

Blackett, R.E., 1981b, Preliminary investigation of the geology and geothermal resources at Guyer Hot Springs and vicinity, Blaine County, Idaho: University of Utah Research Institute, Earth Science Laboratory Report ID/GHS/ESL-1, (with maps) 26 p.

Blackett, R.E. and Kolesar, P.T., 1983, Geology and alteration of the Raft River Geothermal System, Idaho, <in> Geothermal Resources: Energy on tap!: Geothermal Resources Council Transactions, v. 7, p. 123-128.

Blackwell, D.D., 1988, Heat flow and geothermal resources of Idaho: unpublished manuscript, 91 p.

Blackwell, D.D., 1989, Regional implications of heat flow of the Snake River Plain, northwestern United States: Tectonophysics, v. 164, p. 323-343.

*Blackwell, D.D., Kelley, S., and Steele, J.L., 1992, Heat flow modeling of the Snake River Plain, Idaho: EG&G, Idaho, Report EGG-C91-103450, 109 p.

Bliem, C.J. and Walrath, L.F., 1983, Raft River binary-cycle geothermal pilot plant final report: EG&G Idaho, Inc. Report EGG-2208.

Breckenridge, R.M., and Hinkley, B.S., 1978, Thermal springs of Wyoming: Geological Survey of Wyoming Bulletin 60, 104 p.

Breckenridge, R.P., Wheeler, L.R., and Ginsburg, J.F., 1983, Biomass production and chemical cycling in a man-made geothermal wetland: EG&G Idaho, Inc. Report EGG-M-11383, 18 p.

Brott, C.A., Blackwell, D.D., and Mitchell, J.C., 1976, Geothermal investigations in Idaho: Heatflow study of the Snake River Plain region, Idaho: Idaho Department of Water Resources Water Information Bulletin 30, Part 8, 195 p.

Brott, C.A., Blackwell, D.D., and Mitchell, J.C., 1978, Tectonic implications of the heat flow of the western Snake River Plain, Idaho: Geological Society of America Bulletin, v. 89, p. 1697-1701.

Burkett, G.R. and Litke, R.T., 1989, Warm Springs Creek geothermal study: Idaho Department of Health and Welfare, Division of Environmental Quality, Water Quality Status Report 84, 76 p.

Christopherson, K., Senterfit, M., and Dalati, M., 1980, Telluric profiles and location map for Vulcan Hot Springs Known Geothermal Resource Area, Idaho: U.S. Geological Survey Open-File Report 80-518, 4 p.

Cole, L.T. and Schmitt, R.C., 1980, Fluidized-bed potato waste drying experiments at the Raft River geothermal test site: EG&G Idaho, Inc. Report EGG-2036.

Corbett, M.K., Anderson, J.E., and Mitchell, J.C., 1980, Geothermal investigations in Idaho: An evaluation of thermal water occurrences in the Tyhee area, Bannock County, Idaho: Idaho Department of Water Resources Water Information Bulletin 30, Part 10, 67 p.

Covington, H.R., 1980, Subsurface geology of the Raft River geothermal area, Idaho, <in> Geothermal: Energy for the eighties: Geothermal Resources Council Transactions, v. 4, p. 113-115.

Dansart, W.J., Kauffman, J.D., and Mink, L.L., 1994, Bibliography of Idaho Geothermal Resources: Idaho Water Resources Research Institute publication, 64 p.

*Dellinger, M., Higbee, C., Justus, D., Rafferty, K., and Rivenes, R., 1982, Geothermal Energy in the Northwest: Oregon Institute of Technology (OIT) Geo Heat Center site specific development analyses, p. 110-173.

Dingee, B.E., 1987, Geology, hydrology and geochemistry of the geothermal area east of Lowman, Idaho: M.S. thesis, Washington State University, 138 p.

Dolenc, M.R., Hull, L.C., Mizell, S.A., Russell, B.F., Skiba, P.A., Strawn, J.A., Tullis, J.A., and others, 1981, Raft River geoscience case study: EG&G Idaho, Inc. Report EGG-2125, in two volumes, 304 p.

Foley, D. and Street, L.V., 1985a, Geothermal systems of the Snake River Plain, Idaho batholith and northern Rocky Mountains transition zone: University of Utah Research Institute, Earth Science Laboratory Report ESL-85011-ABS.

Foley, D. and Street, L.V., 1985b, Geothermal systems of the Snake River Plain, Idaho batholith and northern Rocky Mountains transition zone (abs.): Geologic Society of America Abstracts with Programs, v. 17, no. 4, p. 218-219.

Foley, D. and Street, L.V., 1986, High fluoride in geothermal waters from Idaho (abs.): Geological Society of America Abstracts with Programs, v. 18, p. 604.

Foley, D. and Street, L.V., 1988, Hydrothermal systems of the Wood River area, Idaho, <in> P.K. Link and W.R. Hackett, eds., Guidebook to the geology of central and southern Idaho: Idaho Geological Survey Bulletin 27, p. 109-126.

Foley, D., Zeisloft, J., and Blackett, R.E., 1983, Hydrothermal systems of the Wood River district, ID (abs.): Geological Society of America Abstracts with Programs, v. 15, no. 5, p. 416.

Gardner, L.S., 1961, Preliminary geologic map of the Irwin Quadrangle, Caribou and Bonneville Counties, Idaho, and Lincoln and Teton Counties, Wyoming: U.S. Geological Survey Water-Supply Paper 1473, 363 p.

Goldman, D., 1982, Development of a low-temperature hydrothermal energy resource: PhD dissertation, University of Idaho, 298 p.

Hoover, D.B., Pierce, H.A., and Long, C.L., 1985, Is Island Park a hot dry rock system?, <in> International Symposium on Geothermal Energy: Geothermal Resources Council Transactions, v. 9, Part 2, p. 25-30.

Hubbell, J.M., 1981, Description of geothermal flow systems in the vicinity of the Caribou Range, southeastern Idaho: M.S. thesis, University of Idaho, 105 p.

*Idaho Department of Water Resources, 1979-1993, Well Driller's Reports, on file at Boise office, Boise, Idaho.

Kuhns, R.J., 1980, Structural and chemical aspects of the Lochsa geothermal system near the northern margin of the Idaho batholith: M.S. thesis, Washington State University, 103 p.

*Kunze, J.F. and Marlor, J.K., 1982, Industrial food processing and space heating with geothermal heat: U.S. Department of Energy Report DOE/ET/27028-5, 71 p.

Kunze, J.F. and Stoker, R.C., 1979, Madison County Rogers Potato geothermal space/process heating project: Department of Energy Document DOE/ET/27028-2.

Leeman, W.P., 1982, Geology of the Magic Reservoir area, Snake River Plain, Idaho, <in> B. Bonnichsen and R.M. Breckenridge, eds., Cenozoic geology of Idaho: Idaho Bureau of Mines and Geology Bulletin 26, p. 369-376.

*Lewis, R.E. and Stone, M.A.J., 1988, Geohydrologic data from a 4403-foot test hole, Mountain Home Air Force Base, Elmore County, Idaho: U.S. Geological Survey Open-File Report 88-166, 30 p.

Lewis, R.E. and Young, H.W., 1980a, Geothermal resources in the Banbury Hot Springs area, Twin Falls County, Idaho: U.S. Geological Survey Open-File Report 80-563, 22 p.

Lewis, R.E. and Young, H.W., 1980b, Thermal springs in the Payette River basin, west-central Idaho: U.S. Geological Survey Open-File Report 80-1020.

Lewis, R.E. and Young, H.W., 1982a, Geothermal resources in the Banbury Hot Springs area, Twin Falls County, Idaho: U.S. Geological Survey Water-Supply Paper 2186, 27 p.

Lewis, R.E. and Young, H.W., 1982b, Thermal springs in the Boise River Basin, south-central Idaho: U.S. Geological Survey Water Resources Investigations 82-4006, 22 p.

Lewis, R.E. and Young, H.W., 1989, The hydrothermal system in central Twin Falls County, Idaho: U.S. Geological Survey Water Resources Investigations Report 88-4152, 44 p.

Lindgren, W. and Drake, N.F., 1904, Nampa, Idaho-Oregon: U.S. Geological Survey Folios of the Geologic Atlas of the United States, Folio 103, 5 p., 2 maps.

Mabey, D.R., 1978, Regional gravity and magnetic anomalies in the eastern Snake River Plain, Idaho: U.S. Geological Survey Journal of Research, v. 6, p. 553-562.

Mabey. D.R., 1983, Geothermal resources of southern Idaho: U.S. Geological Survey Circular 866, 24 p.

Malde, H.E. and Powers, H.A., 1962, Upper Cenezoic stratigraphy of the western Snake River Plain, Idaho: Geological Society of America Bulletin, v. 73, p. 1197-1219.

Mansfield, G.R., 1952, Geography, geology, and mineral resources of the Ammon and Paradise Valley quadrangles, Idaho: U.S. Geological Survey Professional Paper 238, 92 p.

Mariner, R.H., Presser, T.S., and Evans, W.C., 1983, Geochemistry of active geothermal systems in the northern Basin and Range province, <in> Geothermal Resources Council Special Report 13, p. 95-120.

Mariner, R.H., Young, H.W., Evans, W.C., and Parliman, D.J., 1991, Chemical, isotopic, and dissolved gas compositions of the hydrothermal system in Twin Falls and Jerome counties, Idaho, <in> Geothermal Resources Council Transactions, v. 15, p. 257-265.

Mariner, R.H., Young, H.W., Parliman, D.J., and Evans, W.C., 1989, Geochemistry of thermal water from selected wells, Boise, Idaho: Geothermal Resources Council Transactions, v. 13, p. 173-178.

Mayo, A.L., Muller, A.B., and Mitchell, J.C., 1984, Geothermal investigations in Idaho: Geochemical and isotopic investigations of thermal water occurrences of the Boise Front area, Ada County, Idaho: Idaho Department of Water Resources Water Information Bulletin 30, Part 14, 60 p.

McClain, D.W., 1980, A site evaluation model for geothermal resource development in southwest Idaho: M.S. thesis, University of Idaho, 146 p.

McClain, D.W. and Eastlake, W.B., 1979, Hailey, Idaho site specific development analysis: Idaho Office of Energy, Idaho Geothermal Report DOE/ID/12010-6.

*McClain, D.W., Eastlake, W.B., and Stoker, R.C., 1979, Fairfield, Idaho site specific development analysis: Idaho Office of Energy, Idaho Geothermal Report DOE/ID/12010-7.

Mickelson, C.R., 1985, Detailed review of retail pricing strategies, marketing efforts and performance of the Boise City District Heating System, 1983-1985, <in> International Symposium on Geothermal Energy: Geothermal Resources Council Transactions, v. 9, part 1, p. 39-44.

Mink, L.L., Lease, R.D., and Nichols, C.R., 1982, The Raft River, Idaho 5MW(e) binary project: Proceedings of International Conference on Geothermal Energy, Florence, Italy, paper H8, p.283-294.

Mitchell, J.C., 1976, Geothermal investigations in Idaho: Geochemistry and geologic setting of the thermal waters of the northern Cache Valley Area, Franklin County, Idaho: Idaho Department of Water Resources Water Information Bulletin 30, Part 5, 47 p.

Mitchell, J.C., 1981a, Geological, hydrological, geochemical, and geophysical investigations of the Nampa-Caldwell and adjacent areas, southwestern Idaho, <in> C.A. Ruscetta & D. Foley, eds., Geothermal Direct Heat Program: State Coupled Geothermal Assessment Program.

*Mitchell, J.C., ed., 1981b, Geothermal investigations in Idaho: Geological, hydrological, geochemical and geophysical investigations of the Nampa-Caldwell and adjacent areas, southwestern Idaho: Idaho Department of Water Resources Water Information Bulletin 30, Part 11, 143 p.

*Mitchell, J.C., Bideganeta, K., and Palmer, M.A., 1984, Geothermal investigations in Idaho: Stable isotopic evaluation of thermal water occurrences in the Weiser and Salmon River drainage basins and adjacent areas, west-central Idaho: Idaho Department of Water Resources Water Information Bulletin 30, Part 12, 45 p.

*Mitchell, J.C., Johnson, L.L., and Anderson, J.E., 1980, Geothermal investigations in Idaho: Potential for direct heat application of geothermal resources: Idaho Department of Water Resources Water Information Bulletin 30, Part 9, 396 p.

*Morrison Knudsen Company Mining Group, 1983, Geothermal lease assessment for Castle Creek KGRA, Mountain Home KGRA, Raft River KGRA: unpublished company report, 38 p.

National Oceanic and Atmospheric Administration (NOAA), 1980, Geothermal resources of Idaho: map prepared for Idaho Department of Water Resources by National Geophysical and Solar Terrestrial Data Center.

Nichols, C.R., Brockway, C.E., and Warnick, C.C., 1972, Geothermal water and power resources exploration and development for Idaho: Idaho Water Resources Research Institute Publication, 48 p.

*Parliman, D.J. and Young, H.W., 1992, Compilation of selected data for thermal-water wells and springs,1921 through 1991: U.S. Geological Survey Open-File Report 92-175, 201 p.

Prostka, H.J. and Embree, G.F., 1978, Geology and geothermal resources of the Rexburg area, eastern Idaho: U.S. Geological Survey Open-File Report 78-1009, 15 p.

*Ralston, D.R., Arrigo, J.L., Baglio, J.V., Coleman, L.M., Hubbell, J.M., and Souder, K.C., 1981, Geothermal evaluation of the thrust zone in southeastern Idaho: Idaho Water and Energy Resources Research Institute, 110 p.

Ralston, D.R. and Mayo, A.L., 1983, Thermal groundwater flow systems in the thrust zone in southeastern Idaho: U.S. Department of Energy Report DOE/ET/28407-4, 336 p.

Rashrash, S.M. and Ralston, D.R., 1988, Fracture flow analysis at the Raft River geothermal area (abs.): Geological Society of America Abstracts with Programs, v. 20, no. 6, p. 464.

Reed, J.D., 1986, The geology, geochemistry, and hydrology of four hot springs areas along the South Fork Payette River, between Lowman and Banks, Boise County, Idaho: M.S. thesis, Washington State University, 112 p.

Renner, J.L., White, D.E., and Williams, D.L., 1975, Hydrothermal convection systems, <in> Assessment of geothermal resources of the United States: U.S. Geological Survey Circular 726, p. 5-57.

Ross, S.H., 1971, Geothermal potential of Idaho: Idaho Bureau of Mines and Geology Pamphlet 150, 72 p.

Sammel, E.A., 1978, Occurrence of low-temperature geothermal waters in the United States, p. 86-131, <in> L.J.P. Muffler, ed., Assessment of geothermal resources of the United States--1978: U.S. Geological Survey Circular 790.

Sass, J.H., Diment, W.H., Lachenbruch, A.H., Marshall, B.U., Munroe, R.T., Moses, T.H., and Urban, T.C., 1976, A new heat-flow contour map of the conterminous United States: U.S. Geological Survey Open-File Report 76-756.

Sass, J.H., Lachenbruch, A.H., Munroe, R.J., Greene, G.W., and Moses, T.H., 1971, Heat flow in the western United States: Journal of Geophysical Research, v. 76, p. 6376-6413.

Sibbett, B.S. and Capuano, R.M., 1984, Potential for a geothermal resource near Mackay, Idaho: University of Utah Research Institute, Earth Science Laboratory Report 137, DOE/ID/12079-120, 13 p.

Sifford, A., 1984, Survey of geothermal direct use pricing terms in five western states, <in> Geothermal energy: Bet on it!: Geothermal Resources Council Transactions, v. 8, p. 169-172.

Smith, R.N., 1980, Heat flow of the Western Snake River Plain, <in> Geothermal: Energy for the eighties: Geothermal Resources Council Transactions, v. 4, p. 89-92.

*Souder, K.C., 1985, The hydrochemistry of thermal waters of southeastern Idaho, western Wyoming and northeastern Utah: M.S. thesis, University of Idaho, 139 p.

*Spencer, S.G. and Russell, B.F., eds., 1979a, Bruneau Known Geothermal Resource Area: An environmental analysis: EG&G Idaho, Inc. Report EGG-GTH-5004, 139 p.

Spencer, S.G. and Russell, B.F., eds., 1979b, Castle Creek Known Geothermal Resource Area: An environmental analysis: EG&G Idaho, Inc. Report EGG-GTH-5003, 143 p.

Spencer, S.G. and Russell, B.F., eds., 1979c, Crane Creek Known Geothemal Resource Area: An environmental analysis: EG&G Idaho, Inc. Report EGG-GTH-5002, 118 p.

Spencer, S.G. and Russell, B.F., eds., 1979d, Mountain Home Known Geothemal Resource Area: An environmental analysis: EG&G Idaho, Inc. Report EGG-GTH-5005, 119 p.

Spencer, S.G. and Russell, B.F., eds., 1979e, Vulcan Hot Springs Known Geothermal Resource Area: An environmental analysis: EG&G Idaho, Inc. Report EGG-GTH-5001, 125 p.

Spencer, S.G., Russell, B.F., and Sullivan, J.F., 1979a, Potential use of geothermal resources in the Snake River Basin: An environmental overview. Volume I: EG&G Idaho, Inc. Report EGG-2001, v. 1, 85 p.

Spencer, S.G., Russell, B.F., and Sullivan, J.F., 1979b, Potential use of geothermal resources in the Snake River Basin: An environmental overview. Volume II, annotated bibliography: EG&G Idaho, Inc. Report EGG-2001, v. 2, 90 p.

Stanley, N.E. and Schmitt, R.C., 1980, Effects of irrigation on crops and soils with Raft River geothermal water: EG&G Idaho, Inc. Report EGG-2005.

Stearns, N.D., Stearns, H.T., and Waring, G.A., 1937, Thermal springs in the United States: U.S. Geological Survey Water-Supply Paper 679-B, p. 59-206.

Stoker, R.C. and Kunze, J.F., 1980, Madison County Rogers Potato evaluation of the geothermal potential around Rexburg, Idaho: Department of Energy Document DOE/ET/127028-1.

*Street, L.V., 1990, Geothermal investigations in Idaho: Geothermal resource analysis in the Big Wood River Valley, Blaine County, Idaho: Idaho Department of Water Resources Water Information Bulletin 30, Part 17; also U.S. Department of Energy Report DOE/ID/12748-1, 43 p.

Street, L.V. and DeTar, R.E., 1987, Geothermal investigations in Idaho: Geothermal resource analysis in Twin Falls County, Idaho: Idaho Department of Water Resources Water Information Bulletin 30, Part 15, 46 p.

Struhsacker, D.W., ed., 1981a, An analysis of geothermal electrical power generation at Big Creek Hot Springs, Lemhi County, Idaho: U.S. Department of Energy Report DOE/10/12079-37, 71 p.

Struhsacker, D.W., 1981b, Preliminary evaluation of the geothermal potential of Big Creek Hot Springs, Lemhi County, Idaho, <in> D.W. Struhsacker, ed., An analysis of geothermal electric power generation at Big Creek Hot Springs, Lemhi County, Idaho: U.S. Department of Energy Report DOE/10/12079-37, p. 1-17.

Struhsacker, D.W., 1981c, Suggested geothermal exploration strategy for Big Creek Hot Springs, <in> D.W. Struhsacker, ed., An analysis of geothermal electric power generation at Big Creek Hot Springs, Lemhi County, Idaho: U.S. Department of Energy Report DOE/10/12079-37, p. 18-33.

Struhsacker, D.W., Jewell, P.W., Zeilsloft, J., and Evans, S.H., 1983, The geology and geothermal setting of the Magic Reservoir area, Blaine and Camas counties, Idaho: University of Utah Research Institute, Earth Science Laboratory Report 123, DOE/ID/12079-106, 58 p.

Struhsacker, D.W., Jewell, P.W., Zeisloft, J., and Evans, S.H., 1984, The geology and geothermal setting of the Magic Reservoir Area, Blaine and Camas counties, Idaho, <in> B. Bonnichsen and R.M. Breckenridge, eds., Cenezoic geology of Idaho: Idaho Bureau of Mines and Geology Bulletin 26, p. 377-393.

Struhsacker, E.M., Smith, C., and Capuano, R.M., 1983, An evaluation of exploration methods for low-temperature geothermal systems in the Artesian City area, Idaho: Geologic Society of America Bulletin, v. 94, no. 1, p. 58-79.

Trans Energy Systems, Inc., 1981, Great Western Malting Company geothermal project, Pocatello, Idaho: U.S. Department of Energy report DOE/ID/12194-T1.

Vance, D.B., 1986, The geology and geochemistry of three hot spring systems in the Shoup Geothermal Area, Lemhi County, Idaho: M.S. thesis, Washington State University, 153 p.

Waag, C.J. and Wood, S.H., 1987, Analysis of historical and current drawdown and production data from the Boise geothermal system: Idaho Water Resources Research Institute Research Technical Completion Report 14-08-0001-G1222-02, 47 p.

Walton, W.C., 1962, Groundwater resources of Camas Prairie, Camas and Elmore Counties, Idaho: U.S. Geological Survey Water-Supply Paper 1609, 57 p.

Waring, G.A., 1965, Thermal springs of the United States and other countries of the world--a summary: U.S. Geological Survey Professional Paper 492, 383 p.

Warner, M.M., 1972, Geothermal Resources of Idaho: Geothermal overviews of the western United States, <in> Geothermal Resources Council El Centro Proceedings, 1972.

Warner, M.M., 1975, Special aspects of Cenozoic history of southern Idaho and their geothermal implications, <in> Proceedings 13th Annual Engineering Geology and Soils Engineering Symposium, p. 247-270.

Williams, P.L., Pierce, K.L., McIntyre, D.H., Covington, H.R., and Schmidt, P.W., 1975, Geologic setting of the Raft River geothermal area, Idaho (abs.): Geological Society of America Abstracts with Programs, v. 7, no. 5, p. 652.

Wood, S.H. and Burnham, W.L., 1983, Boise, Idaho geothermal system, <in> Geothermal resources: Energy on tap!: Geothermal Resources Council Transactions, v. 7, p. 215-223.

Young, H.W., 1985, Geochemistry and hydrology of thermal springs in the Idaho batholith and adjacent areas, central Idaho: U.S. Geological Survey Water Resources Investigations 85-4172.

Young, H.W., Jones, M.L., Parliman, D.J., and Tungate, A.M., 1990, Results of test drilling and hydrologic monitoring in the Indian Bathtub area, Owyhee County, southwestern Idaho, January 1989 through September 1990: U.S. Geological Survey Open-File Report 90-597, 40 p.

Young, H.W. and Lewis, R.E., 1982a, Hydrology and geochemistry of thermal ground water in southwestern Idaho and north-central Nevada: U.S. Geological Survey Professional Paper 1044-J, 20 p.

Young, H.W. and Lewis, R.E., 1982b, Thermal springs in the Salmon River Basin, central Idaho: U.S. Geological Survey Open-File Report 82-104, 27 p.

Young, H.W., Lewis, R.E., and Backsen, R.L., 1979, Thermal groundwater discharge and associated heat-flux, Bruneau-Grand View area, southwestern Idaho: U.S. Geological Survey Water Resources Investigations 79-62.

Young, H.W. and Mitchell, J.C., 1973, Geothermal investigations in Idaho: Geochemistry and geologic setting of selected thermal waters: Idaho Department of Water Resources Water Information Bulletin 30, Part 1, 43 p.

Young, H.W. and Parliman, D.J., 1989, Hydrologic and chemical data for selected thermal-water wells and springs in the Indian Bathtub area, Owyhee county, southwestern Idaho: U.S. Geological Survey Open-File Report 89-589, 19 p.

Young, H.W., Parliman, D.J., and Mariner, R.H., 1988, Chemical and hydrologic data for selected thermal-water wells and nonthermal springs in the Boise area, southwestern Idaho: U.S. Geological Survey Open-File Report 88-471, 35 p.

Youngs, S.W., 1981, Geology and geochemistry of the Running Springs geothermal area, southern Bitteroot lobe, Idaho batholith: M.S. thesis, Washington State University, 125 p.

Zeisloft, J., Foley, D., and Blackett, R., 1983, Water geochemistry of hydrothermal systems, Wood River District, Idaho: University of Utah Research Institute, Earth Science Laboratory Report 124, DOE/ID/12079-107, 20 p.