A-39

THERMOPOLIS / EAST THERMOPOLIS, WYOMING
Site Specific Development Analysis

by the
Wyoming Geothermal Commercialization Office
P.O. Box 4096, Universtiy Station
Laramie, Wyoming 82071

in cooperative agreement with
the U.S. Department of Energy, Idaho Operations Office
Cooperative Agreement No. DE-FC07-79ID2013

June, 1981

THERMOPOLIS / EAST THERMOPOLIS, WYOMING

Author:
Patti Burgess-Lyon

Research Assistance:
Keith Bray

Editor:
Karen Marcotte

Wyoming Geothermal Commercialization Office
in cooperative agreement with
the U.S. Department of Energy, Idaho Operations Office
Cooperative Agreement No. DE-FC07-79ID12013

June, 1981

DISCLAIMER

Table of Contents

Major Headings — Page Number

Table of Contents (continued)

List of Figures

List of Tables

Table Page Number

INTRODUCTION

Site Specific Development Analyses (SSDA's) are comprehensive reports which address the potential development of geothermal resources in a specific site. Each SSDA discusses the various aspects of geothermal development as they apply to a specific site. Some of the topics addressed are: what the area is like currently in terms of its land use, economics and demographics, reservoir potentials, how the reservoir might be developed, marketing the final "product", financial assistance for development, the legal aspects of development, and barriers to possible development.

There are many steps involved in developing a geothermal resource, once a potential resource has been accurately identified and assessed. The following are all required prior to development: an adequate resource, a developer, a specific use matched with a resource of usable temperature and flow capabilities, a market or user, financial backing, and economic incentives for development. Geothermal development requires a great deal of planning effort in the preliminary stage if it is to be successful.

Many legal and environmental regulations must also be met by the potential developer. The time involved in acquiring all necessary permits and leases can range from six months to six years, depending upon the unique situation of the resource and the size and type of proposed development. Specifically, there are many more requirements regarding development on federal lands than those required for private or state lands in Wyoming. These additional permitting requirements can postpone development and generate additional planning time and effort on the part of the developer. These requirements can all be met efficiently _if_ the developer is aware of all prerequisites to development before project development actually gets underway. Additional information on the institutional aspects of development in the State of Wyoming can be attained from the Geothermal Commercialization Office.

Geothermal energy is a cost-effective renewable resource, when the appropriate prerequisites are met. The cost-effectiveness of geothermal energy is a tremendous incentive for proceeding with the developmental process whenever possible. As the price of non-renewable fuel sources continues to rise dramatically, the more stable costs of a renewable fuel will become increasingly attractive. The cost of geothermal energy is already competitive with conventional fossil fuel costs in many cases. In the future, we can look towards the cost of geothermal energy becoming even less expensive in comparison to fossil fuels. It is hoped that the geothermal resource will be utilized wherever conceivable.

SITE SPECIFIC DEVELOPMENT ANALYSIS - METHODOLOGY

1.0 Introduction
    1.1 Description of Methodology
    1.2 General Overview of Geothermal Use Potentials
    1.3 General Overview of Economic Markets
2.0 Site Description
    2.1 Geography - Maps
        2.1.1 Location of County in State
        2.1.2 Location of City in County
        2.1.3 Location of Site in City
        2.1.4 Site Map
    2.2 Demographics
        2.2.1 Labor Force
        2.2.2 Population Statistics
    2.3 Economy of Site Area
        2.3.1 Economic Base
        2.3.2 Elements of the Economy by % Contribution
    2.4 Public Considerations
        2.4.1 Previously Established Development or Business Prejudices
        2.4.2 Land Use Patterns
            2.4.2.1 Federal
            2.4.2.2 State
            2.4.2.3 Local Municipal
            2.4.2.4 Private
        2.4.3 Usable and Available Land

Site Specific Development Analysis - Methodology

- 3.0 Resource Evaluation
  - 3.1 Springs
  - 3.2 Wells
  - 3.3 Reservoir Description
    - 3.3.1 Apparent Surface Extent
    - 3.3.2 Apparent Volume
    - 3.3.3 Energy Content
  - 3.4 Exploration Resluts
    - 3.4.1 Drilling
    - 3.4.2 Geochemistry
    - 3.4.3 Geophysics
  - 3.5 Potential Applications of the Resource
- 4.0 Site Specific Application
  - 4.1 Process/Application
  - 4.2 Available Resource Compatability
  - 4.3 Eco System Evaluation
    - 4.3.1 Intra Application
    - 4.3.2 Extra Application
  - 4.4 Economics of Application
    - 4.4.1 Market Analysis
      - 4.4.1.1 Raw Material Market Area
      - 4.4.1.2 Area to which Product is Marketed
      - 4.4.1.3 Transportation of Finished Product
    - 4.4.2 Process Analysis (Economics)
  - 4.5 Outside and Special Factors
    - 4.5.1 Reservoir Use Allocations and Rights
    - 4.5.2 Government Assistance, i.e., tax incentives

Site Specific Development Analysis - Methodology

5.0 Development Process
 5.1 Financial Factors
  5.1.1 Private
  5.1.2 Public (GLCP, etc.)
 5.2 Leasing and Permitting
  5.2.1 Delination of All Needed Permits
  5.2.2 Timeline for Permitting Process
  5.2.3 Obtain, Leases
 5.3 Technological Factors
  5.3.1 State of the ARts Discoveries
  5.3.2 New Technologies Needed for Project Feasibility
 5.4 Barriers to Development
  5.4.1 Institutional
  5.4.2 Environmental
  5.4.3 Financial
  5.4.4 Others
6.0 Conceptual Timeline for Project Development
7.0 Summary and Recommendations

General Overview of Geothermal Use Potentials and Economic Markets

The temperatures of the thermal waters in the Thermopolis area are not sufficiently high to generate electicity. Direct use would therefore be a more realistic utilization of that resource. The Thermopolis geothermal resource is considered to be a low temperature resource (maximum surface temperature of approximately 150°F), and has many potential applications as shown in Figure 1.

Geothermal uses best suited to Thermopolis and its low temperature resource are agribusinesses such as vegetable drying, greenhousing, soil warming, mushroom culture, and pickling. Other uses compatible to Thermopolis are space heating, concrete curing, bentonite drying, and carcass wash and clean-up to name a few.

SITE DESCRIPTION

Figure 2 shows the location of Thermopolis in Hot Springs County and in relation to the State of Wyoming. Figure 3 is a geologic map that shows locations of wells that have been drilled in the Thermopolis region. Depth and temperature gradients are given at each well location.

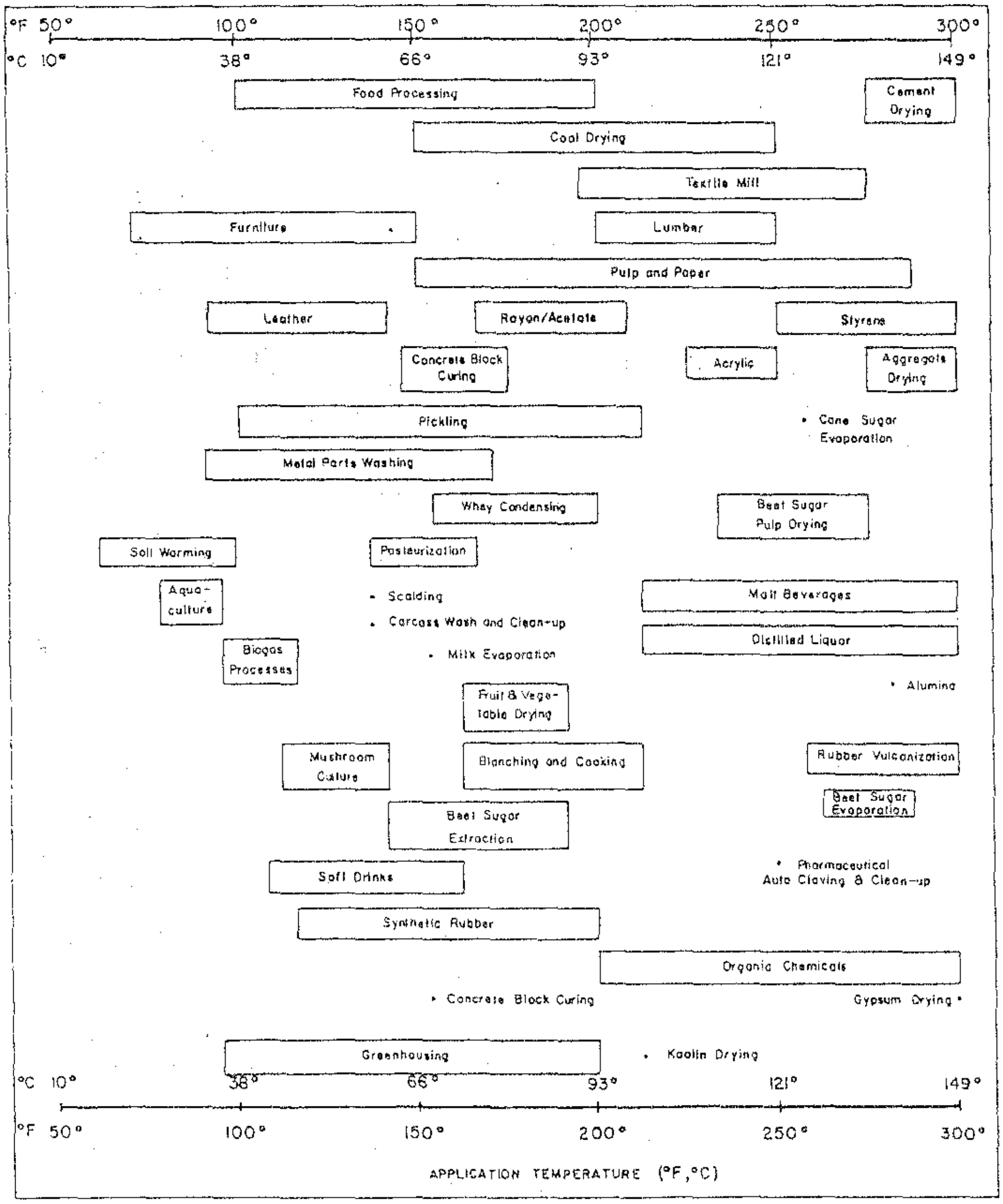


Figure 1. Application temperature range for some industrial processes and agricultural applications.
Source: Anderson, David N., and John W. Lund, 1979.

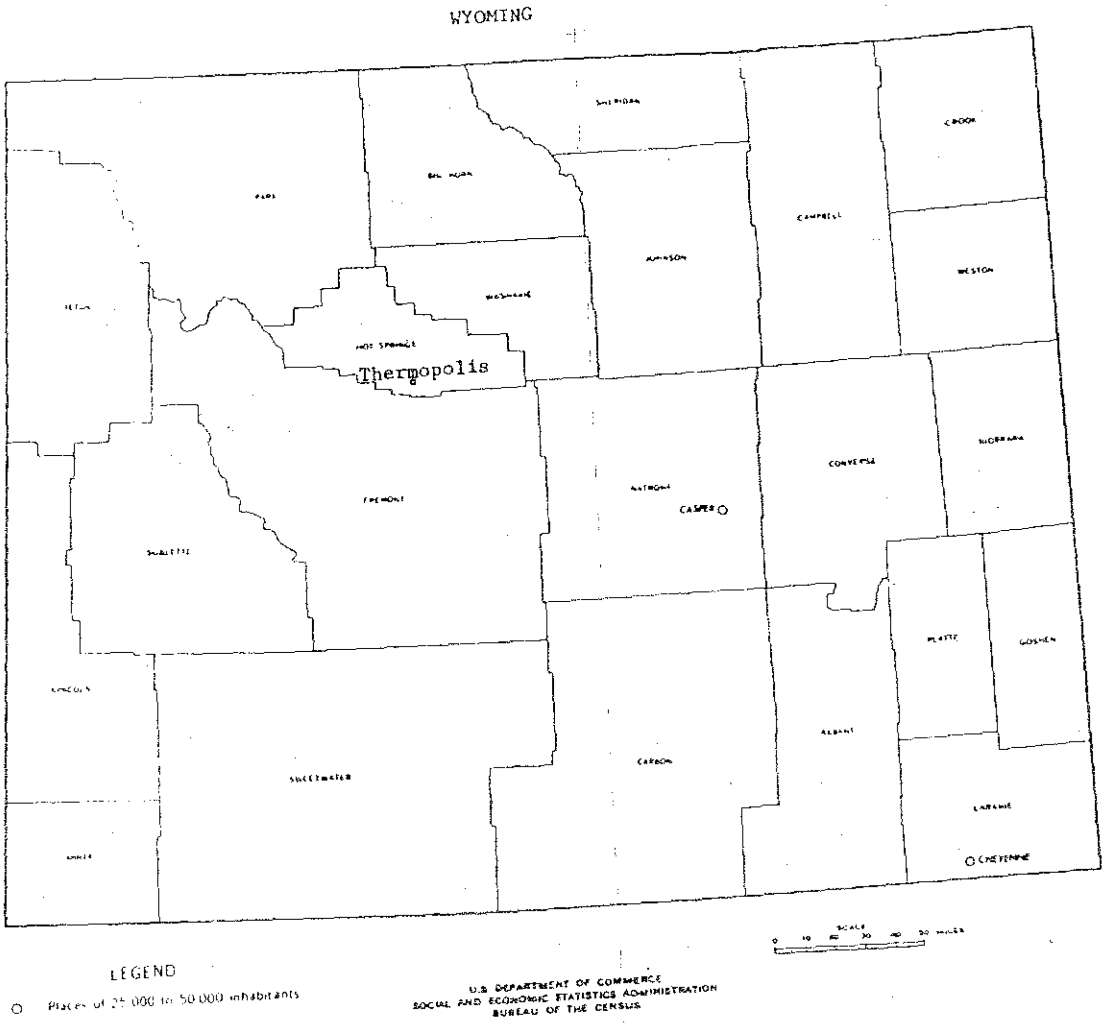
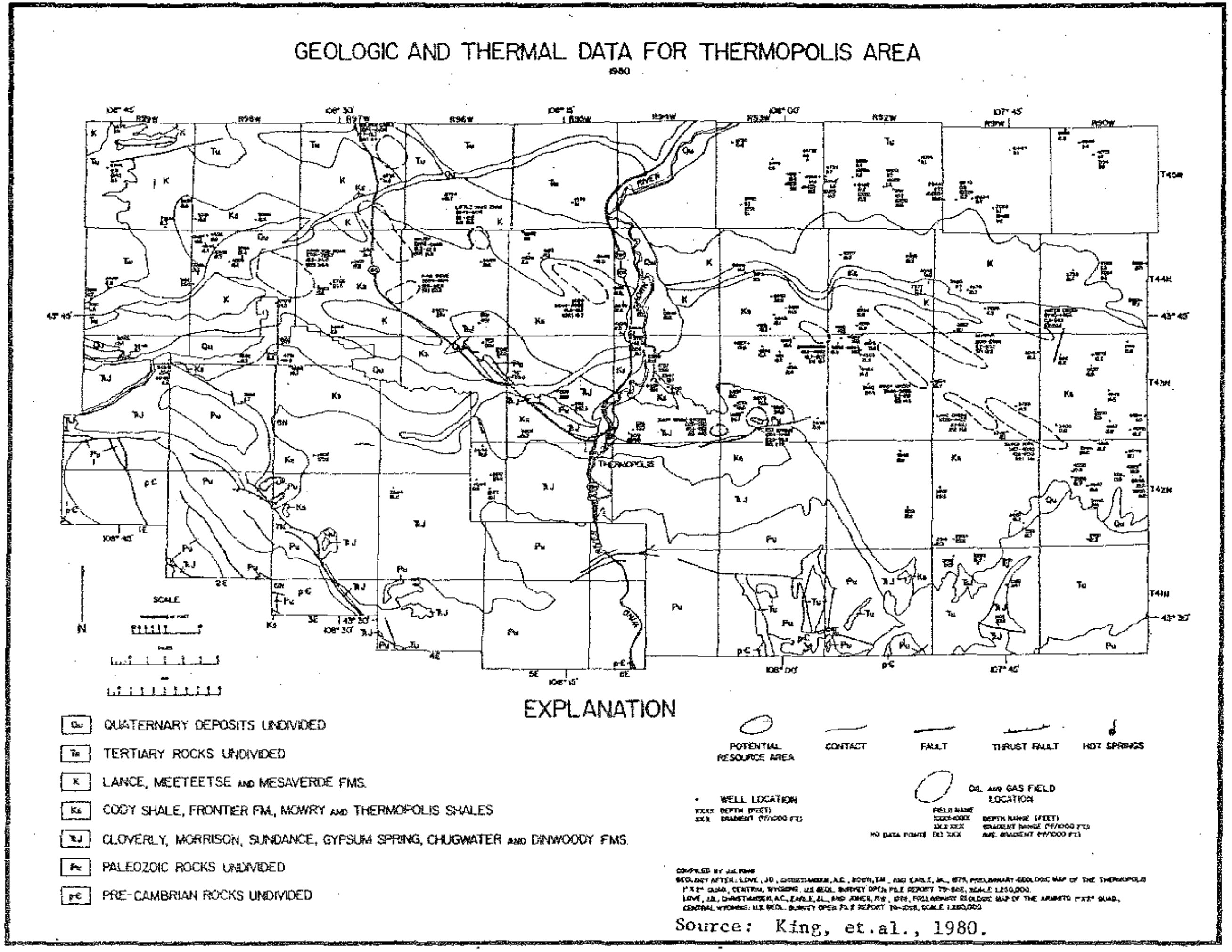


Figure 2. Location of Thermopolis in Hot Springs County and Wyoming.



Source: King, et.al., 1980.

Figure 3. Geologic and thermal data for Thermopolis area

DEMOGRAPHICS

Labor Force

According to the Department of Economic Planning and Development (DEPAD), the annual average of employed persons in Hot Springs County was 2,654 for 1979. Of these, 1,622 were male and 1,032 were female employees. The unemployment average for that year in Hot Springs County was 38 persons, 22 male and 16 female, which brings the unemployment rate to 1.4%. Table 1 shows the distribution of the labor force among industries operating in Hot Springs County during 1979. One can see from this table that Services, Government, Mining, and Trade are the four major industries in terms of employment.

Population Statistics

The population of Thermopolis increased about 30% between 1970 and 1979. The majority of this increase, as illustrated in Figure 4, occurred between 1975 and 1979. The projected population trend for Hot Springs County is also shown in Figure 4. The County's decrease in population from 1979 to 1975 was of the same magnitude as the population increase of Thermopolis the same time period.

Table 1

Employment and Contribution to Economic Base of Hot Springs County by Industry (1979) and Distribution of Labor Force in Hot Springs County, 1979

Industry	Number of Firms	Number of Employees	% of Total Employment	Ave. Weekly Wage Rates	% Contribution to Economic Base Based on Ave. Weekly Wage
Mining	25	307	13.1%	$307.23	27.9%
Construction	31	207	7.7%	$297.39	12.2%
Manufacturing	5	6	2.0%	$178.81	1.2%
Transportation	19	96	3.6%	$311.05	8.0%
Trade	63	373	13.9%	$489.88	17.4%
Finance	14	54	2.0%	$170.23	3.5%
Service	62	714	26.7%	$152.64	29.8%
Agriculture*		202	17.9%		
Government		480	7.5%		
Other*		197	7.4%		

* "Agriculture" sector includes farm proprietors, and "Other" sector includes non-farm proprietors.

Source: Industrial Development Division, 1980, DEPAD, and Division of Research and Statistics, 1980, DAFC.

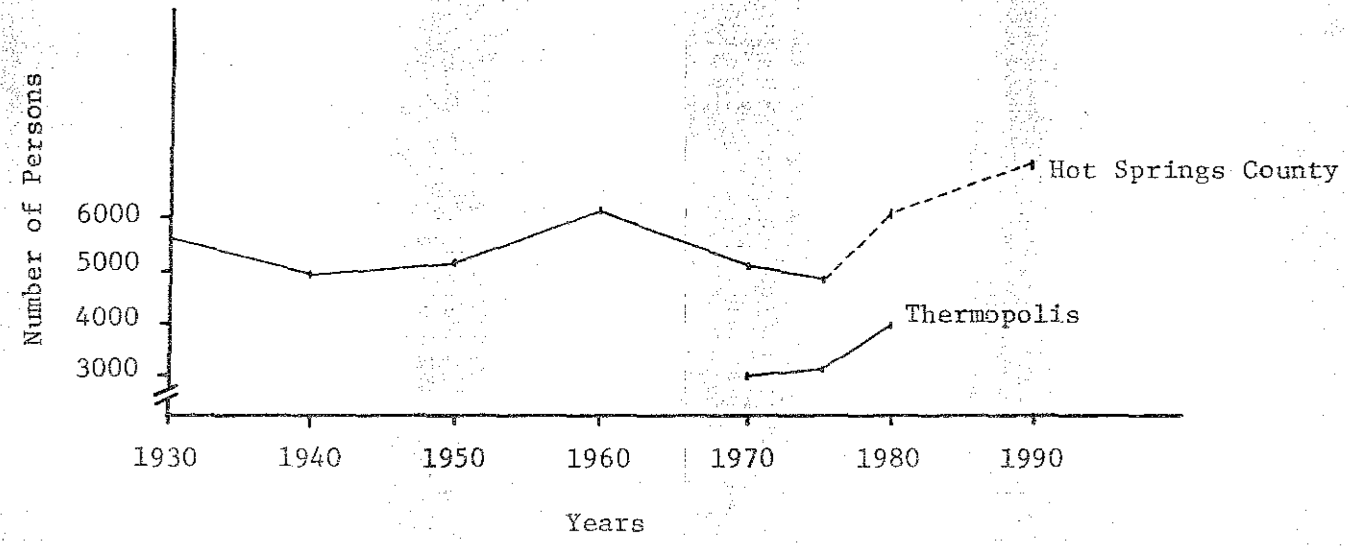


Figure 4: Population Trend for Population of Hot Springs County

Sources: Big Horn Basin Area Development Plan, GCO, 1979.
Thermopolis, Wyoming 1980 community profile, DEPAD.

ECONOMY OF THE SITE AREA

Economic Base

In Hot Springs County, the oil fields appear to be the major employers. Parts of the construction and trade sectors are directly related to the oil industry. Services, especially those in the Health Services category are another major employer in Hot Springs County. This is due to the location of the Big Horn Basin Children's Center, the Gottsche Rehabilitation Center, and the Pioneer Home for senior citizens, all in Thermopolis. An estimated 30% of Thermopolis' population are elderly.

Elements of the Economy by Percent Contribution

An accurate breakdown of each industry's contribution to the economic base of Hot Springs County was not available at the time of writing. One may assume, however, that industries' contribution to the economic base is a direct reflection of the distribution of the labor force among those industries.
(See Table 1)

PUBLIC CONSIDERATIONS

Previously Established Development or Business Prejudices

Thermopolis and its surrounding area has historically been linked to oil production and exploration and has also become a haven for elderly persons. (Approximately thirty percent of Thermopolis' population is elderly.) Referring back to Table 1, the distribution of the Hot Springs County labor force clearly refelcts this. Services, of which Health Services is a major component due to the large elderly population, employs the greatest percentage of the labor force. Mining, due to oil exploration and production, is the second principal industry with respect to employment in Hot Springs County.

Land Use Patterns

With the exception of Hot Springs State Park, the land surrounding Thermopolis is privately owned. Hot Springs State Park, owned by the State of Wyoming, is located in the northeast corner of the city and occupies one section of land.

Municipal Land Use Patterns

Based on the Thermopolis land use map (Figure 5), Thermopolis city land has basically four functions: open space, residential use, business district, and industrial use. In general, residential and open space area lie to the east and to the west of the business district, the latter being the larger of the two. Residential

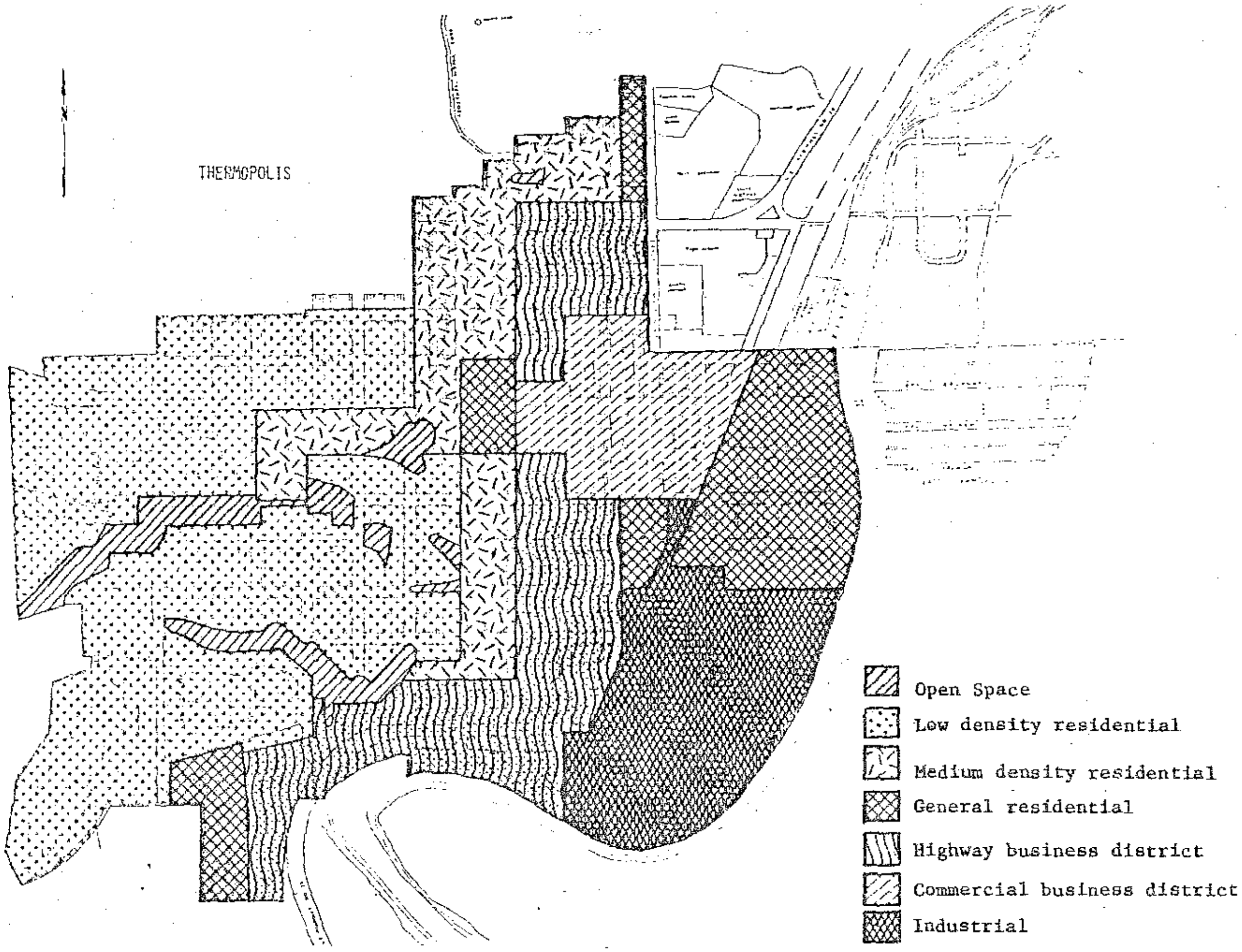


Figure 5. Thermopolis Land Use Map for 1979.
Source: after Hot Springs County Planning Office.

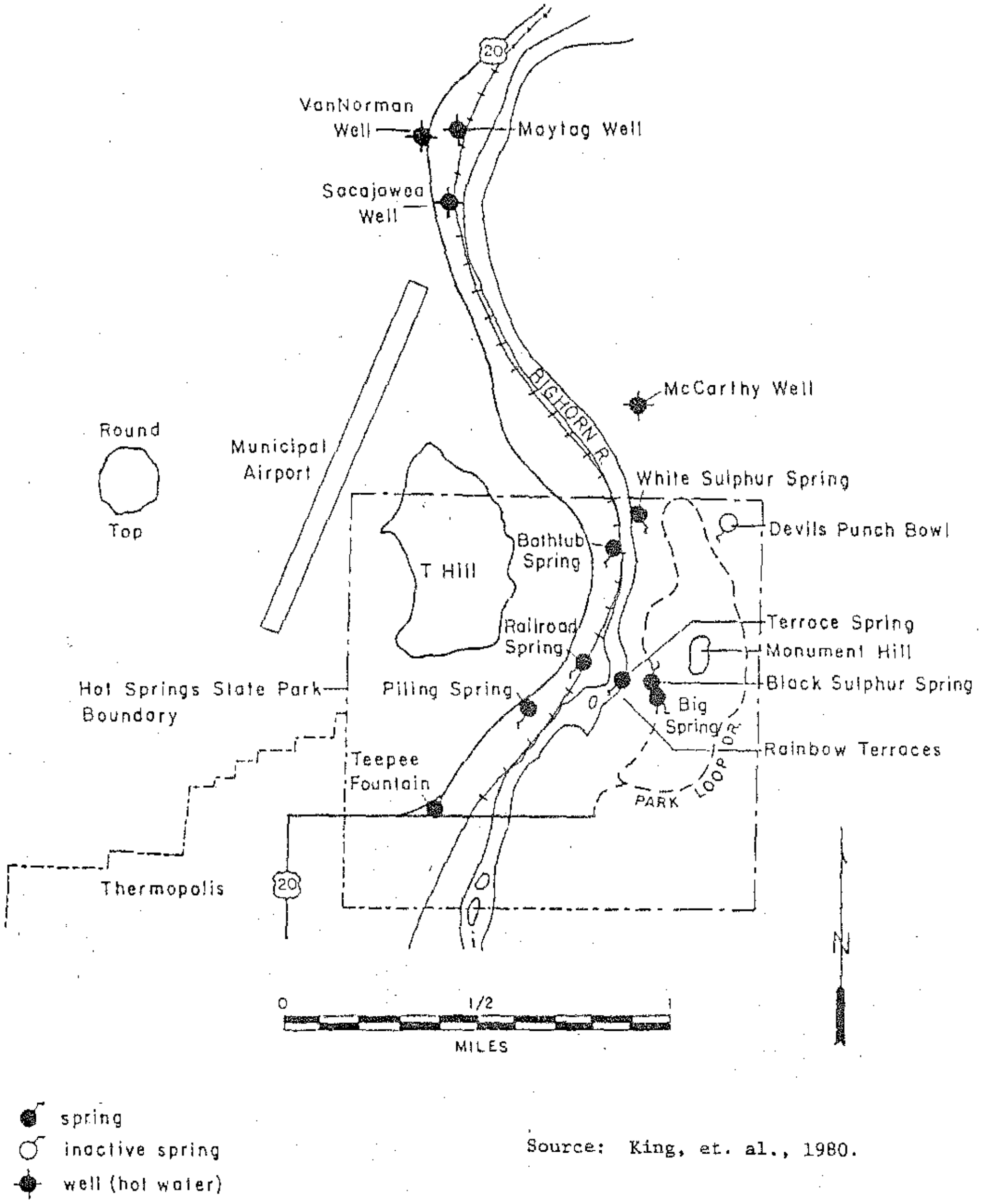
land and open space make up roughly one-half of the city. The business district is centrally located with a north-south orientation. It utilizes about one-third of the Thermopolis city area. The industrial sector is located on the west side of the Bighorn River, occupying the southeast corner of the city and utilizing approximately one-sixth of the city's land.

RESOURCE EVALUATION

Springs

Hot Springs State Park contains within its boundaries seven hot springs: Bathtub Spring, White Sulphur Spring, Railroad Springs, Piling Spring, Black Sulphur Spring, Terrace Spring, and Big Spring. The location of the springs are displayed in Figure 6. Of these hot springs, Big Spring is the largest. It supplies hot water to several pools and bath houses and a large complex of terraces. Big Spring's temperature is the highest (133°F, 56°C) of all the springs in the park. The flow rate of Big Spring is also the highest, (2908 gpm) of all the Park Springs (Breckenridge and Hinckley, 1978). The temperatures and rates of flow of the other six springs are listed in Table 2.

An additional spring, Wind River Canyon Spring, is located outside the park. According to King, et.al. 1980, it may be found south of Thermopolis on U.S. Highway 20 about fifty feet east of the road at the mouth of Wind River Canyon (NW 1/4, NW 1/4 sec. 25 T42NR95W). The temperature and rate of flow of Wind River Canyon Spring are also given in Table 2.



Source: King, et. al., 1980.

Figure 6. Location of hot springs and wells at Hot Springs State Park, Thermopolis, Wyoming.

Table 2: Well and Spring Data for Thermopolis

Name	Temp. F° (C°)	Flow (gpm)	Depth ft (m)	Gradient of/100 ft (°C/km) *
Bathtub Spring	127°F (53°C	2 gpm	----	----
Big Spring	133°F (56°C)	2908 gpm	----	----
Black Sulphur Spring	131°F (55°C)	little or none	----	----
Piling Spring	95°F (35°C)	<3 gpm	----	----
Railroad Spring	not measured	<3 gpm	----	----
Terrace Spring	not measured	10 gpm	----	----
White Sulphur Spring	127°F (53°C)	206 gpm	----	----
Wind River Canyon Spring	72°F (22°C)	989 gpm	----	----
Maytag Well	129°F (54°C)	539 gpm	900 ft (274m)	99.2°F/100ft (180.8°C/km)
McCarthy Well	129°F (54°C)	583 gpm	510 ft (155m)	162.8°F/100ft (296.7°C/km)
Sacajawea Well	126°F (52°C)	1220 gpm	900 ft (274m)	88.9°F/100ft (162°C/km)
Van Norman Well	124°F (51°C)	controlled artesian	498 ft (152m)	156.6°F/100ft (285.4°C/km)

Sources: Breckenridge & Hinckley (1978)
*King, et.al. (1980)

Table 3 gives a summary of chemical analyses for some of the springs mentioned. It should be noted that rate of flow and concentration of chemicals vary from time to time. Over the period of eight years Big Spring's flow fluctuated irregularly between 2280 and 3173 gpm (Breckenridge and Hinckley, 1978). Flow estimations of Big Spring since 1909 indicate a relatively constant flow. If this was not the case, temperature measurements would be expected to fluctuate in correspondence to extreme variations in flow. Temperature measurements have, however, been consistent through time.

The waters in Hot Springs State Park do not meet U.S. Public Health Service requirements for potable water in sulfate, chloride, flouride and total dissolved solids. They have, however, been attributed with curative properties by enthusiasts since before it was purchased by the U.S. Government.

Wells

There are four geothermal wells that have been drilled in the immediate Thermopolis area. The Maytag Well, McCarthy Well, Sacajawea Well, and the Van Norman Well. The Maytag Well is owned by an irrigation district, and the other three are owned by private individuals. All four are located to the north of Hot Springs State Park (see Figure 6). Water temperature, flow, depth, and temperature gradients are presented in Table 2. Chemical analyses of the Sacajawea and McCarthy Wells are shown in Table 3. The Van Norman and Maytag Wells were not sampled for

Table 3: Chemical Analyses for Some Thermopolis Springs and Wells*

Chemical Constituents	Black Sulphur Spg.	Bathtub Spring	White Sulphur Spg.	Big Spring	Wind River Canyon Spg.	Sacajawea Well	McCarthy Well
Ca	385	340	340-383	310-385	140-146	340-396	350
Mg	75	73	77-80	67-113	49-50	76-79	76
Na	266	270	253-270	83-280	40-41	227-270	270
K	49	44	42-45	37-91	6.7-7.4	40-46	40
CO_3	---	0	0	0	0	0	0
HCO_3	740	730	750-784	708-766	377-390	741-760	760
SO_4	777	780	773-820	556-777	276-290	819-840	830
Cl	334	330	300-308	84-355	38-39	300	300
NO_3	.10	0	0-.10	0-.10	0-.3	0-.1	0
F	3.8	4.2	3.8-8.1	3.0-6.8	1.2-1.3	5.4	4.4
S	---	.001	<.001	.006	<.001	<.001	<.001
SiO_2	71	39	37	35-40	12-13	35	36
B	---	.49	.45	.54-.61	.10-.12	.37-.45	.41
Fe	.05	---	.05	0-.08	.09	0	---
TDS	2378	2330	2321-2350	2190-2373	759-800	2390	2380
Cond	2990	3090	2990-3090	2860-3150	1150-1160	3140-3170	3120
pH	---	7.1	7.0	6.4-7.0	7.5-8.0	6.6-7.0	7.1
Na%	---	33	32	33	13	27-32	32
Hard	1262	1100	1200-1286	1100-1274	560-570	1200	1200
Tot.CO_3	---	360	370	350-443	190	370	370
H_2S	1.4	---	2.3	4.5	---	---	---
Temp	55°C(131°F)	53°C(127°F)	53°C(127°F)	56°C(133°F)	22°C(72°F)	52°C(126°F)	54°C(129°F)
Flow	Little or none	2 gpm	206 gpm	2908 gpm	989 gpm	1220 gpm	583 gpm

Source: Breckenridge and Hinckley (1978)

*For notes on the chemical analysis, see Appendix A.

chemical analysis. All four wells have artesian flow.

The waters from the Van Norman Well and the McCarthy Well are used to heat the owners' homes. The Sacajawea Well provides hot water for a large swimming pool, and the Maytag Well is cooled before it is used for irrigation.

Many more wells exist in the general Thermopolis area. King, et.al. 1980, collected temperature and depth data from over 400 well logs in the area (see Figure 3). These wells and their pertinent information (temperature, depth, gradient) were plotted on a geologic map of the region (see Figure 3). This was done to determine relationships between the regional geology and the occurrance of thermal waters.

RESERVOIR DESCRIPTION

Apparent Surface Extent

The potential resource area, as shown in Figure 3, for Thermopolis and vicinity lies in a zone 20 miles long by 3 miles wide along the Thermopolis and Red Springs anticlines. (King, et.al. 1980). This area is defined by the abnormally high thermal gradients which occur there in contrast to lower, or more normal thermal gradients, in the adjacent areas (18°F/1000 feet is "normal" for the Big Horn Basin).

The Thermopolis anticline trends east and south from the southeast corner of T44N, R96W to the southwest corner of T43N, R93W. The Red Springs anticline is roughly parallel to the Thermopolis anticline but much smaller. It sits immediately to the northeast of the eastern end of the Thermopolis anticline, and measures almost five miles long.

Evidence of the resource area appears at the surface in Thermopolis in the form of travertine, sulphur and gypsum deposits, hot springs in the Hot Springs State Park (already described), abundant small hot springs in the Big Horn River, and the four private wells, also previously described (King, et.al. 1980).

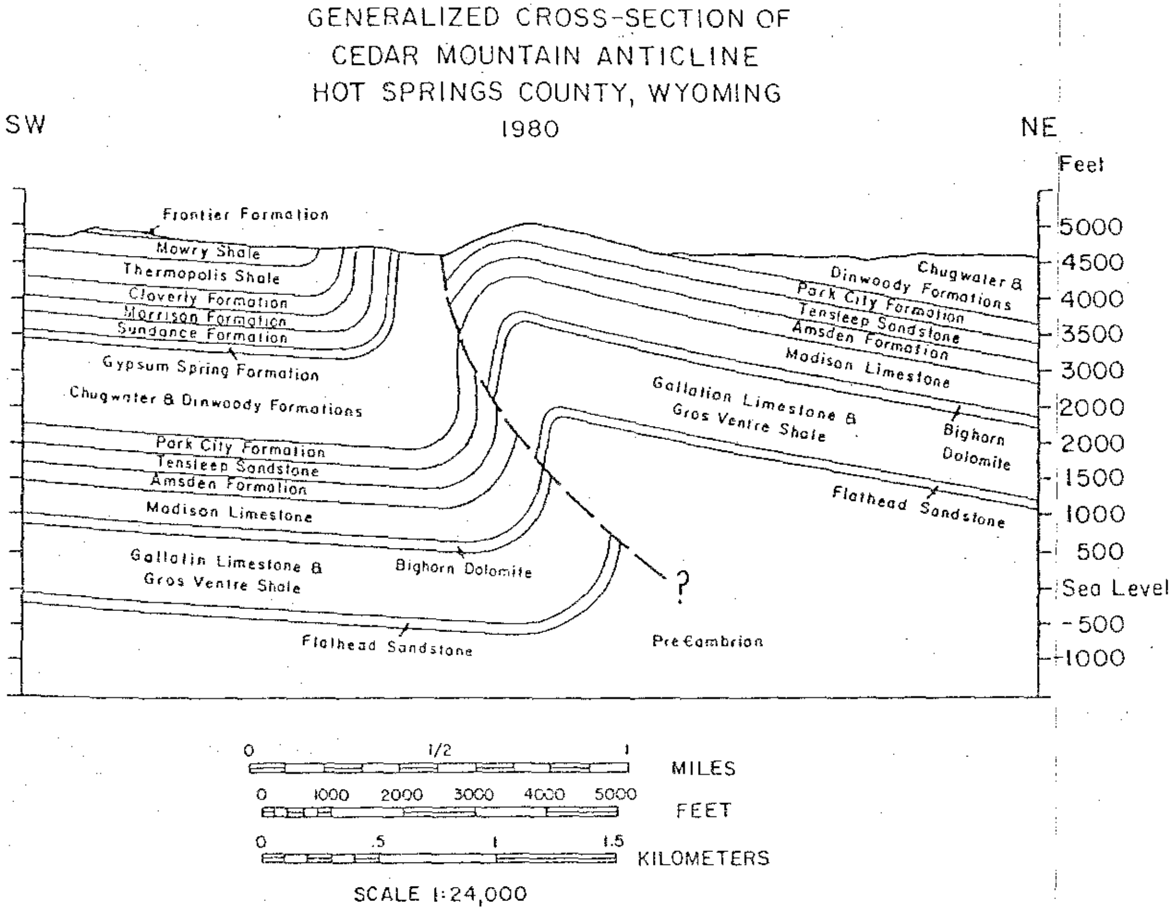
Temperature gradients along the Thermopolis anticline range from 43 - 300°F/1000 feet but five to six miles to the northeast, gradients drop to 12 - 23°F/1000 feet. Five to ten miles southwest of the anticline gradients are 12 - 23°F/1000 feet.

The Red Springs anticline has gradients of 24 - 51°F/1000 feet, but within two miles (3.2km) to the northeast gradients are 16 - 25°F/1000 feet. The potential resource area was delineated by outlining the higher temperature gradients.

Apparent Volume

The apparent volume of the geothermal reservoir in the potential Thermopolis resource area is not known. According to King, et.al. 1980, the most likely candidates for aquifers with hot water are the Park City, Tensleep sandstone, Amsden, Madison limestone, and Bighorn dolomite formations. The Madison is the most probable source of the majority of water. The problem, as King states is that the potential aquifers do not contain water throughout the formations. Yields change from place to place due to variations in permeabilities, and these variations are even more striking along the anticline. This variability is due to the increased permeability induced by fractures in the rock caused by tightly folding rocks into an anticlinal (upwarp) structure. (see Figure 7).

Depth to possible aquifers varies with each aquifer and the structural geology at that site. The aquifers,



Jon King

Figure 7. Geologic cross-section through Cedar Mountain anticline

Source: King, et.al. 1980.

generally speaking, are closest to the surface along the axis of the anticline. Depth to the water might be great, due to increased elevation, whereas sites lower in structural elevation with greater depths to an aquifer may have the water rising closer to or above ground level due to artesian pressure. (King, et.al. 1980).

Estimated depths to the Tensleep sandstone range from 260 feet (79m) from the top of the Park City formation along the crest of the Thermopolis anticline, to 2300 feet (701m) from the top of the Cloverly formation. The Madison limestone is estimated to range in depth from 820 feet from the top of the Park City formation along the anticline's crest, to 2860 feet (872m) from the top of the Cloverly formation. Along the northern flank of the anticline these depths may increase by 140 feet (43m). Along the southern flank depth increases very rapidly due to the steep dip of the beds.

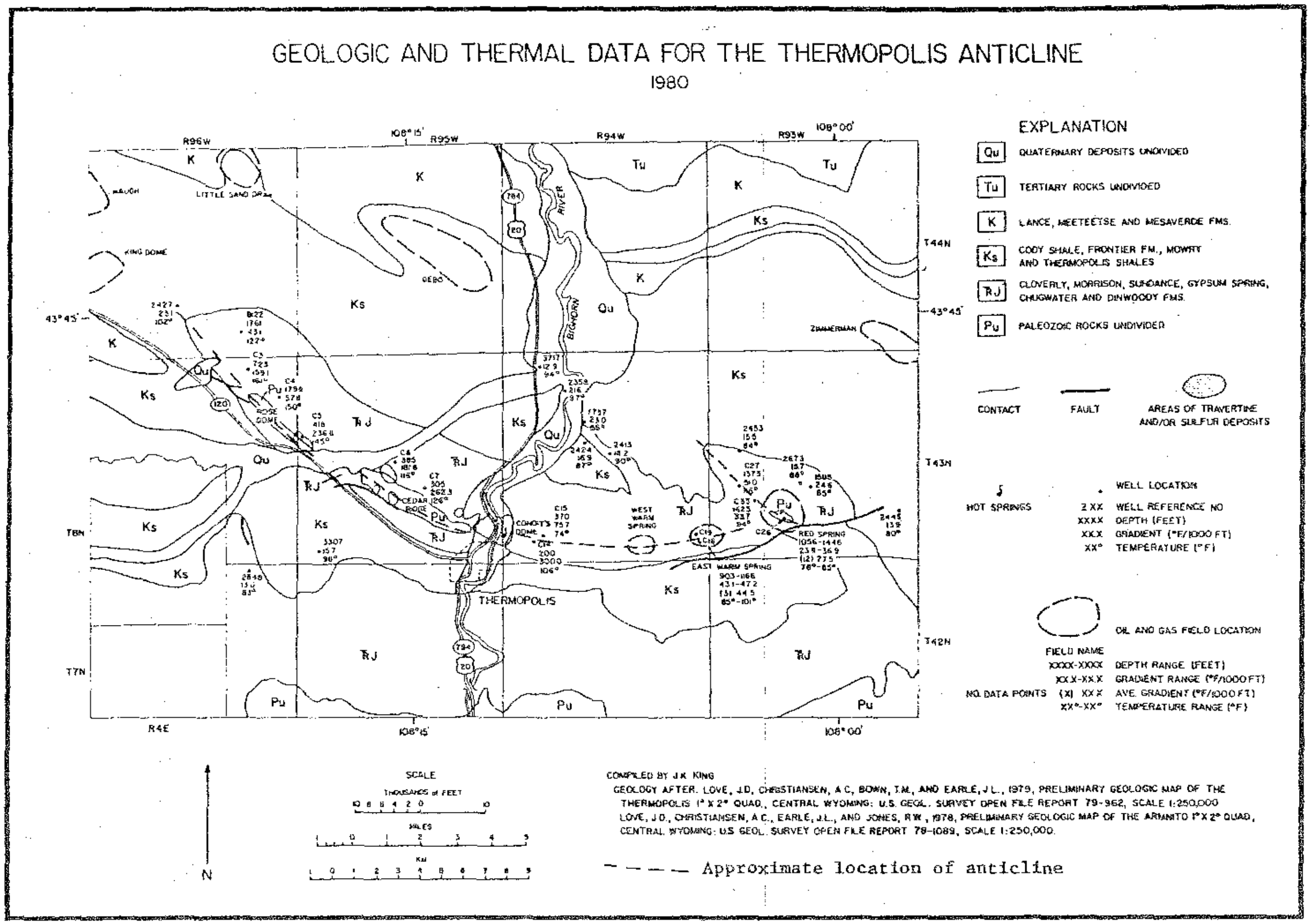
Energy Content

Temperature gradients within the potential resource area of the Thermopolis anticline range from 43° - 300°F/ 1000 feet. Bottom hole temperatures range from 74° - 161°F (23.3 - 71.7°C) at depths less than 1800 feet (550 meters).

Well temperatures appear to be highest along the center of the anticline. The center runs from East Warm Spring (east of Thermopolis) to West Warm Spring, Condit's Dome, Cedar Ridge (west of Thermopolis) and Rose Dome. For example, the higher temperature of Big Spring (133°F, 56°C) gives way to somewhat lower temperatures (129°F, 54°C) in the wells north of the State Park. Another illustration of this point is well C3 (see Figure 8) with a temperature of 161°F (72°C) in contrast to well B122 at 122°F (50°C). An increase in well temperatures is also evident from east to west. East Warm Spring at the easternmost end of the anticline shows temperatures of 101°F(38°C). Continuing west, Condit's Dome measures 106°F(41°C), 126°F(52°C) at well C7 near Cedar Ridge, 145°F(63°C) at well C5 on the southeast end of Rose Dome, well C4 at 150°F(66°C), and well C3 at 161°F(72°C). It is important to note, however, that the anticline migrates with depth, and drilling on the heart of the anticline does not necessarily guarantee wells bearing hot water.

Red Springs anticline is a marginal resource area at the easternmost end of the potential resource area. Temperature gradients in this area range from 15° - 51°F/1000 feet. Well temperatures range from 85° - 116°F (29.4° - 46.7°C). Decker, et.al. 1980, states that 140°F water may be found in this vicinity at depths between 3900 - 4500 feet.

Temperature profiles provided by King, et.al. 1980, comprise Appendix B. These profiles demonstrate rate of temperature increase with depth. An important point dramatically illustrated by the Elleborn Govt.-2 profile is that although a temperature gradient may be given, many times



COMPILED BY J.K. KING
GEOLOGY AFTER: LOVE, J.D., CHRISTIANSEN, A.C., BOWN, T.M., AND EARLE, J.L., 1979, PRELIMINARY GEOLOGIC MAP OF THE THERMOPOLIS 1° X 2° QUAD., CENTRAL WYOMING: U.S. GEOL. SURVEY OPEN FILE REPORT 79-962, SCALE 1:250,000
LOVE, J.D., CHRISTIANSEN, A.C., EARLE, J.L., AND JONES, R.W., 1978, PRELIMINARY GEOLOGIC MAP OF THE ARMINTO 1° X 2° QUAD., CENTRAL WYOMING: U.S. GEOL. SURVEY OPEN FILE REPORT 78-1089, SCALE 1:250,000.

– – – – Approximate location of anticline

Figure 8. Geologic and thermal data for the Thermopolis anticline
Source: After King, et.al. 1980.

temperature will increase with depth up to a certain point, after which temperature levels off, and further drilling for hotter water would be pointless. Therefore, extrapolation of gradient data is not always an accurate method for predicting specific temperatures at depths that have not yet been tested for actual temperature measurements.

EXPLORATION RESULTS

Drilling

There has been no recent drilling for geothermal purposes in the Thermopolis potential resource area. The four private geothermal wells north of Thermopolis were drilled between 1919 and 1920. Other wells in the area have been drilled for oil and gas exploration, but their dates are unknown to this office.

Geochemistry

King, et.al. 1980, attempted to compare chemical compositions of hot well and spring waters to formation waters. Problems arose due to the lack of homogeneity of formations, and the mixing of waters from several formations in uncased wells. Chemical composition of the waters was sometimes found to vary more within a single formation than between distinct formations. The hot springs and wells in the immediate Thermopolis area were more chemically consistant than those from any one formation. The chemical analyses from the formations are in Appendix C.

Geophysics

Three heating mechanisms for the spring and well waters have been proposed by King, et.al. 1980. They are: heat derived from a hot intrusive mass at depth, exothermic chemical reactions in the aquifer, and deep circulation of water.

A hot igneous mass at depth is highly unlikely. The nearest volcanic rock is 30 miles (48 km) west of Thermopolis and the nearest igneous intrusion is 50 miles (90km) west of Thermopolis. In both instances the rock is of Eocene age and would by now have cooled to the point of producing essentially no heat.

It is also unlikely that naturally occurring chemical reactions would be able to supply such a large amount of heat to a voluminous flow of water (2.73 billion gallons/year) for any length of time.

Deep circulation of water seems to be the most feasible explanation for thermal waters. It is believed that water descends the northern flank of the Owl Creek anticline in the aquifers. It moves down into an assymetrical syncline (see Figure 9) immediately south of the Thermopolis anticline. As the water descends into the syncline it is heated and reaches its highest temperature at the deepest point of its

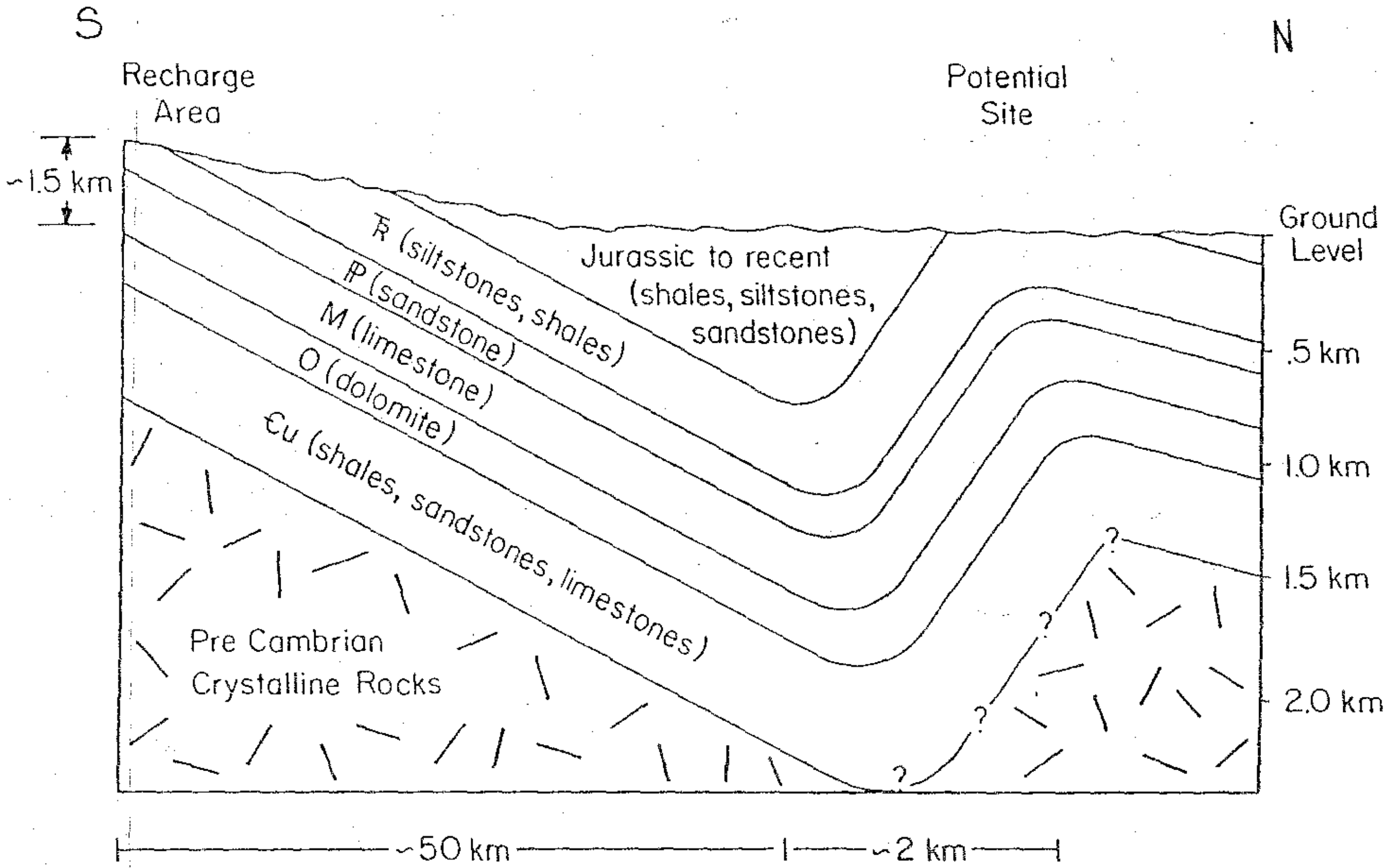


Figure 9: Generalized cross-section for the Thermopolis hydrothermal system
Source: King, et.al. 1980.

journey. A fault in the Precambian basement rock would provide even deeper circulation and higher temperatures. Possible faults and fractures on the south flank of the anticline could facilitate water movement and increase permeability and allow water to rise rapidly with minimal loss of temperature.

Potential Applications of the Resource

The Thermopolis potential resource area is considered by Decker, et.al. 1980, to be a "viable low temperature hydrothermal resource area". The depth of the hot water is shallow enough to make drilling economically feasible. The water temperatures are sufficiently high to warrant some types of industrial applications.

Temperatures of about 130°F may be obtained at less than 2000 feet. Potential industrial uses for water of this temperature are shown in Figure 1. Applications for which development has been proposed in the Thermopolis area are: greenhouses, ethanol production, and a district heating system for the City of Thermopolis.

Other applications compatible to the Thermopolis resource are: aquaculture, soil warming, carcass wash and clean-up, beet sugar extraction, space heating, bentonite drying, and mushroom culturing.

SITE SPECIFIC APPLICATION

Process/Application (Greenhouse)

A geothermal greenhouse has been proposed in which tomatoes would be grown commercially. Depending on the success of the initial endeavor, cucumbers and lettuce production could later be attempted.

The proposed greenhouse would operate off of the McCarthy Well, which is already used for space heating. It has an ample flow of 583 gpm and an adequate temperature of 129°F(54°C) to accomodate both uses. In reference to Figure 1, greenhousing requires a minimum of 90°F water, so the McCarthy Well water should prove to be a sufficient heat source.

Eco System Evaluation (Greenhouse)

The thermal waters used in this system would be contained from well to greenhouse and after use discharged into the Big Horn River. Before the water is discharged into the river, it must be cooled to 90°F or less. The Department of Environmental Quality (DEQ) also requires that the effluent be kept within standards set concerning ppm of chemical constituents before releasing the water into the eco system.

Market Analysis (Greenhouse)

The proposed geothermal greenhouse would be located about 150 feet from the source well.

The tomatoes, and later the cucumbers and lettuce produced in the proposed greenhouse, would be marketed locally in Thermopolis. If the Thermopolis market becomes saturated, the market area could be expanded to include other areas of the Big Horn Basin. The products would probably be transported by truck to the market areas.

Process Analysis (Economics of Greenhousing)

The main objective in heating a greenhouse is maintaining the environment at an optimum day temperature (60° - 75°F) and an optimum night temperature (50° - 65°F) for the particular plants being grown. The more critical of the two is maintaining a minimum night temperature. Only a limited amount of heat would be needed during the day, even on a cloudy day, because of solar radiation.

The basic elements of a geothermal heating system for a greenhouse involve: adequate supply of hot water, heat exchangers, and a method of heat distribution by forced air where natural convection in inadequate. These elements vary in sophistication from a simple on/off thermostat that is changed manually for day and night operations to a multimode controller with programmed changes in temperature from day to night.

Cooling systems include ventilation fans and openings to discharge hot air and draw in fresh air. Shades or heat reflecting materials may also be implemented (Task Force Report on Klamath Falls' Greenhouse Production Potential, 1977).

When building a greenhouse the main concern is to keep heat loss to a minimum. Heat loss is directly related to the amount of exposed surface area. An arched roof, for example, has 14 per cent more surface area than a gabled greenhouse with the same amount of floor space. Glazing material chosen for construction material also affects heat loss. The material best minimizing heat loss is a double layer of polyethylene with an air space between the layers. Following in descending order of heat loss are: flat fiber glass, glass, single layer polyethylene, and corrugated fiberglass. The latter has a lower overall heat transfer coefficient than polyethylene, but the corrugations increase surface area, and thus heat loss (Task Force, 1977).

A gabled double layer polyethylene structure not only loses the least amount of heat, but also requires the smallest capital investment. Tables 4, 5, and 6 itemize investment, operating and heating costs, and equivalent annual costs for glass, corrugated fiberglass and double layer polyethylene

Table 4 Itemized Investment, Annual Operating Cost, and Equivalent Annual Cost for a One Acre Glass Gable Greenhouse Heated with Alternative Energy Resources and Located in Klamath Falls Basin, Oregon

Item	Year 1	Year 10	Year 11-30	Equivalent annual cost[a]
		Natural Gas		
Investment:				
House	$125,336[b]			$ 13,888
Heating and cooling equip.	38,190[c]	7,210	10,748	4,658
Operating Costs:				
Maintenance, electricity taxes, insurance[d]	4,440	7,062	212,571	6,698
Natural gas[c]	39,744	76,440	3,579,472	77,870
		Total equivalent annual cost		$103,114
		Fuel Oil		
Investment:				
House	$125,336[b]			13,888
Heating and cooling equip.	38,190[c]	7,210	10,748	4,658
Operating Costs:				
Maintenance, electricity taxes, insurance[d]	4,440	7,062	212,571	6,698
Fuel oil[f]	45,268	72,066	2,572,434	70,639
		Total equivalent annual cost		$ 95,883
		Coal		
Investment:				
House	$125,336[b]			13,888
Heating and cooling equip.	66,552[g]			7,374
Operating Costs:				
Maintenance, electricity, taxes, incurance[h]	5,708	9,080	286,567	8,885
Coal[i]	32,700	52,944	1,947,610	52,046
		Total equivalent annual cost		$ 82,193
		Geothermal		
Investment:				
House	$125,336[b]			13,888
Heating and cooling equip.	36,150[j]			4,006
Operating Costs:				
Maintenance, electricity, taxes, insurance[k]	4,758	7,476	224,047	7,298
Geoheat[l]	2,000	3,378	131,744	3,343
		Total equivalent annual cost		$ 28,535

Source: Task Force Report on Klamath Falls Greenhouse Production Potential, 1977.

Footnotes, Table 4

[a] Equivalent annual cost is calcuated to compare costs of investment with different useful life expectancies. It represents costs discounted and then spread evenly over the useful life of the investment. The discount rate is 12 percent per annum.

[b] An initial investment of $3.20 per square foot of area and a 30-year useful life are assumed.

[c] An initial investment of $0.98 per square foot of area is assumed. Equipment includes: Gas unit heaters, cooling fans, controls, evaporative cooling pads, piping, and ducting. Major burner repairs required every 10 years.

[d] Includes house maintenance of $134 increased six percent per year, heating and cooling maintenance of $48 increased six percent per year, cooling pad and duct replacement of $1,134 in year two increased six percent per year, electricity of $56 (1,568 kwh) increased 4.2 percent per year, property taxes of $3,270 increased 0.1 percent per year, and insurance of $932 increased six percent per year.

[e] A heating requirement of 10,598 MBtu and a natural gas price of $3 per MBtu (30¢ per therm) increased 7.5 percent per year is assumed. Heating efficiency is 80 percent.

[f] A heating requirement of 10,598 MBtu and a fuel oil price of $2.99 per MBtu (42¢/gal.) increased 5.4 percent per year are assumed. Heating efficiency is 70 percent.

[g] An initial investment of $1.69 per square foot of floor area is assumed. Equipment includes 176 hp of a 200 hp hot water boiler, finned tube heat exchangers, cooling fans, controls, evaporative cooling pads, piping and ducting.

[h] Includes house maintenance of $134 increased six percent per year, heating and cooling maintenance of $98 increased six percent per year, cooling pad and duct replacement of $1,134 in year two increased six percent per year, boiler operating labor of $900 increased six percent per year, electricity of $374 (10,456 kwh) increased 4.2 percent per year, property taxes of $3,270 increased 0.1 percent per year, and insurance of $932 increased six percent per year.

[i] A heating requirement of 10,598 MBtu and a coal price of $1.85 per MBtu ($49.95/ton) delivered at greenhouse site are assumed. Coal contains 13,500 Btu per pound. Heating efficiency is 60 percent. Coal price is increased 5.5 percent per year.

[j] An initial investment of $0.92 per square foot of area is assumed. Equipment includes finned tube heat exchangers, cooling fans, controls, evaporative cooling pads, piping and ducting.

[k] Includes house maintenance of $134 increased six percent per year, heating and cooling maintenance of $48 increased six percent per year, electricity of $374 (10,456 kwh) increased 4.2 percent per year, property taxes of $3,270 increased 0.1 percent per year, and insurance of $932 increased six percent per year.

[l] Payment of $2,000 increased six percent per year commands 10,598 MBtu of geothermal energy delivered at the greenhouse site.

Table 5 Itemized Investment, Annual Operating Cost, and Equivalent Annual Cost for a One Acre Corrugated Fiberglass Gable Greenhouse Heated with Alternative Energy Resources and Located in Klamath Falls Basin, Oregon

Item		Natural Gas Year		
Investment:				
House	$117,504[b]			$ 14,048
Heating & cooling equip.	38,190[c]	7,210		4,876
Operating Costs:				
Maintenance, electricity, taxes, insurance[d]	5,556	11,174	155,940	9,726
Natural Gas[e]	42,900	82,511	1,258,114	71,584
		Total equivalent annual cost		$100,234
		Fuel Oil		
Investment:				
House	$117,504[b]			14,048
Heating & cooling equip.	38,190[c]	7,210		4,876
Operating Costs:				
Maintenance electricity, taxes, insurance[d]	5,556	11,174	155,940	9,726
Fuel Oil[f]	48,862	77,788	1,044,905	69,284
		Total equivalent annual cost		$ 97,934
		Coal		
Investment:				
House	$117,504[b]			14,048
Heating & cooling equip.	66,552[g]			7,956
Operating Costs:				
Maintenance, electricity, taxes, insurance[h]	6,824	13,192	183,234	11,524
Coal[i]	35,307	57,166	776,512	50,732
		Total equivalent annual cost		$ 84,260
		Geothermal		
Investment:				
House	$117,504[b]			14,048
Heating & cooling equip.	36,150[j]			4,322
Operating Costs:				
Maintenance, electricity, taxes, insurance[k]	5,874	11,588	160,382	10,110
Geoheat	2,000	3,378	47,200	2,977
		Total equivalent annual cost		$ 81,457

Source: Task Force Report on Klamath Falls Greenhouse Production Potential, 1977.

Footnotes, Table 5

[a] Equivalent annual cost is caluclated to compare costs of investments with different useful life expectancies. It represents costs discounted and then spread evenly over the useful life of the investment. The discount rate is 12 percent per annum.

[b] An initial investment of $3.00 per square foot of floor area and a 20 year life are assumed.

[c] An initial investment of $0.98 per square foot of area is assumed. Equipment includes: gas unit heaters, cooling fans, controls, evaporative cooling pads, piping and ducting. Major burner repairs required in year 10.

[d] Includes house maintenance of $402 increased six percent per year, heating and cooling maintenance of $48 increased six percent per year, cooling pad and duct replacement of $1,134 in year two increased six percent per year,electricity of $56 (1,568 kwh) increased 4.2 percent per year, property taxes of $3,112 increased six percent per year and insurance of $1,938 increased six percent per year.

[e] A heating requirement of 11,440 MBtu and a natural gas price of $3.00 at $1.20/1000 ft.^{3}=$1.50MBtu, per MBtu increased 7.5 percent per year are assumed. Heating efficiency is 80 percent.

[f] A heating requirement of 11,440 MBtu and a fuel oil price of $2.99 per MBtu increased 5.4 percent per year are assumed. Heating efficiency is 70 percent.

[g] An initial investment of $1.69 per square foot of floor area is assumed. Equipment includes 176 hp of a 200 hp hot water boiler, finned tube heat exchangers, cooling fans, controls, evaporative cooling pads, piping and ducting.

[h] Includes house maintenance of $402 increased six percent per year, heating and cooling maintenance of $88 increased six percent per year, cooling pad, and duct replacement of $1,134 in year two increased six percent per year, boiler operating labor of $900 increased six percent per year, electricity of $374 (19,456 kwh) increased 4.2 percent per year, property taxes of $3,112 increased 0.1 percent per year, and insurance of $1,938 increased six percent per year.

[i] A heating requirement of 11,440 MBtu and a coal price of $1.85/MBtu delivered at greenhouse site are assumed. Coal contains 13,500 Btu per pound. Heating efficiency is 65 percent. Coal price is increased 5.5 percent per year.

[j] An initial investment of $0.92 per square foot of area is assumed. Equipment includes finned tube heat exchangers, cooling fans, controls, evaporative cooling pads, piping and ducting.

[k] Includes house maintenance of $402 increased six percent per year, heating and cooling maintenance of $48 increased six percent per year, electricity of $374 (10,456 kwh) increased 4.2 percent per year, property taxes of $3,112 increased 0.1 percent per year and insurance of $1,938 increased six percent per year.

[l] Payment of $2,000 increased six percent per year commands 11,440 MBtu of geothermal energy delivered at the greenhouse site.

Table 6 Itemized investment. Annual Operating Cost, and Equivalent Annual Cost for a One Acre Double Polyethylene Gable Greenhouse Heated with Alternative Energy Resources and Located in Klamath Falls Basin, Oregon

Item	Year 1	Year 10	Year 11-25	Equivalent annual cost[a]
		Natural Gas		
Investment:				
House	$107,712[b]			$ 12,262
Heating & cooling equip.	38,190[c]	7,210	10,748	4,786
Operating Costs:				
Maintenance, electricity, taxes, insurance[d]	3,541	7,599	158,956	7,071
Natural gas[e]	23,220	44,660	1,259,138	42,313
		Total equivalent annual cost		$ 66,432
		Fuel Oil		
Investment:				
House	$107,712[b]			12,262
Heating & cooling equip.	38,190[c]	7,210	10,748	4,786
Operating Costs:				
Maintenance, electricity, taxes, insurance[d]	3,541	7,559	158,956	7,071
Fuel oil[f]	26,450	42,106	977,654	39,592
		Total equivalent annual cost		$ 63,711
		Coal		
Investment:				
House	$107,712[b]			12,262
Heating & cooling equip.	52,400[g]			5,965
Operating Costs:				
Maintenance, electricity, taxes, insurance[h]	4,809	9,617	206,435	8,972
Coal[i]	19,111	30,942	731,517	29,078
		Total equivalent annual cost		$ 56,277
		Geothermal		
Investment:				
House	$107,712[b]			12,262
Heating & cooling equip.	38,190[j]			4,347
Operating Costs:				
Maintenance, electricity, taxes, insurance[k]	3,859	8,013	166,896	7,465
Geoheat[l]	2,000	3,378	83,158	3,176
		Total equivalent annual cost		$ 27,250

Source: Task Force Report on Klamath Falls Greenhouse Production Potential, 1977.

Footnotes, Table 6

[a] Equivalent annual cost is calculated to compare costs of investments with different useful life expectancies. It represents costs discounted and then spread evenly over the useful life of the investment. The discount rate is 12 percent.

[b] An initial investment of $2.75 per square foot of floor area and a 25-year life is assumed.

[c] An initial investment of $0.98 per square foot of area is assumed. Equipment includes: gas unit heaters, cooling fans, controls, evaporative cooling pads, piping and ducting. Major burner repairs required in years 10 and 20.

[d] Includes house maintenance of $67 first year, $1,210 second year and thereafter (polyethylene replaced annually) increases six percent per year. Heating and cooling maintenance of $48 first year and $1,185 second year (cooling pad and ducts replaced) increased six percent per year, electricity of $56 (1,568 kwh) increased 4.2 percent per year, property taxes of $2,918 increased 0.1 percent per year, and insurance of $932 increased six percent per year.

[e] A heating requirement of 6,192 MBtu and a fuel oil price of $2.99 per MBtu increased 5.4 percent per year are assumed. Heating efficiency is 80 percent.

[f] A heating requirement of 6,192 MBtu and a fuel oil price of $2.99 per MBtu increased 5.4 percent per year are assumed. Heating efficiency is 70 percent.

[g] An initial investment of $1.33 per square foot of floor area is assumed. Equipment includes 96 hp of a 200 hp hot water boiler, finned tube heat exchangers, cooling fans, controls, evaporative cooling pads, piping and ducting.

[h] Includes house maintenance of $67 first year and $1,210 second year and thereafter (polyethylene replaced annually) increased six percent per year, heating and cooling maintenance of $98 increased six percent per year, cooling pad and duct replacement of $1,134 in year two increased six percent per year, boiler operating labor of $900 increased six percent per year, electricity of $374 (10,456 kwh) increased 4.2 percent per year, property taxes of $2,918 increased 0.1 percent per year and insurance of $932 increased six percent per year.

[i] A heating requirement of 6,192 MBtu and a coal price of $1.85 per MBtu delivered at greenhouse site are assumed. Coal contains 13,500 Btu per pound. Heating efficiency is 60 percent. Coal price is increased 5.5 percent per year.

[j] An initial investment of $0.92 per square foot of area is assumed. Equipment includes finned tube heat exchangers, cooling fans, controls, evaporative cooling pads, piping and ducting.

[k] Includes house maintenance of $67 first year and $1,210 second year and thereafter (polyethylene replaced annually) increased six percent per year, heating and cooling maintenance of $48 increased six percent per year, cooling pad and duct replacement of $1,134 in year two increased six percent per year, electricity of $374 (10,456 kwh) increased 4.2 percent per year, property taxes of $2,918 increased 0.1 percent per year and insurance of $932 increased six percent per year.

[l] Payment of $2,000 increased six percent per year commands 6,192 MBtu of geothermal energy delivered at the greenhouse site.

greenhouses one acre in size, and heated with natural gas, fuel oil, coal, and geothermal fluids (costs are specific to Klamath Basin, Oregon). These cost estimates show potential total annual cost savings from using geothermal energy as opposed to using the other three energy options to be between $29,000 to $74,500 per acre during the useful life of the structure. The actual amount of savings, of course, depends on which structures and which energy sources are being compared.

Estimated costs, revenues, and returns to the capital investment for winter tomato crop production is shown in Table 7. These figures were for a geothermal greenhouse in Klamath Basin, Oregon, 1976, one acre in size. Return to capital after nine to ten months of the winter tomato production was almost $24,500 (Task Force, 1977).

Greenhouses are not labor intensive nor do they require skilled labor. Except for harvest time, three or four workers are sufficient for a one acre greenhouse raising tomatoes.

Process/Application (Ethanol)

A small scale ethanol production plant has been proposed that would operate off of the McCarthy Well in addition to the previously discussed greenhouse. Because temperatures of about 300°F are needed for ethanol production, (and the well's water temperature is 129°F, 54°C), the geothermal heat source would be supplemented by heat pumps and passive solar energy.

Table 7 Winter Tomato Production: Estimated Costs, Revenues and Returns to Capital Investment for a One Acre Geothermal Greenhouse in the Klamath Basin: 1976[a]

	Labor				
Cultural Costs	Hours	Cost[b]	Materials & Equipment	Cost	Total Cost
Bed preparation	23.1	57.75	Equipment allowance	43.64	101.39
Growing medium sterlization	15.4	38.50	Fuel and equipment	349.15	387.65
Planting	115.5	288.75	11,000 plants	374.96	663.71
Prepare and hang support strings	323.40	808.50	231,000 ft. twine	187.67	996.17
Prune and train (once weekly, 20 weeks)	1,540	3,850.00			3,850.00
Pollinate, vibrator (3 times weekly, 16 weeks)	539	1,347.50			1,347.50
Lower plants (2 times per crop)	770	1,925.00			1,925.00
Fertilizer and irrigation	38.5	96.25	Fertilizer, water	1,527.53, 305.51	1,929.29
Pest control	38.5	96.25	Pesticides	56.74	152.99
Harvest (grade and pack)	3,388	8,470.00	Cartons and packages	7,260.00	15,730.00
Postharvest plant removal	57.8	144.38			144.38
Other Costs					
Building and equipment maintenance, taxes insurance and electricity				5,828	5,828.00
Geoheat (lease costs)				2,000	2,000.00
Interest on average operating capital @ 10%				1,752.80	1,752.80
General overhead (4% of cash costs)				1,402.24	1,402.24
Management charge (5% of gross revenue)				3,300.00	3,300.00
Totals	6,849.2	17,122.88		24,388.24	41,511.12
Revenues					
Tomatoes (20 lbs. per plant per year) @ 30¢/lb.					66,000.00
Returns to capital invested in buildings, land and heating and cooling equipment					24,488.88

[a] Based on costs appearing in Johnson, Hunter Jr. Sample Costs for Producing Greenhouse Tomatoes and Cucumbers in California, University of California, Riverside. July 1975. Winter tomato production requires from 9 to 10 months of greenhouse use.

[b] Labor costs of $2.50 per hour include basic wate rate, SAIF, and social security payments.

Source: Task Force Report on Klamath Falls Greenhouse Production Potential, 1977.

The raw material for this proposed plant is river moss which grows wild in the Big Horn River. The river moss would be harvested from the bottom of the river by a water powered paddle wheel.

Eco System (Ethanol)

As in the case of the greenhouse, the heating water from this plant would be discharged into the Big Horn River after it has been cooled to at least 90°F. The ppm of its chemical constituents must be brought within limits to conform with DEQ standards.

The effects upon the Big Horn River's ecosystem due to the repeated churning of water and removal of the river moss is uncertain. At present the river is periodically dredged to remove the moss which grows superfluously due to the warm temperature of the river water. This is due, in turn, to numerous small hot springs that empty into the Big Horn River. Because the river moss grows so abundantly, it is dredged out to avoid eutrophication of the river and the adverse effect this would have on other life the river supports.

As the proposed ethanol plant will utilize geothermal and solar energy and heat pumps, a coal fired steam plant with its inherent particulate emissions would be eliminated.

Market Analysis (Ethanol)

In this case river moss is the raw material for the proposed ethanol plant. The source for the moss is the Big Horn River which lies within 1/4 mile of the proposed plant location.

It is probable that Husky Oil in Cody, Wyoming would purchase any ethanol produced by this plant. Husky Oil has made verbal commitments in the past to purchase any ethanol produced in the Big Horn Basin for use in gasohol production. Transport of the finished product would presumably be by truck.

Process Analysis (Economics of Ethanol Production)

The standard process for producing alcohol is basically comprised of four stages. These are: saccharification, fermentation, distillation and dehydration.

Saccharification converts the starch in grain feedstock into a simpler carbohydrate sugar. When sugar beets are used as a raw material, this step is a direct extraction of sugar.

During fermentation the sugar is biologically hydroloyzed to ethyl alcohol and carbon dioxide. This "beer" containing 5 - 12% alcohol in water is then pumped to the distillation unit.

The distillation unit removes most of the water to concentrate the alcohol at about 95%. The dehydration process then removes the remaining 5% of the water. These later two steps require the bulk of the energy demands.

Table 8 shows cost estimates for an ethanol plant producing 10 million gallons of ethanol per year. This is considerably larger than the plant proposed for Thermopolis. The cost estimates presented assume barley as the raw material, and coal as a heat source. Although the discrepencies between systems is great, Table 8 was included to give a general idea of kinds of costs involved in ethanol production, and a comparison of their magnitude.

Process/Application (District Heating)

A district heating system has been proposed for the City of Thermopolis for quite some time. Such a system would work off of a series of wells. The hot water from these wells would provide the heat for space heating for sections of the city or for the entire City of Thermopolis.

Referring back to Figure 8, it appears that the central City of Thermopolis is not located directly above the best potential resource area. To insure hot temperatures at relatively shallow depths, the wells may have to be drilled either in the northern reaches of the city or even farther to the north if necessary. It is probable that temperatures of 130°F (55°C) at depths less than 2000 feet may be encountered in this area.

TABLE 8 ECONOMIC ANALYSIS FOR ETHANOL PRODUCTION

INVESTMENT, MANURACTURING AND ADMINISTRATIVE COSTS, AND NET PROFIT BEFORE INCOME TAXES PER YEAR FOR YEARS 2 THROUGH 5

	Dollars
Investment	
New Facilities	21,700,000
Working Capital	3,744,900
Total	25,444,900
Sales Income	
Alcohol ($1.59/gal.)	16,799,460
By-Product (Feed)	6,035,250
Total	22,834,710
Cost of Manufacture (COM)	
Raw Materials	8,501,800
Chemicals and Denaturants	892,990
Labor*	921,370
Mgmt. & Sup.*	550,000
Utilities	590,600
Maintenance and Materials	325,500
Depreciation	1,446,700
Property Taxes	451,300
Insurance	271,300
Total (COM)	13,951,560
General Administration, Sales, and Research	685,000
Total Cost	14,636,560
Profit (Before Tax)	8,198,150

*Includes overhead

Source: Garing, et.al.

The actual design of the district heating system has not been attempted through our office. The system design should be done by an experienced engineering firm once the scope of the overall project has been determined by the City of Thermopolis.

District heating systems can be set up in a variety of ways. A central surface heating exchange unit could be utilized to eliminate the risks of the potentially corrosive geothermal water from travelling throughout the entire system. In this way, only the heat from the geothermal source would be extracted, and another heat-carrying medium such as domestic water could be used to transport the heat to individual buildings. Depending upon the actual size, depth and volume of the geothermal reservoir(s) encountered, a large number of shallow wells could be drilled and downhole heat exchangers could be utilized. This method is presently being used in Klamath Falls, Oregon and eliminates any surface travel of the geothermal fluid entirely. Various types of heat exchangers are explained in the Technological Factors section.

Eco System Evaluation (District Heating)

A district heating system is potentially less contaminating than the two previously proposed projects. District heating projects are usually self-contained systems. At the end of the system the cooled water would be reinjected back into the water bearing formation(s). In this way, the aquifer would not be depleted, and the geothermal water would be reheated. To insure against cooling off the supply reservoir by reinjection the supply well and reinjection well need to be at some distance from one another.

One of the critical considerations in the development of a district heating system for Thermopolis is whether tapping geothermal resources in the city would reduce, or in some way alter, the flow or temperature of the geothermal waters in Hot Springs State Park. Those waters are protected by state law and must remain unchanged. Geologists remain indecisive as to whether or not drilling in the Thermopolis area will or will not affect temperature or flow of the hot springs in Hot Springs State Park. It is believed that the further drilling occurs to the north and west of the park the less likely it is that the State Park springs would be altered.

Market Analysis (District Heating)

The market area depends on where the city decides to drill its supply wells for the district heating system. If drilling occurs within city limits, the market area would be within about one mile. If it proves necessary to drill outside the city limits the market area would be larger.

The marketing of the heat itself could be accomplished in a number of ways. The geothermal heat would probably be sold through either a public or private utility. A municipal development would be the least expensive to the general public in terms of overall heating costs. In general terms, a geothermal source for heat would be cheaper in operating costs to the consumer than traditional fuel sources, although the initial investment is high.

Process Analysis (Economics of District Heating)

Appendices D-F outline three different computer models of the possible expenses to be incurred in developing and installing a geothermal district heating system for Thermopolis. Initial investment costs are estimated to range from about 2 1/2 million to almost 10 million dollars. To understand the differences in these cost estimates, the assumptions made by the models must be considered.

Appendix D proposes a capital cost of $3,299,650 and assumes that all of the money would be borrowed at commercial rates. Thermopolis however, may qualify for various financial aid programs which are discussed later in the Financial Factors section. This model also assumes the square footage per home to be much larger than is actually the case for homes in most Wyoming cities.

The model presented in Appendix F assumes a shipping distance of eight miles over which some cooling of the water would occur. This would probably not be the case for Thermopolis, since the potential resource lies much closer to the city.

Excessive drilling depths are another assumption made by the models not applicable to Thermopolis. Viable thermal waters may be found at depths less than 2000 feet.

All models assume a MMBTU cost at $3.13 for natural gas. This has since risen to $3.50 and will continue to increase with time.

The difference in suppliers and the quality of materials must also be examined when considering cost. A similar study for district heating in Klamath Falls, Oregon reported that prices quoted by suppliers varied 2% to 200%. The study also pointed out that although steel pipes are more expensive, they radiate heat better than cheaper plastic pipes and corrode less than copper pipes (Anderson ed., Direct Utilization, 1979).

OUTSIDE AND SPECIAL FACTORS

Reservoir Use Allocations and Rights

On April 22, 1896, U.S. Indian Inspector James McLaughlin made an agreement with Chiefs Washakie and Sharp Nose of the Shosone and Arapahoe tribes respectively. In the agreement the U.S. government agreed to pay the tribes a total of $60,000 for 10 square miles of land. This included area which is now Hot Springs State Park and the City of Thermopolis. The agreement was such that the hot springs would forever remain available to the general public (Senate Doc. No. 247).

In 1897, these lands were ceded to the State of Wyoming and subsequently placed under control of the State Board of Charities and Reform.

The water right for the flow of the Big Horn Hot Springs was adjudicated with a priority date of February 17, 1899. The State Engineer is required by Wyoming law §41-1-109 to take any actions necessary to protect "geothermal springs on state lands". The

State Engineer may take court action to eliminate dangers to geothermal springs and set standards and regulations for spring protection.

Government Assistance

The majority of government assistance for developing geothermal resources consists of grant programs and loan guarantee programs which are described in the "Financial Factors" which follows.

Federal tax incentives are in the form of credit against income tax. This credit is given for expenditures for equipment used to produce, distribute or use geothermal energy. This does not apply to public utilities.

Residential energy credit is given against the income tax of an individual taxpayer for expenditures for installing a geothermal system in a principal residence. The credit is 30% of the first $2000 and 20% of the next $8000.

The State of Wyoming does not offer any tax incentives for the development of geothermal energy.

DEVELOPMENT PROCESS

Financial Factors - Private Sector

There are no private funding programs for geothermal development at this point in time. It is possible, however, to sell stock to raise money at the individual or corporate level for geothermal projects.

Financial Factors - Public Sector

General Obligation Bonds - Cities and counties may issue general obligation bonds to raise funds for specified purposes. Such bonds create a debt on the public treasury and are repaid with property taxes. They must be approved by the voters at a general or special election.

This method of financing is available only for the purposes listed in the law. Geothermal development is not included, though municipalities may finance "waterworks", and "water rights for supplying the city or town with water." Furthermore, general obligation bonds are available only for publicly owned and operated facilities.

Municipal Revenue Bonds - A somewhat more versatile funding mechanism, the municipal revenue bond, is available to cities and towns. The bonds create a lien on the facility itself rather than on the general credit of the municipality. They are repaid through user fees rather than through property taxation, and they do not require voter approval.

It is unclear whether this mechanism is available for geothermal systems. Revenue bonds may be used to fund, inter alia, water systems and "other revenue-producing facilities and services authorized in these codes for cities and towns". Revenue bonds are available only for publicly owned and operated facilities.

Industrial Development Projects - Perhaps the most flexible public funding mechanism is authorized by the Industrial Development Project Act. In essence, this law makes the credit of cities and counties available to private developers to assist in financing commercial, agricultural or industrial enterprises. The city or town council, or board of county commissioners, issues limited obligation revenue bonds for the construction or operation of the project, and then leases or sells the project to the private developer. In this way, the developer can take advantage of the tax-exempt status of municipal or county bonds. To qualify, the project must be found to be in the public interest. Unlike projects financed by general obligation or revenue bonds, projects financed under this law are in no way operated by the local government.

The law applies to, inter alia, "commercial, manufacturing, agricultural, or industrial enterprises." There is no reason why geothermal developments could not be included under this definition.

The Geothermal Loan Guarantee Program - The Geothermal Loan Guarantee Program is designed to stimulate commercial development of geothermal energy by minimizing the financial risk incurred by development capital lenders. Under this program, the United States government pledges its full faith and credit to the lender to guarantee the repayment of principal and interest on geothermal development loans. The objective is to provide financial incentives for the early and rapid development of geothermal alternatives, while helping to establish the resources and technologies necessary for a self-sustaining industry. As the industry develops, normal financial relations between borrowers and lenders will also develop, eliminating the need for this program.

Loan guarantees of up to 75 percent of the estimated cost of a project may be granted for up to 30 years. At least 25 percent of the project cost must be in borrower's equity. The maximum loan guaranty for a single project is set at $100,000,000 with allowances for larger amounts for projects considered to be in the national interest. The maximum loan guaranty amount that any single borrower may have outstanding is $200,000,000. The granting of a geothermal loan guaranty does not prohibit the borrower from qualifying for or obtaining other federal financial assistance.

The range of eligible projects is very broad. Any project that falls into one or more of the following categories is eligible for a loan guaranty.

- Determination and evaluation of the commercial potential of geothermal resources.
- Research and development in geothermal extraction and utilization technologies.
- Obtaining rights to geothermal resources.
- Development, construction, and operation of equipment or facilities for the commercial production of electrical energy from geothermal resources.

Any organization, public or private, can be granted a geothermal loan guaranty. According to the program regulations, preferential consideration is given to projects that are to be carried out by small independently-owned and -operated businesses and small utilities. In addition, priority is given to projects that promise to produce geothermal applications quickly, projects that use new technological advances, and projects undertaken in new geothermal resource areas.

For additional information and for application forms for the Geothermal Loan Guarantee Program, contact:

Geothermal Loan Guarantee Office
San Francisco Operations Office
U.S. Department of Energy
1333 Broadway
Oakland, CA 94612
415/273-7151

Normal evaluation and approval times have been established at approximately 4 months in the San Francisco DOE office and 2 months in the DOE Washington Headquarters. Applications may be submitted at any time during the year.

Program Research and Development Announcement (PRDA) - The Program Research and Development Announcement (PRDA) granting system is designed to provide an opportunity to interested parties to propose engineering and feasibility studies in energy-related areas. Several of these PRDAs have been specifically issued for geothermal projects.

Past PRDA announcements have awarded from six to twelve grants per proposal. Most of the projects have received less than $125,000.

Proposals may be submitted under this program by individuals, non-profit organizations, educational institutions, and companies that either own the geothermal resource area in question or can gain access from the owners of the resource.

The Department of Energy mails out notices of upcoming PRDAs periodically, usually about once a year. These PRDAs are not necessarily aimed at geothermal development, since any energy related area may be covered in a PRDA. In order to receive notice of these PRDA mailings, write to:

Idaho Operations Office
U.S. Department of Energy
Geothermal Program
550 Second Street
Idaho Falls, ID 83401

Program Opportunity Notice (PON)- In September 1977 and April 1978, the Department of Energy (DOE), Division of Geothermal Energy, issued a document indicating DOE's desire to receive and consider for partial support proposals for direct heat utilization or combined electric/direct heat utilization field experiments demonstrating single or multiple usages of geothermal energy. This document was issued under the title, "Program Opportunity Notice - Direct Utilization of Geothermal Energy Resources - Field Experiments." Although Program Opportunity Notice (PON) is the name of this offering document, it has become common practice to call any program resulting from these notices a PON.

These solicitations are part of DOE's national geothermal energy program plan, of which the goal is commercial development of hydrothermal resources by the private sector, for direct use purposes. Encouragement is being given to the private sector by DOE's cost-sharing a significant portion of the front-end financial risk.

DOE's primary interest under these PON's was to encourage field experiments in space/water heating and cooling for residential and commercial buildings, agricultural and aquacultural uses, and industrial processing.

Under the last PON, 15 proposals were selected for funding. The government is not obligated to make any particular aggregate sum.

Individuals, corporations, educational and other institutions, and state and local agencies were eligible under the last PON. Federal agencies, government laboratories and other government facilities were not eligible. Eligibility may vary from PON to PON. All grants are awarded on a cost-shared basis.

PON notices are released sporadically. It is therefore necessary to get on the DOE mailing list to receive the PON notices as they are announced. To get on the mailing list, write:

U.S. Department of Energy
San Francisco Operations Office
1333 Broadway
Oakland, CA 94612

Appropriate Technology Small Grants Program - This program is designed to encourage development, demonstration and dissemination of information concerning energy related systems and supporting technologies. The program goals include applying existing technologies to new and innovative uses, encouraging the use or renewable resources such as goethermal, wind, and solar energy, and encouraging the conservation of fossil fuels.

Grants up to $50,000 are available for project development and demonstration, with the average grantee receiving $12,000. Between $300,000 and $500,000 will be available in 1981 to the six-state region that includes Wyoming. During 1979, 540 proposals were submitted, of which 30 were funded. The number of funded proposals in 1980 is unknown at this writing, but over 900 were submitted. Of the 1979 proposals, 3 percent dealt with geothermal projects, and one funded project involved a geothermal heat exchanger for a Durango, Colorado school.

Individuals, local non-profit organizations and institutions, state and local agencies, small businesses, and Indian tribes are eligible to submit grant applications.

Application forms for the 1981 granting period will be available in January 1981, and must be returned by March 1981. Grant recipients will be notified within four months of the deadline for grant submittals. To receive a copy of the 1981 grant application, contact:

Program Manager
Appropriate Technology Small Grants Program
U.S. Department of Energy
c/o Westpo
333 Quebec Street, Suite 2300
Denver, CO 80207

U.S. Department of Energy- The U.S. Department of Energy sponsors a program to share drilling costs associated with confirming a geothermal reservoir for direct use applications. Confirmation of reservoir temperatures, flow rates and longevity are often high-cost and high-risk ventures. This program is designed to stimulate the direct use of geothermal energy by reducing the economic risks associated with confirmation.

The federal percentage share of costs will be determined by a negotiated formula between the developer and the government. This formula is based on the degree of success in confirming an economically usable resource. If the drilling project is completely successful, the Department of Energy's cost share will be about 20 percent; for a completely unsuccessful project (no usable resource is found), the Department of Energy's cost share will be about 90 percent. Most cost shares will range between these two extremes. The total amount of funding available under this program is approximately $10,000,000 in 1980 and $20,000,000 in 1981.

Private individuals, private companies, and state and local government agencies are eligible under this program.

A competitive procurement announcement will be released once a year. This announcement can be received by writing or by calling:

Susan Prestwich
Idaho Operations Office
Department of Energy
550 2nd Street
Idaho Falls, ID 83401
208/526-1146

The application must include the following information:

1. Good geological evidence for the existence of the resource.
2. The final use of any geothermal fluids discovered.
3. An adequate outline of the exploration, drilling and flow testing program.
4. An acceptable cost sharing plan.

Alcohol Fuels Program - Geothermal energy can be used in several stages of alcohol production, including distillation, mash drying and space heating. Funding for the development of alcohol fuels is available from several federal agencies, including the Department of Energy, the Small Business Administration, the Department of Agriculture, and the Department of Housing and Urban Development.

The U.S. National Alcohol Fuels Commission, established in 1978 to further alcohol fuel development, has prepared a compendium of all the federal funding sources that can be used by a geothermal developer who is interested in alcohol production facilities. Eligibility and funds available varies from program to program. To receive the compendium write to: (Ask for the Federal Agency Compendium of Alcohol Fuels)

U.S. National Alcohol Fuels Commission
412 First, S.E.
Washington, D.C. 20003
202/426-6490

The Old West Regional Commission, consisting of the Governors of the states of Montana, North Dakota, Nebraska, South Dakota and Wyoming, was organized to provide leadership to the states in coping with the region's economic problems. The Commission's major objectives include increasing per capita personal income, achieving environmental quality goals, and increasing citizen participation in government.

One method used in achieving these goals is to provide grants for research, development and demonstration projects directed to solving economic problems of the region. Project funding varies widely, with awards ranging from $10,000 to over $1,000,000. State agencies or institutions, private organizations, committees or firms may apply for funding. Proposals may be submitted to the Commission Alternate for Wyoming at any time during the year. Proposals for funding and requests for further information should be submitted to:

Dick Hartman
State Planning Coordinator
2320 Capitol Avenue
Cheyenne, Wyoming 82002

Urban Development Action Grants (UDAG) was designed to stimulate the economy and revitalize "distressed" communities. It encompasses a wide range of activities such as loans to private businesses and public improvements to get a business to expand or locate. It may also include something like a geothermal system for an industrial park.

There must be a direct link with UDAG funds and private investment in the city or area. These "leverage funds" help cities induce new private capital investment. The private investment must be at least in a ratio of $3 private to $1 UDAG.

UDAG funds can be used to match other federal funds. If the total proposed project cost creates and extremely high private investment requirement, other funding programs may be incorporated. This would reduce both the UDAG dollar requirement and the private investment dollar requirement.

It is essential that the project would not occur without UDAG funds. (This is the "but for" provision.) Because they have large amounts of funds, all eligible projects proposed have been funded so far.

Eligible cities must meet 3 of the following 5 criteria:

1. Age of housing - 33.7% constructed prior to 1940.
2. Per capita income - net increase from 1969 to 1975 of $1,762 or less.
3. Poverty - 11.07% or more below poverty level based on 1970 data.
4. Population decline - population growth rate from 1970 - 1976 of 0.032% or less.

5. Job lag - a rate of growth in retail and manufacturing employment of 7.08% or less.

The UDAG application process is competitive. Cities over 50,000 population apply in February and May; and cities under 50,000 population apply in January and April.

Award announcements will be made 90 days after the first of the application month.

Merit of the project is the basis for evaluation and for selection, rather than need. Selection is based on:

1. Amount of leverage (average ratio is 6:1).
2. The number of jobs likely to arise from UDAG dollars (average is 1 to $5,000 UDAG).
3. Likelihood of recapture of funds (i.e.: revenue returned through stimulation of tax revenue).
4. Improvement in tax revenue position.

More information and application forms may be obtained from:

Betty Miller, Area Manager
Executive Tower
1405 Curtis Street
Denver, Colorado 80202
(303) 837-4513

National Consumer Cooperative Bank (NCCB) was established by Congress and signed into law in 1978. It is composed of 2 parts: the Bank, and the Office of Self Help Development and Technical Assistance. The former makes loans to eligible cooperatives at prevailing interest rates, and the latter provides capital advances and technical assistance to cooperatives that are just forming or that serve or include low income members.

When the Bank makes a loan to a cooperative, the cooperative must purchase stock in the Bank as part of the loan agreement. A cooperative may purchase stock without taking a loan.

The Self Help Development Fund assists cooperatives that cannot meet the Bank's loan criteria. These cooperatives are likely to:

- serve low income people
- have special needs or financial problems
- be emerging cooperatives with no financial history.

The Self Help Development Fund may offer capital advances at interest rates lower than those charged by the Bank. Such capital advances do not require purchase of Bank stock.

The office of Self Help Development and Technical Assistance provides information and services concerning the organizing, financing, and management of cooperatives. This office also provides information regarding existing funding and technical assistance programs from government agencies and other organizations.

To borrow from the NCCB a consumer cooperative must:

- be chartered or operate on a cooperative, non-profit basis.
- produce, supply goods, services, or facilities for the benefit of its members as consumers.
- have voluntary, open membership policy.
- observe one member one vote principles.

For information on loan eligibility, applications for loans and technical assistance, to be put on the Bank mailing list, and other information call toll free:

(800) 424-2481

or write:

National Consumer Cooperative Bank
2001 South Street, N.W.
Washington, D.C. 20009

HUD District Heating System Program The U.S. Department of Housing and Urban Development has announced solicitation for proposals for technical assistance to develop district heating systems. The technical assistance provided would be in terms of grant money awarded to conduct detailed feasibility studies for proposed district heating systems. The proposals must involve Community Development Block Grant eligible communities. More information is available by writing to:

Christopher Lee
HUD Office of Procurement and Contracts
Room B-133 (711 Bldg.) (ACC-CLO)
451 Seventh Street, S.W.
Washington, D.C. 20410

Other Funding Sources (SBA, EDA, FMHA) The Small Business Administration, Economic Development Administration and the Farmer's Home Administration have a variety of financial assistance programs available. Each organization has its own set of eligibility criteria and types of financial assistance available.

For more information contact:

Economic Development Representative
Room 194, New Custom House
721 Nineteenth Street
Denver, Colorado 80202

Rudy Knoll
State Director
Farmer's Home Administration
100 East B Street
Casper, Wyoming 82601

or call:

(307) 265-5550

LEASING AND PERMITTING

Delineation of All Needed Permits

Tables 9, 10, and 11 list agencies directly concerned with geothermal development from which permits must be obtained during the developmental process. Each table names the agency, the nature or title of the permit needed, point in development when the permit is required, estimated time for issuance, and special conditions related to the permit.

Timeline for Permitting Process

The timelines illustrated in Figure 10 give an idea of the time needed to fulfill permit requirements for geothermal development. All permits may be processed at the same time, with the exception of the Air Quality Construction Permit and the Industrial Siting Permit.

TABLE 9

Local Agencies and Permits Involved in Geothermal Development in Wyoming

City Agency	Permit	Required Prior To	Estimated Time for Issuance	Note
City Planning Commission	Zoning	Construction	Several Weeks	Extensive review by many people and public hearings
City Building Inspector	Building Permit	Start of Construction	Several Days	
	Certificate of Occupancy	Use of Building	Several Days	
County Agency	Permit	Required Prior To	Estimated Time for Issuance	Note
County Planning Commission/ Board of Adjustment	Zoning	Construction	Several Weeks	May not be required; extensive review by many people and public hearings
County Engineer	Business License	Sale of Utility	Several Days	
County Clerk	Building Permit	Start of Construction	Several Days	May not be required

TABLE 10

State Agencies and Permits Involved in Geothermal Development in Wyoming

State Agency	Permit	Required Prior To	Estimated Time for Issuance	Note
Board of Land Commissioners	Exploration Permit	Exploration	30-60 days	
	Land Lease	Development	30-60 days	Not yet issued to anyone in Wyoming
Wyoming Department of Highways	Encroachment Permit	Building Utility Lines	Several days	Required to build utility lines or place steam pipe in highway right of way
	Oversize Vehicle Permit	Moving Oversize/Over weight Equipment	One day	
State Engineer	Permit to Appropriate Groundwater	Drilling Geothermal Well	3-5 weeks	
	Exploratory Permit to Appropriate Groundwater Production	Operation of Plant	3-5 weeks	
Department of Environmental Quality				
Air Quality Division	Construction Permit	Start of Construction	120-175 days	May require public hearings
Land Quality Division	"Reclamation" Permit	Start of Construction	68-233 days	May require extensive site studies

TABLE 10 (Cont.)

State Agency	Permit	Required Prior To	Estimated Time for Issuance	Note
Department of Environmental Quality				
Solid Waste Management Program	Industrial Solid Waste Disposal Permit	Start of Construction Operation of Plant	75-150 days	Site inspections required but may be waived by the agency
Water Quality Division	Construction Permit	Start of Construction	45 days	
	National Pollution Discharge Elimination System Permit	Start of Plant Operation	180 days before plant begins operation	
Public Service Commission	Certificate of Public Convenience and Necessity	Sale of Utility	12-18 months	Rarely disapproved
Industrial Siting Council/ Administration	Industrial Siting Permit	Start of Construction	90-450 days	May require extensive socio-economic and site studies. For projects over $67,400,000 in 1979 dollars only.

TABLE 11

Federal Agencies and Permits Involved
in Geothermal Development in Wyoming

Federal Agency	Permit	Required Prior To	Estimated Time for Issuance	Note
U.S. Department of the Interior U.S. Geological Survey	Conduct Site Specific Environmental analyses and Approval of Operation and Development Plans	Exploration and development (after lease by surface management agency)	5-8 years	
	Exploration	Exploration		Requires many letters of permission and site easements
	Environmental Baseline Data	Gathering of 1 years' environmental data		Must be complete before development plan is submitted
	Development	Drilling of production wells		Development, utilization, and production plans can be submitted and processed concurrently
	Utilization	Construction of power plants or area heat plants, injection systems, etc.		
	Production	Commercial Utility Use		Includes production data from wells and delivery timelines

TABLE 11 (Cont.)

Federal Agency	Permit	Required Prior To	Estimated Time for Issuance	Note
U.S. Department of the Interior Bureau of Land Management	Permit for pre-lease Operation	Exploration	30 days	Extensive geophysical studies before approval
	Lease for BLM Lands	Major exploration and construction	6 months	
	Plant Siting Permit	Plant Construction	6 months - 1 year	
	Approval of Operation Plans with U.S. Geological Survey			
U.S. Park Service	Unknown, although geothermal legislation allows Park development			No development in Yellowstone, carefully regulated
U.S. Fish and Wildlife Service	Advise and Consent on Environmental Impact Statements	Development	varies	Essential veto power over development based upon environmental impacts
U.S. Department of Agriculture U.S. Forest Service	Special Use Permit for Pre-lease Operations	Exploratory Activities	30 days	Extensive geophysical studies before approval
	Leasing of Forest Service Lands	Major Exploration	app. 18 months	Lease grants all rights to the geothermal resource

TABLE 11 (Cont.)

Federal Agency	Permit	Required Prior To	Estimated Time for Issuance	Note
U.S. Department of Agriculture U.S. Forest Service	Approval of Operation Plans with U.S. Geological Survey			
U.S. Environmental Protection Agency	Review and Approval of Environmental Impact Statements	Exploration and/or Construction	varies	

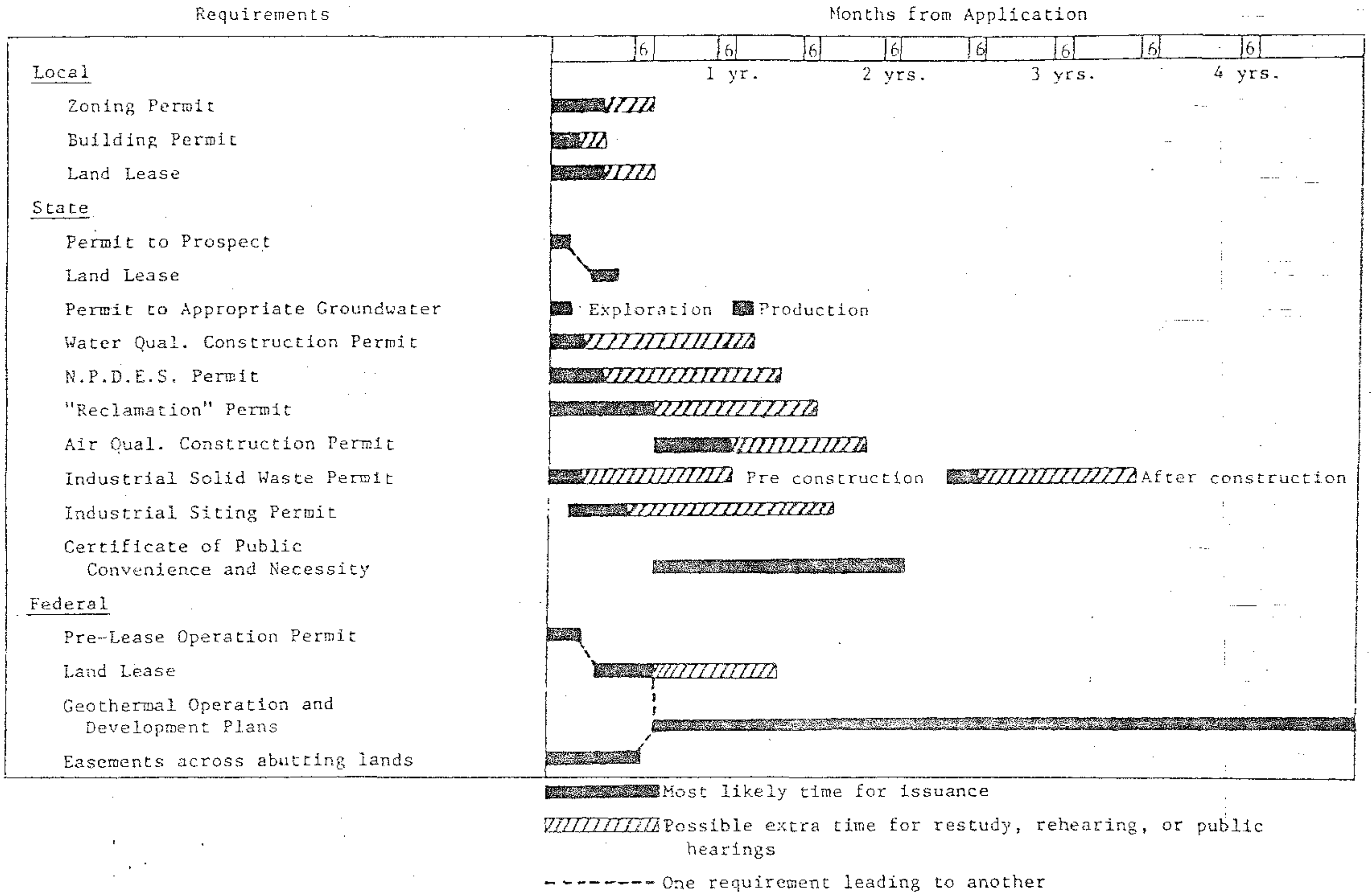


Figure 10. Timelines for Geothermal Development in Wyoming

Source: Aspinwall, et.al., 1980.

OBTAINING LEASES

Federal Land Leasing

Required for: Geothermal Development on Federal Lands

Processing time: 6 months to 1 year

Prerequisites: none

Generally, the agency managing the surface of federal lands issues two permits to develop geothermal resources: a pre-lease, special use permit allowing site visits but no exploration and a lease to the geothermal, mineral resources on the site. Before the lease is issued, the agency performs a geophysical/geological study to decide if the lease is warranted.

Under current regulations, a non-competitive lease is issued for areas not designated as Known Geothermal Resource Areas (KGRA). Competitive KGRA leases are issued when the site shows signs of geothermal potential (such as a hot spring) or when two applications for a geothermal lease are made which overlap areas by 50% or more.

Prior to conducting any geothermal activities, a plan of operations must be submitted to and approved by the U.S.G.S. Most plans of operations require an environmental analysis, which is reviewed by numerous organizations and individuals. After the environmental analysis has been conducted by the U.S.G.S., it requires reviewal by the surface management agency and must be approved jointly by both agencies. The developer will have to deal with the surface management agency regarding abutting lands and access.

Federal surface management agencies include: the Bureau of Land Management, the U.S. Park Service, and the U.S. Forest Service. Each agency has somewhat different lease application requirements; and each agency processes leases at different speeds. For federal leases, federal, state and local permits are required.

State Land Leasing

Required for: Geothermal Development of State Lands

Processing time: 30-60 days for a geothermal lease

Prerequisites: none

All applications for geothermal development on Wyoming owned lands must be made to the Board of Land Commissioners in Cheyenne. The Land Commissioners issue: 1) a Permit to Prospect for Geothermal Resources and 2) a Geothermal Resource Lease. Although several permits have been issued, no leases have ever been applied for in Wyoming. For state leases, state and local permitting requirements apply.

Local Land Leasing

Required for: Geothermal Development on Municipal or County owned lands

Processing time: 3 to 6 months

Prerequisites: none

Land may be rented from any of the 93 municipalities or 23 counties in Wyoming. The lease must be negotiated with either the County Commissioners or the City Council.

The leasing requirements and lease processing times vary according to local regulation and the size of the community. Such leases always require some public hearing. Local protest can substantially extend the interval from lease application to approval. For local leases, state and local permitting requirements apply.

Private Land Requirements

Required for: Geothermal Development on Privately owned lands

Processing time: variable

Prerequisites: none

This form of development is least restrictive from a site acquisition standpoint. However, all state and local permitting requirements still apply.

Technological Factors

Proposed and potential development of the geothermal resource in the Thermopolis area can be accomplished by utilizing existing technology. The discussions of heat exchangers and corrosion which follow show how this existing technology can be applied to minimize certain problems inherent in geothermal systems.

HEAT EXCHANGERS FOR GEOTHERMAL HEATING SYSTEMS

The purpose of heat exchangers is to transfer the heat from a geothermal fluid to a secondary fluid. The secondary fluid is usually water taken from a municipal (or other fresh groundwater) supply. Heat exchangers are designed to extract the heat from a geothermal source, while isolating corrosion and scaling on the pipes caused by the geothermal fluid to a relatively small area. Therefore, when corrosion and scaling of the pipes and other hardware does occur, only a small portion of the total system needs to be cleaned or replaced.

Within a heat exchanger, the secondary fluid is run through a pipe which comes in contact with the primary, or geothermal fluid. After the enclosed secondary fluid has been heated by its proximity to the geothermal source, it is circulated through the rest of the system.

There are essentially two kinds of heat exchangers: downhole heat exchangers and surface heat exchangers, the latter of which have various designs. Heat exchangers that are discussed below are: downhole heat exchangers, shell-and-tube heat exchangers, and direct-contact heat exchangers.

Downhole Heat Exchangers

The downhole heat exchanger is essentially a simple hairpin loop, or multiple loops of pipe extending down into the well and suspended near the well bottom (see Fig. 11). For maximum output, the well must have an open spacing (annulus) between the well walls and the casing, with perforations above and below the heat-exchange surface. Natural convection circulates the geothermal water down inside the casing, through the lower perforations, up through the annulus and back inside the casing. The secondary fluid flows through the pipe down into the hole where it is heated, the then hot secondary water rises up the other limb of the loop and on to provide heat to homes.

Advantages to the downhole heat exchangers are that they are economical, they minimize corrosion and scaling problems, they conserve the geothermal resource, and waste water discharge problems are eliminated.

Corrosion of the heat exchange pipe is common at the air-water interface, and where pipes touch the side of the casing or where they rub or touch each other. Pipes commonly used are of black iron. Some are double strength near the top to reduce stress in deep wells and to provide longer resistance to corrosion. Brass and lead at the waterline seem to extend the life of the system. However, the most common, economical and efficient method of controlling corrosion is to pour motor oil or paraffin into the well. It seems that they reduce evolved gases and water vapor and/or provide a protective coating on the pipe.* Corrosion resistant paints don't appear to be as effective. (Anderson, 1979.)

*Motor oil or paraffin should only be used in water wells, not intended for consumption.

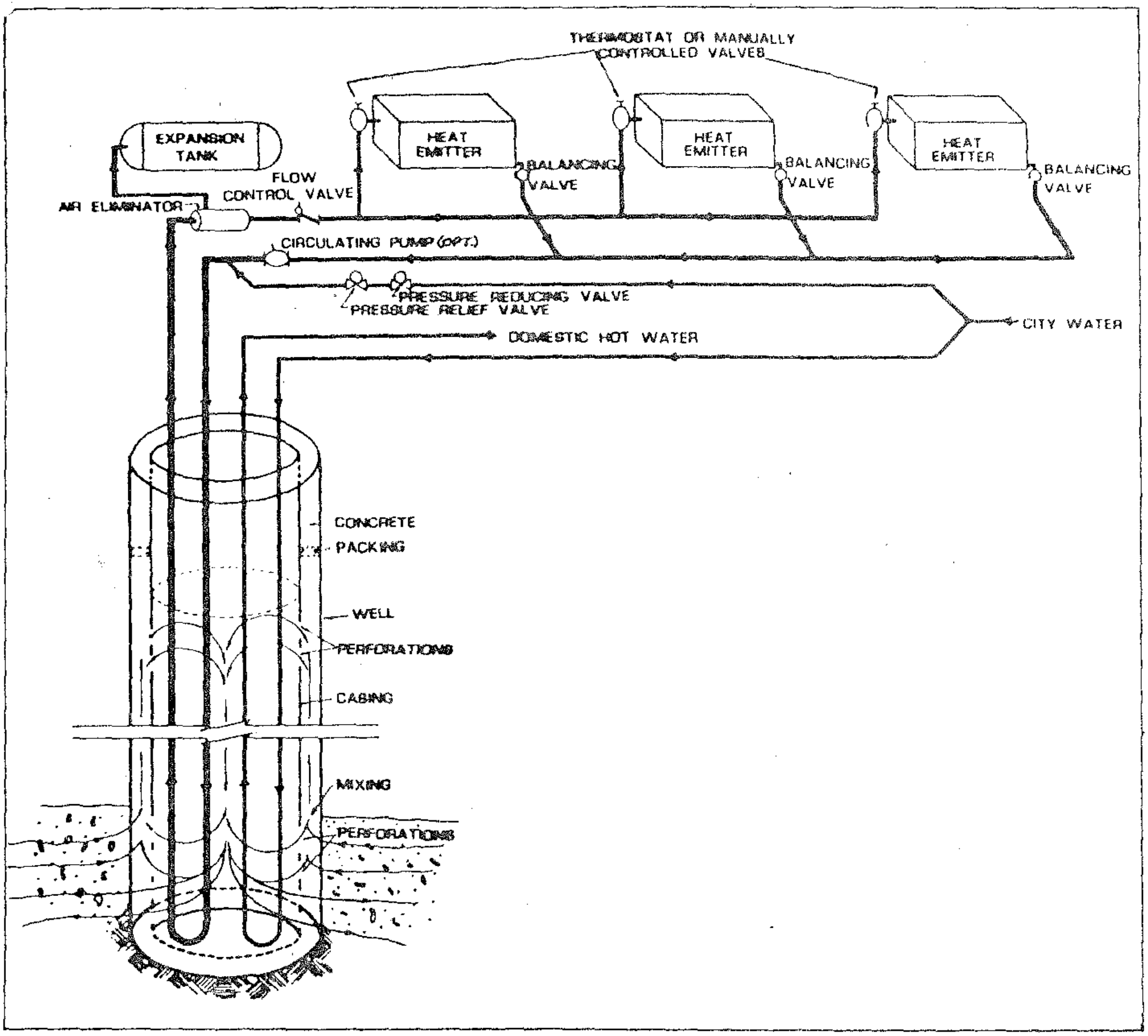


Figure 11. Typical Hot-Water Distribution System Using a Downhole Heat Exchanger

Source: Anderson, 1979.

Plate-Type Heat Exchanger

The plate-type heat exchanger consists of a series of plates held in a frame by clamping rods (see Figure 12). The geothermal fluid and the secondary fluid flow through alternating passages between the plates in a single-pass counter flow arrangement. Since plate material is cheaper than tube material, plate type heat exchangers can be constructed of corrosion resistant materials economically.

The advantages of plate-type heat exchangers over shell and tube heat exchangers are:

1. more economical material costs
2. less floor space required
3. closer approach temperatures at reduced costs
4. easy disassembly for cleaning
5. easy to expand by adding plates for increased heating load
6. series and parallel systems can be incorporated into one frame

The disadvantages to plate heat exchangers are:

1. Vapors and gases are difficult to handle.
2. Because of gaskets between the plates, temperatures are limited to 500°F.

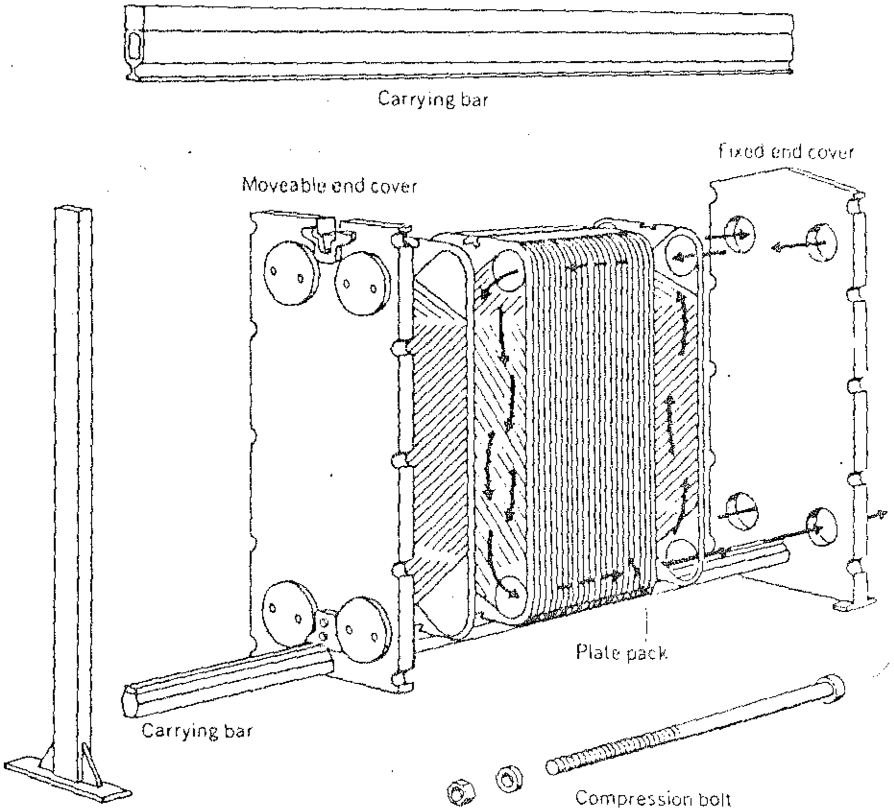


Figure 12. The plate heat exchanger is easy to disassemble and clean. The modular construction simplifies adaptation of the unit's size to accomodate any changes in the system's needs.

Source: Spencer, 1980.

Shell and Tube Heat Exchangers

The shell and tube heat exchanger is also a surface (or above ground) operation. In this system, a series of tubes carrying secondary fluid are enclosed by an insulated shell (see Figure 13). The geothermal fluid circulates within the shell, and its contact with the secondary fluid tubes warms that fluid. The secondary fluid then circulates throughout the rest of the system as the heat-bearing liquid.

Fluidized-Bed Heat Exchanger

The fluidized-bed heat exchanger is designed in a similar manner to the shell and tube heat exchanger. The difference is that a meduim that can behave as a liquid is maintained in the shell (see Figure 14). It can be sand or almost any granulated uniform material. The geothermal fluid is pumped into the bed and mixes with this medium through which pipes pass containing the secondary fluid to be heated. The advantage to this system is that the medium provides a constant scrubbing action on the pipes and thus eliminates most scaling problems on those pipes.

Direct-Contact Heat Exchangers

The direct-contact heat exchanger is comprised of a pressure vessel with its longitudinal axis on the vertical. The geothermal

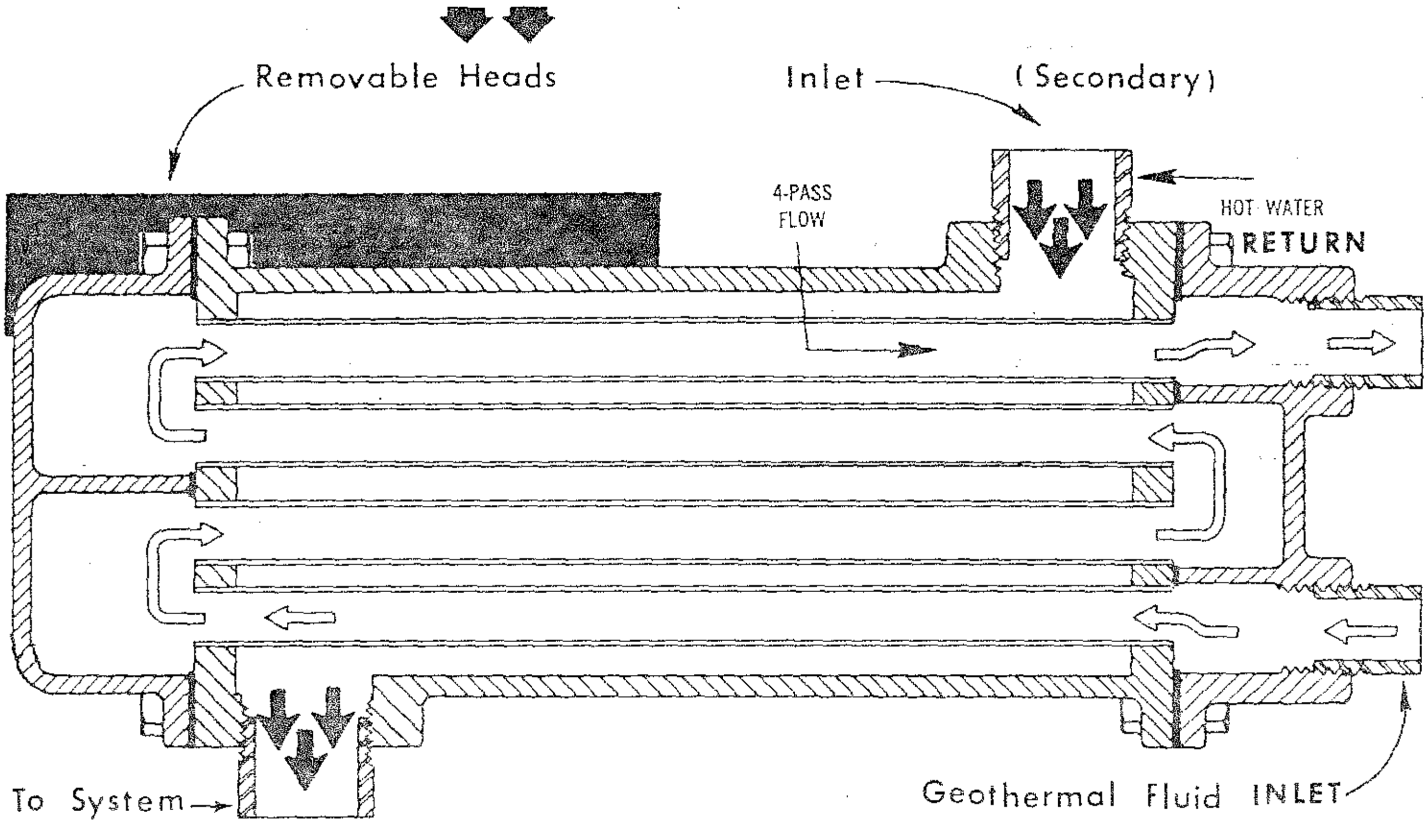


Figure 13. A typical shell and tube heat exchanger with straight tubes and removable heads applicable for a geothermal heating system.

Source: Wehlage, 1976

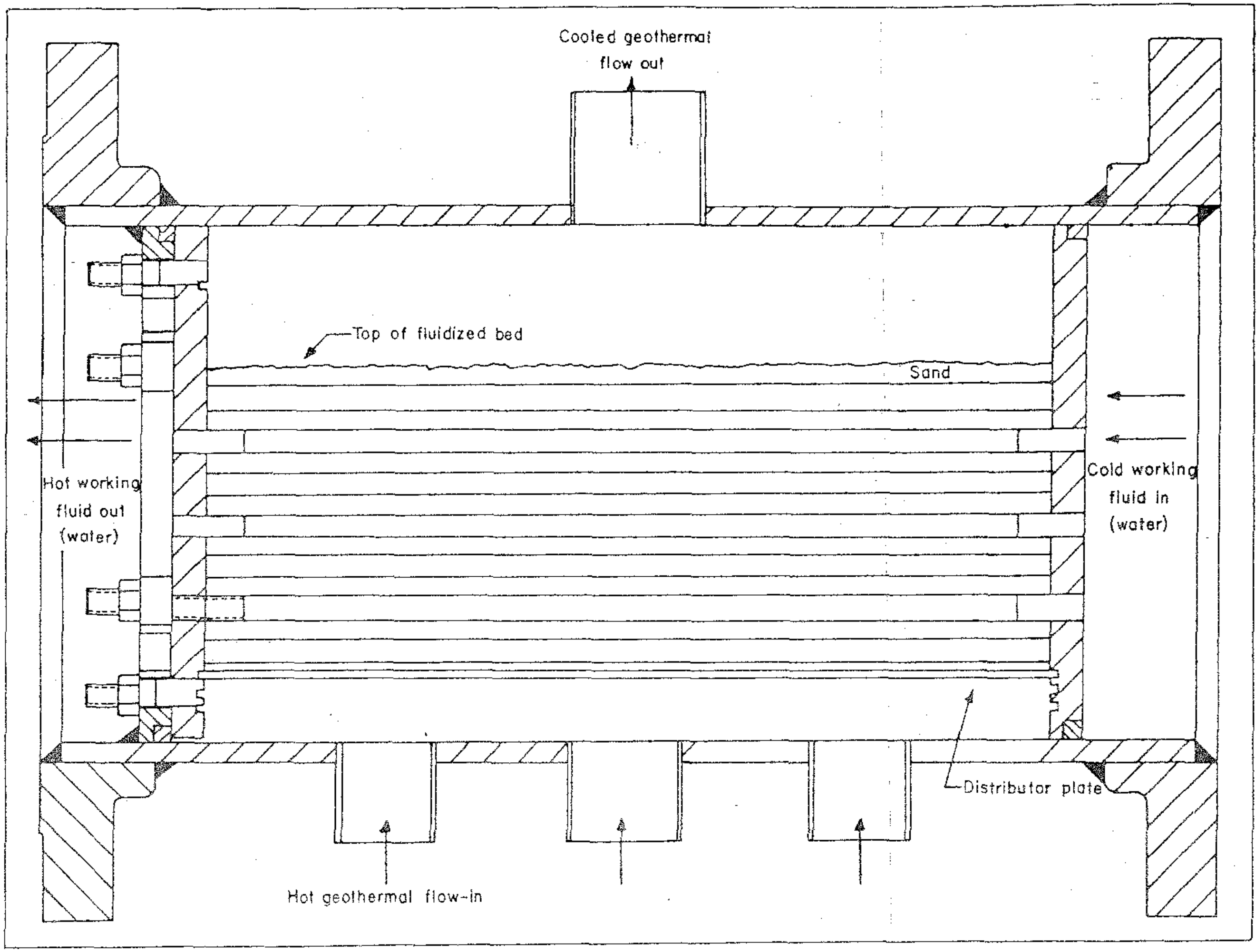


FIGURE 14. Horizontal arrangement of a liquid fluidized-bed heat exchanger.

Source: Anderson, 1979.

and secondary fluids pass through nozzle arrangements that facilitate mixing and maximum contact between them (see Figure 15). After mixing, the fluids are allowed to separate due to changes in state or density. The secondary fluid should be chosen on the basis of chemical and thermal characteristics so as to minimize carry over of the secondary fluid into the geothermal fluid. Some carry over is nevertheless inevitable in this method of heat exchange.

An advantage to the direct-contact heat exchange system is its simple design and the small volume size required for large heat-transfer rates.

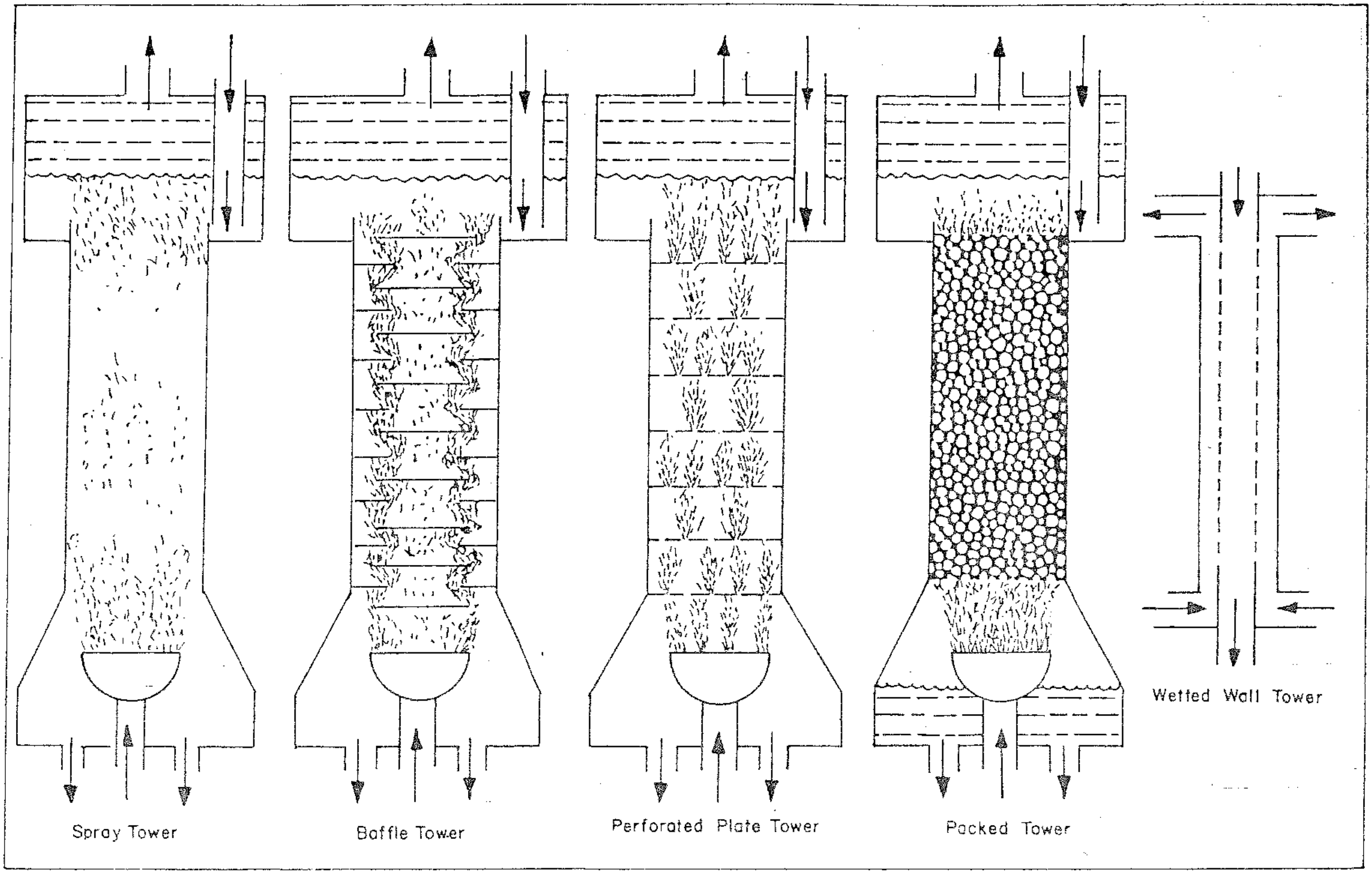


FIGURE 15. Schematic of various types of direct-contact counter-flow devices.

Source: Anderson, 1979

The following section on corrosion is an excerpt from Direct Utilization of Geothermal Energy: A Technical Handbook, pp. 4 - 61 to 4 - 72.

CORROSION, SCALING AND MATERIALS SELECTION

Properly managed boiler water, steam or hot-water heating systems are free of the typical geothermal fluid components. These fluids are substantially less aggressive than geothermal fluids and have little tendency to form scales by deposition of dissolved solids. The chemical species present in geothermal fluids are the primary factors that result in corrosion and scaling when these fluids are used as heat sources.

Geothermal-fluid Chemistry

Geothermal-fluid temperature and chemistry are so closely related that there is a general increase in total dissolved solids (herein referred to as salinity) as temperature increases. The chemical species found in the fluids are a function of the local, in situ geology. Certain important species are found to a greater or lesser extent in all geothermal fluids and are tabulated in Table 12. Hydrogen concentration, as expressed by pH, is a function of other species, e.g., carbon dioxide. Oxygen is not present in most geothermal reservoirs since oxygen and hydrogen sulfide do not coexist in significant amounts at equilibrium. The presence of significant concentrations of oxygen (>10 ppb) in the presence of hydrogen

Table 12

Dissolved major corrosion and scaling species in most geothermal fluids

Corrosion	Scaling	Character
Oxygen (in leakage)		Gas
Hydrogen Sulfide		Gas
Carbon Dioxide		Gas
Ammonia		Gas
Hydrogen		Ions
Sulphates		Solid
Chlorides		Solid
	Silicates	Solid
	Carbonates	Solid
	Sulfides	Solid
	Oxides	Solids

Source: Anderson 1979

sulfide is usually an indication of leakage of air into the piping system or the mixing of very near surface water with the fluid.

Hydrogen sulfide. Probably the most severe effect of H_2S is its attack on certain copper and nickel alloys. Copper, cupronickel and nickel copper alloys have performed well in seawater but are practically unusable in geothermal fluids containing H_2S. The effect of H_2S on iron-based materials is less predictable. Accelerated attack occurs in some cases and inhibition in others. High strength steels are often subject to sulfide-stress cracking. H_2S may also cause hydrogen blistering of steels. Oxidation of H_2S to H_2SO_4 in aerated geothermal process streams increases the acidity of the stream.

Carbon dioxide. In the acidic region, CO_2 can accelerate the uniform corrosion of carbon steels. The pH of geothermal fluids and process streams is largely controlled by CO_2. Carbonates and bicarbonates can display mild inhibitive effects.

Ammonia. Ammonia can cause stress-corrosion cracking of some copper alloys. It may also accelerate the uniform corrosion of mild steels.

Sulfate. Sulfate plays a minor role in most geothermal fluids. In some low-chloride streams, sulfate will be the main aggressive anion. Even in this case, it rarely causes the same severe localized attack as chloride.

Oxygen. The addition of small quantities of oxygen to a high-temperature geothermal system can greatly increase the chance of severe localized corrosion of normally resistant metals. The corrosion of carbon steels is sensitive to trace (in the low ppb range) amounts of oxygen.

Hydrogen ion (pH). The general corrosion rate of carbon steels increases rapidly with decreasing pH, especially below pH 7. Passivity of many alloys is pH-dependent. Breakdown of passivity at local areas can lead to serious forms of attack, e.g., pitting, crevice corrosion and stress-corrosion cracking.

Chloride. Chloride causes local breakdown of passive films which protect many metals from uniform attack. Local penetration of this film can cause pitting, crevice corrosion or stress-corrosion cracking. Uniform corrosion rates can also increase with increasing chloride concentration, but this action is generally less serious than local forms of attack.

Transition metal ions. "Heavy" or transition metal ions might also be included as key species. Their action on most construction materials at low concentrations is ill-defined. However, the poor performance of aluminum alloys in geothermal fluids may be due in part to low levels of copper or mercury in these fluids. Salton Sea geothermal fluids contain many transition metal ions at greater than "trace" concentrations. Some oxidized forms of transition metal ions (Fe^{+3}, Cu^{+2}, etc.) are corrosive, but these ions are present in the lowest oxidation state (most reduced form) in geothermal fluids. Oxygen can convert Fe^{+2} to Fe^{+3}, which is another reason to exclude oxygen from geothermal streams.

An important factor to be considered when evaluating a geothermal resource is the variability of the chemical characteristics of the fluids. The compositions of geothermal fluids vary considerably from field to field. There are significant differences between wells in a given reservoir resulting from localized variations in the geology. There are variations with time in a well due to changes in the flow patterns resulting from production of the reservoir.

Corrosion and Scaling Inhibitors

The volumes of fluid required for most geothermal-heating applications are typically too large for economical use of corrosion inhibitors. The EPA requirement for the removal of any chemical added to the fluid for corrosion control prior to disposal provides further incentive for alternate corrosion-control methods. These factors suggest that materials selection is the most economical means of corrosion control.

Unlike the requirement for removal of corrosion inhibitors, EPA regulations regarding scale-control chemicals are much more liberal. Scale-control chemicals fall into two general classes: those that modify surface characteristics and retard nucleation and those that change the chemical character of the deposited species.

These chemicals interfere with nucleation and growth mechanisms rather than altering the equilibrium solubility of the depositing mineral. Polysulfinates, polyacrolates and other low-molecular weight polymers are frequently used for scale control. One point should be borne in mind: corrosion scales frequently provide nucleation sites for mineral scale deposits.

Corrosion and Materials Selection

This section describes the forms and mechanisms of corrosive attack that can occur in geothermal-process liquid streams. These generalizations are especially useful when materials must be specified for conditions at which tests have not been done. If the corrosion rate of a material has been tested at the stream conditions of interest, this information is still useful. It explains the effects of fabrication practices, equipment configuration and operating stresses. It also identifies some additional ways materials can deteriorate.

Table 13 contains information about the performance of specific metals in liquid streams.

General Guidelines

By taking appropriate precautions, carbon steels can be used for thick-walled applications in contact with most geothermal fluids. Thin-walled applications will be limited by the susceptibility of

TABLE 13

Forms and causes of corrosion for metals in liquid geothermal streams and ways to prevent attack.

Material	Major Forms of Corrosion	Main Environmental Factors	Limits and Precautions	Other Comments
Mild & Low Alloy Steels	uniform	pH chloride	Rapid rate increase below pH 6 Rapid rate increase above 2% Cl^-	Air in-leakage is a major hazard; local flashing in pipes can cause very high flowrates and erosion/corrosion
		flow velocity	Limit flow to 5-7 fps (1.5-2.1 m/s)	Avoid direct impingement on steel
	pitted, crevice	temperature chloride	Susceptibility increases with increasing temperature and chloride concentration	Avoid mechanical crevices
		scale	Remove mill scale; avoid deposits	
	sulfide stress	H_2S	Can occur at very low H_2S levels	Complex interactions
		yield strength (hardness)	Use low strength material wherever possible ($Rc < 22$ g $YS < 100{,}000$ psi)	
		temperature	Hazard greater at lower temperatures	
	hydrogen blistering	H_2S	Use void-free materials	Possible at very low H_2S concentrations
	galvanic coupling	electrical contact with more noble metal	Avoid coupling close to large area of cathodic metal	More severe when material has porous coating or scale

(continued)

TABLE 13 (continued)

Forms and causes of corrosion for metals in liquid geothermal streams and ways to prevent attack.

Material	Major Forms of Corrosion	Main Environmental Factors	Limits and Precautions	Other Comments
		scale	Avoid scale deposits	
		stagnant or low flow	Avoid stagnation or low flow conditions	
		oxygen	O_2 greatly increases susceptibility	
	intergranular	chloride, temperature	Avoid by proper welding and heat treating procedures	
martensitic alloys	as above	as above	As above	
	sulfide stress cracking	H_2S, temperature, stress, hardness	More severe at lower temperatures; use low strength levels where possible	General corrosion resistance depends on composition
cast alloys	as above			See comments for equivalent wrought alloy; good crevice corrosion resistance needed for pumps and valves
Titanium Alloys	crevice, pitting	chloride temperature pH	Maximum temperature for resistance depends on chloride and pH	Several alloys have better resistance than pur Ti. Precracked Ti may undergo stress corrosion cracking
	galvanic coupling	electrical contact with more active metal	Coupling to large area of more active metal may cause hydrogen embrittlement of Ti	

(continued)

TABLE 13 (continued)

Forms and causes of corrosion for metals in liquid geothermal streams and ways to prevent attack.

Material	Major Forms of Corrosion	Main Environmental Factors	Limits and Precautions	Other Comments
Stainless Steels				
ferritic alloys	pitting, crevice	chloride	In general, susceptibility increases with increasing concentration and temperature	Lower alloys may also have high uniform rates in sever environments; O_2 is a hazard. Higher alloys are much more resistant; Cr and Mo most effective alloying agents
		scale	Avoid scale deposits	
		stagnant or low flow	Avoid stagnant or low conditions	
		oxygen	O_2 greatly increases susceptibility	
	intergranular	chloride, temperature	Avoid by proper welding and heat treating procedures	
austenitic alloys	stress corrosion cracking	chloride oxygen temperature	Complex interaction; depending on other factors, cracking can occur for $Cl^- > 5$ppm; O_2 100 ppb; T > 140°F (60°C)	Hazard increases with increase in Cl^-, O_2, T; some alloys more resistant; protect exterior surfaces
	pitting, crevice	chloride temperature	See ferritics above	Resistance increases with Mo content; avoid mechanical crevices

(continued)

TABLE 13 (continued)

Forms and causes of corrosion for metals in liquid geothermal streams and ways to prevent attack.

Material	Major Forms of Corrosion	Main Environmental Factors	Limits and Precautions	Other Comments
Nickel Alloys	crevice, pitting	chloride, temperature	Similar to stainless steels except higher alloys more resistant to crevice corrosion; high flow rates	Resistance depends on alloy composition. May be susceptible to hydrogen embrittlement when coupled to steel
Copper Alloys	pitting, uniform, de-alloying	H_2S chloride, temperature, CO_2	H_2S as low as 0.1 ppm can cause attack	Usefulness limited in H_2S environment
	stress corrosion cracking	ammonia, pH		
Other Metals				
cobalt alloys			Avoid galvanic coupling to steel or other active metal	Several alloys have good sulfide stress cracking resistance at high strength
zirconium & tantuiun				Resistant to low pH, not chloride solution
aluminum	pitting, crevice	Hg and Cu ions, pH, chloride, temperature, lack of oxygen	Poor results obtained in geothermal tests	May be useful as exterior siding and construction material

these materials to localized attack, such as pitting and crevice corrosion. High-salinity geothermal fluids will cause high uniform corrosion as well as localized corrosion and will severely limit the use of carbon steels. The application of mild steels to geothermal environments requires that precautions be taken for aeration, flow rate, scaling, galvanic coupling, protection of exterior surfaces and steel specifications.

Aeration. Acceptable uniform corrosion rates of carbon steels in fluids containing <10,000 ppm chloride ion are due mainly to the reducing, oxygen-free nature of the fluids. The introduction of small quantities of oxygen can increase uniform corrosion by at least tenfold and initiate pitting and crevice corrosion.

The effect of oxygen on the corrosion of a mild steel is shown in Figure 16 for an otherwise nearly gas-free seawater stream. The same effect occurs in geothermal systems. The solubility of oxygen in saline fluids decreases with increasing temperature up to 212°F (100°C), at which point it increases again. The electrochemical reaction rate increases with temperature.

Aeration damage during plant operation should be minimized by guarding against leaks in the lower-temperature vacuum sections of the plant. The highest potential for serious damage from aeration occurs due to inleakage during plant outages or layups. Stagnant conditions are conducive to crevice and pitting corrosion promoted by oxygen. Oxidation of ferrous ions and H_2S in the

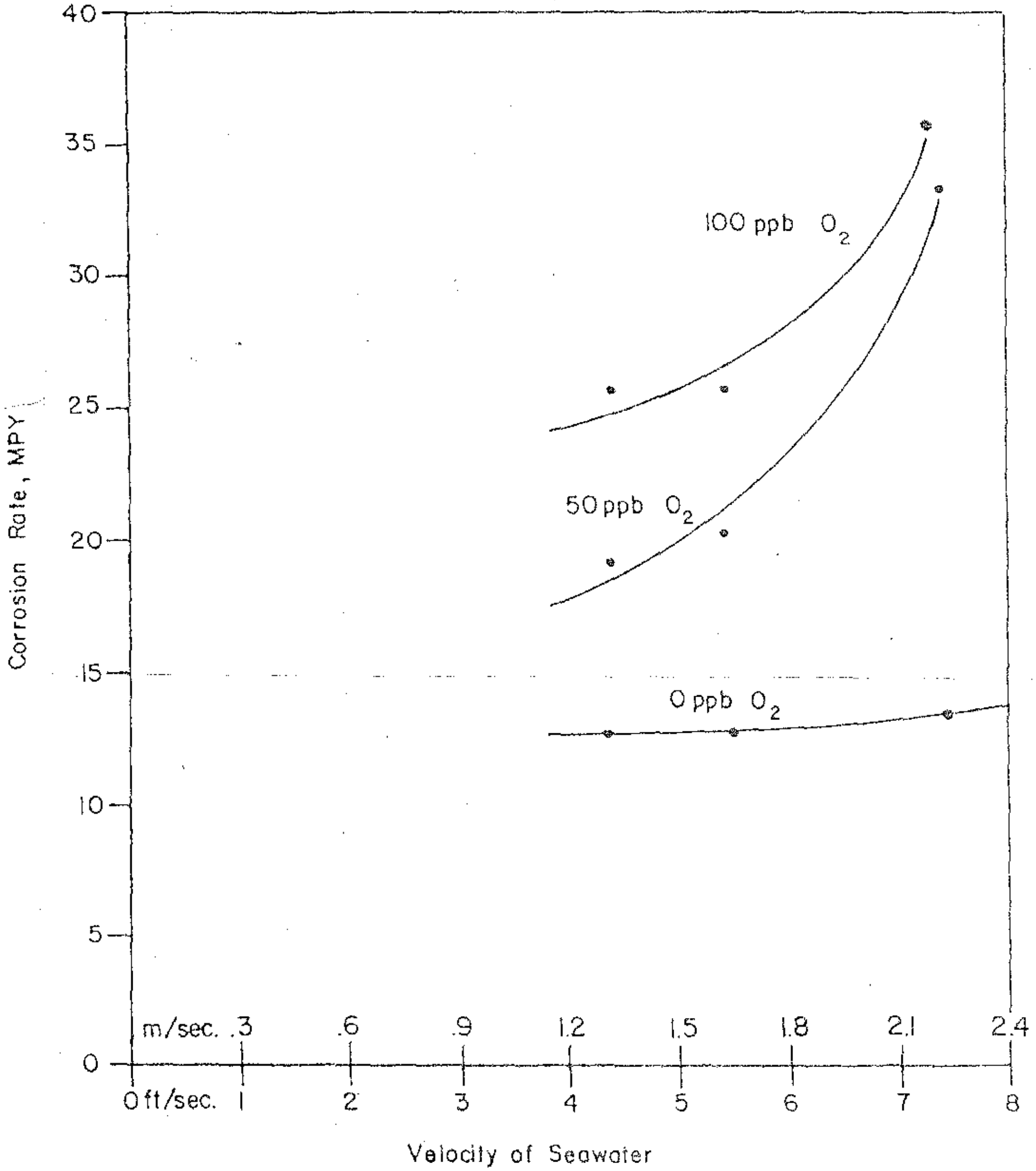


FIGURE 16. Effect of oxygen on uniform-corrosion rate of 1010 mild steel in 250°F (121°C) seawater.

Source: Anderson, 1979.

geothermal fluid can produce ferric ions and local acidity, which accelerate attack. Procedures for avoiding damage during shutdowns include draining and rinsing equipment and purging with an inert gas. Oxygen scavengers might be applicable, but possible side reactions with species in the specific fluid should be evaluated.

Flow rate. The best performance of carbon steels occurs when liquid flow rates are limited to 5-7 ft/sec (1.5-2.1 m/s). Localized, uncontrolled flashing in geothermal streams can cause high flow rates in the system. This action can produce bubbles of non-condensable gas which can cause impingement attack. Entrained solids in the stream can cause erosion-assisted corrosion. The relative hardness of particle and metal has little effect on this type of corrosion.

Failure of components, such as pipe ells, has occured in fluids as diverse as those at Salton Sea and Raft River. These failures are probably caused by the flow conditions noted above. Designs to avoid direct impingement on carbon steels and localized flashing should alleviate these types of failures. Providing liquid buffer zones may help. Pump impellers, especially for downhole applications, may be subject to severe cavitation damage. The CO_2 content of many geothermal fluids can cause an apparent vapor pressure that exceeds steam-table values by tens to hundreds of psi (100's to 1000's kPa).

Effects of high velocities are illustrated in Figure 17 for seawater at 250°F (121°C).

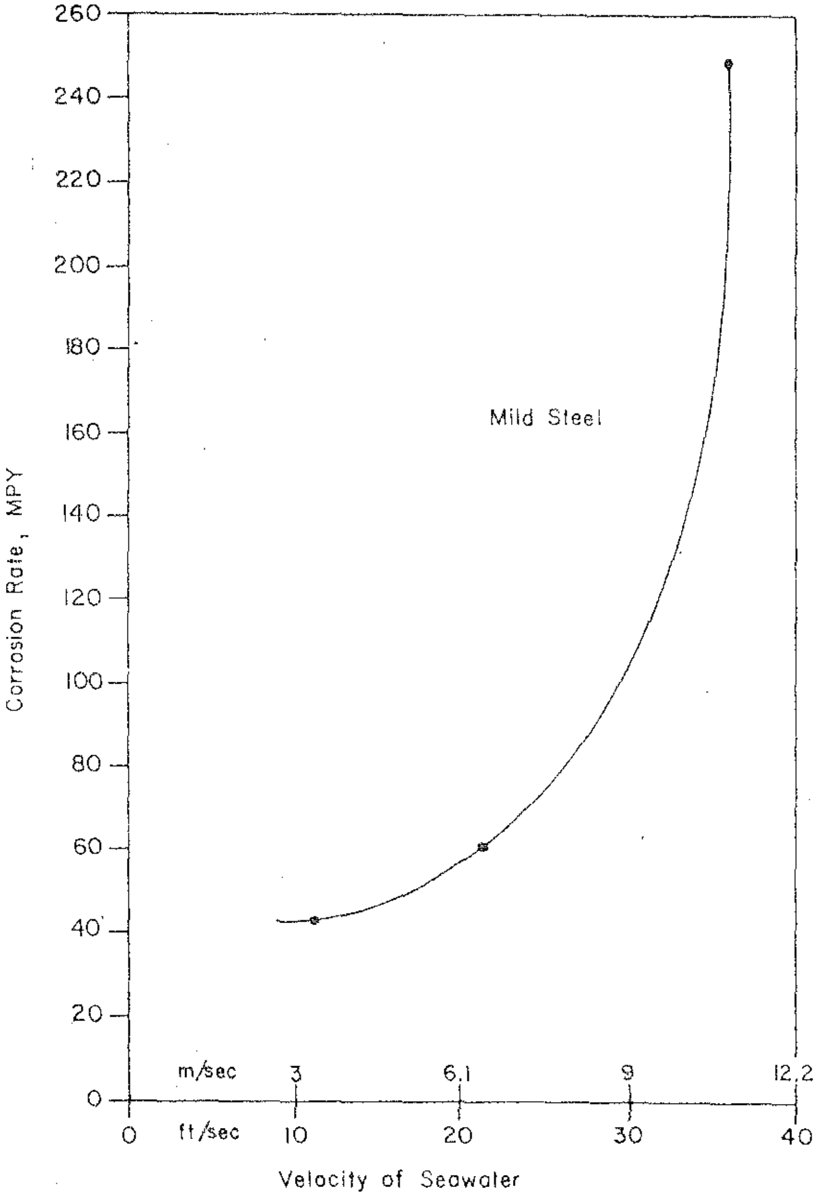


FIGURE 17. Weight-loss corrosion rates of mild steel in high-velocity, high-temperature oxygen-free seawater.

Source: Anderson, 1979

Scaling. Some mechanical protection against uniform corrosion may result from scales formed on steel by precipitation from geothermal fluids, but localized corrosion can also occur under the scales. Scales in geothermal systems are porous and prone to cracking by differential thermal expansion. The exposure of the base metal to a geothermal fluid can lead to local acidity and high chloride concentration similar to conditions during crevice corrosion. Accelerated attack by H_2S is increased in acidic environments such as this.

Attack at small exposed areas can become more serious if the steel is galvanically coupled to a more noble metal. In extreme cases, this concentration of the corrosion-steel dissolution current can cause perforation of thick-walled steel components in a very short time.

Chemical cleaning solutions used to remove scale should be evaluated carefully since some types (such as inhibited HCl) accelerate corrosion of mild steel. Severe attack can occur if aggressive cleaning solution is trapped in or under incompletely removed scale.

Stainless steels. The uniform-corrosion rate of most stainless steels is low in geothermal fluids, but many are subject to the more serious forms of corrosions: pitting, crevice corrosion, stress-corrosion cracking, sulfide-stress cracking, intergranular corrosion and corrosion fatigue. Stainless steels have been used successfully in geothermal environments, but care must be taken in their selection and application.

1. Aeration.

Many stainless steels that could perform well in oxygen-free geothermal environments can be subject to severe pitting and crevice corrosion in the presence of small quantities (low ppb concentrations) of oxygen. Stress-corrosion cracking of commonly used austenitic stainless steels in high-temperature chloride solutions can occur minutes after introducing oxygen in ppm quantities or less. This failure is often catastrophic. Other alloys are more resistant. Pits, crevice attack or cracks initiated during upset or plant-outage conditions can continue to grow once normal operation is resumed. Special care should be taken during plant commissioning due to the likelihood of unstable conditions.

2. Flow rate.

Stainless steels are more resistant to high velocities than plain and low-alloy steels. Continuous high-velocity flow is more desirable than low-flow rates or stagnant conditions. Under stagnant conditions, settling of entrained solids or spot deposition of loose scale can lead to crevice corrosion.

Stagnant conditions should be avoided, and stainless components should be drained and rinsed during plant shutdown. Resistance to erosion-corrosion is more closely related to general corrosion resistance than hardness of the metal.

3. Scale.

Local concentration cells can develop under porous or cracked scale on stainless steel and lead to crevice corrosion to which many stainless steels are susceptible. After an attack is initiated, local increases in acidity and chloride concentration cause intense corrosion.

4. Welding.

Good welding procedures are important to the successful application of stainless steels. Physically poor welds may have crevices that are susceptible to crevice corrosion. Stress-corrosion cracking may initiate at pits close to poor welds. Sensitization of base metal during welding will cause rapid failure.

5. Exterior surfaces.

Measures should be taken to protect the exterior of stainless-steel components that are exposed to air. Leaks and splashes of hot chloride solutions combined with the high oxygen content of air can subject these components to stress-corrosion cracking conditions. Flange leaks leading to conditions in which geothermal fluid concentrates and dries under insulation can be dangerous. Non-porous gaskets are required to guard against cracking at flanges.

Titanium and titanium alloys. Titanium and its alloys have given good results in all but the most extreme environments when tested for geothermal applications. Titanium was used successfully for hydrogen and oil coolers exposed to aerated cooling water/condensate at the Cerro Prieto geothermal facility. Two other heat exchanger materials had failed in this environment.

Nickel-based alloys. High nickel alloys are frequently used to combat severe corrosion problems. The Ni-Cr-Mo alloys appear to be the most applicable to high-temperature geothermal fluids. Similar alloys containing iron in place of molybdenum face competition from the most resistant stainless steels, but may find application where their mechanical properties are desirable. Cupronickels will have limited usefulness in geothermal streams containing even trace (ppb) quantities of H_2S.

Aluminum alloys. Aluminum alloys have not shown good resistance in tests conducted in direct contact with geothermal fluids. Low levels of transition metal ions, especially copper and mercury, greatly increase localized attack of aluminum alloys. These ions are present in most liquid-dominated geothermal fluids. Aluminum alloys have also given poor results in geothermal-condensate cooling-water systems.

Copper-based alloys. The use of copper alloys in geothermal fluids is severely limited by the relatively high concentrations of sulfide found in most sources. The Raft River KGRA, with a low sulfide concentration of 0.1 ppm, appears to be an exceptional case. Even in this fluid, the performance of copper-nickel alloys (Monel 400, 70Cu/30Ni and 90Cu/10Ni) was very poor. De-alloying of some copper alloys was observed. However, some nickel-free brasses and bronzes gave acceptable performance.

Scaling

Scaling results from two sources: deposition of minerals from the fluid as a result of super-saturation and scales that result from accumulation of corrosion products. Either of these scales reduce the efficiency of the system by increasing the resistance to heat transfer and fluid flow. Such scales often promote localized corrosion.

Deposition of scales from solution. The minerals most frequently deposited from geothermal fluids are calcium carbonate (usually calcite) and silica. To a lesser extent, calcium sulfate (gypsum, anhydrite, selinite) may be deposited. Some geothermal wells carry high concentrations of heavy metals and sulfides; these fluids may yield sulfides of copper, lead, silver, etc., in addition to silica or carbonate scales.

Both calcium carbonate and calcium sulfate exhibit retrograde solubility (solubility is a strong function of pH and carbon dioxide concentration) and are related by several equilibria.

$$CO_2 + H_2O = H_2CO_3$$

$$CaCO_3 + H_2CO_3 = Ca(HCO_3)_2$$

$$H_2CO_3 = H^+ + HCO_3^-$$

$$HCO_3^- = H^+ + CO_3^{2-}$$

$$CaCO_3 = Ca^{2+} + CO_3^{2-}$$

Because the solubility of calcium carbonate increases with decreasing temperatures and is pH-dependent, no deposition will occur if the partial pressure of CO_2 is maintained at a level equal to downhole level.

As pH is decreased, the solubility of the calcite increases; however, many materials are degraded as hydrogen-ion concentrations increase. The presence of calcite scales frequently results in decreased corrosion by interfering with the diffusion of corrodants to the metallic surface. For this reason, calcite scales my be grown to controlled thickness as a general corrosion-control measure.

Calcium sulfate solubility is given by

$$CaSO_4 = Ca^{2+} + SO_4^{2-}$$

The solubility product constant is

$$Ksp = [Ca^{2+}] \quad [SO_4^{2-}]$$

When concentrations are expressed in mg/kg of fluid (ppm) the Ksp is reached at about 400,000. Geothermal fluids having a concentration product in this range or higher should be viewed as having a tendency towards calcium sulfate deposition.

The solubility of silica (SiO_2) is dependent on the form of the deposit. Amorphous silica has a much higher solubility than quartz, the familiar crystalline form. The usual assumption is that the geothermal fluid is in equilibrium with amorphous silica in above-ground environments and with quartz in the geological formation.

If the concentration of silica in the water is known, the temperature below which precipitation of amorphous silica can occur (from data in GRC, 1976) is given by

$$t = \frac{1531.98}{10.064 - \text{In } SiO_2} - 273.16$$

where

t = temperature °C

In SiO_2 = natural log of silica concentration in ppm.

If only the reservoir temperature is known, the amount of silica in the water assuming equilibrium with quartz is given by

$$\mathrm{InSiO_2} = \frac{13.281 - 3531}{t + 273.16}$$

where

t and $\mathrm{InSiO_2}$ are defined as above.

This value can also be substituted into the previous equation to find the temperature below which amorphous silica scaling is possible.

The rate of scale deposition is critically dependent upon the material being deposited. Silica deposition is very slow, often requiring several hours or days for equilibrium to be established. Calcite deposition is very rapid and its equilibria are achieved in short time periods, frequently milliseconds. Calcium sulfate deposition lies between these extremes.

Corrosion-product scales. Corrosion products may form a coherent scale on the substrate metal. In the case of plain carbon and low-alloy steels in geothermal fluids, the primary corrosion products are iron oxides, hydrous iron oxides, iron silicate and iron sulfides. The very low solubility of these in the fluid results in solid corrosion products. These oxides, silicates and sulfides tend to form and grow on the substrate metal. Other corrosion products, such as metal chlorides that form in pits and crevices, are more likely to leave the reaction site. Copper and copper-base alloys, including combinations of copper and nickel, tend to react with the sulfides in the geothermal fluids to form copper sulfides, nickel sulfides and copper-nickel sulfides. These sulfides tend to form on the metal. Zinc and aluminum in brasses form relatively soluble corrosion products and are not, typically, found in association with the sulfides.

Corrosion-product scales usually exhibit lower heat-transfer properties than the metals from which they are formed. These scales also are rougher than the substrate metal. Both of these factors result in lower efficiencies that require, for example, larger heat exchangers and pumps. However, these scales do form a barrier between the fluid and the metal and may provide some general corrosion protection to the metal. In some cases, the corrosion-product scales contain cracks and/or small holes that permit localized corrosion in the form of crevice corrosion and pitting. The corrosion scales cannot be relied on for corrosion protection.

Control of corrosion-product scales is best achieved through materials selection because of the limited economic and environmental applicability of corrosion inhibitors. Care must be exercised in materials selection because some metals depend on a stable corrosion-product film for general corrosion resistance. Aluminum is one such material. The stable aluminum oxide protects the relatively reactive aluminum metal from the aggressive water. Geothermal fluids are reducing and this may retard repair of damaged film sites on the aluminum, resulting in rapid localized corrosion of the metal. Reduceable metal ions, such as copper and mercury, may also cause rapid corrosion of aluminum. Desalination environments, on the other hand, are oxidizing, and aluminum finds application in this type of service.

Many consider seawater experience to be directly transferrable to geothermal situations. However, seawater is usually free of sulfides and, in near surface sources, nearly saturated with air. Copper/nickel alloys are used extensively in seawater applications and are frequently the materials of choice. The hydrogen sulfide present in geothermal fluids, however, rapidly degrades copper and copper alloys containing nickel. These two examples suggest that care must be exercised when using data from either seawater or desalination service for materials selection for geothermal environments. Sublte differences in geothermal-fluid chemistry frequently result in the use of a heat exchanger and a "clean" secondary fluid for many heating applications. (Anderson, et. al., 1979)

BARRIERS TO DEVELOPMENT

Institutional Barriers

One of the most critical barriers to development of geothermal resources is the lack of incentive to capital investment caused by the unavailability of tax benefits traditionally given to other resource developers.

A barrier specific to Thermopolis is that of a nonexistant "Five Mile Law". Public understanding of this "Law" is that any drilling (for water or otherwise) is prohibited within a five mile radius of Big Spring. However, State Engineer George Christopulos and Hot Springs State Park superintendent both state that the alleged "Five Mile Law" does not exist. Wyoming statutes §41-1-109 to 41-1-111 state:

> "The state engineer is given the authority to abolish, correct, discontinue, or stop any condition which interferes with the natural flow of any thermal spring on state lands. Nothing in this act shall be construed to limit any non-thermal water, or mineral development so long as said development does not interfere with the natural flow of the thermal springs covered by this act. The state engineer may seek injunctive relief to implement this act [§41-1-109 to 41-1-111]."

Geologists remain uncertain in regards to whether drilling in the Thermopolis area would or would not interfere with flow in Hot Springs State Park. They will concede, however, that the further drilling occurs to the north and/or west of the park, the smaller the chance that Hot Springs State Park will be affected.

Federal leasing and permitting are time consuming processes which need to be streamlined to encourage geothermal development, not inhibit it.

Due to the high risk and the relative originality of the idea of using geothermal heat, additional incentive programs would be welcome. Until geothermal developments and projects become more common place, capital investors are going to be wary.

Environmental Barriers

Environmental concerns related to geothermal exploration and utilization involve possible stream pollution, air pollution, noise pollution and possible contamination of the aquifer.

The Big Horn River already receives input from numerous small hot springs. Bringing thermal waters to the surface for various utilization purposes and then releasing that water into the river may cause an impact. DEQ does, however, require that water discharge be cooled to at least 90°F and conform to standards of chemical ppm content before release into the river.

Due to the low temperature of the Thermopolis geothermal resource, and the present day economic impossibility of electrical generation and thus the elimination of discharging by-product gases into the atmosphere, the atmospheric effluents would be minimal. Air pollution due to release of geothermal waters at the surface would consist only of a slight sulphur odor.

Noise pollution due to the drilling of supply or reinjection wells would be short lived.

Reinjection of geothermal water would have to be carefully controlled to prevent aquifer contamination or cooling of the aquifer. Carefully cased wells and thoughtful selection of a reinjection site could eliminate potential aquifer contamination problems.

Financial Barriers

In the case of the district heating system for the City of Thermopolis, the financial barrier will probably prove to be the most imposing one. As outlined previously, this project could cost anywhere from 2.5 to 9 million dollars and as inflation continues to rise, so will the installation cost of such a system. One must, however, weigh against it the ever increasing cost of natural gas and electricity and the fact that fossil fuels are not a renewable resource. At this point in time, the price of natural gas is still relatively inexpensive in the State of Wyoming, but it will soon rise far beyond the equivalent cost per MMBTU of the geothermal heat source.

Although the installation cost for a district heating system may seem staggering, operating and maintenance costs are projected over the life of the geothermal project, the price for heat received becomes very reasonable.

SUMMARY AND RECOMMENDATIONS

The prospects for development of the potential geothermal resource area in Thermopolis and East Thermopolis are very encouraging. There are a wide variety of low-temperature, direct use geothermal projects that would be applicable to the Thermopolis resource.

Geothermal uses as greenhousing, vegetable drying, bentonite drying, and aquaculture (the raising of aquatic species in controlled geothermal environments) are all compatible uses with the existing business patterns of the community.

District heating of portions of Thermopolis and East Thermopolis is a possibility that should be researched in more detail. It is recommended by this office that the Thermopolis community apply for a HUD District Heating Program Grant. As a recipient of the grant, the community of Thermopolis could conduct (through subcontractors) a detailed feasibility study in economics, engineering and additional resource assessment. This information would better equip the government of Thermopolis to begin the planning and organization processes required to get a geothermal project on line, should the feasibility study indicate that the project would most likely be a successful one.

It is our additional recommendation that a geothermal task force be organized within the Thermopolis region. This task force should consist of individuals from the public and private sectors who are interested in pursuing the concept of geothermal projects for Thermopolis. These individuals would be responsible for keeping records on permits and leases that have been applied for or obtained. They could also assist any potential developer (including the city government) in the preparation of grant and loan proposals, as well as keeping the public informed as to the progress of geothermal projects in the area.

There were several geothermal applicants for Appropriate Technology Small Grants from Thermopolis in 1980. It is our understanding that they did not receive funding. We urge you to refine your proposals and try again in 1981. Geothermal energy is slowly gaining publicity and acceptance amongst the other "alternate" energy resources of the western United States.

It is our final recommendation that the geothermal resource be used wherever possible to offset the use of non-renewable fossil fuels. It is hoped that the potentially bright geothermal future of Thermopolis will be realized.

REFERENCES

Anderson, David N. and John W. Lund, eds., 1979, Direct Utilization of Geothermal Energy: A Technical Handbook, Geothermal Resources Council Special Report No. 7, pp 4-25 t0 4-30.

Aspinwall, Carol, Jim Caplan, Rick James and Karen Marcotte, 1980. Wyoming Geothermal Institutional Handbook. Wyoming Geothermal Commercialization Office. 42 pp.

Breckenridge, Roy M. and Bern S. Hinckley, 1978, Thermal Springs of Wyoming. Geological Survey of Wyoming, pp 25-40.

Caplan, James and Karen Marcotte, 1980, Big Horn Basin, Wyoming Area Development Plan, Wyoming Geothermal Commercialization Office, 50 pp.

Decker, Edward R., Henry P. Heasler, and Jon K. King, 1980, Hydrothermal Resources In Wyoming: A Preliminary Report on the University of Wyoming's Research in 1979. Dept. of Geology, University of Wyoming, 13 pp.

Department of Administration and Fiscal Control, 1980, Wyoming Population and Employment Forecast Report, Cheyenne, Wyoming.

Garing, Kenneth L. and Glenn E. Coury, Adaptation of Geothermal Energy to Produce Alcohol from Agricultural Commodities. Coury and Associates, Inc., Lakewood, Colorado, pp 241-244.

Industrial Development Division, 1980, Thermopolis Wyoming 1980 Community Profile, Dept. of Economic Planning and Development, Cheyenne, Wyoming, 4 pp.

King, J.K., H.P. Heasler, and E.R. Decker, 1980, The Thermopolis Hydrothermal System, Rough Draft, Department of Geology, University of Wyoming, 47 pp.

Nellis, Lee, 1979 and 1980, Hot Springs County Planner, personal communication.

Perlmutter, Steven and Jeff Birkby, 1980, Montana Geothermal Institutional Handbook, Montana Dept. of Natural Resources and Conservation, and Renewable Energy Bureau, 93 pp.

References

Senate Document No. 247, 54th Congress, 1st session. House of Representatives Report no. 1932, 54th Congress, 1st session, Sale of Hot Spring, Thermopolis, Wyoming, State Archives and Historical Dept, 21 pp.

Spencer, Glenn J. and M. Jane Cohen, 1980, Geothermal Space Heating Applications for the Fort Peck Indian Reservation in the Vicinty of Poplar, Montana, U.S. Dept. of Energy, 90 pp.

Task Force Report on Klamath Fall's Greenhouse Production Potential, 1977, Klamath Basin: A Potential Greenhouse Development Site, 31 pp.

Wehlage, Edward F., 1976, The Basics of Applied Geothermal Engineering, Geothermal Information Services, California, 211 pp.

Wyoming State Law §41-1-109 to §41-1-111.

Appendix A

Appendix A

Notes on the Chemical Analyses

Many chemical species are dissolved in natural water. In our tables of chemical analyses, all major ions or elements, and trace elements are reported in parts per million (ppm) by weight, nearly equivalent to milligrams per liter (mg/l) in dilute solution.

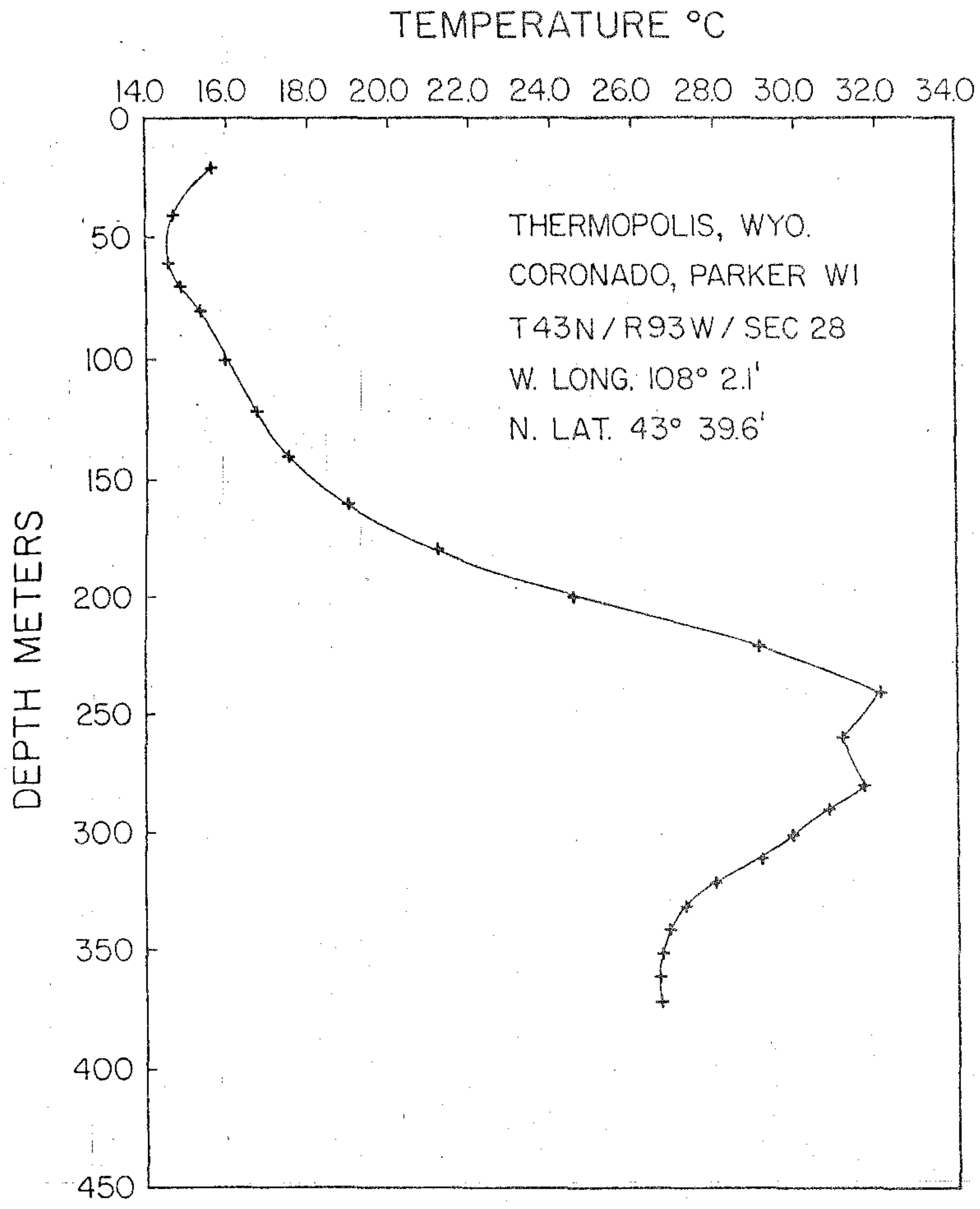
	Cations		Anions	
Major:	Ca	calcium	CO_3	carbonate
	Mg	magnesium	HCO_3	bicarbonate
	Na	sodium	SO_4	sulfate
	K	potassium	Cl	chloride
			NO_3	nitrate
Minor:	F	fluoride		
	S	sulfide		
	SiO_2	silica		
	B	boron		
Trace:	As	arsenic	Cr	chromium
	Cu	copper	Pb	lead
	Fe	iron	Se	selenium
	Mn	manganese	Ag	silver
	Zn	zinc	Hg	mercury
	Ba	barium	Ni	nickel
	Cd	cadmium		

Temp	Temperatures are given in degrees Celsius, unless otherwise noted.
TDS	Total Dissolved Solids is the weight of the solid, anhydrous salts residual of an evaporated water sample, converted to ppm.
Cond	The Specific Conductance of a solution, measured in micromhos, is a general measure of the amount of dissolved constituents. For most waters, conductance, times a factor dependent upon the general chemical character of the water, approximates TDS.
pH	pH is a measure of the hydrogen ion concentration or activity in a solution. A value of seven is neutral, lesser values are more acidic, and higher values to fourteen are progressively more basic. Most natural waters in the United States are slightly basic. The normal range is 6.0 to 8.0.
Tot CO_3	Total CO_3 is a measure of all the possibly available carbonate in a solution which could be precipitated as $CaCO_3$, and is the sum of the reported CO_3 and one-half the reported HCO_3.

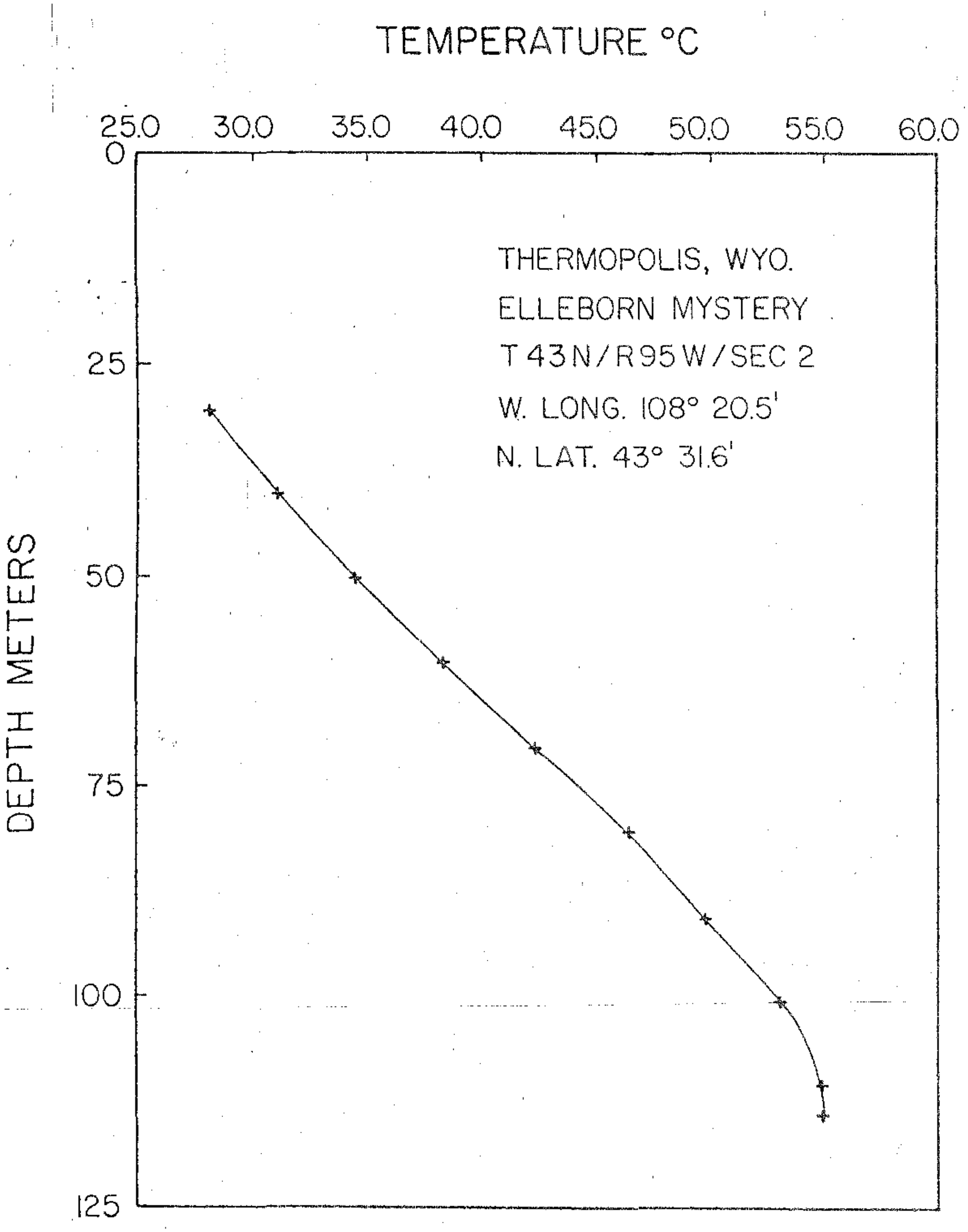
Source: Breckenridge and Hinckley, 1978.

Appendix B

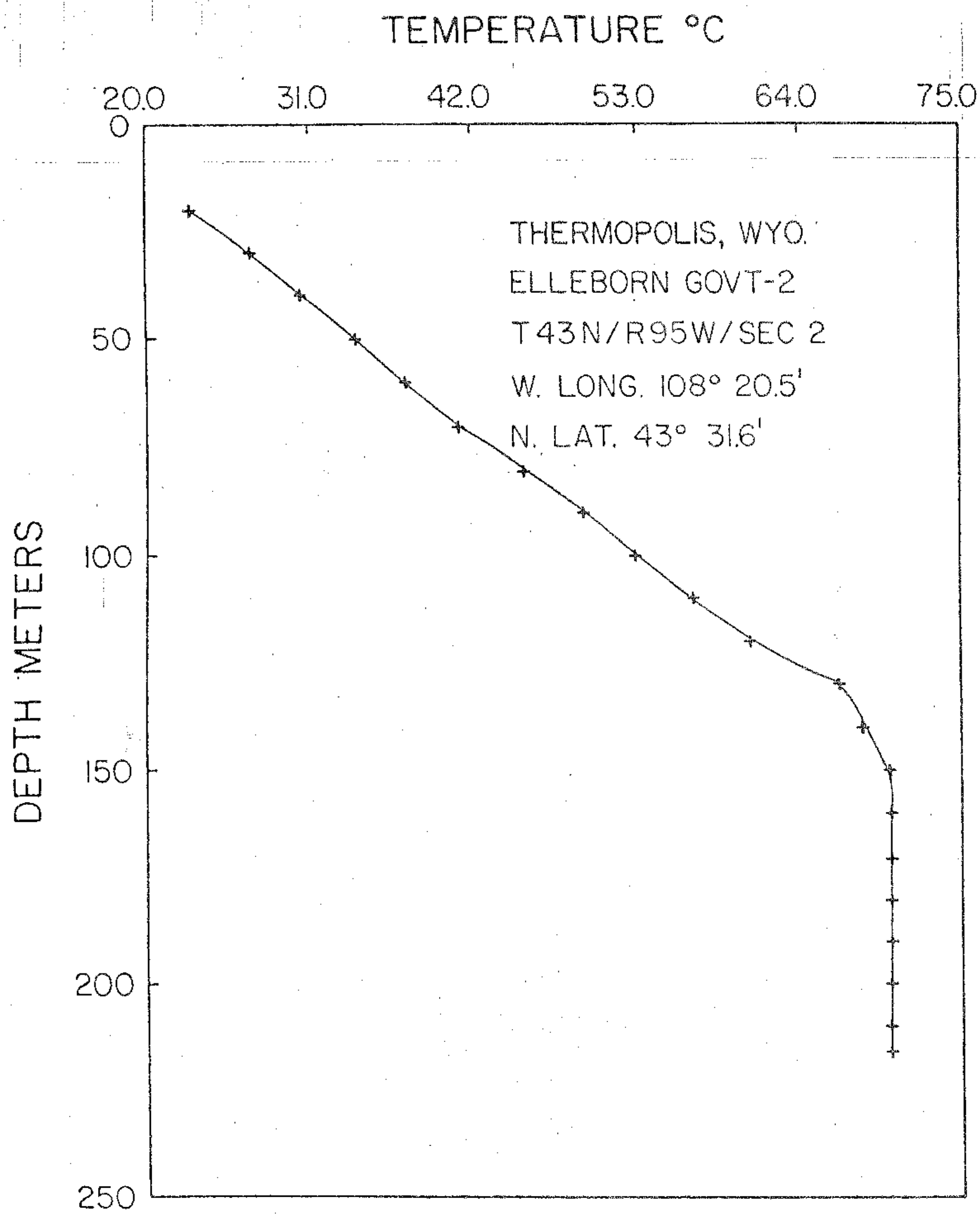
Appendix B



Source: King, et. al. 1980.

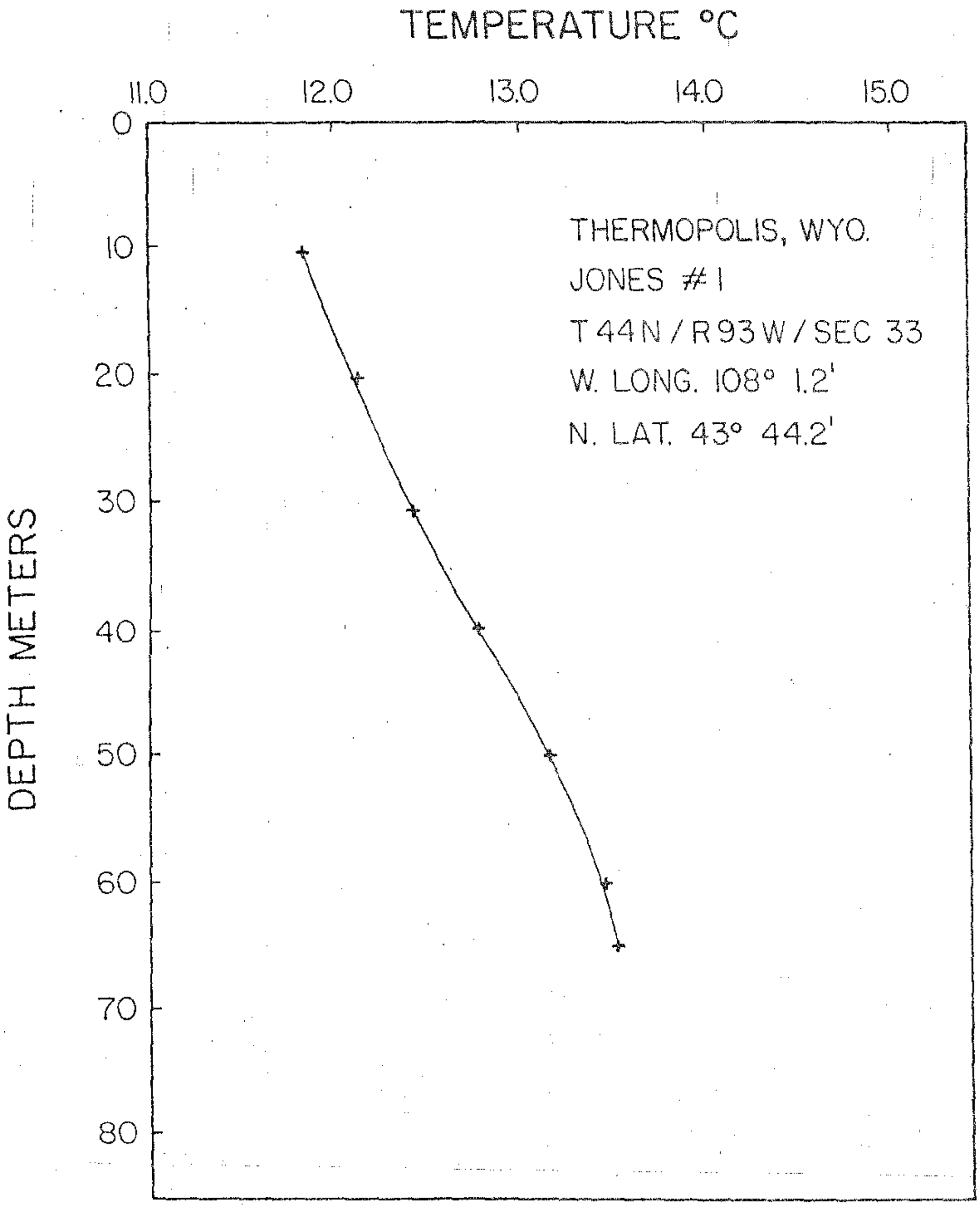


Source: King, et. al. 1980.



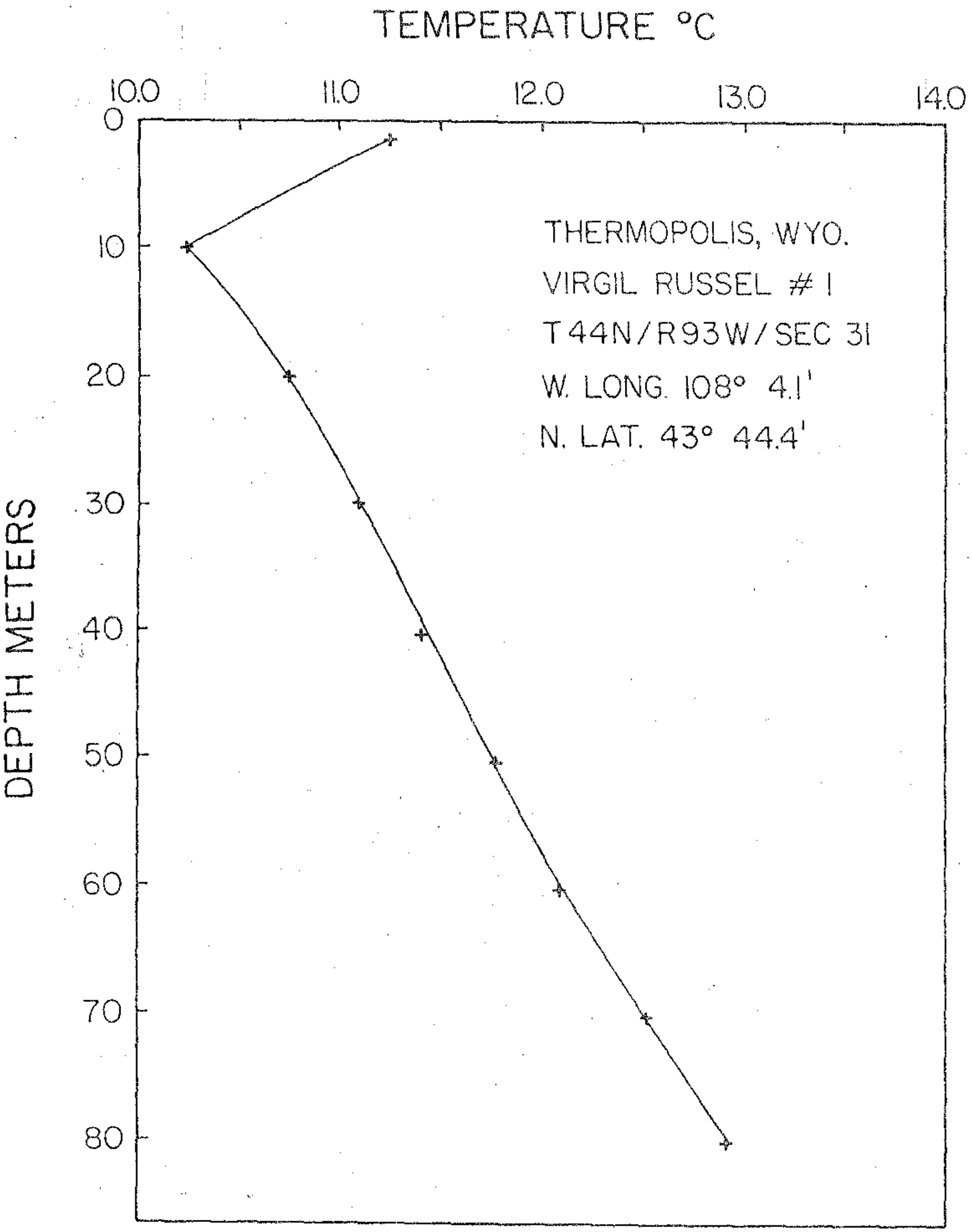
Source: King, et. al. 1980.

Appendix B (continued)

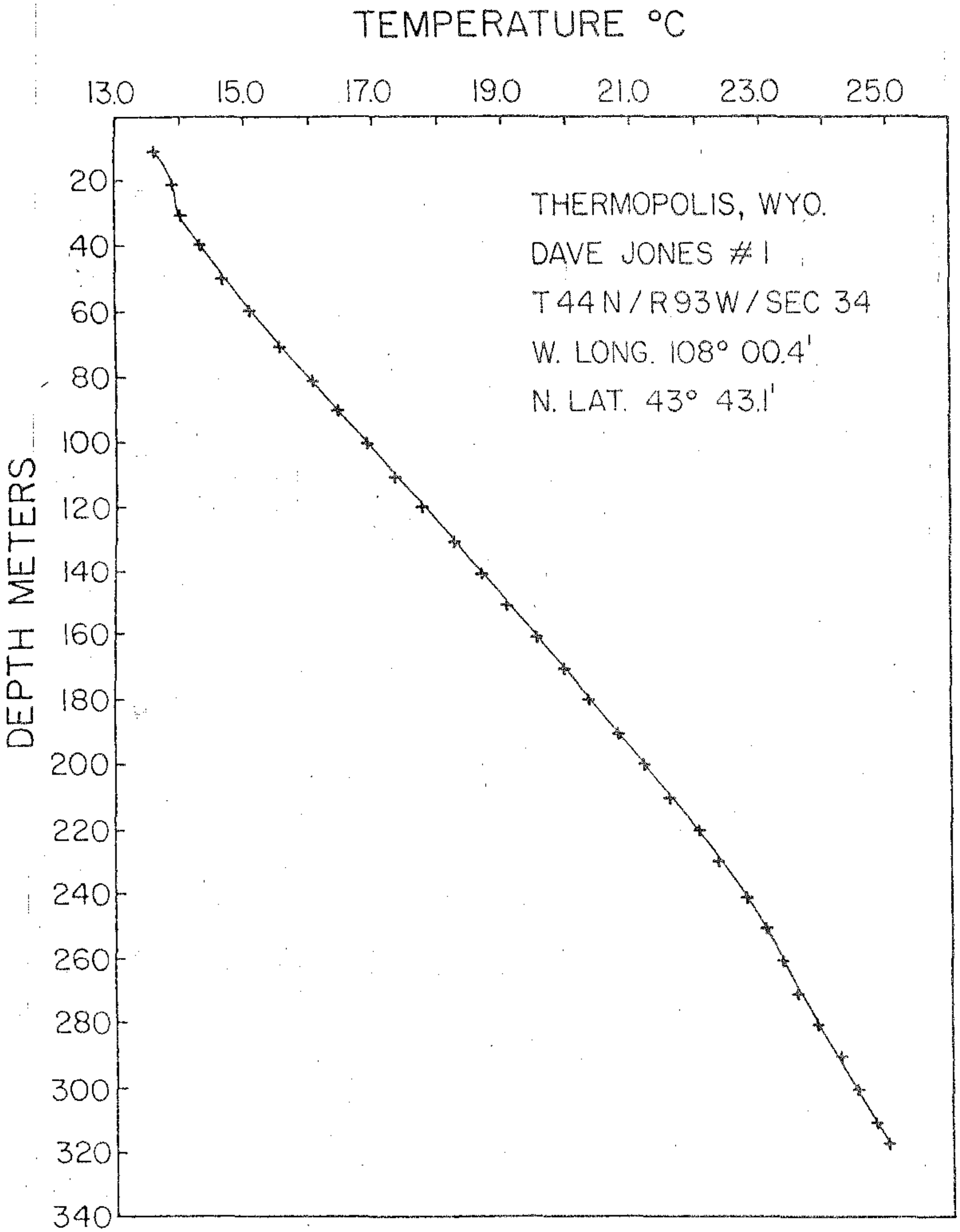


Source: King, et. al. 1980.

Appendix B (continued)



Source: King, et. al. 1980.



Source: King, et. al. 1980.

Appendix C

Appendix C

Notes on the Chemical Analyses

In the tasks of chemical analyses ions and elements are reported in parts per million (ppm) by weight and milligrams per liter (mg/l) unless otherwise noted. The two types of measurements are nearly equivalent in dilute solutions. Values from Lowry and Lines, (1972) and Cooley, written communication are in mg/l, while those from Crawford, (1940) and Breckenridge and Hinckley (1978) are in ppm.

Abbreviations used in the tables are listed below:

SiO_2	silica	HCO_3	bicarbonate
Fe	iron	CO_3	carbonate
Ca	calcium	SO_4	sulfate
Mg	magnesium	Cl	chloride
Na	sodium	F	fluoride
K	potassium	NO_3	nitrate
		B	boron

Boron and total iron are given in terms of micrograms per liter (ug/l).

Temperature is in degrees Celsius.

Total dissolved solids (TDS) heated is the weight of the solid anhydrous salts remaining after evaporation of a water sample, converted to ppm or mg/l.

TDS sum is the sum of the dissolved solids from the chemical analysis.

Symbol (Xnd) means no data for X number of samples.

Within the tables, analyses have been grouped according to formation; the hot springs and wells have also been grouped together. This leads to a range of values. In several cases the chemical compositions of formation waters are so diverse that analyses from ore formation have been divided into separate groups on the basis of the analyses.

Source: King, et. al. 1980.

Appendix C (continued)

Source	Flathead Sandstone	Mainly Flathead Sandstone	Flathead Sandstone and Precambrian
Depth (ft)	4900	2287-3995	2708
Location	T55N R92W Sec 33	T47N R88W Sec 16 T48N R89W Sec 25 T49N R88W Sec 29 T50N R89W Sec 31	T47N R87W Sec 33
Temperature °C	32.0	20-25.5 (3nd)	25.0 (1nd)
SiO_2	15	9.2-11	9.8-10
Fe total μg/l	80	50 (8nd)	---
Ca	7.6	21-32	62-66
Mg	0.9	15-20	31
Na	146	3.5-9.9	3.5-4.8
HCO_3	176	149-180	290-300
CO_3	8	0-3	0
SO_4	140	8.2-19.0	41-64
Cl	24	0.0-1.8	1.8-2.5
F	1.6	0.2-0.4	0.2
NO_3	0.2	0.2-1.1	0.1-1.0
B (μg/l)	140	10 (8nd)	---
TDS heated	440	136 (8nd)	---
TDS sum	433	142-175	297-324
No. sources	1	4	1
No. samples	1	9	2
Reference:	Lowry and Lines, 1972	Cooley, written comm.	Cooley, written comm.

Source: King, et.al. 1980.

Appendix C (continued)

Source	Madison Limestone and Madison Limestone Bighorn Dolomite Mix	Bighorn Dolomite	Gros Ventre Shale
Depth (ft.)	944-6660 (1nd)	5400	2092
Location	T47N R88W Sec 5,16 T47N R90W Sec 8 T47N R89W Sec 6 T49N R89W Sec 28,35 T50N R90W Sec 23,34	T46N R98W Sec 18	T43N R93W Sec 28
Temperature °C	11-25 (2nd)	14.0	30.0
SiO_2	9.0-11	30	19
Fe total µg/l	0-80 (6nd)	120	1000
Ca	39-47	614	429
Mg	19-28	122	7.2
Na	1.2-3.5	284	530
K	0.7-2.0	160	12
Na+K	---	---	---
HCO_3	210-270	1210	36
CO_3	0	0	0
SO_4	2.0-17	1360	1010
Cl	0-2.5	272	859
F	0.1-0.4	3.4	2.5
NO_3	0.9-2.5	0.0	0.0
B (µg/l)	0-50 (6nd)	1500	1300
TDS heated	202-207 (6nd)	3410	3010
TDS sum	183-230	3440	2870
No. sources	8	1	1
No. samples	11	1	1
Reference:	Lowry and Lines,1972 Cooley, written comm.	Lowry and Lines,1972	Lowry and Lines,1972

Source: King, et.al.1980

Appendix C (continued)

Source	Madison Limestone and Madison - Amsden Fm. Mix (?)	Madison Limestone	Madison Limestone
Depth (ft.)	2895	2000-4500	1082-8319
Location	T49N R89W Sec 6	T50N R90W Sec 14 T58N R97W Sec 31	T43N R93W Sec 28 T46N R98W Sec 28 T57N R99W Sec 29
Temperature °C	21 (1nd)	14-34.5	22 (3nd)
SiO_2	9.8-11	7.9-15	30-39 (2nd)
Fe total μg/l	60 (1nd)	50-130	240 (3nd)
Ca	50-59	89-192	359-646
Mg	22-25	47-72	92-171
Na	3.8-4.8	2.3-12.0	290-301 (2nd)
K	1.9-2.3	2.0-3.0	130-170 (2nd)
Na+K	---	---	80-180*
HCO_3	200-230	176-200	220-1080
CO_3	0	0	0
SO_4	54-74	272-595	607-1510
Cl	1.3-1.8	0-2.5	234-378
F	0.3-0.4	0.8-2.5	3.8-5.4 (2nd)
NO_3	2.2-2.3	0.3-4.6	0.2-0.3 (2nd)
B (μg/l)	40 (1nd)	50-60	10-2800 (2nd)
TDS heated	280 (1nd)	560-1040	2072-3840
TDS sum	261-274	526-979	2910-3390 (2nd)
No. sources	1	2	3
No. samples	2	2	4
Reference:	Lowry and Lines,1972 Cooley, written comm.	Lowry and Lines,1972	Lowry and Lines,1972 Crawford, 1940

*values in ppm

Source: King, et.al. 1980.

Appendix C (continued)

Source	Tensleep Sandstone	Tensleep Sandstone	Amsden Formation and Amsden-Madison Limestone Mix (?)
Depth (ft.)	550-4000	443-1040 (2nd)	172-1410 (2nd)
Location	T42N R94W Sec 36 T42N R95W Sec 13 T43N R92W Sec 11	Southeast Bighorn Basin *	T46N R87W Sec 10 T47N R88W Sec 1,2 T48N R88W Sec 28
Temperature °C	19.5 (2nd)	10-14.5 (2nd)	10.5-14.0 (2nd)
SiO_2	12-21	8-11	9.2-11
Fe total µg/l	120 (2nd)	0-3600 (1nd)	110 (3nd)
Ca	79-280	43-59	38-47
Mg	33-86	16-29	20-25
Na	10-113	1.3-12	1.1-2.7
K	1.6-2.2	1.0-3.6	0.5-2.6
Na+K	---	---	---
HCO_3	289-711	166-290	230-270
CO_3	0	0	0
SO_4	84-542	2.0-60	5.8-23
Cl	3.1-125	1.0-3.0	0-1.8
F	0.6-2.2	0.2-0.6	0.2
NO_3	0-0.4	0-5.5	0-2.6
B (µg/l)	0-960	0-210 (1nd)	10 (5nd)
TDS heated	442-1620	188-282	214 (5nd)
TDS sum	420-1530	187-272	185-323
No. sources	3	9	4
No. samples	3	11	6
Reference:	Lowry and Lines,1972	Lowry and Lines,1972	Lowry and Lines,1972 Cooley, written comm.

* Southeast Bighorn Basin includes:
T42N R88W Sec 21, T43N R87W Sec 11,21; T44N R87W Sec 8,17; T46N R87W Sec 21;
T47NR88W Sec 21; T47N R89W Sec 12; T48N R88W Sec 9.
Source: King, et.al. 1980.

Appendix C (continued)

Source	Goose Egg Formation	Probably Goose Egg Formation	Tensleep Sandstone Black Mtn. oil field
Depth (ft.)	200 +	230-505 (2nd)	3160-3460
Location	T47N R88W Sec 16	T47N R88W Sec 10,15,16,21	T43N R91W Sec 25,36
Temperature °C	13-14 (1nd)	9-14.5 (2nd)	---
SiO_2	11	7.4-12	---
Ca	85-96	36-64	41-78
Mg	32-35	18-27	16-30
Na	2.3-4.3	1.6-6.4	---
K	1.2-1.6	0.7-3.7	---
Na+K	---	---	20-74
HCO_3	200-220	200-230	287-425
CO_3	0	0	0
SO_4	180-200	9.1-97	21-92
Cl	0-1.8	1.8-2.2	8-16
F	0.3-0.4	0.2-0.6	---
NO_3	0.6-1.1	0-1.1	---
TDS heated	---	---	261-461
TDS sum	410-445	184-309	---
No. sources	2	6	3
No. samples	3	6	4
Reference:	Cooley, written comm.	Cooley, written comm.	Crawford, 1940*

*All values are in ppm

Source: King, et.al. 1980

Appendix C (continued)

Source	Embar Formation Hamilton Dome	Park City Formation	Park City Formation
Depth (ft.)	2300-2800	1200	6200
Location	T44N R98W Sec 14	T52N R101W Sec 31	T46N R100W Sec 24
Temperature °C	---	---	---
SiO_2	---	46	39
Fe total µg/l	---	700	260
Ca	56-338	566	532
Mg	32-90	154	155
Na	---	---	420
K	---	---	---
Na+K	3294-5166	145	---
HCO_3	245-990	1466	1330
CO_3	0	0	0
SO_4	3851-5787	971	1350
Cl	2500-3925	80	368
F	---	---	4.1
B (µg/l)	---	---	1100
TDS heated	---	2840	3730
TDS sum	10,543-15,787	2690	3680
No. sources	3	1	1
No. samples	5	1	1
Reference:	Crawford, 1940*	Lowry and Lines,1972	Lowry and Lines,1972

*All values in ppm

Source: King, et.al. 1980.

Appendix C (continued)

Source	Chugwater Formation Oregon Basin Hamilton Dome	Embar Formation Wangh Dome	Embar Formation Black Mtn. & E. Warm Springs oil fields
Depth (ft.)	2410-3840	3881-4168 (lnd)	2900-3200 (lnd)
Location	T51N R100W Sec 19 T51N R101W Sec 36 T44N R98W Sec 14	T44N R97W Sec 7,12	T 43N R91W Sec 35 T 43N R94W Sec 36
Temperature °C	---	---	---
SiO_2	---	---	---
Ca	500-696	57-173	548-673
Mg	81-187	65-79	99-154
Na	---	---	---
Na+K	10,580-15,349	640-705	263-428
HCO_3	135-285	245-915	781-1097
CO_3	0	0	0
SO_4	10,472-16,520	1,356-1,376	1,376-2,176
Cl	5,300-15,850	173-340	35-235
F	---	---	---
NO_3	---	---	---
TDS heated	---	---	---
TDS sum	33,116-44,489	2,426-3,309	2,995-3,802
No. Sources	3	2	2
No. Samples	3	2	3
References:	Crawford, 1940*	Crawford, 1940*	Crawford, 1940*

*All values in ppm
Source: King, et.al. 1980.

Appendix C (continued)

Source	Thermopolis Hot Springs and Wells	Wind River Canyon Spring	Mouth of Wind River Canyon Embar Formation
Depth (ft.)	---	---	250
Location	T43N R94W Sec 30,31 T43N R95W Sec 25	T42N R95W Sec 25	T42N R95W Sec 24
Temperature °C	51-56 (3nd)	21.5-22	---
SiO_2	35-82	12-13	---
Fe total µg/l	0-80 (3nd)	90 (1nd)	---
Ca	310-385	140-146	182
Mg	67-86	49-50	76
Na	250-280	40-41	---
K	37-53	6.7-7.4	---
Na+K	---	---	45
HCO_3	708-766	377-390	490
CO_3	0	0	0
SO_4	730-840	276-290	355
Cl	294-330	38-39	66
F	3.0-8.1	1.2-1.3	---
NO_3	0.0-0.10	0.0-0.3	---
B (µg/l)	410-610 (3nd)	100-120	---
TDS heated	2190-2390	800-812	---
TDS sum	2200-2332 (6nd)	759 (1nd)	965
No. sources	6	1	
No. samples	9	2	
Reference:	Breckenridge and Hinckley, 1978* Lowry and Lines,1972	Breckenridge and Hinckley, 1978* Lowry and Lines,1972	Crawford, 1940*

*All values in ppm
Source: King, et.al. 1980.

Appendix D, E, F

APPENDIX D*

THERMOPOLIS DISTRICT HEATING SYSTEM

INVESTMENT COSTS

CATEGORY	NET PRESENT VALUE (1980 - 2010) DISCOUNTED AT COST OF CAPITAL
Research Investment	$ 334,957
Design	$ 816,675
Management Fees	0
Wells	$ 2,907,342
Transmission	0
Distribution:	
Residential Retrofit	$ 1,095,403
Residential Hookup	$ 380,606
Commercial Conversion	$ 771,424
Industrial Conversion	0
Heat Exchangers	$ 242,329
Central System	$ 3,381,197
Total	$ 9,929,934

Price per MMBTU: $ 4.94
Year on line: 1989

COST AND BENEFIT SUMMARY (1980 - 2010); DISCOUNTED

Federal Factors:	Fed. Tax	Tax Credit	Royalty
	$ 3,506,177	$ 2,002,477	$ 563,317
State Factors:	State Tax	Sales Tax	Property Tax
	$ 0	$ 0	$ 1,371,539
Net Savings Through Year:	1990	2000	2010
	$ 246,000	$ 3,734,000	$ 7,370,000

EVALUATION OF INVESTMENT (NET PRESENT VALUE)

Investors return on investment:	$ 5,350,511
Equity Investment:	$ 3,435,983
Equity Portion:	0.3
Economic Judgement:	$ 1,914,529
Ratio of Rate of Return to Investment:	1.6
Investors Break-Even Year:	1999
Total Project Break - Even Year:	2008

Price of Geothermal: $4.94 / MMBTU
Price of Natural Gas: $3.30 / MMBTU ($ 5.16 by 1987)
Year on Line: 1989

APPENDIX D
(continued)

REQUIRED FLOW RATE

Available Flow:	5000 GPM
Required Flow Rate:	4883 GPM
Spare Flow Rate:	117 GPM

Source: NMEI printout from BTHERM computer model, May, 1980.

ASSUMPTIONS MADE IN APPENDIX

1. Research investment includes first production and injection well, in addition to engineering and geophysical studies.

2. Design is 10% of initial pre-production investment.

3. Management fees are included only for municipal development.

4. Transmission is pipeline cost from field to central distribution system.

5. Well costs indicate any wells required over initial well included in research investment, and all pumps, royalties or other associated well costs.

6. Developer's share of money was assumed at 75%.

7. Degree days were assumed at 7200. The actual figure for Thermopolis is 7248.

8. Depth of resource was assumed at 3500 feet. This is a "worst-case" figure. Satisfactory temperatures might be achieved at significantly shallower depths.

9. Shipping distance was assumed at 0 miles.

10. Temperature of geothermal fluid was assumed to be 140°F (60°C).

11. This computer run assumed a sales tax of 0. Wyoming actually has a 3% sales tax at the present time.

12. There are many other assumptions made by the BTHERM Base Case inputs that will not be elaborated on in a report of this scope. Data will be provided to NMEI in the future that will provide a more accurate reflection of Thermopolis district heating potentials than base case figures.

* Appendix D taken from Aspinwall, et.al., 1980, <u>Big Horn Basin Area Development Plan</u>.

APPENDIX E*

THERMOPOLIS / CODY DISTRICT HEATING SYSTEM

	PRICE / MMBTU (GEOTHERMAL)	INVESTMENT COST	25 YEAR DISCOUNTED FUEL SAVINGS	25 YEAR DISCOUNTED RETURN ON INVESTMENT
Case 1	$ 5.02	$ 2,458,855	$ 743,000	0
Case 2	$ 6.27	$ 2,458,855	$ 306,000	$ 636,551
Case 3	$ 8.20	$ 2,704,740	$ 114,000	$ 700,203
Case 4	$ 12.30	$ 3,748,764	0	$ 749,753

Source: January, 1980 data provided by PSL - NMEI in personal letter.

ASSUMPTIONS FOR APPENDIX

Case 1: Interest rate (0.08), time (25 years), distance from resource (8 miles), temperature (122°F or ≅50°C), depth (4000 feet), annual commercial heat demand (55,000 MMBTU/yr.), operating cost (2% of investment), alternative fuel price ($3.13/MMBTU), with real annual growth rate in conventional energy price of 6.6% for 10 years, and 5% per year for the following 30 years. The following financial factors were sll set to zero: rate of return on investment, Federal and State taxes, royalty rates, depletion allowances and investment credits.

Comments of Case 1: This is the most unrealistic of the four cases and was completed to illustrate how the model can be played with rather than to provide any real information. Resource distance, temperature and depth are all worst case values. The financial factors are impractical from a developers standpoint.

Case 2: The assumptions are identical to Case 1, except that it is a private developer who must earn a rate of return on investment, who must pay taxes and who will receive credits and allowances. This developer has 20% equity financing.

Case 3: The assumptions are identical to Case 2, except a design cost equal to 10% of other investment has been included.

Case 4: The assumptions are the same as Case 3, except it contains PSL - NMEI standard cost estimates for wells, well casings and pumps. These costs are for a 500 gpm, 4000 foot well with accessories. The PSL - NMEI costs are unspecified in this case. It is assumed that GCO well costs were used in the other three cases.

General Comments on Assumptions:

Most of the variables and assumptions that are usually described in an economic analysis are lacking in this one. It is not known what other estimates have been made other than those specifically listed above. This table is only included to show the broad range of values that the GCO has received for geothermal price per MMBTU for the Thermopolis / Cody system.

* Appendix E taken from Aspinwall, et.al., 1980, Big Horn Basin Area Development Plan.

APPENDIX F*

THERMOPOLIS / CODY COMMERCIAL DISTRICT HEATING SYSTEM

A. Capital Cost Assumptions

1. Reservoir System	
a. Exploration	$ 25,000
b. Well System - Intangibles	
i. Wells and Casings	
2 - Production wells (3000 feet @$100/ft.)	$ 600,000
1 - Reinjection well (2500 feet @$ 75/ft.)	$ 187,500
ii. Pump tests	$ 10,000
iii. Geologist (5 days at well site)	$ 1,500
iv. Contingency (10%)	$ 80,000
v. Engineering Fee (15%)	$ 131,850
Subtotal	$1,010,850
c. Well System - Tangibles	
i. Submersible pumps (2)	$ 80,000
ii. Well Head Equipment and Pad	$ 15,000
iii. Powerline, etc.	$ 2,000
iv. Contingency (10%)	$ 9,700
v. Engineering Fee (15%)	$ 16,005
Subtotal	$ 122,205
2. Transmission System (to point of distribution)	
a. Pipeline (2 miles X 16" diameter)	$ 528,000
b. Circulations pump	$ 10,000
c. Power lines	$ 2,000
d. Controls and valves	$ 5,000
e. Contingency (10%)	$ 54,500
f. Engineering Fee (15%)	$ 90,000
Subtotal	$ 689,500
3. Distribution Network (for 1 mile X 1/3 mile network)	
a. Supply pipeline (8" diameter X 21,120 feet and	$ 316,800
16" diameter X 1,320 feet)	$ 66,000
b. Return pipeline (same dimensions as above)	$ 382,800
c. Curb to building lines (20)	$ 80,000
d. Building retrofits (20)	$ 100,000
e. Return pipeline to reinjection well (16" diameter X 0.5 mile)	$ 132,000
f. Reinjection pump	$ 35,000
g. Circulation pumps (4)	$ 20,000
h. Power lines	$ 2,000
i. Controls and valves	$ 2,000
j. Contingency (10%)	$ 113,960
k. Engineering Fee (15%)	$ 188,034
Subtotal	$1,441,594
4. Regulatory Costs (institutional costs)	$ 10,000
5. Total Capital Cost	$3,299,649

APPENDIX F
(continued)

THERMOPOLIS / CODY COMMERCIAL DISTRICT HEATING SYSTEM

B. Other Cost Assumptions

1. Working Capital (2.5% of Capital Costs)	$ 82,500
2. Operating and Maintenance Costs	
a. Case A - 6% per year of Capital Costs	$ 197,979/yr.
b. Case B - 3% per year of Capital Costs	$ 98,989/yr.
3. O & M Cost Escalation Rate	10% per yr.
4. Municipal Bond Interest Rate	8% per yr.
5. Rate of Return to Municipality	
a. Case 1 - 8% per year	
b. Case 2 - 3% per year	
6. Replacement Fuel: Natural Gas	
a. Current (1980) Price	$ 3.13/MMBTU
b. Escalation Rate	11% per yr.
c. Amount of fuel required	55,000 MMBTU/yr.
7. Life Cycle Duration	25 years

8. Bond Issuances

A - Bonds: $ 3,299,650 (CC) plus $ 82,500 (WC) issued at beginning of year 0, to provide capital for construction during year 0 (full operation begins at beginning of year 1, end of year 0); 26 year issuance with equal annual P & I payments.

B - Bonds: $264,000 issued at beginning of year 1 to pay interest due on A - Bonds at end of year 0: 5 year issuance with equal P & I payments.

C. Result of SEER Calculations

1. Three Cases Evaluated:

	Discount Rate (ROR)	O & M Costs
Case 1	8%	6% of Capital
Case 2	3%	6% of Capital
Case 3	3%	3% of Capital

2. Items Calculated:

DCFRIR = Discounted cashflow rate of return
NPV = Net present value (at minimum rate of return to municipality)
Dis Payback = Discounted payback period
Annualized Revenue = Actual escalated dollar revenue required each year for 25 years
Energy Price = Annualized Revenue divided by 55,000 MMBTU

SOURCE: Western Energy Planners, Ltd., 1980.

ASSUMPTIONS OF APPENDIX F

1. Capital costs were assumed at 100% borrowing with no grants. In the case of East Thermopolis, a UDAG grant would probably be available. This table also does not account for federal programs such as the User-Couple Drilling Program or the Geothermal Loan Guarantee Program.

2. Heating demand may be innaccurate as it is based on square footage figures that are much higher at an averaged rate than those actually found in most cities in Wyoming. Figures that more accurately reflect actual heating demand will be used in the Thermopolis Site Specific Development Analysis (SSDA).

3. Drilling and pump costs may be inaccurate for Thermopolis, although they resemble the real life situation of Cody pretty well. In Thermopolis, there is a good chance that artesian flow could be achieved, as well as finding a good production well (with adequate temperature and flow rates) at depths much less than 3000 feet. This would significantly reduce the Captal Costs.

*Appendix F taken from Aspinwall, et. al., 1980, Big Horn Basin Area Development Plan.