Engineering & Economic Studies
for Direct Application of Geothermal Energy

**GEOHERMAL SPACE HEATING APPLICATIONS
FOR THE FORT PECK INDIAN RESERVATION
IN THE VICINITY OF POPLAR, MONTANA**

Final Report, August 20, 1979 - May 31, 1980

Project Administration
Fort Peck Indian Reservation
Carl Fourstar, Tribal Research
Elliot Todd, Housing Authority

October 1980

Work Performed Under
Contract No. DE-FC07-79ID12046
for the Idaho Operations Office

PRC Toups Corporation
Orange, California

By
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U. S. DEPARTMENT OF ENERGY
Geothermal Energy

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ABSTRACT

This report presents the results of a first-stage evaluation of the overall feasibility of utilizing geothermal waters from the Madison aquifer in the vicinity of Poplar, Montana for space heating. The report includes a preliminary assessment of the resource characteristics, a preliminary design and economic evaluation of a geothermal heating district and an analysis of environmental and institutional issues. Preliminary investigations were also made into possible additional uses of the geothermal resource, including ethanol production.

The results of the resource analysis showed that the depth to the top of the Madison occurs at approximately 5,500 feet at Poplar, and the Madison Group is characterized by low average porosity (about 5 percent) and permeability (about 0.004 gal/day-ft), and by hot water production rates of a few tens of gallons per minute from intervals a few feet thick. Temperatures of water in the Madison were found to range from about 150°F to at least 265°F. Waters produced from the Madison in this region were found to be highly saline, with data showing a variability of from 35,000 to 288,000 ppm. Although the aquifer parameters and reported production rates are low, the investigation revealed reason to expect that a target rate of 500 gpm can be achieved if attempts are made to produce water from substantial thicknesses of the Madison.

The preliminary heating district system effort for the town of Poplar included design heat load estimates, a field development concept, and preliminary design of heat extraction and hot water distribution systems. A "cascading loop" distribution system was developed as a means of maximizing resource heat extraction and minimizing capital investment. The environmental analysis, based on current data, indicated that resource development is not expected to result in undue impacts. The institutional analysis concluded that a Tribal geothermal utility could be established, but no clear-cut procedure can be identified without a more comprehensive evaluation of legal and jurisdictional issues.

The economic evaluation found that, if the current trend of rapidly increasing prices for fossil fuels continues, a geothermal heating district within Poplar could be a long-term, economically attractive alternative to current energy sources.

ACKNOWLEDGEMENTS

Significant contributions to this report were made by the Council of Energy Resource Tribes (CERT). These contributions included an analysis of legal, institutional, regulatory, environmental and financial aspects. The results of this analysis were documented in a separate report to the Fort Peck Tribes which was used in large part in preparing Chapter 5 of this report. The CERT effort was directed by Dr. Warner Reeser with contributions from Mr. Sean Muller, Mr. Frank Long, Mr. Gary Parker, and Mr. David Redhorse.

PRC Troups would also like to acknowledge the assistance and cooperation of the following participants in the development of this report:

Bruce M. Barron
Strata-Analysts Group

James A. Krohn
James Slosson, PhD.
Slosson & Associates

John Sonderegger
Montana Bureau of Mines and Geology

George Thompson
Ed Smith
Fort Peck Tribal Research Office

INTRODUCTION

This engineering and economic study is concerned with the question of using the natural heat of the earth, geothermal energy, as an alternative to other energy sources such as electricity and natural gas which are increasing in cost. This document represents the final report on the effort directed toward determining the availability of geothermal energy from the Madison aquifer underlying the Fort Peck Indian Reservation, Montana (Figure 1), and evaluating the feasibility of beneficial direct use of this resource for space heating applications, including analysis of engineering, economic, environmental, and institutional considerations. The project was administered by the Tribal Research Office, Assiniboine and Sioux Tribes, Fort Peck Indian Reservation, Poplar, Montana under a contract to the United States Department of Energy. PRC Toups, the major subcontractor, was responsible for engineering and economic studies and the Council of Energy Resource Tribes (CERT) provided support in assessing the environmental, financial, and institutional issues.

This study was conducted in two phases. The primary emphasis of the first phase of the study was to define the characteristics of the Madison aquifer in the vicinity of Poplar, Montana, and to provide a preliminary assessment of the overall feasibility of geothermal space heating applications for Poplar. A preliminary feasibility assessment was intended for a new housing development to the east of Poplar. However, the development is being re-evaluated currently. The results of the first phase of the study, published as the Phase I report for this project in early January, indicated that direct use of geothermal waters from the Madison aquifer could be a feasible long-term alternative to conventional energy sources which are currently available for Reservation residents.

The efforts of the second phase were primarily focused on developing a preliminary design and economic assessment of a geothermal heating district for the town of Poplar, and assessing the issues related to its implementation.

LOCATION OF FORT PECK INDIAN RESERVATION AND STUDY AREA

Figure 1

BACKGROUND - FORT PECK RESERVATION

The Fort Peck Indian Reservation is located in the northeast corner of Montana (see Figure 1) and it encompasses approximately 2.1 million acres of land. The Reservation is bounded on the south by the Missouri River, on the east by the Big Muddy Creek, and on the west by the Porcupine Creek. The Reservation encompasses all of Roosevelt County, one fifth of Valley County, and small portions of Daniel and Sheridan Counties (See Figure 2). The major trade center for the Reservation is the town of Wolf Point. However, the Tribal Government, the Bureau of Indian Affairs, and Indian Health Services are located in Poplar (See Figure 3 and Photograph 1).

Northeastern Montana is considered to have a "continental" type climate. Temperatures vary widely by season and year. Frost-free periods range from approximately 100 days in the higher benches to 130 days along the Missouri Bottom.

Sioux and Assiniboine Indians make up approximately 45 percent of the total population of the Reservation. The Indian population is concentrated in the warm southern third of the Reservation. As of April 1979, there were 5,131 Indians living on or near the Reservation.

HISTORY AND LAND OWNERSHIP

The Fort Peck Indian Agency has been in existence since 1871. The Reservation boundaries were finalized in 1888 and 2,093,318 acres were set aside for the Fort Peck Tribes. The Dawes Act of 1887 allows the Tribal lands to be allocated to individual Indians in tracts containing 320 acres of grazing land and some timber and irrigable land. Sale of surplus lands and opening parts of the Reservation to non-Indians for homesteading was authorized by Congress in 1907. After 1911, land within the Reservation was opened to homesteading.

Present land ownership and leasing patterns have had a fragmenting effect on trust lands. The Reservation has a checkerboard land ownership pattern. Trust and fee lands are vastly interspersed, creating management problems with agricultural trust lands. Distances and accessibility to scattered tracts has an economic impact, therefore limiting returns on agricultural lands.

During the period from 1966 to 1973, the amount of trust land reverting to fee for non-Indian status was approximately 6,287 acres per year. The Tribal Land Purchase Program, made possible by an FHA loan, slowed the rate of loss considerably. Through the FHA Land Purchase Program, the Tribes are attempting to correct this problem by purchasing of land surrounding Tribal-owned lots.

Table 1 is a summary from the status of the lands within the Fort Peck Reservation. In all, Indians have available to them about 950,000 acres of trust and government land. The use of these lands is summarized in Table 2.

FIGURE 2

FORT PECK RESERVATION VICINITY MAP

FIGURE 3 POPLAR VICINITY MAP

NORTHEAST VIEW OF POPLAR, MONTANA

PHOTOGRAPH I

TABLE 1. FORT PECK RESERVATION LAND OWNERSHIP

Fort Peck Reservation Land Ownership	Acres	Percentage
Non-Trust Fee Land	1,162,733	55.6
Individual Indian-Allotted Land	567,320	27.1
Tribal Government-Owned Land	362,309	17.3
Government-Owned Land	762	-0-
Total	2,093,124	100.0

Source: "Assiniboine and Sioux Tribes Financial Report,"
Galusha, Higgins and Galusha, June 30, 1976.

TABLE 2. LAND USE CLASS OF TRUST LANDS

Land Use Class	Used by Indian	Used by Non-Indian	Idle	Total
Open				
A. Grazing	214,637	428,019	8,194	649,850
Comm.				
B. Timber	2,700	XXX	XXX	2,700
Non-Comm.				
C. Timber	9,300	XXX	XXX	9,300
Dry				
D. Farm	144,985	127,841	1,340	274,166
Irrig. Proj.				
E. 1. Irrig.	4,053	2,782	199	7,034
2. Dry Farm	1,680	1,168	-0-	2,848
3. Other	XXX	XXX	-0-	-0-
Private				
F. Irrigation	1,015	1,160	-0-	2,175
Wild Lands				
G. Ex. Timber	-0-	-0-	-0-	-0-
Other Uses				
H. Non-Agr.	2,511	2,598	-0-	5,109
I. Total	380,881	563,568	8,733	953,182

Source: 1975 Land Use Inventory and Production Record Report 50-1, BIA.

GENERAL CLIMATE

Climatic conditions across the Reservation are reasonably uniform due to the absence of predominant geographic factors. Wide seasonal variations in temperature can be expected as illustrated in Figure 4. The low of -63°F at Poplar is the lowest recorded temperature in the Reservation area, while the highest recorded temperature in the area was 117°F at Medicine Lake. Summer temperatures can be expected to exceed 100°F each year, and winter temperature -35°F to -45°F are not uncommon. The cold, dense air settles to the valley bottom when the air is still, and slightly warmer temperatures are experienced on higher land. Streams in the area are frozen over an average 120 days per year. The growing season in the region varies from 100 to 120 days throughout the area, with a slightly longer season in the south.

FIGURE 4 TEMPERATURE AND PRECIPITATION REPRESENTATIVE OF
FORT PECK INDIAN RESERVATION

MONTHLY MEANS AND EXTREMES OF PRECIPITATION

Source: US Department of Commerce. National Oceanic and Atmospheric Administration. Climatological Data, Montana
1/Base Period: 1901-1909, 1911-1914, 1918-1972
2/Base Period: 1931-1979

MONTHLY TEMPERATURE MEANS AND EXTREMES

Source of Data: National Oceanic and Atmospheric Administration. Climatological Data: Montana.
1/60 Years of Record.
2/85 Years of Record.

I.

SUMMARY

This report presents the results of a first-stage evaluation of the overall feasibility of utilizing geothermal waters from the Madison aquifer in the vicinity of Poplar, Montana for space heating. The report includes a preliminary assessment of the characteristics of that resource, a preliminary design and economic evaluation of a geothermal heating district and an analysis of environmental and institutional issues. Although the project was primarily concerned with space heating, preliminary investigations were also made into possible additional uses of the geothermal resource. Included in these were agricultural (greenhouses) and aquacultural (prawn farms), as well as ethanol production. The results of these preliminary investigations are presented as an appendix to this report.

RESOURCE ASSESSMENT

The existence of a potentially valuable geothermal resource within the Fort Peck Indian Reservation was first detected from an analysis of temperatures encountered in oil wells drilled in the area. This data, produced by the Montana Bureau of Mines and Geology, pointed to a possible moderate temperature source near the town of Poplar, Montana. For this report, data to assess this resource was primarily derived from oil well logs and data summaries for producing oil wells in the Poplar Oil Field as well as "dry wells" in the vicinity. The well log data include depth, lithology, several types of resistivity, spontaneous potential, radioactivity, sonic, density, and caliper profiles. In addition, some drill stem test data and sonic core analysis data on porosity and permeability were also provided.

The results of the analysis showed that the depth to the top of the Madison occurs at approximately 5500 feet at Poplar, and the Madison Group is characterized by low average porosity (about 5 percent) and permeability (about 0.004 gal/day-ft), and by hot water production rates of a few tens of gallons per minute from intervals a few feet thick. Temperatures of water in the Madison were found to be higher than expected from the normal geothermal gradient and range from about 150°F to at least 265°F.

Although the aquifer parameters and reported production rates are low, the investigation revealed reason to expect that a target rate of 500 gpm can be achieved. This is because the tested intervals represent only a small fraction of the entire thickness of the Madison, and from its geologic nature and post-depositional history, several types of processes are expected to have formed thin zones of high porosity and permeability. This is supported by wide ranges in salinity, temperature, production rates (by drill stem tests), and the responses of several types of well-bore logging, not only from well to well but also within individual wells. If attempts are made to produce water from substantial thicknesses of the Madison, the yield should be high and at the temperatures necessary for the application.

Moreover, although this study has focused on the Madison, some of the underlying carbonates should provide about the same rates of production at higher

temperature, and some of the overlying formations, which have higher porosity and permeability values, should provide higher rates of production at acceptable temperatures.

There are several processes which can be used to explain why temperatures of water in the Madison region are higher than would be expected from the normal geothermal gradient. At this time, the preferred explanation is that this is due to upward leakage of water from deeper formations, rising along faults or joint systems, in particular the Brockton-Froid fault zone, and spreading laterally along permeable zones in the Madison as well as in any other formation in the stratigraphic section.

Waters produced from the Madison in this region were found to be highly saline. Data from oil wells showed a variability of from 35,000 to 288,000 ppm total dissolved solids, with an average of 102,000 ppm. The brines are predominantly sodium chloride type, with sulfate the most abundant constituent. Operators of the Poplar oil field have had nearly thirty years experience in handling these brines, as the product of many of the wells is comprised of up to 90 percent brine and 10 percent oil. During this period, the field operators have developed methods of controlling scaling and corrosion.

ENGINEERING AND ECONOMIC FEASIBILITY

A preliminary design was prepared for a heating district for the town of Poplar based upon the resource characteristics resulting from the resource investigation. The design effort included estimating the design heat loads for the major buildings and residences of Poplar, as well as preparation of a field development concept, and preliminary design of heat extraction and hot water distribution systems. Due to the high salinity expected, the design was based upon using heat exchangers to transfer the heat from the geothermal fluid to a secondary hot water distribution system. The distribution system design features a "cascading loop" system. This design concept was developed in order to maximize use of the extractable resource heat from the 190°F resource within the minimum temperature limitations of the space heating application. With this concept, the heated water is reused within the distribution system until a minimum 60 degree temperature drop has been attained (the equivalent of 20 a degree drop across three home heat exchangers). This concept would effectively triple the output of a well as compared to a system which is based upon one 20 degree drop.

Use of the geothermal resource to provide heat for Poplar could provide long-term economic benefit, although the present-day cost would be higher than that of natural gas, the current predominant fuel. The economic benefit is predicated upon a continuation of the rise in natural gas prices. If current price and rate structure trends continue, the use of this alternate energy resource could become particularly attractive for use by the major structures within Poplar.

RESOURCE DEVELOPMENT FACTORS

The Tribes could implement geothermal resource development through establishing a geothermal utility similar to a co-operative or municipality. The procedures and

institutional issues were investigated, and are presented as suggested actions only, since no clear-cut procedure could be identified without a more comprehensive evaluation of legal and jurisdictional issues.

Development of the geothermal resource is not expected to result in undue environmental impacts, based upon the data available at this time. However, the question of the impact on groundwater resources of continued geothermal fluid reinjection as currently practiced by the oil field development and planned within the proposed design would require further investigation.

DISCUSSION OF RESULTS

This study must be considered preliminary. The engineering and economic studies were based upon assumptions concerning the characteristics of the resource, and the design and economic base could change as a result of a more comprehensive assessment of that resource. Although the results of the resource assessment agree with those of other studies of the Madison, and although there appears to be internal consistency from more than one type of approach in the Poplar area, there are several serious deficiencies.

Not all the available well information at Poplar was used, and the geographic distribution of the studied wells is not such that the results can be considered properly representative of conditions throughout the area. Further, within the scope of this study, data from the well log profiles had to be generalized rather than worked out in detail across short intervals. The drill stem tests, from which the yield data were derived, necessarily related to zones which were thought most likely to produce oil rather than water. In addition, the tests were for periods of a few hours or less, which is much shorter than the normal period for tests of aquifer yield. Actual hot water production rates have yet to be acquired from the present operators of the oil field. The kinds of changes which have been occurring over time are vital to the objective of this project and remain to be determined. Finally, bottom-hole temperature data for this report represents less than half of the data that could be made available, and more downhole temperature logs may also be in existence. As temperature is the other of the two vital parameters, the results of this study are incomplete in that not all the temperature information that can be expected to exist is at hand.

Nevertheless, the results appear to be adequate, and the indications are sufficiently favorable that successful hot water production wells for direct use geothermal applications can be expected in the Poplar area. Those factors which cannot be determined at this time are the best sites for such wells, a reasonably accurate prediction to optimum depths, yield, and expected temperature, and a better evaluation of the degree of risk involved.

RECOMMENDATIONS FOR FURTHER RESOURCE INVESTIGATION

For the reasons outlined in the previous discussion, it is recommended that additional well data be acquired and a more comprehensive analysis be performed to further refine the resource characteristics. This investigation should include the following:

1. A search of remaining well logs for specific wells in other localities in which the Madison is known from the literature to be a high water producer to determine which zones produce high flows.
2. A comparison of the logs from the Poplar area with those obtained from other localities to identify good aquifer horizons and investigate whether similar responses occur in any of the Poplar area logs.
3. A more comprehensive interpretation of well logs used during this investigation together with the additional well logs for the Poplar area in order to improve the predictability, productivity, temperature, and salinity.
4. An information search and analysis of recorded data which may be obtained from the operators of the Poplar Oil field related to the quantity, temperature, and quality of water produced from their operations, as well as historic reinjection data.
5. An investigation of the feasibility, and if feasible, selection and testing of existing wells for hot water production from the Madison.

Before a drilling program can be justified, it would be advisable to perform additional ground temperature work in specific localities to define more precisely the configuration of the thermal anomaly. Following this, surface electrical resistivity studies should be performed using the mode of vertical electrical sounding to investigate the depth zone at which the indicated shallow hot water resource exists. Slim hole drilling to measure thermal gradients may also be recommended, but the need and the locations, if justified, should be determined from the results of the additional ground temperature and resistivity work.

II.

GEOLOGIC INFLUENCES WITHIN THE FORT PECK AREA

The Fort Peck Indian Reservation covers approximately 2.1 million acres in northeastern Montana in the northern portion of the Great Plains physiographic province. Located in the Missouri River Basin, the Reservation is bounded on the south by the Missouri River, on the east by Big Muddy Creek and the west by Porcupine Creek. Both Big Muddy Creek and Porcupine Creek are north-south trending tributaries of the Missouri River.

The following discussion presents the results of investigations of near-surface geologic conditions which could influence the assessment and development of geothermal resources in the Fort Peck area. As an aid to the reader, a stratigraphic sequence of the area derived from literature and a geologic time scale, are included as Appendices A and B, respectively.

PHYSIOGRAPHY

The Fort Peck Indian Reservation consists of a series of rolling upland benches dissected by tributaries of the Missouri River and is typical of much of the northern Great Plains.(32) Its present day landscape symbolizes an area that has undergone gentle, intermittent uplift, and successive invasions and retreats of Pleistocene ice sheets.

The most dominant physical feature within the study area is the meandering Missouri River with an alluvial flood plain which ranges from 2-1/2+ to 4+ miles in width (Figure II-1). Much of the lower land on the flood plain is covered with brush and trees. Farm crops are grown on the high parts of the flood plain.

North of the Missouri River, its flood plain is bordered generally by gradually rising, gently rolling land. The average gradient of this area is approximately 50+ feet per mile, with local gradients of up to 200+ feet per mile. The gentleness of this more northerly, glacially affected area contrasts markedly with the more dissected topography found south of the Missouri River.

Total relief within the study area is approximately 260+ feet. The highest elevations (2,200+ feet) occur in the upland area both north and south of the Missouri River. The lowest elevation (1,940+ feet) is located along the Missouri River in the eastern portion of the study area. (Note: All elevations are relative to mean sea level.)

DRAINAGE

Although the Missouri River does not appear to be structurally controlled (i.e., along faults, folds, etc.), several of its tributary drainage courses may be influenced by the bedrock structure. The Poplar River, for example, flows roughly along the axis of the Opheim Syncline for much of the length of the River. In

- LEGEND**
- Qal Alluvium
 - Qki Kintyre Formation
 - Ql Till
 - Qo Outwash deposits
 - Qac Fan alluvium and colluvium
 - Qd Dune sand
 - Ql Lake and pond deposits
 - Qs Spole Silt
 - Qw Wlofa Gravels
 - Khc Heil Creek Formation
 - Kfh Fox Hills Formation
 - Kb Bearpaw Shale
 - Strike and dip of apparent bedding
 - - - - - Contact, dashed where approximate
 - ... Fault, dotted where concealed
 - Lineation on aerial photography
 - Ice-crack moraines

FIGURE II-1 GEOLOGIC MAP OF A PORTION OF THE FORT PECK INDIAN RESERVATION
(modified from R.B. Colton, 1963)

addition to the folds and/or faults, some of the drainage may also be locally controlled by glacially-related features (e.g., ice moraines).

Most drainage or runoff within the study area (especially in the less cultivated areas) is via sheetwash, rill or gullies. This runoff is eventually channelled into one of several north-south trending tributaries which drain into the Missouri River. Tributaries from the north generally appear to be larger than those from the south. The Poplar River and Box Elder Creek represent the two largest tributaries north of the Missouri River. Of these, only the Poplar River is sufficient in size to maintain a channel within the Missouri River flood plain.

SOILS AND FOUNDATIONS

Earth materials exposed within the area consist of Quaternary (i.e., Recent and Pleistocene) surficial materials underlain by Cretaceous bedrock materials. The surficial materials consisted of soil alluvium, colluvium, dune sand lake and pond deposits, as well as assorted glacial deposits. Bedrock units consist of the Hell Creek Formation, the Fox Hill Formation, and the Bearpaw shale. A detailed discussion of soils and bedrock units is presented in Appendix C, Earth Materials.

SOILS

The soils and other surface deposits mantle the ground surface to varying depths, ranging up to several hundred feet thick.(7) Soils are relatively young deposits derived from underlying earth material. Because of their recent origin and mode of accumulation, many of the soils tend to be rather loose, porous and either unconsolidated or poorly consolidated. In addition to the surficial material commonly considered as soil or topsoil, other surficial material present include alluvium, colluvium, dune sand, land and pond deposits as well as assorted glacial deposits.

The physical properties of soils are engineering and design considerations which impact construction and maintenance of building foundation and pipelines. Among the physical properties that often can affect construction are: soil drainage characteristics, permeability, shrink swell behavior and corrosivity.

Both the town of Poplar and the proposed housing development are underlain by glacial tills which may be in excess of 100+ feet thick. The till consists of a moderately to well-compacted, heterogeneous mixture of clay with lesser amounts of silt, pebbles and boulders which were deposited as unsorted debris by glacial ice. Because of this method of deposition, the till is typically unsorted and unstratified.

The U.S. Department of Agriculture, Soil Conservation Service (SCS) is currently conducting a soil investigation in the Poplar, Montana area (personal communication with Edward Stein of the Wolf Point, SCS office). Although their survey is not yet completed, initial field data suggests that the town of Poplar and the proposed housing development site (i.e. located east of Poplar) are mantled by Williams and Zahill loams. These soils are typically well drained, greater than 5+ feet thick, have low permeabilities, and are moderately expansive. Corrosivity of these soils is low for concrete and high for uncoated steel (personal communication with Dennis Smitana, Wolf Point, SCS office).

EXPOSED BEDROCK

Bedrock material exposed within the area include, in increasing order of age, the Hell Creek Formation, Fox Hills Formation, and the Bearpaw Shale. These bedrock units are of Cretaceous age. Both the Hell Creek and Fox Hills formations are exposed south of the Missouri River, while the Bearpaw shale is exposed north of Poplar. (See Figure II-1).

The Hell Creek Formation is of continental freshwater origin and consists chiefly of gray to tan shales, siltstones, sandstones, and carbonaceous shales.(7) Total thickness of this formation varies locally, but it ranges up to 280+ feet in the bluffs south of the Missouri River, between Poplar and Brockton.(24) Locally the Hell Creek Formation unconformably overlies the Fox Hills Formation.

The Fox Hills Formation, which locally reaches a thickness of as much as 120+ feet, consists of an assemblage of transitional marine claystone, siltstones, and sandstones. The lower portion (i.e. 35+ to 60+ feet) of the formation is composed of thin beds of alternating gray claystone, siltstone and yellow, very fine-grained sandstone. The finer-grained beds are located predominantly near the base of the formation when they are transitional with the older, underlying Bearpaw Shale.

The Bearpaw Shale, estimated to be approximately 1,100 + feet thick, is the oldest bedrock unit exposed within the study area. It consists of a marine, dark-gray to black clayey shale that is somewhat sandy in the upper part. In addition to shale, the Bearpaw contains distinct bentonite layers (1/4+ to 2+ inches thick), gypsum crystals and calcareous concretions.(32)

SOIL STABILITY

Creep is the extremely slow and intermittent movement of soil and other surficial materials downslope. Creep generally can occur in almost any area when soil or accumulations of other surficial deposits exist on slopes. It is particularly common where expansive material may be present.

Landslides or slumping refer to the processes involving moderately rapid to rapid downslope transport of earth material in mass, under the influence of gravity. Minor landsliding and/or slumping occurs generally in the hilly upland areas which are underlain by bedrock of the Bearpaw Shale.

Neither of these two processes should be significant hazards to the proposed geothermal project. This is primarily due to the lack of appreciable slope gradient sufficient to cause downslope movement.

STRUCTURE

The two major structural features affecting the study area appear to be the Poplar dome and the Brockton-Froid fault zone.

POPLAR DOME

The Poplar dome represents a broad, slightly elongated, north trending dome, some 30+ miles long, and 25+ miles wide and centered approximately 6+ miles north of the town of Poplar.(34) Bedrock formations in proximity to the dome tend to dip away from it in every direction, with the direction of dip at any particular point being determined by the direction of such a point of observation from the center of the dome. Dips along the Greenhorn Formation (See Appendix A) in the northern and eastern portions of the dome range from 100+ to 135+ feet per mile exist in the southern and eastern portions of the dome.(8)

Bedrock units exposed at the surface generally appear to be gently dipping, similar to the bedrock units and contoured by Colton and Bateman.(8) Although the surface bedrock units appear to be gently dipping, they also appear to be somewhat undulatory. As a result, the bedding appears to fluctuate locally from the regional trend in both dip direction and/or dip angle. North of Poplar, for example, the bedding of the Bearpaw shale appears to dip southeasterly as well as southwesterly (Figure II-1). Subject to possible slope creep, attitudes taken in the Bearpaw shale ranged from 5+ to 15+ degrees. These attitudes appear to be steeper than the regional trend.

Local dip fluctuations were also noted in some of the surficial materials. Reportedly, the Kintyre Formation is nearly horizontal in many places, but in many other places it has been folded, broken, or otherwise contorted.(24) The amount of folding and contortion is believed to be an indirect reflection in thickness and shape of the ice upon which beds of the Kintyre Formation were deposited.(24) In those areas where the ice was thin or comparatively uniform in thickness, the sediments probably settled down onto the underlying material with little to no distortion during ice retreat. However, where the melting of large blocks or irregular masses of ice took place, extensive readjustment and distortion occurred as overlying Kintyre sediments settled.(24) The nature of the Kintyre Formation within the study area was not determined because of a lack of outcrop exposure.

In addition to the Kintyre Formation, the Sprole silt may also be locally contorted. The Sprole silt was deposited in a lake formed when the ice advanced and blocked the Missouri River.(6) Deformation of the Sprole silt may have occurred when ice overrode the lake deposits (Colton, personal communication).

Deformed Sprole silt exists in a series of small road cuts located approximately one and one-half miles northwest of the town of Sprole (See Photograph 2). The bedding noted appears to be highly variable in dip direction and angle. Dips recorded range from 25+ to 50+ degrees (See Figure II-1).

BROCKTON-FROID FAULT ZONE

A zone of normal faulting has been mapped between the towns of Brockton and Froid.(8) As shown on Figure II-1, the western section of this zone apparently extends southwest of Brockton into the eastern portion of the study area.(7) The Brockton-Froid fault is the only fault that has been mapped within the study area. However, this may be due in part to a lack of available outcrops or exposures within the subject area.

SPROLE SILT EXPOSED IN ROAD CUT NORTHWEST OF SPROLE, MONTANA

Colton of the U.S. Geological Survey shows the Brockton-Froid fault zone to be a few thousand feet in width and about 30 miles in length.(7) He shows a fault zone consisting of at least two roughly parallel faults, with a graben or downdropped block between the faults.(7) These faults are shown to affect Pleistocene glacial beds.(7) Furthermore, Colton and Bateman's structural contour map shows offset of basement rock near Brockton of less than 100_± feet to over 400_± feet near Froid.(8)

The existence of the Brockton-Froid fault zone is important to the geothermal resource, as the fault may act either as a barrier or a vehicle along which hot waters at depth can migrate upwards. If water is migrating upwards along the fault, this hot water apparently is not reaching the ground surface. No hot springs were noted along the fault zone within the study area.

In addition to the Brockton-Froid fault zone, Colton indicated the existence of several lineations.(7) These northeast-southwest trending lineaments are roughly parallel to and approximately one and one-half miles north of the Brockton-Froid fault zone. Colton indicates that these lineaments may be surface traces of possible faults.(7)

As shown in Figure II-1, the longest of these lineaments intersects the previously mentioned road cuts northwest of Sprole, and a projection of this lineament continues southwest beyond the road. This lineament is also shown in Photographs 3 and 4.

As previously indicated, Sprole silt is exposed in the road cuts, which intersects the subject lineaments. This silt appears to be locally contorted, with variable dip directions, and dip angles of up to 50_± degrees (See Photograph 2). Several lithologic changes were noted within the silt (e.g., a pebble free silt juxtaposed against a pebbly silt). Generally, a sharp contact existed between these lithologic changes (See Photograph 2). The absence of fault gouge, (i.e., clay) or slickensides, along the contacts could possibly suggest that the deformation noted in the Sprole silt may be depositional in origin, rather than fault related. However, because of the weathered nature of the silt, vegetation over and/or limited vertical and lateral extent of the existing roadcuts, faulting cannot be eliminated based upon available outcrop exposures. Additional investigation (i.e., subsurface exploration) would be necessary to solve this apparent enigma.

SEISMICITY

Less is known about the earthquake history of the Western Mountain Region, which included Montana, than any other section within the United States.(41) However, with the data that is known, the seismicity for the Poplar, Montana area appears to be relatively low. A computer search of all earthquake epicenters of Magnitude 3 and above was obtained from the National Oceanic and Atmospheric Administration (NOAA). (Note: The NOAA seismological records extend as far back as 1937.) The computer search which was requested included a 60+ miles radical search from the town of Poplar, Montana.

LINEAMENT IN CULTIVATED FIELD NORTHWEST OF SPROLE, MONTANA

LINEAMENT LOCATED NORTHWEST OF SPROLE, MONTANA

The computer search revealed that two epicenters were located within 60+ miles of Poplar. The first earthquake occurred on either 24 or 25 June 1943, and was located about 28+ miles north-northeast of Poplar. (Note: Computer search indicated 25 June, whereas Reference 43 indicates 24 June.) According to available records,(41) a well-constructed granary at Froid cracked so severely that wheat spilled out. Plaster and chimneys were also cracked in nearby Homestead, Redstone, and Reserve. The second earthquake apparently occurred approximately 41+ miles northeast of Poplar. Both earthquakes were small, with probable magnitudes of between 3 and 4. Based upon the approximate location of these earthquakes, it is conceivable that they may be related to the Brockton-Froid fault zone.

Shaking from other earthquakes may have been felt within the Poplar area (i.e., 1935, 1944, 1946) as indicated by Colton (personal communication). Colton feels that this may have been related, at least in part, to the Brockton-Froid fault zone and concludes this fault zone is active (personal communication). However, there is no apparent evidence to associate this shaking with the Brockton-Froid fault zone.

During the investigation for Fort Peck Dam,(28) Krinitzsky indicated that the Maximum Credible Earthquake for the Brockton-Froid fault zone ranged between Magnitude 6.0 and 7.2. The larger magnitude assumes that the Brockton-Froid fault zone is connected to the Weldon fault, which is located some 43+ miles southwest of Poplar. (Note: Colton (5) does not continue the Brockton-Froid fault zone south of the Missouri River.)

A Maximum Credible Earthquake along the Brockton-Froid fault zone would subject the town of Poplar, as well as nearby areas, to strong seismic shaking, generating possible differential compaction, liquefaction and seismic consolidation of the more unconsolidated earth materials. Ground rupture could also occur along the Brockton-Froid fault zone. However, based upon the existing seismic data, the possibility of 6.0 to 7.2 magnitude earthquake along the Brockton-Froid fault zone appears to be remote, at best.

III.

GEOTHERMAL RESOURCE ASSESSMENT

This section presents the results of the investigations which were performed to define and characterize the geothermal resources located in the vicinity of Poplar, Montana within the Fort Peck Indian Reservation. Since the existence of a geothermal resource within the Madison Formation had previously been detected, the primary emphasis of the resource investigation was to further define the characteristics of that reservoir. Existing data, which was available as a result of the oil well drilling activities in the area, was collected and analyzed as the basis of this assessment. In addition, information obtained during the course of this study led to the hypothesis that hot water resources of high potential benefit for geothermal heating application in this area may occur at depths shallower than the Madison Formation. Therefore, in order to investigate this potentially valuable resource further, additional field work was performed using shallow temperature survey techniques. (This additional work was partially funded by the Montana Bureau of Mines and Geology.)

SOURCES OF INFORMATION USED IN ANALYSIS

Sources of published data used in this part of the study consist of reports of the U.S. Geological Survey, the Montana Bureau of Mines and Geology, and technical periodicals. These sources provide general information on the Madison Group in Montana in general and to some extent, in the Poplar area.

Much information relating specifically to the Poplar area was derived from oil well logs and data summaries for producing oil wells in the Poplar Oil Field, as well as "dry" wells in the vicinity. This data was provided by the Murphy Oil Company, from files of the State of Montana, and from the files of the Fort Peck Indian Reservation.

The location of the Poplar oil field is shown in Figure III-1. Figure III-2 shows the location of 46 wells near the town of Poplar for which the majority of the data used in this report was obtained. The shaded area in Figure III-3 delineates the oil producing zone. (Note: The well numbers shown on Figure III-2 are identification numbers which were assigned only as an index for purposes of relating data within other figures, tables, and the text of this report.) It was decided at the outset of this study to restrict the analysis to data from wells reasonably close to the project area. Of the available well logs and other data summaries for the Poplar area, not more than 25 percent were used within the scope of the study.

The well logs include lithology, several types of resistivity, spontaneous potential, radioactivity, sonic, density, and caliper profiles. In addition, some drill stem test data and sonic core analysis data on porosity and permeability were also provided.

Murphy Oil, operator of 90 percent of the Poplar Oil field, also provided information relating to the production and disposal of geothermal fluids based upon their operating experience in that field.

FIGURE III-1 POPLAR FIELD

FIGURE III-2 LOCATION OF OIL WELLS USED IN ANALYSIS

FIGURE III-3 DELINEATION OF OIL PRODUCING AREA

Certain of the wells in the Poplar field produce oil mixed with geothermal fluids. According to Murphy Oil, these wells currently produce from 18,000 to 20,000 barrels of geothermal fluid per day at a temperature of 185°F+. The oil is separated from the brine in large tanks, and the geothermal fluid is then pumped into an aquifer at a depth of about 1100+ feet (below the Bearpaw shale). Murphy Oil has indicated that these wells could produce up to 40,000 barrels of geothermal fluid per day, if additional disposal capability was developed. The fact that geothermal fluids are presently brought to the surface in significant amounts may present an opportunity for their beneficial use. Discussions regarding this opportunity are continuing.

Murphy Oil has been disposing of this geothermal fluid since the mid 1950's. During the course of this study, the question arose regarding the possibility that this practice may have led to the creation of a shallow geothermal aquifer. This possibility is in keeping with studies now being done to evaluate aquifer thermal energy storage systems. Without a detailed study, however, this concept must remain conjectural.

GEOLOGY

The Madison Group is Mississippian in age. It is considered by most authors to consist of three formations, in ascending order of age: the Lodgepole Formation, the Mission Canyon Formation, and the Charles Formation. The Madison Group extends throughout large areas of Montana, Wyoming, and the Dakotas, and consists mostly of limestone and dolomite and also contains anhydrite and halite.(30)

The formation involved both normal marine deposition in open waters, as well as restricted marine in which some evaporities were formed. Erosion occurred locally during the time of formation. After deposition, there was widespread subaerial erosion with the development of karst topography and resulting solution breccias.

In southeastern Montana, the Lodgepole Formation (oldest) is thin-bedded, argillaceous, and contains limestone (calcium carbonate) and dolomite (calcium magnesium carbonate), especially in its upper part. The overlying Mission Canyon Formation is thick-bedded and contains much dense crystalline limestone and dolomite and some evaporite. The Charles Formation (youngest) largely contains restricted-marine sediments which consist of anhydrite (calcium sulfate) and halite (sodium chloride) with interbedded limestone and dolomite.(30) Volitic and fragmental reef structures are present locally throughout the Madison.

The Madison Group becomes more shaly, thicker, and deeper eastward into the Williston Basin. At Poplar, the top of the Madison occurs at depths of 5500 feet (Figure III-5). Thicknesses of the individual formations are: Lodgepole, 592-593 feet; Mission Canyon, 490-755 feet; Charles, 605-755 feet, providing a total thickness range of 1687 feet to 2103 feet.(33)

In the Poplar area, the Madison Group occurs within the western (rising) flank of the Williston Basin. The formations would thus, in general, descend eastward, except for the Poplar Dome, which occurs as a structural rise a few miles north of Poplar. The detailed structural configuration in the Poplar area is somewhat

complex and may be influenced in part by northeast-southwest faulting in addition to folding.

Well histories for 47 wells were analyzed in order to define further the Madison Formation within the specific study area. Depth data from the histories for those wells are summarized in Table III-1. These data were used to determine more specifically the nature and extent of the drilling required to develop a geothermal production well near Poplar.

A cross-section of the geologic formations underlying the area, which have been encountered in past oil well drilling activities, was developed, and is included as Figure III-4. Drilling operators have consistently reported a 30-day drilling period to reach the top of the Madison. This is consistent with the type of structure which overlies the Madison and underlies the Bearpaw, as shown in that figure.

The well history data was also analyzed in order to provide an estimate of the drilling depth required to reach the Madison formation in the vicinity of Poplar. This data was used to develop an elevation contour map of the top of the Madison Formation within the Poplar area (Figure III-5). Three cross-sectional illustrations depict the erosional surface elevation of the top of the Madison in relation to the ground-level elevation it underlies. The location of these cross sections are identified in Figure III-6, and the cross-sections are shown in Figure III-7. As shown in Figure III-7, the total drilling depth to the top of the Madison Formation varies from location to location within the area due to the effects of changes in both ground surface elevation and the Madison surface elevation.

In the Poplar area, the Madison Formation, as well as the Nisku and Duperow Formations which underlie the Madison, produce crude oil and hot, highly mineralized water from well depths of 5,500 to 7,500 feet. In the vicinity of the town of Poplar (T27NR51E), only water with traces of oil is produced. (Overlying formations have not been tested, but may contain producible water of slightly lower temperatures.) As these formations are under an active water drive, reservoir pressures often allow fluid to flow to the surface.

POROSITY

Porosity values were derived from several different types of geophysical logs from a number of wells located as far south as the Missouri River and north to the Poplar Dome. The derivations were made using log interpretation charts and other publications on methods of determining aquifer characteristics.(9, 13, 29)

Table III-2 presents some of the hydraulic parameters and other information which was derived from analyzing the well logs or provided with the well summary reports. Except where the designation core laboratory is used, porosity values were derived from analyzing the types of logging profiles indicated. Permeability values were provided in some instances by core analyses. Other values represent indicated equivalent permeability values based upon empirical relationships.(25)

Table III-2 shows a porosity range of from 1.0 percent to 19.0 percent within the Madison. Most of the high values were obtained over short intervals of a few feet to about 20 feet. The average porosity weighted for thickness intervals represented is 5.08 percent.

FIGURE III-4 GEOLOGY CROSS SECTION OF
FORMATIONS ENCOUNTERED
DRILLING IN POPLAR AREA
DATA FROM SUBSURFACE WELL DATA.

FIGURE III-5 ELEVATION CONTOUR MAP- TOP OF THE MADISON

FIGURE III-6 IDENTIFICATION OF CROSS-SECTIONS

TABLE III-1. WELL DATA FROM WELL HISTORIES, OIL AND GAS DEPARTMENT, STATE OF MONTANA

Well Location Map Number*	Well Location Township Range Section	Well	Well Surface Elevation (Ft)	Depth to Top of Madison (ft)	Elevation Top of Madison Charles (ft)	Total Depth Drilled (ft)	Well Type
1	28-50-2	States Oil - Huron #1	2,181	5,437	-3,256	7,600(a)	Dry
2	28-50-13	Ashland Oil - Chaser #1	2,182	5,446	-3,264	7,666(a)	Dry
3	28-50-13	Murphy Oil - Lowe #1	2,115	5,386	-3,271	7,809	Dry
4	27-50-27	Great Northern Drilling Co. Basden #1	2,153	5,737	-3,584	6,600(b)	Dry
5	28-51-1	Murphy Oil #99	2,184	5,494	-3,310	5,811	Oil
6	28-51-2	Murphy Oil #18	2,114	5,397	-3,283	5,808	Oil
7	28-51-2	Murphy Oil #17	2,223	5,500	-3,277	5,908	Oil
8	28-51-2	Murphy Oil #5	2,114	5,400	-3,286	5,800	Oil
9	28-51-2	Murphy Oil EPU #1	2,123	5,395	-3,272	9,163(c)	Oil
10	28-51-3	Murphy Oil #32	2,078	5,370	-3,292	5,800	Oil
11	28-51-3	Murphy Oil #80	2,069	5,375	-3,306	5,832	Oil
12	28-51-4	Murphy Oil #59	1,999	5,320	-3,321	5,750	Oil
13	28-51-4	Murphy Oil #45	2,054	5,351	-3,294	5,770	Oil
14	28-51-9	Murphy Oil #67	2,054	5,354	-3,300	5,815	Oil
15	28-51-10	Polumbus Oil #4A	2,091	5,399	-3,308	5,795	Oil
16	28-51-10	Polumbus Oil #110X	2,104	5,390	-3,296	7,360(a)(d)	Oil
17	28-51-10	Thomas #2	2,098	5,400	-3,302		Oil
18	28-51-10	Murphy Oil #6	2,101	5,370	-3,269	5,786	Oil
19	28-51-10	Polumbus Oil #5	2,092	5,372	-3,280	7,307(a)	Oil
20	28-51-11	Murphy Oil #68	2,213	5,510	-3,297	5,960	Oil
21	28-51-11	Murphy Oil #9	2,148	5,417	-3,269	5,800	Oil
22	28-51-11	Murphy Oil #6A	2,215	5,478	-3,263	5,850	Oil
23	28-51-12	Murphy Oil #24	2,199	5,500	-3,301	5,900	Oil
24	28-51-13	Murphy Oil #74	2,172	5,498	-3,326	5,930	Dry
25	28-51-14	Murphy Oil #22	2,222	5,493	-3,271	5,900	Oil
26	28-51-15	Murphy Oil #32	2,088	5,386	-3,298	5,900	Oil
27	28-51-16	T. Wagner	2,048	5,450	-3,402	5,850	Oil
28	28-51-22	Mesa Petroleum #1-22	2,086	5,446	-3,360	5,845	Oil
29	28-51-22	Murphy Oil #72	2,157	5,486	-3,329	5,899	Dry
30	28-51-23	Murphy Oil #26	2,192	5,494	-3,302	5,915	Oil

TABLE III-1. WELL DATA FROM WELL HISTORIES, OIL AND GAS DEPARTMENT, STATE OF MONTANA (CONTINUED)

Well Location Map Number	Well Location Township Range Section	Well	Well Surface Elevation (Ft)	Depth to Top of Madison (ft)	Elevation Top of Madison Charles (ft)	Total Depth Drilled (ft)	Well Type
31	28-51-23	Murphy Oil <55	2,230	5,533	-3,303	5,937	Oil
32	28-51-24	Murphy Oil <44	2,186	5,508	-3,322	5,976	Oil
33	28-51-25	Tenneco Oil Morse <1	2,197	5,578	-3,399	6,380	Dry
34	28-51-26	H. Partee Catlikln <1	2,230	5,560	-3,330	5,624	Dry
35	28-51-26	Natol Oil <1-26	2,204	5,568	-3,364	6,038	Dry
36	28-51-27	Amorco Res Schmitt <1	2,091	5,480	-3,389	5,852	Dry
37	28-51-27	Murphy Oil <63	2,162	5,460	-3,298	852(c)	Oil
38	28-51-33	Ajax Oil <1	2,100	5,462	-3,362	5,962	Dry
39	28-51-35	Empire State Oil <1	2,192	5,560	-3,368	6,026(b)	Dry
40	27-51-5	Danielson <1	2,032	5,360	-3,360	6,514	Dry
41	27-51-8	E.L. Byers Jerome <7	1,958	5,315	-3,357	5,989(b)	Dry
42	27-51-8	Buttes Petroleum <1	1,964	5,320	-3,356	8,936(f)	Dry
43	27-51-8	Juniper Oil - Plenty Horses	1,961	5,322	-3,361	5,925(g)	Dry
44	27-51-8	Hickerson Oil - Wilke <1	1,960	5,296	-3,336	5,949	Dry
45	27-51-8	Hickerson Oil - Jerome <1	1,960	5,296	-3,336	6,000	Dry
46	27-51-8	Davis Oil <1	1,959	5,300	-3,341	5,946	Dry
--	27-51-36	Shoreline Petroleum State <1	1,978	5,534	-3,556	6,565	Dry

- (a) Duperow
 (b) Mississippi Canyon
 (c) Devonian
 (d) Nisku Production
 (e) Silurian
 (f) Ordovician
 (g) McGowan

TABLE III-2. POROSITY VALUES DERIVED FROM WELL LOGS AND CORE ANALYSES; MADISON GROUP

Well No.	Name	Location (Township Range Section)		Derived From	Porosity (%)		Permeability (millidarcys)		Dept. Range (ft. below surface)	Interval ft	Total Depth (ft. below surface)	Bottomhole Temp (°F)
					Range	Average	Range	Average				
40	Danielson #1	27/51	5	long normal	1.8-4.7	3.2	-	.05	5350-6510	1160	6510	174 (260 max. at 6000')
43	Plenty Horses #1	27/51	8	Microlaterolog	1.0-6.5	3.8	.02-.2	-	5320-5920	600	5950	149
44	Wilke #1	28/51	8	laterolog drill stem test	2.0-6.2	4.1 14.0	-	.005	5290-5950	660	5950	149
--	Lockman #1	28/51	35	microlaterolog sonic sonic	2.5-11.0 6.0-16.0 4.0	6.8 11.0	.005-.05	-	5560-6020	460	6020	176
--	Ogleetal #1	27/51	8	sonic sonic	4.0-16.0 2.7	10.0 -	- -	10 0.8	5300-7200	1900	8940	243
24	Murphy	28/51	14	core laboratory	0.3-13.0	6.6	.07-2.8	-	5718-5726	8	5957	-
				core laboratory	4.5-19.0	11.8	.019-4.9	-	5736-5750	14		
				core laboratory	0.6-16.8	8.7	.01-0.24	-	5882-5894	12		
--	Murphy #7	28/51	11	core laboratory	-	10.0	0-200	-	5517-5530	13	-	-
				core laboratory	-	12.0	0-5	-	5795-5811	16		
--	Murphy #15	28/51	11	core laboratory	4.2-13.1	8.6	.08-6.4	-	5480-5500	20		
				core laboratory	1.0-5.0	3.0	.02-28.0	-	5505-5511	6	-	-
				core laboratory	0.7-3.0	1.8	.01-2.6	-	5512-5520	8		
				core laboratory	2.0-17.3	-	.01-5000	mode approx. 2	5624-5660 and 5801-5815	30 tests in 1-ft intervals	-	

TABLE III-2. POROSITY VALUES DERIVED FROM WELL LOGS AND CORE ANALYSES; MADISON GROUP (CONTINUED)

Well No.	Name	Location (Township) Range Section	Derived From	Porosity (%)		Permeability (millidarcys)		Dept. Range (Ft. Below Surface)	Interval Ft	Total Depth (Ft. Below Surface)	Bottomhole Temp (°F)
				Range	Average	Range	Average				
6	Murphy #18	28/51 2	core laboratory	1.1-5.5	3.3	0-0.1		4907-4932	25	-	-
			core laboratory	1.5-16.8	9.1	0.1-2.4		5531-5545	14		
			core laboratory	7.5-14.7	9.1	0.1-0.6		5652-5658	6		
			core laboratory	5.6-13.3	11.1	0.1-1.6		5676-5678	2		
			core laboratory	1.1-4.7	9.4	0- 0.1		5799-5807	8		
7	Murphy #17	28/51 2	core laboratory	0.5-3.3	1.9	0.1-1.2		5615-5625	10	-	-
			core laboratory	2.3-12.0	7.2	0.1-2.7		5738-5746	8		
			core laboratory	4.6-9.7	7.2	0.3-1.9		5757-5764	7		
			core laboratory	2.2-9.1	5.6	0.1-0.6		5890-5899	9		
-	Murphy #3	28/51 1	core laboratory	-	11.6	-	8.6	Upper Charles	14	-	-
			core laboratory	-	8.6	-	3.7	Lower Charles	17		
			core laboratory	-	9.6	-	0.1	Mindison	8		
37	Murphy #63	28/51 27	sonic	3.7	3.4	-	1.0	5480-5860	380	8520	242
			long normal	3.0		-					
38	Ajax Patch #1	28/51 33	sonic	2.7	2.4	-	0.8	5462-5952	490	5952	168
			long normal	2.0							
45	Jerome #1	27/51 8	sonic	-	7.5	-	5.0	5310-5990	680	6000	165,194
-	Victor Bowden #1	27/50 33	sonic	4.7	4.7	-	2.0	5740-6660	920	6668	164

Both the range and average porosity values compare well with results found in other studies. Miller found porosity values ranging from 3 percent to about 20 percent, and averaging about 7 percent in the Madison in southeastern Montana.(30) Mudge and Others report porosity of 11 percent for an 8-foot pay zone in the East Poplar field.(33)

Porosity values were measured using the normal resistivity curve through the Bearpaw (highest), Judith River, and Clagett (lowest) Formations, in the Werner <1A, B well located in T27N, R50S, Sec 10, C, NE, SW. The total depth of the hole is 2,600 feet, with a bottom hole temperature of 98°F. The porosity values range from 14.5 percent in the Bearpaw Shale to 22 percent in the Judith River and Clagett sands.

PERMEABILITY

Permeability values were calculated mainly from drill stem tests, and in some instances values had been determined by the core analyses and provided with the data from the files. In addition, permeability values were estimated from corresponding derived porosity using published empirical curves relating measured porosity and permeability in ancient formations in other regions.(29, 37) In general, absolute values of permeability cannot be derived directly from geophysical logs. A method described by Croft could not be used because it was not possible to derive reliable values for the formation factor from the data available.(10)

In working out the values, the Madison formations penetrated were first marked on the geophysical logs using the lithologic descriptions and identifications of the Madison which were provided with the logs. Next, the appropriate correlation charts were selected according to the types of geophysical recordings on the log, sonde spacings, mud resistivity, temperature, salinity of formation water, and other data necessary for utilization of the charts.

Bottom hole temperatures were provided on most logs, in addition to a down-hole temperature profile for one of the wells. Some salinity data were recorded on the logs. Other salinity data were provided as water analyses reports from several of the wells.

In some instances, the average responses were determined by scanning the entire interval of Madison formation appearing on the log; in others, specific intervals were chosen in order to provide ranges of values.

Table III-2 shows permeability values ranging from near zero to as much as 5,000 millidarcys. The high values relate to very short intervals representing thin zones. The extremely high value of 5,000 millidarcys found in one of the cores may be due to vuggy (open-hole) porosity and, in view of all the other low values, should not be considered representative of much of the Madison.

The representative value of permeability for the Madison found in this study appears to be about 2 millidarcys, or in conventional hydrologic units, about 4×10^{-3} gal/day-ft². The extremely high value of 5,000 millidarcys is equivalent to about 9 gal/day-ft² which is within the range of values found by Miller in southeastern Montana.(30) The spontaneous potential curve developed from the

data for the Werner <1A, B well (described previously) shows slightly increasing permeabilities with depth.

TRANSMISSIVITY

Transmissivity values were calculated from the data using standard hydrologic techniques. For the intervals tested, transmissivity values range from as low as 0.006 gal/day-ft to as high as 34 gal/day-ft. Most values fall within the range of 0.05 to 0.1 gal/day-ft. The average transmissivity value weighted for the intervals tested is 10.59 gal/day-ft.

In southeastern Montana, Miller estimated values from drill stem tests within the Madison Group.(30) His values range from about 0.07 gal/day-ft to one extreme value of 38,000 gal/day-ft. This is extremely close to the value derived in the present study at Poplar.

In general water hydrology, such low values of transmissivity are considered to represent extremely poor aquifers. Good aquifers have transmissivity values on the order of 100,000 gal/day-ft.

YIELD

From the very low values of porosity, permeability and transmissivity as generally indicative of the Madison, very little water production would seem to be obtainable. Drill stem tests, however, appear to indicate that at least locally, high production rates can be expected. Several factors indicative of secondary porosity and permeability within the Madison, which could provide for higher production rates, are discussed below.

Fractures resulting from faulting and other deformation, especially in geologically young formations, provide additional openings for migration of fluid. The Brockton-Froid fault zone is long enough so that it can be expected to penetrate at least as deep as the Madison.(5) This is one example of a fracture system that may have important implications in productivity from the Madison. Moreover, the ground temperature measurements made in the Poplar study area (discussed later) suggest that other faulting also exists. Tension joints resulting from the Poplar Dome folding would also provide additional open space and increased porosity and permeability if not resealed after formation.

As discussed previously, some of the Madison has been subjected to subaerial erosion and karstification. Karst features are cavities dissolved by groundwater. Where these are extensively developed and interconnected, the permeability is very large (water moves in open channels). At the present depth of burial, it is unlikely that many large cavities remain open, but even if collapsed, the resulting breccia provides coarse texture within which permeability is likely to be higher than the dense fine-grained material.

Dolomitization provides another possibility. The transformation from calcite (CaCO_3) to dolomite ($\text{CaMg}(\text{CO}_3)_2$) normally occurs with a decrease in volume. Thus, the dolomitized zones should have increased porosity and permeability. Further, the evaporite units, particularly the halite, may have larger permeability and even porosity, perhaps because of a coarser grain size when deposited, or by

solution of these extremely soluble materials since deposition. Some supporting evidence for this appears to be in the emphasis on the Charles Formation for oil production, which contains much of the evaporite materials.

The existence of intervals of potentially high yield within the Madison due to factors such as those described above is also supported by the data in Table III-3, which summarizes rates of water production calculated from drill stem test data provided for some of the wells. Using the available data from sixty tests (in 21 wells), flow rates ranged from zero to as high as 460 gallons per minute. The average was 65 gallons per minute. Production intervals tested ranged from 4 feet to 126 feet, and averaged 19.3 feet.

Several important points can be drawn from the information in Table III-3. The range of values and the averages are reasonably similar to those found in the Madison in southeastern Montana by Miller (30) and elsewhere in Montana by Hopkins. (19) If the drill stem test results are representative of actual conditions, high flow rates can be expected locally. Large differences in flow rates within short vertical distances and the fact that some of the high flow rates occur in very thin zones suggest that some of the permeability is due to solution cavities within the Madison. Finally, the flow rate of 277 gpm in the interval 7,236-7,250 feet (Signal <5, 28/51 10) indicates that significant production can be expected in some of the formations below the Madison, in this instance probably the Duperow, a Devonian formation predominantly carbonate.

Independent evidence that significant production of hot water can be obtained from the Madison appears to be provided by operations of the Murphy Oil Company which reports that presently wells of the Poplar Oil Field produce a total of from 18,000 to 20,000 barrels of hot water per day from 180°F to 210°F.

Other data provided by Murphy Oil Company for sixteen wells show production of hot water ranging from 5 gpm to 81 gpm with an average of 20 gpm (Table III-4). As shown on this table, many of these wells are producing with flow restrictors, up to a choke size of 6/64".

Mudge and *Others report water production of 1.5 gpm from a 22-foot interval containing perforations in the Madisons.(35) They also report water production at 35 gpm from a 2-foot perforated interval in the Nisku Formation.

If the data are reliable, it is encouraging that there are rates of a few gallons per minute to a few tens of gallons per minute from very thin zones within the Madison and even the deeper formations. Given the fact that the objective of drilling has been oil and not water, that secondary porosity is indicated, and that the Madison is about 2,000 feet thick in the Poplar area, it seems that the target production rate of 500 gpm can be achieved. Using the averages from Table III-3 (65 gpm; 19.3-foot interval) would require not more than eight such intervals, or a total of 150 feet. This represents about 7 percent of the total thickness of the Madison.

TEMPERATURE

Bottom-hole temperatures from sixteen wells in the vicinity of Poplar were obtained from drill-stem tests. The temperatures and depths for these wells are listed in Table III-5. The data shown in Table III-5 show temperatures ranging from

TABLE III-3. RATES OF WATER PRODUCTION CALCULATED FROM DRILL STEM TESTS; MADISON GROUP

Well Designation*	Location (Township/ Range Section)	DST Range (ft below surface)	Interval (ft)	Duration (hrs)	Rate (gal/min)
32	28/51 24	5632-5650	18	4.0	2.2
		5774-5782	8	4.0	72.6
		5757-5778	21	4.0	8.7
33	28/51 25	5164-5227	63	1.5	-0-
		5349-5378	29	1.5	53.2
		5635-5676	41	2.0	115.9
		5806-5819	13	2.0	24.6
Bicie #1	28/51 22	4859-4985	126	1.0	185.6
		5135-5177	42	2.0	46.1
		5785-5800	15	2.0	19.3
29	28/51 22	5842-5881	39	2.0	-0-
		5864-5872	8	4.0	4.7
		5706-5722	16	4.0	19.6
26	28/51 15	5497-5508	11	3.5	5.9
25	28/51 14	3014-3025	11	0.5	230.6
		5004-5008	4	1.0	231.9
		5592-5603	11	2.8	-0-
		5901-5916	15	2.2	-0-
23	28/51 12	5598-5607	9	4.0	-0-
		5609-5625	16	1.0	66.1
		5749-5760	11	4.0	11.2
		5735-5748	13	4.0	8.4
		5891-5902	11	4.0	1.4

TABLE III-3. RATES OF WATER PRODUCTION CALCULATED FROM DRILL STEM TESTS; MADISON GROUP (CONTINUED)

Well Designation*	Location (Township/ Range Section)	DST Range (ft below surface)	Interval (ft)	Duration (hrs)	Rate (gal/min)
Murphy #61	28/51 12	5604-5615	11	4.0	1.6
		5733-5754	21	4.0	10.4
		5751-5765	14	4.0	96.6
		5909-5925	16	4.0	8.9
Murphy #11	28/51 10	7266-7280	14	1.6	221.7
		7282-7290	8	2.0	269.2
Thomas #4	28/51 10	5494-5512	18	2.0	330.4
Murphy #100	28/51 11	5013-5025	12	0.6	-0-
		5745-5758	13	2.0	5.6
		5762-5778	16	2.0	160.0
		5780-5803	23	2.0	2.5
		5801-5817	16	2.0	-0-
Murphy #7	28/51 11	5761-5771	10	4.0	6.2
		5777-5791	14	4.0	130.0
		5928-5937	9	4.0	-0-
Murphy #15	28/51 11	4891-4904	13	1.0	55.5
Signal #5	28/51 10	4876-4910	34	1.5	15.0
		7236-7250	14	1.0	277.0
13	28/51 4	5471-5480	9	4.0	5.3
		5627-5639	12	4.0	10.6
12	28/51 4	5429-5438	9	4.0	1.8
		5593-5603	10	4.0	103.2
		5712-5736	24	4.0	7.5

TABLE III-3. RATES OF WATER PRODUCTION CALCULATED FROM DRILL STEM TESTS; MADISON GROUP (CONTINUED)

Well Designation*	Location (Township/ Range Section)	DST Range (ft below surface)	Interval (ft)	Duration (hrs)	Rate (gal/min)
14	28/51 9	5480-5489	9	4.0	17.4
		5521-5540	19	4.0	16.8
		5781-5791	10	3.0	3.7
6	28/51 2	5800-5810	10	1.4	-0-
9	28/51 2	2904-2921	17	0.2	149.6
		4772-4785	13	0.5	21.2
		5170-5183	13	0.3	463.8
		6077-6145	68	3.0	3.7
5	28/51 1	5745-5758	13	2.0	15.6
Murphy #3	28/51 1	5600-5626	26	0.5	85.0
		5740-5760	20	0.2	-0-
		5760-5773	13	0.5	30.4
		5752-5766	14	1.0	20.6
		5938-5960	22	1.0	261.0

* Number designations refer to Figure III-2

TABLE III-4. SAMPLE OIL WELL WATER YIELDS AND TEMPERATURES PROVIDED
BY MURPHY OIL COMPANY

Section	Well No.	Water P.D.	Choke Size	Approx. Temp.(°F)
10	6F	396	6/64	200
2	1 - F&P Duel	1,133	-	200
2	18P	459	-	180
14	20P	441	-	190
12	24F	311	O-F	180
23	55F	173	12/64	150
14	10P	2,804	22/64	210
34	88P	941	-	200
33	16P	351	-	180
32	39P	670	-	190
31	102F	574	-	190
28	42F	530	6/64	210
20	21F	654	18/64	210
20	84F	206	4/64	200
13	48F	966	21/64	200
31	102F	574	6/64	200

TABLE III-5. BOTTOM-HOLE TEMPERATURES FROM DRILL-STEM TESTS.

Well Location Map Number *	Well	Depth (ft)	Temperature (°F)
1	States Oil - Huron <1	6,000 7,400	186 256
3	Murphy Oil - Lowe <1	7,700	256
34	Partee <1	5,800	236
35	Natol <1-26	5,800	236
37	Murphy <63	5,900	174
38	Ajax <1	5,900	168
39	Empire <1	6,000	176
40	Danielson <1	6,000	260
41	Byers <1	5,900	165
42	Buttes <1	8,900	243
43	Juniper <1	5,900	230
44	Hickerson-Wilke <1	5,900	198
45	Hickerson-Jerome <1	5,900	185
46	Davis Oil <1	5,600	194
--	Shoreline <1	5,400 6,200	150 198

* Figure III-2

150°F to as high as 260°F within a well depth range of 5,400 feet to 7,700 feet. At a normal geothermal gradient of about 2°F per 100 foot depth, bottom hole temperatures should be on the order of 150°F at 5,000 foot depth, and 180°F at 7,000 foot depth. Thus, many of the bottom-hole temperatures are higher than expected from the geothermal gradient alone.

Bottom-hole temperature was plotted as a function of depth in an attempt to determine the relationship, if any, between the two (Figure III-8). As shown in that figure, no clear relationship is found between bottom-hole temperature and depth within the depth range of about 5,000 feet to 6,000 feet. However, the temperatures at depths greater than 7,000 feet are higher than in many of the wells shallower than about 6,200 feet. One downhole temperature log available for this study (Danielson #1, 27/51 5) shows higher than expected temperatures throughout the logged interval (3,500 feet-6,000 feet). Moreover, the temperature profile does not show a steady increase with depth, but shows increases and decreases through intervals of a few feet.

The downhole temperature data was used to derive the temperature contour map shown in Figure III-9. The temperature contouring indicates that temperatures useful for space heating could occur below Poplar, and that even higher temperatures occur to the east of Poplar in approximately the area in which higher-than-average ground temperatures were mapped by the shallow survey (discussed later in this report). This also correlates in general with a structural rise in the Madison (Figure III-7).

There are several processes which can be used to explain why temperatures of water in the Madison are higher than would be expected from the normal geothermal gradient. Heat from an underlying magmatic source is the least likely. Eastern Montana is not an area known to contain active or even geologically young volcanism, nor is there any evidence of such a process eastward throughout the Williston Basin, where hot water is also known to exist. Frictional heat produced by faulting, such as the Brockton-Froid zone, does not seem likely, as this too would be restricted to narrow zones rather than broadly distributed. Heat from radioactive decay, especially in the shales, cannot be eliminated, as this is a distributive process and could be expected to occur throughout broad regions. The amount of heat generated per volume of rock is small, and this process does not seem to be capable of producing the temperatures found throughout a section consisting mainly of carbonates.

Based upon an analysis of the well temperature/depth data, (Figure III-8), and temperature contours relative to the Brockton-Froid fault zone (Figure III-9), the preferred explanation at this time, is that higher-than-normal temperatures in the Madison are due to upward leakage of water from deeper formations, rising along faults or joint systems and spreading laterally along permeable zones in the Madison and in any other formation in the stratigraphic section.

This process would explain the order of magnitude of temperatures involved, which are within the range of the geothermal gradient not much deeper than the Madison. It also agrees with the evidence that large ranges occur in some of the hydraulic parameters of the Madison. It is supported by the increasing and decreasing values of temperature with depth shown by the downhole temperature log of the Danielson No. 1 well. It relates to the other indications that the Madison and other

FIGURE III-8 CORRELATION-TEMPERATURE VS. DEPTH

FIGURE III-9 BOTTOMHOLE TEMPERATURE CONTOURS

aquifers are dynamic recharging artesian systems which leak upward along faults, some of which are known to exist. Conversely, it would be difficult to eliminate that this process is occurring, given the known geological conditions in eastern Montana and the region in general.

RECHARGE AND PIEZOMETRIC SURFACE

Although some of the water may be connate, it is likely that recharge is occurring. This is inferred from the regional geologic setting of the Madison as an artesian aquifer, from its thermal characteristics if correctly interpreted, and from irregular mineralization of the shallow ground water which suggests that upward leakage, probably along faults, is occurring. If recharge is occurring, it is most likely slow and should not be considered capable of restoring depletion due to production.

According to most investigators, water in the Madison is recharged from the mountainous areas in the west and southwest where the Madison crops out or is near enough to the surface to receive surface water through thin overlying formations. Therefore, migration of water in the Madison is easterly or northeasterly toward the Williston Basin. As the formations become deeper northeasterly away from their recharge areas, their contained fluids are under increasing hydrostatic head, hence, the aquifers are increasingly artesian. At Poplar, a more comprehensive analysis of available data will be required to plot the piezometric surface, but it should be well above the top of the Madison.

Other sources of recharge to the Madison would be from upward migration from deeper formations via fractures into the Madison. There may also be the possibility of lateral recharge from other directions, depending upon pressure distributions in other areas as related to conditions at Poplar. These have implications regarding the origin and expected life of the geothermal resource and should be investigated.

WATER QUALITY

The salinity of the Madison is high. Table III-6 presents some of the data from chemical analyses made available for some of the oil wells which have produced water near Poplar. Total dissolved solids for the samples which were analyzed range widely, varying between about 35,000 to about 288,000 ppm, with the average about 102,000 ppm. The composition of the samples exhibit marked differences in chemical constituent concentrations, although all are predominantly sodium chloride type, with sulfate the next most abundant constituent. The pH values range from 5.9 to 8.4. Twelve of the sixteen pH values are lower than 7.0. Because the solids concentration is predominantly higher than that of present sea water, it is likely that an important cause is the solution of soluble salts from the enclosing formations or from other formations through which the water has migrated. The chemical nature of the water is consistent with solution of halite (NaCl) and anhydrite (CaSO_4) from the Charles or other formations within the Madison at Poplar.

Although the data do show a wide variation in salinity and other characteristics, the range of values among the samples are not necessarily representative of the fluids that would be produced from wells drilled for the purpose of producing high

TABLE III-6. SALINITY VALUES FOR WATERS PRODUCED
FROM OIL WELL OPERATIONS NEAR POPLAR

Well Location	Depths (Feet below surface)	Formation Description	Total Dissolved Solids (ppm)*	Chloride as Na Cl	Sulfate (ppm)	pH
28/51 27	4981-4988	Heath	65,240	61,283	1,456	6.7
28/51 27	5231-5243	Kibbey Sand	140,800	130,630	2,099	6.0
28/51 27	5231-5243	Kibbey Sand	130,992	130,630	2,099	6.0
28/51 5	5553-5593	Charles	288,120	276,471	1,946	5.2
28/51 27	5585-5595	Charles "A"	180,000	173,458	2,567	6.2
28/51 33	5572-5613	Charles "A"	109,826	101,414	5,802	8.2
28/51 22	5706-5722	Charles "B"	127,960	69,438	7,268	6.4
28/51 27	5712-5724	Charles "C"	101,820	96,763	2,873	6.3
28/51 27	5864-5883	Charles "C"	34,640	19,997	8,831	8.5
28/51 27	5883-5892	Charles "C"	52,020	46,446	2,938	6.8
28/51 27	5895-5913	Charles	44,300	35,480	5,609	8.4
28/51 33	5922-5934	Madison	58,740	52,438	4,230	6.2
28/51 5	5964-5982	Charles "C"	61,620	50,021	2,218	6.3
28/51 27	7412-7435	Nisku	113,560	108,859	1,144	6.1
28/51 22	-	-	63,500	60,100	2,000	7.2
28/51 2	-	-	72,100	69,100	2,000	7.5

*By Evaporation

volumes of hot water. The reason for this is illustrated in Figure III-10, which is plots total dissolved solids versus depth. As shown in Figure III-10, there is a strong possibility that salinity is correlated with certain horizons or depth intervals. Although further study will be required to determine the distribution and reliability of this correlation, the data are consistent with production variations across depth intervals as discussed previously. The last two samples in Table III-6 were obtained from currently-producing oil wells which produce water under high artesian flows. Further, the extremely high salinity zones are not necessarily intervals of low permeability.

The primary water quality consideration is the effects the impurities contained within the geothermal fluid will have upon the equipment with which it comes in contact. A high level of impurities can result in serious operating problems caused by deposit formation (scaling) and corrosion of metals. The extent of the corrosion is a function of electrical potential as well as a function of the capability of ions and electrons to travel through the water phase and participate in chemical reactions. Waters high in dissolved solids are more conductive and therefore tend to cause more severe corrosion problems. However, corrosion rates in some heavily concentrated solutions may actually decrease as a result of precipitation of dissolved salts as their solubility products are reached.

Scaling occurs when the precipitated salts of calcium and magnesium form dense films or scales on the material with which it comes in contact. Calcium carbonate (CaCO_3) is probably recognized as the most common type of scale. Scale occurs as the saturation point of calcium carbonate is reached and concentrations in excess of this limit are precipitated out. In addition, calcium and bicarbonate alkalinity are found in most waters. Although bicarbonate salts are moderately soluble, the carbonate salts have a very low solubility. As heat is added to water, or if there is a sharp rise in pH, calcium bicarbonate is broken down to carbon dioxide and calcium carbonate, thereby adding even more scaling potential to the water.

Table III-7 compares two diverse water quality samples taken from two wells in the study area. Both samples, as would be expected, are a sodium-chloride (NaCl) base. For Sample A, both calcium (CA) and sulfate (SO_4) contribute approximately one percent (1 percent) each to the total dissolved solids (in terms of equivalent weights), while calcium (Ca) and sulfate (SO_4) contribute approximately four percent (4 percent) to the total dissolved solids content for Sample B.

Several methods have been developed to predict whether water will tend to dissolve or precipitate calcium carbonate. If the water precipitates calcium carbonate, scale formation may result. If the water dissolves calcium carbonate, it has a corrosive tendency. The most universally used and accepted of these predictive methods are the Langelier Saturation Index and the Ryznar Stability Index. The Langelier Saturation Index relates dissolved solids content, temperature, calcium hardness, alkalinity and pH to determine a saturation pH or pHs. The Ryznar Stability Index relates these pHs to either a corrosion or scaling potential.

TABLE III-7. COMPARISON OF TWO DIVERSE GEOTHERMAL FLUID
CHEMICAL COMPOSITIONS FROM THE MADISON AQUIFER

Constituents(a)	Sample A	Sample B
Sodium	67,807	20,406
Calcium	1,140	1,844
Magnesium	232	177
Sulfate	2,567	4,230
Chloride	105,190	31,800
Carbonate	0	0
Bicarbonate	342	575
TDS	177,140	58,740
pH	6.2	6.2

- (a) All concentrations in mg/l except pH which is in pH units.
- (b) Sample collected from the Madison Formation for the Murphy Corporation on 10/15/55.
- (c) Sample collected from the Madison Formation for the Ajax Oil Company on 9/11/52.

Legend:

LOCATIONS 28N/51E	
SYMBOL	SECTION
□	5
△	22
○	27
◇	33

FIGURE III-10 TOTAL DISSOLVED SOLID VS. DEPTH

The Langelier Saturation Index and the Ryznar Stability Index for the water samples in Table III-7 were estimated and are summarized below:

	<u>Sample A</u>	<u>Sample B</u>
Langelier Saturation Index	+0.65	+1.2
Ryznar Stability Index	+4.9	+3.8

As shown above, both samples were determined to have a positive Langelier Saturation Index, which would indicate that a scaling potential exists. The Ryznar Stability Index (a light scaling tendency between values of 5.0-6.0 and a heavy scaling tendency at values lower than 5.0) also indicates that both waters would be classified as scaling forming.

Another potential concern is that of a calcium-sulfate (CaSO_4) scale. A measure of predicting potential problems can be obtained by computing the solubility products by simply multiplying the CA concentration by the SO_4 concentration (both in mg/l). A review of the literature reveals that the generally accepted safe solubility product limit for this compound in water lies within the range of 400,000. The calcium sulfate multiple for both samples exceeds the 400,000 value by over 600 percent, indicating that there may also be a potential for calcium sulfate scaling.

The values computed above are intended only as representative approximations. Because of the very high concentration of dissolved solids, an estimate was made as to what the "C" value used in the Langelier Index would be. In both cases, an assumed water temperature of 150°F was used. On this basis, both samples exhibited a definite scaling tendency, with the Sample "B" value more severe than that of Sample "A". However, these analyses were made on samples with high salinities, and precipitation limits of calcium carbonate are not well defined for high salinity waters.

The chemistry of geothermal fluids is complex, and experience has shown that brines calculated to have scaling potential by various predictive indexes have actually been corrosive to piping materials in the field. Part of the reason for this has been due to the limitations of both the accuracy of the actual laboratory analyses and the accuracy of the indexes relating to high TDS waters.

Operators of the Poplar oil field have had nearly thirty years experience in handling the high TDS waters from the Madison in this region: the product of many of the wells is comprised of up to 90 percent water and 10 percent oil. This mixture is moved as far as two miles before reaching a separation vat, and temperature drops across these pipelines reach 100°F . Methods of chemical treatment have been developed which enable the highly saline geothermal fluids to be handled with relative success. Although the specifics of the nature of the treatment were not disclosed during discussions with operators, its relative success is evidenced by the use of some pipes for twenty years or more.

PRELIMINARY GROUND TEMPERATURE SURVEYS

Ground temperatures were measured at 10 ft depth on October 30 and November 5, 1979 throughout an area of approximately 25 square miles as shown on Figure III-11. The survey area includes the Missouri River alluvial plain north of the river and extends a few miles north of the alluvial plain.

One objective of the temperature survey was to investigate a possibility that hot water resources may occur at depths shallower than the Madison aquifer.

Four principal facts induced a model on which the ground temperature study was based. These are:

1. Very hot water is known to exist in the Madison limestone some 6,000 feet below the surface at Poplar.
2. The Brockton-Froid fault zone is shown by the U.S. Geological Survey as extending for many miles from the northeast to the northern edge of the alluvial valley.
3. The Bearpaw Formation, a Cretaceous shale several hundred feet thick immediately underlies the Quaternary and late Tertiary formations in the Poplar area.
4. Water wells within the alluvial and other young deposits have considerable variation in contaminants, some of which appear to be related to oil well-type brines.

The resulting model is that hot water from the Madison may be leaking upward along fractures such as the Brockton-Froid fault zone and other fractures not yet found in the geologic mapping. Upward movement would be largely trapped by the Bearpaw shale acting as an aquiclude. Hot water could spread laterally into the more permeable sandstones beneath the Bearpaw shale, thus providing a water reservoir much shallower than the Madison limestone. Any leakage through the Bearpaw shale would result in local contamination of the existing water wells.

The ground temperature survey showed a strong thermal trend in line with and extending southwest from the mapped terminations of the Brockton-Froid faults. The highest temperature of the survey was observed approximately four miles east of Poplar, in line with one of the Brockton-Froid faults. Another strong thermal trend extends beneath the City of Poplar. It appears at this time that several additional faults occur subparallel with the Brockton-Froid zone.

Based upon previous experience, the range in temperature is anomalous, and the configuration is best interpreted as due to control of rising thermal fluids by the faults. Moreover, the anomalous area appears to be broad, suggesting lateral spread of the hot fluids beneath the confining layer as in the model. A diagrammatic sketch of the model is presented as Figure III-12.

In summary, preliminary results fit the model extremely well. If correct, the implications are that a large hot water reservoir, much shallower than the Madison,

FIGURE III-11

THERMAL SURVEY

POPLAR, MONTANA

NOVEMBER 5, 1979

PRELIMINARY

● PROBE LOCATION AND STATION NUMBER

— 10.2 —
TEMPERATURE CONTOUR
CONTOUR INTERVAL IS 0.2°C
CLOSED DEPRESSIONS INDICATED BY HACHURES.

--- INDICATED FAULTING (TENTATIVE)

0 0.5 1
MILES

**Figure III-12 DIAGRAMMATIC MODEL OF GEOTHERMAL RESERVOIR
POPLAR, MONTANA**

does underlie Poplar and its vicinity. Depending upon a number of other factors, exploration and development would be much less expensive than in the Madison, except where deep wells producing hot water already exist. Moreover, other possibilities for shallower hot water should occur throughout large areas of eastern Montana and the Dakotas wherever the geologic conditions are similar to those at Poplar.

These conclusions, although encouraging, must be considered tentative. In this first survey, the temperature probes were widely spaced. As a result, it is not known whether the indicated shallow hot water zone is continuous or occurs as discrete zones closely restricted to the faults. Before a drilling program can be justified, it would be advisable to perform additional ground temperature work in specific localities to define more precisely the configuration of the thermal anomaly. Following this, surface electrical resistivity studies should be performed using the mode of vertical electrical sounding to investigate the depth zone at which the indicated shallow hot water resource exists. Slim hole drilling to measure thermal gradients may also be recommended, but the need and the locations, if justified, should be determined from the results of the additional ground temperature and resistivity work.

Although the vertical migration model discussed in the preceding paragraphs is preferred at this time, there is another possible model which should be considered: hot water reinjected by the oil field operators into the more permeable formations beneath the Bearpaw Shale may be moving laterally to the Brockton-Froid fault zone and rising along the faults (lateral migration).

The four principal facts upon which the vertical migration model is based also fit this alternate model. Moreover, the locality of Poplar is downstructure from the center of the Poplar Dome. If the dip directions of the shallow and intermediate formations into which the hot water is being injected also conform in dip directions with the underlying Madison, migration of injected water should move by gravity in the direction of the Brockton-Froid zone.

The vertical migration model described earlier has the advantage of having been in operation through a portion of what can be considered geologic time, thus allowing for the establishment of the thermal anomaly over a broad area extending away from the faults.

The lateral migration model may have been in existence only as long as oil production and injection have been going on - a time measured in tens of years. Unless there are many more faults than have been mapped, it would therefore be expected that the thermal anomaly would be closely restricted to the fault traces. Moreover, the distances from some of the injection points to the anomalous zone east of Poplar is a little greater than the distance from the Madison Formation underlying the anomalous zone. Other aspects relate to the lack of a southeast-trending configuration of the thermal anomaly; such configuration would be expected if heat transfer through the Bearpaw Shale to the surface has already occurred in the relatively short time during which injection has occurred.

The arguments against the lateral migration model are not strong. Because the temperature probes were widely spaced, the breadth of extent of the anomalies away from the fault traces may not be real, and a southeast-trending configuration

may have been missed. Further, much information was not available for this study concerning the details and long-term history of the reinjection. The lateral migration model should be considered possible until both models can be further tested.

Methods are available which could be employed to distinguish between the two models. Such efforts would entail further shallow temperature surveys extending toward the injection wells, with some closer spacing of probes in selected localities, such as near the injection wells, near the faults and in intermediate positions where no faults occur. More comprehensive information would be required on the amount, rate, and history of the reinjection which would allow calculations to assess whether or not the anomaly near Poplar can be expected reasonably given the physical setting. Surface electrical resistivity surveys (vertical electrical sounding) may later be applicable in testing for brine at some localities expected to be reached by the laterally migrating fluid. In addition, there may be specific chemicals used by the oil field operators in treating the brines during separation that could be used as tracers in the well water near Poplar.

It may be important to distinguish between the two models. With the vertical migration model, the shallow hot water source should be essentially limitless, or at least limited only by the continuing deep recharge by ground water. With the lateral migration model, the source of shallow hot water must be limited to the amount that is reinjected, and any environmental effects are produced by human operations rather than natural causes.

IV.

GEOTHERMAL HEATING DISTRICT APPLICATION

This section presents a preliminary design concept and an economic analysis for a geothermal heating district for the town of Poplar. Figure IV-1 is a map of the town. The design and analysis were developed on the basis of resource assumptions consistent with the data analysis and preliminary resource evaluation contained in the Resource Assessment section. Therefore, the preliminary system design parameters could change with additional resource assessment.

Although the preliminary design is based upon a heating district for the entire town of Poplar, the analysis also includes a heating district which would serve only the buildings and nearby residences located in the Central Core shown in Figure IV-2.

The district heating system for the town of Poplar would service the space heating and water heating needs of 30 non-residential buildings, 3 schools and 800 residential units. The design load for this system was determined to be 93 million BTU/hr, with an annual load of 286,560 MBTU (million BTU). The design space heating load was derived from actual fuel consumption data, fuel bills and furnace ratings for the major buildings and homes in the central district.(20,21) Weather data used in calculating the design load was for Glasgow, Montana, which is fairly close to Poplar.(38) The water heating requirements were determined for the Poplar Community Hospital, Poplar Community Health Center and the homes in the district. The water heating requirements for the remaining buildings were assumed to be insignificant in comparison to the total district heat load, and therefore were neglected in the design heat load determination.

The remaining 800 structures were treated as identical residential dwelling units for design purposes. Architectural plans for homes in the Walking Eagle subdivision were utilized to compute the design space heating loads.(35) The total design load per dwelling is 83,000 BTU/hr. The heat load computations were based upon 4 bedrooms per dwelling. The following weather design data for Glasgow, Montana was used: winter design temperature, -25°F; January degree days, 1,711; annual degree days, 8,969.(38) The calculated design space heating load for each dwelling was 74,400 BTU/hr. The domestic water heating design load is 8,400 BTU/hr per residence, based upon the following assumptions: 6 persons per dwelling; 20 gallons/person/day; cold water entrance temperature, 40°F; heated to 140°F; water heater efficiency, 50 percent. A breakdown of the design heat loads for Poplar is presented in Table IV-1.

PRELIMINARY SYSTEM DESIGN

The system design and economic feasibility for the utilization of a geothermal resource is a function of the design interaction between three major factors: 1) the nature of the resource application; 2) the characteristics of the geothermal resource; 3) the heat exchanger system. Table IV-2 summarizes the items considered within each of the three areas in addition to: 1) the impact of each on

TABLE IV-1. DESIGN HEAT LOADS FOR POPLAR

Central Core Major Buildings	Design Load (BTU/hr)	Annual Load (MBTU)
Poplar Community Hospital	4,320,000	21,000
Fort Peck Tribal Building	670,000	1,600
Poplar Community Health Center	2,405,000	16,900
Bureau of Indian Affairs	900,000	2,100
Tribal Law and Order Building	700,000	1,700
Indian Health Service Building	925,000	2,200
Fort Peck Tribal Enterprise	350,000	800
Catholic Church	915,000	2,200
School District Buildings (3)	9,900,000	23,700
Other Buildings	5,600,000	13,400
Central Core Total	26,685,000	85,600
800 Dwelling Units	66,400,000	200,960
Total Poplar Heat Load	93,085,000	286,560

FIGURE IV-1 POPLAR, MONTANA

TABLE IV-2. SUMMARY OF SYSTEM DESIGN CONSIDERATIONS AND PRELIMINARY DESIGN PARAMETERS

DESIGN FACTOR	IMPACT ON SYSTEM DESIGN	DESIGN PARAMETERS	PRELIMINARY DESIGN PARAMETERS
RESOURCE APPLICATION			
Design Heat Load	Establishes hourly quantity of heat which heat exchanger must supply to distribution system.	Poplar Total: 93 MBTU/hr Poplar Core : 30 MBTU/HR	Heat provided to System: Poplar-96.6 MBTU/HR Central Core: 32 MBTU/HR.
Useful Temperature/ Temperature Range	Defines temperatures required for heat delivered from heat exchanger to be useable ("useful heat") for system and system components; Practical temperature drop for system components.	Home Heating Application Min delivery temperature - 130°F Practical temperature drop - 15°F Min exit temperature - 115°F	Hot water delivered to distribution system at 180°F. Components require 15-20° temperature drop. Design approach: "cascading" system: Used hot water is returned to supply main until temperature in main approaches 130°.
RESOURCE			
Production Well Location	Establishes length of transmission pipeline. Pipe cost increases significantly with length. May affect temperature of geothermal fluid.	Assume within Poplar. Use "well island" concept.	
Production Well Depth	Well cost increases with depth.	Average 6,000 foot vertical depth.	2 wells required for Central Core; 6 wells for Poplar.
Fluid Temperature/ Production Well Flow Rate	Determines hourly quantity of useful heat which one well can supply to heat exchanger.	Fluid Temperature - 190°F Flow Rate - 500 gpm with submersible pumps, multiple production zones	
Fluid Characteristics	Determines degree to which scaling, corrosion affect system design. Determines if fluid can be used consumptively or if disposal is required.	High potential for scaling and corrosion problems. Select corrosion-resistant materials; minimize fluid handling. Fluid quality too poor for consumptive use; disposal by injection.	Locate heat exchanger at wellhead; transport heated water in closed distribution loop between wellhead and load. Select stainless steel or better material on geothermal fluid side of system.
Injection Requirements	Determines: Depth of injection wells Number of: injection wells Distance required between production and injection wells.	Fluid need not be injected to production well depth. Shallow injection below Pearpaw will preclude mixing with ground water. Injection of shallower depth removes consideration of distance between production and injection wells.	Injection well depth-1,000 ft. 1 injection well for every two production wells. Locate injection well near heat exchanger.
HEAT EXCHANGER			
	Determines temperature and quantity of useful heat which can be extracted from the fluid delivered by one production well for delivery to distribution system.	Hot side inlet temperature - 190°F Cold side inlet temperature - 115°F Flow Rate/Well - 500 gpm Maximum BTU/HR/Well - 18.8 MBTU/hr Design for maximum heat extraction in order to minimize number of wells and pipe diameter.	Select plate-type Heat Exchanger. Fluid: Inlet-190°F., Exit-125°F Hot Water: Inlet-115°F., Exit-180°F Equal flows on each side. Three exchangers in parallel for Central Core. One exchanger per well for all of Poplar.

general system design, 2) the specific system design considerations for Poplar; 3) the resulting design parameters for this analysis.

Due to the anticipated poor quality of the geothermal fluid, the system design was based upon using heat exchangers to transfer the heat from the geothermal fluid to a secondary hot water distribution system. Therefore, the geothermal heating system is comprised of three major components:

- o Resource Subsystem;
- o Heat Exchanger Subsystem;
- o Hot Water Distribution Subsystem.

RESOURCE SUBSYSTEM

A design concept for the resource subsystem was developed based upon the information acquired from the resources assessment activities. The resource subsystem is based upon developing new wells. Although there are plugged and abandoned wells which could potentially be redeveloped, this option was analyzed and determined to offer no real advantage over new wells, a conclusion which is consistent with the findings of a similar analysis.

The design parameters for the resource subsystem are summarized in Table IV-3. Based upon the data and analysis available, it was assumed that a resource which would meet the minimum design base temperature of 190°F at an average production depth of 6,000 feet could be located in the immediate vicinity of and possibly underlying Poplar. (See Figure III-9.) Although the resource analysis indicates that even higher temperatures may be found in the area to the east of Poplar, the results of earlier work in this area indicated that the increase in pipeline cost could outweigh the potential benefit of increased temperature for the heating application at Poplar. Consequently, a resource development location near the edge of Poplar was therefore assumed as the design concept basis.

The preferred resource development concept at this time is the "well island" system. With this development technique, the well-heads are clustered in a small area, and the wells are directionally-drilled to achieve the appropriate production spacing. Figure IV-3 illustrates a directionally drilled well and basic hole patterns.(23) This system is amenable to development adjacent to the heat load, and the adjacent well heads offer advantages related to ease of operation and minimal fluid handling.

The well design concept to produce the design flow of 500 gallons per minute is the use of a 7-inch production casing, with perforation in multiple production zones. However, it should be noted that, although perforated casing is used in oil fields, DOE has indicated that open hole completion techniques result in the best production characteristics for geothermal wells. Although the Madison Group is largely competent and open hole completion is worthy of consideration, the presence of salt beds within the Madison in the multiple zone production region may cause problems with the open hole technique. Since the resource assessment in terms of geothermal water production near Poplar is still in the preliminary stages, definitive design statements regarding actual completion and production

TABLE IV-3. RESOURCE SUBSYSTEM DESIGN PARAMETERS

PRODUCTION WELL DATA

"Well Island" Production

Location: northeast edge of Poplar

Temperature at Wellhead - 190°F

Fluid Delivery Rate - 500 gpm w/20 HP submersible pumps,
multiple production zones

Well Depth - 6,000 feet

Well Life - 30 years

Well Spacing - directionally drill, 1/4 mile at shallowest
production zone

Number of Wells - Poplar: 6

Central Core: 2

DISPOSAL REQUIREMENTS

Injection - 100%

Injection Flow Rate - 1,000 gpm (1 well for every 2 production wells)

Injection Depth - 1,000 feet (below Bearpaw)

Injection Pressure- 350 psi

Location - near heat exchanger

DIRECTIONAL DRILLING

BASIC HOLE PATTERNS

techniques to be used cannot be made at this time. At such time that more definitive resource information is available, alternative techniques to the perforated casing concept such as open hole completion and use of factory slotted liner (which is cheaper and provides less resistance to flow) will be addressed.

The specific type of hole pattern would also be selected after further resource definition. Figure IV-4 illustrates a production well profile based on vertical drilling. Since the Madison waters in the vicinity of Poplar typically exhibit artesian flows, the system concept employs a low pressure submersible pump to maintain and control flow through the heat exchanger, and high pressure pumps were assumed for injection. The casing sizes shown are considered typically small for a geothermal well, and could increase with resulting cost increases, as the resource characteristics and actual pump requirements become better defined. Injection as currently contemplated would be to a depth of approximately 1000 feet, below the Bearpaw formation.

Based upon the system heat load and required flows, the development would require six wells to serve the entire town of Poplar, or two for the central district alone. One injection well would be required for each of the two production wells.

HEAT EXCHANGER/SUBSYSTEM

The heat exchanger subsystem would be located adjacent to the well island. The process piping and control diagram is shown in Figure IV-5.

Heat Exchangers

The design was based upon the use of plate-type heat exchangers as a means of maximizing heat extraction efficiency from the geothermal fluid consistent with cost and operating reliability considerations. Since the precise characteristics of the geothermal fluid are uncertain, the heat exchanger calculations were based upon water. A heat transfer coefficient of 700, which is conservative for this exchanger, was selected as a means of compensating for the water design basis. One heat exchanger would be provided for each well. The heat exchanger design data are summarized in Table IV-4. Table IV-5 lists frame sizes and surface area available from one manufacturer which could be used to satisfy these requirements.(36)

The plate-type heat exchanger is, by its nature, well suited for this application. Reliability can be built into the system without excess spare capacity. A frame size can be selected which will allow for extra flow capability, and the capacity can be increased by adding plates to the frame. Since a plate-type exchanger can be disassembled in a minimum period of time, if one exchanger needed repair it would therefore be possible to bypass that exchanger and transfer useable plates from those remaining and return to virtually full heat load operation without a major disruption of service. Or, as an alternative, an inventory of spare plates could be maintained. In addition, the unit can be easily maintained (see Figures IV-6 and IV-7), which should allow minimization of scale build-up and thus maintain the coefficient of heat transfer at a high level.(15)

At a minimum, the heat exchanger material will be 304 stainless steel to minimize corrosion. If required, heat exchanger material can be titanium. Use of the latter

FIGURE IV-4. GEOTHERMAL WELL PROFILE

TABLE IV-4. HEAT EXCHANGER PRELIMINARY DESIGN DATA

	POPLAR
Inlet/Exit Temperatures, °F (ΔT)	65°
Fluid	190/125
Hot Water	115/180
Temperature Change, °F (ΔT)	
Fluid	65°
Hot Water	65°
LMTD °F (ΔT_m)	10
Flow Rate, gpm	
Fluid/Hot Water	500/500
Pressure Loss, PSI	10
LMTD Factor, F	0.92
Heat Transfer Coefficient (U)	700
Surface Area, ft ² (A)	2,500
Heat Transferred, MBTU/hr (q)	16.1
Data Relationship Formulae for Water/Water Exchangers, 1:1 Flow Ratio	
$q = (U)(F)(A)(\Delta T_m)$	(actual)
$q = (500)(\text{gpm})(\Delta T)$	(maximum)

TABLE IV-5. EXAMPLES OF PLATE HEAT EXCHANGER DESIGNS WHICH COULD BE UTILIZED FOR POPLAR

Maximum Flow Rate (gpm)	Surface Per Plate (Sq.Ft.)	Maximum Surface Area (Sq.Ft.)	Height	Width	Max. Length	Max. Dry Wt. (lbs.)
750	4.63	2,100	5'4"	2'8"	20'6"	11,000
1,100	6.78	4,068	6'5"	2'5"	15'8"	11,000
2,000	8.6	5,160	7'2"	2'8"	20'6"	11,000
2,000	10.3	6,180	7'6"	2'10"	16'6"	13,000

Design Pressures: Up to 300 PSIG (Full Differential)
ASME Section VIII, Section III Class III

Plate Materials: 304 S.S.
316 S.S.
Titanium
Incoloy 825TM
HastelloyTM
InconelTM

Ease of disassembling and washing the plate-type heat exchanger (left) offers significant savings in maintenance time and labor. Modular construction, wherein a series of plates are

bolted together (right), provides a fairly simple method for increasing or decreasing the unit's heat-transfer surfaces to accommodate changed system needs

FIGURE IV-6 PLATE HEAT EXCHANGER CLEANING

A McGraw-Hill Publication

Electrical World

December 1, 1977

FIGURE IV-7 PLATE HEAT EXCHANGER MAINTENANCE

HOT WATER DISTRIBUTION SUBSYSTEM

LEGEND

- Hot water supply
- Hot water return
- Pump station

FIGURE IV-8

FIGURE IV-8

FIGURE IV-9

LEGEND

- ① ISOLATION VALVE
- ② STRAINER
- ③ PRESS. REGULATOR VALVE
- ④ PRESS. GAUGE
- ⑤ BY-PASS VALVE
- ⑥ SAMPLE/CALIBRATION VALVE
- ⑦ ISOLATION VALVE
- ⑧ AIR/WATER HEAT EXCHANGER
- ⑨ CHECK VALVE
- ⑩ BLOWER
- ⑪ ROOM/HOUSE THERMOSTAT
- ⑫ SOLENOID VALVE
- ⑬ WATER METER

TYPICAL HOUSE CONTROL SYSTEM

FIGURE IV-10.

FIGURE IV-11 COMPARISON OF EFFICIENCY ADJUSTED DELIVERED COST PROJECTIONS: GEOTHERMAL ENERGY, ELECTRICITY, NATURAL GAS. 1980 - 1995

material would approximately double the cost of the exchangers, and would only be selected if necessary for significantly increased design life.

Heat Exchanger Subsystem Operation

As shown in Figure IV-5, the heat exchanger subsystem controls the flow from the wells through the heat exchanger (primary side), as well as the flow through the heating district (secondary side). (See Appendix D for a control symbol key.)

The geothermal well flow through the primary side of the heat exchanger is a closed loop between the production and injection wells, maintained by the low pressure production well submersible pumps and high pressure injection pumps. Flow control is accomplished through use of a variable frequency drive unit which varies the pump speed, and hence flow from the wells, in accordance with system heat load demand. The speed of the pump varies in accordance with the control signal originating from the temperature indicator and controller located at the secondary (hot water) side of the system, after the heat exchangers' discharge manifold.

As shown in Figure IV-5 the six heat exchangers are operated in parallel, and would not always operate simultaneously: the number of operating exchangers will be a function of the heat load, and hence, temperature drop, across the heating district. As heating district demand increases, the temperature of the incoming fluid to the exchangers would drop, causing a signal from the temperature controller to be sent to the variable frequency drive unit to increase flow from the production wells. Similarly, as flow increases, the flow sensor and controller located at the heat exchanger discharge manifold would signal the reinjection well pump variable frequency drive unit to increase capacity.

The secondary side of the heat exchanger is the closed loop of insulated FRP distribution and return piping which supplies the hot water to the heating district, and returns the cooled water to the heat exchanger. The hot water flow to the heating district is controlled by the booster pumps.

As shown in Figure IV-5, the 3000 gpm maximum system flow requirement would be maintained by two 1500 gpm pumps, with one spare. The variable nature of the district heat demand is compensated for through use of variable frequency drive units. This allows the booster pumps to operate at a wide range of head and capacity requirements by varying the pump operating speed in accordance with system heat demand. During periods of low heat demand, only one pump will operate. As system demand increases beyond the capacity of one pump, the second pump will begin operating automatically, first at low speed, and will keep in phase until it reaches maximum speed.

HOT WATER DISTRIBUTION SUBSYSTEM

The hot water distribution preliminary system design layout was developed for Poplar as shown in Figure IV-8. The initial hot water delivery design temperature is 180°F, with an exit temperature of 115°F. The design temperature drop through the forced-air heating systems of individual buildings would be 15-20°F, with supply water degrading through the system to a minimum inlet temperature of 135-140°F. Although the decreasing supply temperature system operation is

somewhat complex, it allows for resource heat extraction maximization and investment and operating economies (due to reduced overall flow requirements) over a system utilizing a uniform temperature supply to all users.

As shown in Figure IV-8, the district heating subsystem will be designed as "cascading" loops. Each pump station in a cascading loop (as depicted in Figure IV-8) would contain a temperature-controlled two-way valve on the discharge side of the pump. These valves would open or close, depending on water temperature. A building in a loop would remove water from the loop supply pipe and return it to the loop return pipe, as shown in Figure IV-9. From the pump station, the loop return pipe will discharge into the subsystem supply main, until the point where the temperature in the supply main would be degraded to approximately 135°F. At that point, the thermostatically controlled valves will cause the loop return pipe to discharge to the heat exchanger return main. Thus, the temperature supplied to the heating loops will progressively drop from 180°F to 135-140°F. However, within this minimum cascading-loop operating temperature range, there should be no material difference in end-user system design and operating costs.(11)

BUILDING HEATING SYSTEM

A typical building heating system utilizing an air-to-water heat exchanger is shown in Figure IV-10. The heating system is primarily controlled by the thermostat. The blower, on the automatic mode, is electrically interlocked with the thermostat. On a call for a heating mode, the thermostat sends a control signal to the energized solenoid valve, thus opening the piping system to hot water flows. At the same time the blower is also energized, thus effecting heat extraction and utilization. Temperature drop and flow rates to the individual buildings will be controlled by the pressure regulating valve (PRV), the isolation valve, the building thermostat, and the flow/temperature rating of the building heat exchanger (20°F drop at maximum flow rate). A calibration valve has been utilized to insure that optimum flow and hence temperature drop through the building heat exchanger is achieved. Buildings located further within a loop will have a slightly higher PRV setting than those located at the beginning of the loop to compensate for the loop distribution system pressure drop and assure equal hot water supply to each building. The pressure regulating valve will also protect the heat exchanger from surges in system pressure caused by intermittent opening and closing of other solenoid valves and other miscellaneous possible hydraulic problems. To prevent the entrance of debris into the heat exchanger and to prolong its useful life, a strainer is placed within the line at the inlet to the heat exchanger. If the building heating system does not seem to be operating properly, i.e., continuous operation with inside temperature remaining relatively low, the control system (Figure IV-10) can be readily checked with the following procedure. Check the solenoid valve (Item 12) to see if it is in proper working order. If the solenoid valve needs replacing, it can be by-passed using valve 5. If it is in proper working order, flow can be checked by closing the downstream isolation valve 7 and opening the calibration valve. Flow can then be measured and calibrated and upstream valve 7 adjusted.

HEAT USE MEASUREMENT

The amount of heat utilized by an individual building will be calculated based upon an individual user's percentage use of total system heat demand. A BTU meter and

recorder located near the heat exchanger (Figure IV-5) will be utilized to determine total heat load for the district. This device is a computer console, pre-programmed to analyze temperature and flow input signals from the system flow and temperature instrumentation. The signals would be received, totaled, and printed as monthly BTU-demand and cost for the system. The individual water meters installed at the hot water inlet to each building would be individually read, recorded, and fed to the computer-recorder. (Since flow through each building system is set by isolation valve 7 (Figure IV-10) and pressure regulating valve, it will be necessary to have these items sealed - as is the case with electric meters with lead tags - as a means of assuring the integrity of this system.) The total of the individual flows would be calculated, and the cost would be calculated for each user based upon the proportionate share of the total.

RELIABILITY CONSIDERATIONS

The preliminary design would provide 100 percent of the maximum hourly design heat load for Poplar utilizing approximately 96 percent of the design heat production from six wells. Due to the variability of the heating district load, coupled with the expense of drilling a well, the preliminary design did not include a spare well. In the event of failure of one well, the system could still provide 86 percent of the design heat load. Based upon a limited review of heating use data for Poplar, it appears that this remaining production could supply the actual heat demand for the majority of the year. In order to provide for reliability in the event a well outage were to occur during a time of peak heat demand, existing equipment could be maintained as a back-up heat supply in major central core buildings.

ECONOMIC ANALYSIS

This section contains an analysis of the cost of a geothermal heating district for Poplar, and an evaluation of those costs as compared with alternative heating sources.

COST ANALYSIS

Capital costs and first year annual and delivered costs were estimated based upon the preliminary district heating system design (Q1, 1980 Dollars). The analysis includes the entire town of Poplar, as well as a smaller heating district comprised of 30 Poplar Central buildings and approximately 40 residences in the immediate vicinity (hereinafter called the Central Core). Costs for the latter were developed on the assumption it could provide a first development phase, with piping sized so the rest of Poplar could be added later. The results of this analysis are summarized in Table IV-6.

System Capital Costs

A breakdown of the estimated capital costs of system components is presented in Table IV-7. The costs for geophysical activities include additional data assessment required to locate the well island as well as data analysis during drilling. Drilling supervision costs were developed on the basis that one rig would be used for a

TABLE IV-6. ESTIMATED COSTS FOR POPLAR GEOTHERMAL HEATING DISTRICT

	Poplar District	Central Core
<u>Capital Costs</u>		
Resource Subsystem	\$2,880,000	\$1,010,400
Heat Exchanger Subsystem	695,500	273,000
Distribution Subsystem	1,720,900	293,600
Engineering and Administration	485,000	115,000
Contingency	<u>530,000</u>	<u>160,000</u>
Total Capital Costs	\$6,311,400	\$1,852,000
<u>First Year Cost</u>		
Debt Services	\$ 561,000	\$ 165,000
Operations and Maintenance	240,000	83,000
Renewal, Replacement	86,000	31,000
Administration	<u>95,000</u>	<u>40,000</u>
Total First Year Cost	\$ 982,000	\$ 319,000
Annual Heat Sales, MBTU	285,560	95,600
Delivered Cost, \$/MBTU	\$ 3.44	\$ 3.34
Delivered Cost, with Customer Hook-up, \$/MBTU	\$ 4.02	\$ 3.54

TABLE IV-7. HEATING DISTRICT COMPONENT DETAIL

	Poplar District	Central Core
<u>Resource Subsystem</u>		
Geophysical Activities	\$ 20,000	\$ 20,000
Drilling Supervision	25,000	15,000
Production Wells	2,249,000	781,000
Injection Wells	300,000	100,000
Pumps	234,000	78,000
Piping Valves	60,000	20,000
Subtotal	\$2,880,000	\$1,010,400
<u>Heat Exchanger Subsystem</u>		
Heat Exchangers	\$ 282,000	\$ 94,000
Pumps, Vessels	135,700	55,200
Instrumentation, Electrical	76,700	43,300
Valves, Piping, Miscellaneous	106,100	45,500
Building	95,000	35,000
Subtotal	\$ 695,500	\$ 273,000
<u>Distribution Subsystem</u>		
Piping		
10", 12" Diameter	\$ 70,900	\$ 58,100
8", 6" Diameter	294,000	54,000
4" Diameter	486,000	54,000
3" Diameter	750,000	67,500
Valves, Pumps	120,000	60,000
Subtotal	\$1,720,900	\$ 293,600

two-production well development for the Central Core, while two rigs would be used for the six production wells for the entire district in order to confine the drilling activities to one summer season.

A detailed production well cost breakdown is contained in Table IV-8. DOE has commented that these costs are low;* however, the estimate is based on actual drilling times and costs experienced in the Poplar area, with additional time and materials costs included to compensate for increased depth and other factors resulting from use of directional drilling. These additional costs include an extra completed well depth of 1,000 feet, 10 days additional drilling time, and 25 percent increases in the estimates for items such as drill bits. The base drilling cost estimate is based upon actual rates quoted for drilling a well for another project approximately four miles east of Poplar, and is consistent with the drilling costs and times available in well report files of the State of Montana. (A copy of that estimate is included as Appendix E). Although drilling operators have consistently reported a 30-day drilling period to reach the top of the Madison, a PRC Troups representative was present during completion of a well in that vicinity (by the same drilling company submitting the cost proposal in Appendix E). The well had a completion time of two weeks and a total depth of 6,000 feet.

The total cost for each injection well was estimated at \$100,000.

Pipeline costs were estimated on the basis of insulated Fiberglass Reinforced Plastic (FRP) pipe, assuming supply and return piping buried in a common trench below the frost line. The basis for those installed costs is as follows:

Diameter at Cost/L.F.	Linear Feet	
	Poplar	Central Core
12" @ \$38/L.F.	350	350
10" @ \$32/L.F.	1,800	1,400
8" @ \$30/L.F.	2,800	1,800
6" @ \$21/L.F.	10,000	-
4" @ \$18/L.F.	27,000	3,000
3" @ \$15/L.F.	50,000	4,500

Engineering and administration costs were estimated as 20 percent of the system's capital budget excluding the cost of the wells. A contingency of 10 percent was applied to the system's total capital budget.

First Year Costs

The first year costs were based upon a non-profit, cost of service pricing system. The debt service computation was based upon obtaining a 30-year loan life, with

*The basic charge of \$3,960/day represents a \$165/hour charge for a 24-hour day. DOE has indicated that oil well rigs drilling to a depth of 6,000 feet are currently charging \$6,500 to \$7,500 per 24-hour day excluding directional drilling charges.

TABLE IV-8. PRODUCTION WELL DETAILED COST ESTIMATE FOR
WELL ISLAND DEVELOPMENT WITH DIRECTIONAL DRILLING

1.	Cost/Well	
	Drilling Basic Charge \$3,960/day @ 40 days	\$159,000
	Drill Bits	20,000
	Cementing	16,000
	Drilling Fluids	36,000
	Water Charge and Transportation	3,000
	Drilling Crew Mileage, Subsistence	12,000
	Completion	
	Equipment for casing run	1,000
	1,200 ±' 10 3/4 " Surface casing	17,000
	7,000 ±' 7" Production casing	58,000
	7,000 ±' Production tubing	35,000
	Perforate Production Interval	5,000
	Miscellaneous	<u>5,000</u>
	Subtotal	\$367,000
2.	Location Preparation	\$ 7,000
3.	ON/OFF Charges	40,000

8 percent cost of money. These economic assumptions are based on obtaining low interest financing through funding mechanisms such as those described in Chapter V, and are not intended to reflect private financing. As such, the economic assumptions are more closely related to those of a tax-exempt municipal public works project.

Operations and Maintenance Costs

Operations and maintenance costs include the cost of electricity, the cost of chemical treatment for the geothermal fluid (to aid in controlling its potentially harmful effects on equipment) and equipment maintenance. Commercial electricity rates applicable to Poplar were obtained from communications with Montana-Dakota Utilities (MDU), which services the area. Computations were based upon rates contained within a recent filing by MDU which is pending approval and expected to remain in effect for the next heating season. Use of the projected, rather than current, rates increases the first year electricity cost by 9 percent, and the delivered heat cost by approximately \$.05 per million BTU. Those rates are as follows:

Base Charge:	\$10.00 per month
Demand Charge:	\$2/KW over 10 KW per month
Energy Charge:	First 2,000 - 4.5754 cents/kw-hr
Per kilowatt hour used	Next 8,000 - 3.5754 cents/kw-hr
	Over 10,000 - 2.5754 cents/kw-hr

Based on these rates and the expected operating load factor (with power use a function of heat demand), the first year electricity costs for the Poplar system and the Central Core are \$156,000 and \$52,000, respectively.

The cost of chemical treatment was based upon the cost and quantity of brine treatment chemicals employed by operators of the Poplar field. The additives are mixed at the ratio of 1 gallon to 1,000 barrels (42,000 gallons). The cost of the additive is \$4.25 per gallon. Maintenance costs for remaining items were estimated at \$30,000 and \$10,000 for the Poplar system and Central Core, respectively.

Renewal, Replacement, Administration

Renewal and replacement costs were estimated as 3 percent of the capital cost of the resource subsystem. The technique was utilized as a means of producing a preliminary estimate consistent with the preliminary nature of available resource information, which can be used for budgeting purposes until additional data allow more precisely defined costs to be developed. Administration costs were based upon an estimate of equivalent full-time manpower which could reasonably operate and manage the system.

Customer Connections

The customer connection cost was based upon an investment of \$1,650 per residential dwelling and \$3,000 per large building. The residential dwelling installed cost is for the heating system shown in Figure IV-10 as itemized on the following page:

<u>House Connection Item</u>	<u>Cost</u>
100', 3/4" insulated piping @ \$8/L.F.	\$ 800
3/4" solenoid valve	\$100
3/4" strainer	\$20
3/4" gate valves - 6 @ \$15	\$ 90
3/4" check valve	\$ 23
3/4" pressure reducing valve	\$ 40
pressure gauge	\$ 50
Water meter	\$ 80
Subtotal	<u>\$1,200</u>
Air-to-water heat exchanger	\$ 450
Total	<u>\$1,650</u>

The above costs assume quantity pricing could be obtained. The total cost for the 800 residential units and 30 buildings within Poplar would be \$1,410,000, with an estimated costs for the Central Core alone of \$155,000.

The results of the investigation of financial and institutional issues indicated that no clear-cut procedure for utility development could be identified at this time. Thus, it was considered premature to define financial/institutional details such as ownership, responsibility, and method of payment for customer connection costs. In order to provide an assessment of the overall delivered cost impact of customer connections, the capital costs were translated to equivalent unit delivered heat costs, shown on Table IV-6. This was accomplished by assuming low interest financing (8 percent) for the total customer connection investment, with a 15-year loan life, and dividing the annual cost by the projected sales. The resulting annual cost for the entire district would be \$165,800, or \$.58/MBTU on an equivalent system basis. Similarly, the annual cost for the Central Core would be \$18,000, or approximately \$0.20/MBTU.

ECONOMIC EVALUATION

The first year delivered costs for geothermal energy for the town of Poplar would be \$3.44/MBTU. For the Central Core, this delivered cost would be \$3.34/MBTU. Adjusting for efficiency, these first year costs would be \$3.62 and \$3.52, respectively. Natural gas and electricity are presently being used in Poplar heating. The equivalent cost of natural gas (delivered to the Poplar area at 920 BTU/C.F.) is \$1.92/MBTU, and the cost of electricity is about \$9.50/MBTU. On an efficiency-adjusted basis, the respective equipment delivered costs would be \$2.56 MBTU and \$9.50 MBTU. These equivalent costs assume heating system efficiencies of 75 percent and 100 percent for natural gas and electricity, respectively [16,42].

The present day costs of these alternatives are summarized below:

	<u>\$/MBTU</u>	<u>\$/MBTU, Efficiency Adjusted</u>
Geothermal		
Town of Poplar	\$3.44	\$3.62
Central Core	\$3.34	\$3.52
Natural Gas	\$1.92	\$2.56
Electricity	\$9.50	\$9.50

As shown above, on a first-year cost basis, geothermal energy would not be competitive with the cost of natural gas, but would offer a significant economic advantage over the cost of electricity.

A comparison of alternate fuel prices should also consider the impact of rising fuel costs for a complete analysis. Geothermal energy can provide a long-term price benefit in that the price for the resource itself need not necessarily be subject to the upward pressures exerted on other fuels. The annual charges on the capital investment would remain fixed over the investment life. Therefore, if energy is priced on a cost-of-service basis, only the annual costs of pump energy, renewal and replacement, and administration would be subject to inflationary increases. These costs comprise approximately 45 percent of the first year costs.

Various studies were reviewed in order to develop escalation factors for a comparison of the impact of future price behavior. Projections such as those reviewed take into account factors such as resource costs increases and fixed/variable cost mixes in preparing overall cost projects for a given energy source. A recent study of energy price projections to the year 2000 compared price projections from various sources [42]. Electricity was not expected to rise much faster than the inflation rate. Colorado School of Mines Research Institute estimates for the projected costs of natural gas through 1995 an annual compound inflation rate of 14 percent. Another projection expected that natural gas would rise to a price equivalent with home heating oil between the years 1990 and 2000 [42]. Projections for the prices of electricity and natural gas were developed to the year 1995 based upon these price behavior projections. The long-term rate of inflation was assumed to be 7 percent per year. Natural gas price projections were then developed for two cases. Case I assumed a 14 percent compound annual increase. Case II was based upon the price of natural gas equaling the inflated price of heating oil by 1995, assuming a conservative price increase in that energy source of 8 percent compound. Electricity prices were projected to increase at a rate of 7 percent per year. Geothermal cost projections were developed for the town of Poplar on the basis that the escalating components of the annual cost rise at a rate of 8 percent per year. The rate of 1 percent above the assumed long-term inflation rate was chosen because the replacement and refurbishment component will be subject to the extreme pressures of the energy development market.

The results of these projections are shown on Figure IV-11. The figure illustrates that, if the geothermal heating district were operating today, the cost of that energy in the future could become less than natural gas by 1985.

In order to evaluate the future competitiveness of a geothermal system installed today with the projected prices of alternatives, equivalent uniform annual costs were computed. These costs are tabulated below:

	<u>\$/MBTU</u>	<u>Efficiency Adjusted</u>
Geothermal		
Town of Poplar	\$ 4.81	\$ 5.06
Central Core	\$ 4.77	\$ 5.02
Natural Gas		
Case I	\$ 5.23	\$ 6.98
Case II	\$ 6.65	\$ 8.87
Electricity	\$16.02	\$16.02

The above tabulation, together with Figure IV-11, show that assuming projected increases in the cost of natural gas occur, a geothermal heating district within Poplar could be a long-term, economically attractive alternative to current energy sources. It should be noted, however, that the long-term economic benefit of a geothermal heating district for natural gas users within the town of Poplar is heavily dependent upon a continuance of the current trend of high escalation rates for fossil fuels.

Changes in the rate structure may also affect the feasibility of a geothermal heating district at Poplar. The natural gas rates currently in effect for Poplar are the same for both residential and commercial users. However, MDU has a natural gas rate increase pending approval which would implement a "lifeline" rate structure. (Personal communication) The proposed rate schedule commodity, charge residential and commercial customers, is given below:

	<u>\$/Thousand Cubic Feet</u>	<u>Equivalent \$/MBTU</u>
January 1 - April 30		
First 15,000 C.F.	\$1.62	\$1.76
Excess over 15,000 C.F.	\$2.15	\$2.34
Remainder of year	\$2.15	\$2.34

The above schedule would represent a real benefit to the small residential users, because the lifeline portion of the rate would represent a significant portion of their energy use during the majority of the heating season. However, the larger users, such as those non-residences within the central district, who may consume between 100,000 and 200,000 cubic feet per month (or more) during the winter season, would effectively pay the higher rates. If MDU follows the trend in a lifeline rate structure being established in other areas, the difference between effective residential and commercial rates will increase. For example, a lifeline rate structure established in another area requires that the non-lifeline portion of the rates increase a minimum of 25 percent before the lifeline rate can be adjusted, which effectively pass through a majority of price increases to large users, which increases their rates at a faster pace than the overall cost of the energy is rising. Thus, changes in the pricing structure for natural gas could negatively impact the economic feasibility of a geothermal heating district for the entire town of Poplar, but at the same time provide an additional economic

incentive for a geothermal heating district which would service the large users within the Poplar Central Core.

V.

ENVIRONMENTAL AND INSTITUTIONAL FACTORS

The following is a discussion of the factors related to implementing the development of geothermal resource for direct heating applications at Fort Peck. The topics include discussion of the potential impacts of resource development, an analysis of the institutional factors relating to that development and Tribal geothermal resource development methods.

RESOURCE DEVELOPMENT IMPACTS

This analysis identifies the major impact considerations involving the geothermal fluid system in the areas of water quality, air quality, subsidence and seismicity, construction and abnormal operation, and social effects.

Although geothermal energy sources are thought to be environmentally "clean" resource, certain environmental problems can occur with development. The nature and significance of some potential problems are very dependent upon the resource's chemical and physical characteristics, location of the development site and adjacent lands, engineering technology to be implemented, and existing environmental conditions of the area to be developed.

SYSTEM DESIGN

The geothermal fluid handling system proposed is a "closed loop" system. The hot geothermal fluid would be brought to the surface and run through a heat exchanger where heat would be transferred to a secondary closed water loop. The cooled brine would then be injected into a stratigraphic layer below the Bearpaw shale. The Bearpaw shale in this case would serve as the confining formation. Any additional use of heat from the resource would be limited to extracting by a secondary heat exchanger loop prior to injection.

The closed loop system was selected as the design basis due to the poor quality of the geothermal fluid. If direct utilization of the brine were to be considered, a full chemical characterization of the fluid and the water quality required for a specific use would have to be known before the anticipated water quality impacts and an accurate cost estimate of disposal could be made. The regulatory requirements associated with any direct use of the brine for secondary use would be specific to that use and, thus, would have to be identified and evaluated on a case-by-case basis.

At this time, information about the environmental factors for the Poplar area are known generally, but not totally. Based upon the information available, a closed-loop system is the environmentally-preferred design, although further investigations may result in a recommendation that the injection depth be increased.

WATER QUALITY CONSIDERATIONS

Degradation of surface water and groundwater quality is one of the more serious potential environmental impacts that can occur with geothermal resource development. The geothermal fluid anticipated for this project is very saline. Therefore, an evaluation of alternative waste disposal methods has been investigated in order to mitigate any potential problems.

Historic Geothermal Waste Disposal

Geothermal fluids, in the form of waste brines from oil production, have been extracted from the Madison Formation in the Poplar Dome area and reinjected into various stratigraphic formations (such as the Judith River, Dakota Sandstone, and Mission Canyon Limestone) for over 20 years. Early brine disposal also was achieved by discharge into unlined earthen pits; prior to 1961 most of the oil production brine was disposed of in this manner. Such discharge was found to cause water quality problems. During a 1961 hearing of the Montana Oil and Gas Conservation Commission, it was demonstrated that the waste brine discharged to the unlined earthen pits was not being contained and that most of the fluid actually was seeping into the underlying gravel strata. This disposal practice resulted in observed contamination of the Poplar River and was found not to be an acceptable disposal method. If the use of unlined earthen pits had been allowed to continue, it is likely that fresh water supplies would have been contaminated and that domestic and agricultural use of the water would have been restricted or eliminated. Presently, all oil field brine is disposed of by reinjection into various stratigraphic units underlying the Poplar Dome area.

Injection

Brine disposal by injection is not without potential environmental impacts, particularly groundwater contamination. Contamination of groundwater aquifers can occur via leakage from the stratigraphic layer serving as the receiving reservoir, or from an injection casing rupture at a level above the receiving reservoir.

At this time, no historic or planned investigations are known to be designed to determine the integrity of the upper stratigraphic layers, such as the Judith River and Dakota Sandstone formations, with respect to isolating the injected brine from other groundwater systems. The possibility of groundwater contamination does exist, as discussed within the alternate model description of the shallow temperature survey analysis (Section III). This potential contamination of groundwater systems from brine injection should be investigated prior to making a determination as to which stratigraphic layer will be used for the brine injection reservoir for the geothermal project. Potential methods of making this determination are discussed within Section III.

Despite potential environmental impacts from injection of geothermal brine, it is currently considered the preferred system design alternative. Based upon this initial assessment, it appears to be the most cost-effective and environmentally acceptable method of disposal. The potential for contamination due to reservoir

leakage or casing rupture can be mitigated by proper planning, design, and implementation of operation and maintenance, emergency response, and monitoring programs.

Disposal Alternatives

Disposal of geothermal brine by containment and evaporation is possible but would require a large amount of land for the holding ponds. Based upon the history of surface water contamination due to seepage from oil production brine evaporation pits, it is obvious that any ponds would have to be lined. An average annual evaporation rate of 67 bbl/day of brine could be evaporated for each acre of surface area, as reported during hearings of the Montana Oil and Gas Conservation Commission. It also was reported that 83 percent of the total evaporation occurred between May and October with an evaporation rate of only 11 bbl/day for each surface acre during the winter.

Based upon this information, it is estimated that a few hundred acres would be required for the evaporation ponds. If 350 acres of land were required and if the synthetic lining costs \$0.30 ft², for example, then the cost of lining the pond (not including pond construction) would be approximately \$4.5 million. This cost alone is significantly higher than the cost of the injection well. Even with lined evaporation ponds, a program would be needed to monitor brine seepage to the underlying groundwater system.

Another alternative for geothermal brine disposal would be to treat the water so it reaches an effluent quality that could be discharged to surface waters or directly used in another process. Treatment would result in a solid residue that would require disposal. Due to the high salinity of the geothermal fluid, the costs of this alternative would be extremely high.

Air Quality Considerations

Existing meteorological and ambient air quality data are lacking for the area around the town of Poplar however, there are no major industrial sources in the area. It can be assumed that the general meteorological situation is similar to that reported for Glasgow, Montana.

Given the topographic location of Poplar and the wintertime cold air drainage, it is possible that the area is subject to very frequent air temperature inversions during the winter months. These inversions could trap air at the surface and prevent proper dispersion of the atmospheric pollutants produced at the surface. Therefore, any significant air pollutant emissions in the Poplar area could measurably degrade the quality of the air.

Geothermal well drilling, plant construction, and plant operation can produce atmospheric emissions of hydrogen sulfide, ammonia, carbon dioxide, mercury, and radioactive particles and gases. The nature of these pollutant emissions depends upon the chemical nature of the geothermal fluid and the type of geothermal plant technology used. Considering the plant technology as it relates to potential air quality impacts, a normally operating closed system (i.e., one in which the

geothermal fluid is not exposed to the atmosphere) which is the proposed design, produces minimal air quality impacts.

The most significant potential air quality impacts that would be anticipated from the Fort Peck geothermal operation would be due to hydrogen sulfide and radioactive components. An initial evaluation of the radioactive potential was performed by analyzing water samples from five wells for gross alpha emissions and Radium 226 concentrations.

This analysis is presented in Table V-1. The levels for both constituents are somewhat elevated, indicating a potential presence of Radon gas in the wells. Although this preliminary assessment would indicate that the levels are not sufficiently high to be potentially harmful during normal operation of a closed geothermal system, the data are insufficient to be conclusive at this time.

There are reported occurrences in the well logs of "rotten egg" gas odors, which would indicate the presence of hydrogen sulfide gas in some wells at the time the logs were made. However, during visits to the oil field, including repeated exposure in the vicinity of the water disposal wells, where the fluid is exposed to the atmosphere, the characteristic hydrogen sulfide gas odor was not detected.

Since the preliminary assessment does indicate the potential presence of Radon and hydrogen sulfide gases in the geothermal fluid, it is recommended that water samples be taken and analyzed for these and other constituents in conjunction with any future geothermal exploration activities.

SUBSIDENCE AND SEISMICITY

As can be expected, whenever fluids are extracted from a pressurized groundwater reservoir, land subsidence may occur. Changes in reservoir pore pressure (due to either injection or withdrawal of large volumes of fluid) may result in instability leading to seismic disturbances along faulted or fractured zones. There are documented cases where injection and withdrawal have both caused geophysical instability.

For this project a significant amount of geothermal fluid will be drawn from the reservoir. There has not been any record of subsidence or induced seismic activity from the local oil operations that have historically drawn oil and geothermal fluid from the underground reservoirs. The lack of subsidence is probably due to the depth of the resource and the sturdy nature of the underlying strata. Although subsidence and seismic activity should be monitored during plant operation, problems are not anticipated at this time.

IMPACTS DURING CONSTRUCTION AND ABNORMAL OPERATION

Other environmental impacts which can occur with the development of a geothermal resource include: noise pollution, soil degradation or disturbance, mineral or thermal pollution, and wildlife disturbance. Given the size, proposed design, and nature of the facility, minimal adverse effects would be anticipated during normal operation. However, the potential for these adverse effects exists

TABLE V-1. REPORT OF WATER SAMPLE ANALYSIS

Lab Designation	706-9544-5-1	706-9544-5-2	706-9544-5-3	706-9544-5-4	706-9544-5-5
Sponsor Designation	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
<u>Determination (pCi/l)</u>					
Gross Alpha, dissolved + Counting Error *	520 $\pm$ 140	480 $\pm$ 130	890 $\pm$ 180	560 $\pm$ 140	880 $\pm$ 250
Radium-226 + Counting Error *	250 $\pm$ 20	220 $\pm$ 20	240 $\pm$ 20	270 $\pm$ 20	190 $\pm$ 20
	132 ^o F	164 ^o F	84 ^o F	196 ^o F	155 ^o F

*Variability of the radioactive disintegration process (counting error) at the 95 percent confidence level, 1.96 σ .

during drilling and construction activities, and during abnormal periods of operations, from unexpected occurrences such as well blow-outs, line ruptures, pump failures, and containment pond failures.

In order to prevent or minimize some of these potential problems, it is recommended that appropriate mitigating measures be taken to provide environmental protection during drilling, construction and abnormal operating periods. These measures may include the installation of noise mufflers during drilling and properly designed containment systems. In addition, an abnormal operations plan should be developed and appropriate design measures implemented to prevent or minimize any environmental problems due to accidents and equipment failures.

SOCIAL IMPACT ANALYSIS

While the primary application of geothermal energy to the proposed and existing buildings and housing on the Fort Peck Reservation possibly may require some social adjustment and investment, the likelihood of any significant social impact is minimal. The size of any one of the possible systems is not great enough to require significant additions to the existing community services and related facilities. Further, the geothermal system physically would not differ much from a commonplace natural gas system; a very small staff should be sufficient to maintain operations. At this time no significant community facilities or services are identified as needed beyond those already planned with conventional energy sources. Therefore, there should be very little difference in the social impacts from either natural gas, electricity, or geothermal energy for heating.

It must be mentioned, however, that the social impact of the geothermal resource development on the Fort Peck Reservation cannot be fully determined until the total system design and any secondary uses are defined. At that time, it may be necessary to reevaluate the sociological impact of the system on the Tribal values.

TRIBAL GEOTHERMAL RESOURCE DEVELOPMENT OPTIONS

Although it is an historic trend for others to develop, or protect, the Tribes' properties and Congress has prescribed several laws, rules, and regulations and has assigned various agencies to supervise activities, the Fort Peck Tribes could establish an entity that explores and develops the geothermal energy resources within the interior boundaries of the Reservation. Also as a proprietor, Fort Peck can exercise management and even lease, or otherwise transfer, interests to the energy resources with concurrence from the U.S. Secretary of the Interior. Using the general power of government and owner, a Tribally-chartered geothermal utility can be organized to serve the Reservation.

The geothermal utility could be established similar to a municipal utility, or a co-operative utility whereby the co-operative's members are the customers. (In either case, the entity would not fall under the jurisdiction of the Montana Public Service Commission). Figure V-1 summarizes the potential Tribal actions to form a

GENERAL COUNCIL

TRIBAL EXECUTIVE BOARD

- 1. Create geothermal utility company
- 2. Appoint management board
 - o defined appointment procedures
 - o defines powers
 - o describes interests
- 3. Delegate power to establish bylaws, subject to approval of General Council or Tribal Executive Board.
- 4. Enumerate business powers
- 5. Outline fiscal accountability
- 6. Assign geothermal resources

Figure V-1. Schematic of Potential Tribal Actions to Form a Geothermal Utility
(Chronologically)

geothermal utility. The Tribes would determine the nature and extent of the utility's power, considering the items such as purpose, powers, organization, and management. The codified Navajo Tribal Utility Authority Charter which creates the utility company of the Navajo Indians, is included as Appendix F to illustrate the application of these codes within a utility structure.

PURPOSE

The purpose of the utility should be described in general terms. A statement such as "to explore for, develop, and market the geothermal resources of the Tribe" is sufficient. Usually an ancillary clause is provided that further generalizes the primary purpose; e.g., "to do everything necessary, proper, advisable, or convenient for the accomplishment of the purpose above set forth." The Tribes can expand, or specify, the purposes of the company. The Tribes can limit the time period of the utility's existence, or provide for perpetual duration.

POWERS

Generally, businesses have some inherent characteristics. These may include:

- o purchase, take, receive, lease, or otherwise acquire, own, hold, improve, use, and otherwise deal in and with real or personal property, or any interest therein, wherever situated,
- o dispose of all or any part of its property and assets,
- o lend money and use its credit,
- o issue and deal in and with shares,
- o make contracts and guaranties and incur liabilities,
- o sue and be sued,
- o conduct its business, carry on its operations, and have offices,
- o elect or appoint officers and agents and define their duties and fix their compensation,
- o make and alter bylaws,
- o transact any lawful business, and
- o have and exercise all powers necessary or convenient to effect its purposes.

Any of these powers can be limited, or ignored, by whatever the Tribe may substitute or prescribe. A crucial concern for any powers, which may be developed, is the management of the real properties of the Tribes. Since the geothermal resources of the Tribes are restricted property, the Tribes can either limit the entity's activity to the producing and marketing of beneficial energy from the resources or they can, in addition, hold, manage, and develop the resources in the best interest of the Tribe. Another concern is the accountability of the monies invested by or returned to the Tribes. The Tribes can prescribe an accounting system that is acceptable to both themselves and the U.S. Secretary of Interior. In addition to the general powers, the entity can be delegated the responsibility to establish rates for services and the means for enforcing collections subject to Tribal or co-operative membership approval with provisions that include notice and public participation suffice.

ORGANIZATION AND MANAGEMENT

The Tribes would describe how the entity is related to the Tribes and how the entity would be managed. One good method is to establish a management board that proposes bylaws to be accepted by the Tribes. The alternative is for the Tribal council to prescribe for the Board its bylaws. Other areas include the definition of employees, identification of officers and employees, and election or appointment of the Board. An example schematic Tribal Geothermal Utility Organization is shown in Figure V-2.

SOURCES OF FUNDING

The following is a discussion of various sources of government funding which could be explored for a geothermal resources direct heat application development by the Tribes. Generally, the availability of funds depends upon criteria relating to the nature of the application.

Office of Small-Scale Technology

Direct grants of up to \$50 thousand are available for the application of geothermal demonstration systems under "real-life conditions" through DOE's Appropriate Technology Small Grants Program. The purpose of the program is to encourage the "development, demonstration, and dissemination of information concerning energy-related systems and supporting technologies" including geothermal projects. Indian Tribes are specifically mentioned as eligible recipients of these grants which are directed toward enhancing community self-reliance through the use of available resources.

To be considered for financial support, projects must pass a technical evaluation by the DOE regional office in Denver, be reviewed at the state level, and be selected by DOE officials in Washington, D.C. All projects must be completed within 24 months from the beginning of funding.

The technical evaluation determines the project's procedural feasibility, quantifiable results, potential environmental impacts, and likelihood of completion within budget constraints. The technical evaluation also will include a review of the qualifications and capabilities of the "key individuals" involved in the projects and an assessment of whether the project's organization and management are capable of completing the projects themselves or of supervising competent subcontractors who can complete the project within the time schedule.

Geothermal Loan Guaranty Program (GLGP)

DOE has been granted the authority to guarantee loans for the development, construction, and operation of equipment or facilities for nonelectric applications of geothermal resources through the GLGP (10 CFR 790). Any organization, public or private, can be granted a guarantee; preferential consideration is given to those projects carried out by small, independently owned and operated businesses and small utilities.

Under the program, federal involvement in any project is limited by Congress to 75 percent of total project costs. Participation by other federal agencies--through

FIGURE V-2 SCHEMATIC EXAMPLE OF TRIBAL GEOTHERMAL UTILITY ORGANIZATION

grants and other forms of assistance--is not prohibited but encouraged since it lowers, on a dollar-for-dollar basis, the amount of project cost that must be borrowed and repaid. Rather, the program criteria simply require an "equity contribution" equal to 25 percent of the total project cost by parties other than the Federal government, whether they are the state government, municipalities, or private investors. According to GLGP officials, allowances can be made for predevelopment and acquisition costs (fees, etc.) in the form of credits against the 25 percent requirement. In addition, the capital contribution by the borrower need not be a down payment but can be phased in (25/75) with all other funds.

The maximum loan guarantee is \$50 million for a single project and \$100 million for a single borrower. The maximum maturity of any loan under the GLGP is 30 years. The guarantees are backed by the "full-faith and credit" of the U.S. government; recourse is limited to DOE itself, with collateral limited to project assets only. An annual user fee, equal to 1 percent of the average outstanding principal, is charged to the borrower by DOE for administrative costs and loan losses. The 1 percent per borrower is only a ceiling and may be lowered as the GLGP reflects lower credit risk of the overall portfolio.

The guarantees under the GLGP can be transferred to cover construction financing as well as operation financing. The program also provides a "takeout window" of one to two years in order to allow conversion to long-term investors from construction financiers at the most favorable rate. Nonetheless, the granting of a geothermal loan guarantee does not prohibit the borrower from qualifying for, or obtaining, other Federal financial assistance.

Application for a GLGP is made to DOE, San Francisco office, which must evaluate the economic risk and environmental impact of the project before meeting with the project developer and sending the proposal to DOE Headquarters in Washington, D.C., with a recommendation. This process generally takes four months, followed by a 60-day evaluation period in Washington.

The critical issue in the DOE evaluation of an application for a guarantee is whether projected cash and interest flows are sufficient to repay the principal on the loan. In addition, the applicant must present plans for the timely and efficient completion of the project, using environmentally acceptable processes.

It is not necessary for the borrower to select a lender prior to submitting an application, although the concurrence of the borrower, lender, DOE, and legal counsel is necessary to validate the guarantee. Nonetheless, once the commitment is given by DOE-Washington, the promise of the guarantee can be used to attract favorable terms from creditors.

Other possible sources include:

- o Department of Commerce. The Economic Development Administration (EDA), through its Business Development Assistance Program provides assistance for production plants related to increased employment and improved income in EDA-approved areas. Business enterprises, including cooperatives, are eligible for direct

loans for up to 65 percent and loan guarantees for up to 95 percent of the cost of fixed assets and/or working capital investments in excess of \$500 thousand. In addition, an unexplored but potential source of assistance may exist in the Public Works and Development Facilities Program of the EDA. Currently applicable to the construction and equipment investment for small-scale alcohol fuel plants, this program provides grants for 60 percent to 80 percent of the total project cost, generally estimated to be \$300,000 per project. Designed to stimulate local economics, the Public Works Program specifically identifies Indian Tribes as eligible beneficiaries.

- o U.S. Department of Agriculture. The Farmers Home Administration has indicated an increased interest in geothermal energy. However, size of the grants available from the Administration is expected to be small and certainly would be applicable only to implementing related agricultural projects.
- o U.S. Department of Health, Education, and Welfare. The Housing and Urban Development Program is considering the development of a program for supporting the direct application of geothermal energy for space-heating requirements. Although this appears to be an ideal source of funding for the Fort Peck project, the program is still being organized.
- o U.S. Department of Defense. The Office of Energy Habitability is a possible source of funding, only if a similar application of the project by the U.S. Army can be demonstrated.

STATE GOVERNMENT PROGRAMS

In the state of Montana, a geothermal commercialization team has been organized through the Renewable Energy Bureau of the State Department of Natural Resources and Conservation to promote geothermal energy development. Through this program, owners of geothermal resources are eligible for grants and assistance in engineering feasibility, resource evaluations, and funding with the provision that all information from grant-supported projects should be made available to the public.

Currently, 2 percent of the 30 percent state severance tax on coal is earmarked for funding alternative energy projects within the State. Although grants now range from \$500 to \$100 thousand, grants of over \$100 thousand are not encouraged and the average grant amount is about \$12 thousand. By 1981, \$250 thousand is expected to be available through this program, all of which can be matched by Federal funds. No loans are made through this program.

Applications for financial assistance under this program are subject to competitive review and are judged for either their innovative approach to geothermal development or their application in a unique area. Thus far, the State is not participating in any development projects on Indian lands or on the Madison aquifer in northeastern Montana.

Once a project is selected for funding, a formal contract is drawn which limits DOE liability, specifies the expected use of the funds, and provides for public access to the completed facility. The time allowed for each project is one year and demonstration projects must allow visitation rights to the general public for up to five years.

The deadline for submitting applications for state grants is October 15 of any year. Approved grants are awarded by January 1 of the following year.

INSTITUTIONAL ANALYSIS

Various institutions prescribe how geothermal resources should be developed, but how statutes and rules and regulations are interpreted and effected is subject to some debate. Furthermore, because the regulatory agencies appear to overlap in their jurisdictions over those who own or who want to develop the rights, the proper controls and regulatory channels become unclear. Therefore, not only are there problems in defining the institutional control of the Tribes' geothermal resource, but the actual definition and correlative ownership of the resource itself are special problems: the patent, transfer, and acquisition history of the Tribal in-trust and allottee lands with geothermal potential need to be qualified with the governing agency and resource definition. The following is a discussion of these institutional factors which could affect Tribal development of geothermal resources.

PATTERNS OF GEOTHERMAL OWNERSHIP

The area of geothermal development interest lies within an area of 16,800 acres in the vicinity of Poplar. Specifically, this area lies in the east quarter of T27N, R50E and the north half of T27N, R51E, although the area overlaps into the west quarter of T27N, R52E, the southern edge of T28N, R51E, and southwest quarter of T28N, R52E. Within the area of interest, a "checkerboard" pattern is formed by the varying private or fee ownerships. Of this checkerboard, the Tribe owns a total of 2,859.45 acres (surface and minerals) and another 480 in-trust acres to which the ownership and reservation of surface minerals have not been completely determined. The remaining ownership is divided between allotted and private land owners in a ratio of about 35:65. Even though these latter ownerships affect large-scale geothermal field development, this ownership investigation is limited to Tribal and in-trust lands. No state surface nor mineral ownership is known to occur in the area of interest.

DEVELOPMENT REGULATION

This section is included to identify major areas of potential regulations which could affect Tribal development of the geothermal resource. The actual regulatory approach followed in developing the geothermal resource will have to be determined by the Tribes with the advice of the Tribal legal council and concurred by the BIA.

If the geothermal resource development is within lands for which the Tribes own surface and mineral rights, the Tribes should be able to follow the basic procedure for Indian Non-Oil and Gas Mineral Development as prescribed in the Code of Federal Regulations (25 CFR 171 et seq. and 25 CFR 172 et seq.). The procedure generally delegates the Bureau of Indian Affairs the responsibility of ensuring that the Tribes have entered into proper arrangements for development of their mineral resources. Also the U.S. Geological Survey is assigned the technical support for the mining management and operation on the Tribe's land (30 CFR, Chapter II). It is not known whether geothermal resources can be developed effectively under general mineral statutes. These regulations are not specific to geothermal as those within 30 CFR 270 which promulgates regulations on public, federal lands. Even though the Geothermal Steam Act of 1970 explicitly excludes Indian lands, USGS may choose to administratively adopt its guidelines. Non-specific federal regulation of mineral resource development within a state's boundary has historically involved state interaction and often times regulatory control.

Of critical concern to the implementation of the geothermal resources is the definition of an authority to conduct the environmental studies and to administer the appropriate development permits. Pending a determination on the development authority and procedures, it is probable that either the BIA or USGS under the federal authority of National Environmental Policy Act (NEPA) will be given the responsibility of conducting an environmental analysis. However, due to the spatial distribution of private and fee lands around the potential Tribal development areas and the questions related to water ownership, state intervention is possible. Also, if the potentially exploitable geothermal resource extends on adjacent fee or private tracts and private development occurs, then unitization of a reservoir block might be required to ensure resource conservation and to maintain fluid pressures. Here again the state might become involved in behalf of the private interests.

Other potential areas of state regulatory involvement could come from the Board and the State Department of Health and Environmental Sciences who administer the state's Clean Air Act (Title 69, Chapter 39, RCM 1947) and the Water Pollution Control Act (Title 69, Chapter 49, RCM 1947). Every effort should be taken, therefore, to establish a lead agency for the environmental appraisals in order to minimize redundancy and to expedite development.

Even though a geothermal resource may be considered a mineral for regulation of development, its disposal on Indian lands by injection would also be subject to federal regulation. The U.S. Environmental Protection Agency (EPA) initially regulated underground injection under the Federal Water Pollution Control Act, but a court decision limited jurisdiction to only injections that might cause surface water pollution. The Safe Drinking Water Act was passed by Congress and provided for EPA control of underground injections under the Underground Injection Control Program. UIC regulations were proposed on 20 April 1979 but to date have not been promulgated. Based upon a substantial number of comments on the proposed regulations, significant changes to the program are anticipated. It is not known at this time if the UIC regulations will be repropoed or promulgated in final form, but some guidance should be available in the second half of 1980. Regardless of when the program regulations are promulgated, it is likely that existing or proposed injections operations will be required to comply with them.

Although the geothermal development may occur totally on Indian lands, the state may attempt to regulate the field development, particularly if the geothermal reservoir extends onto adjacent fee or private lands where the State may impose jurisdiction. Also development of geothermal on lands in Section 16 or 36 that were ceded to the Reservation in 1908 may be a subject of some controversy concerning geothermal ownership.

Several states have had a direct influence on industry's access to mineral resources, even on Indian lands. In the case of a geothermal resource, on a State lease, Montana has provided for the leasing access for exploration and prescribed control methods of drilling, resource production, and waste disposal. In its statutory development to control the geothermal resources separate from water, Montana has effectively delineated geothermal resources separate from water. Thus, water should not be an issue, unless the development requires water usage. Then, if the Tribes accept the primary role of the state to adjudicate water, the Tribes or their developer must apply for appropriations and/or make claim to the state for beneficial water use (State Form No. 600). Water produced through drilling and pumping under 100 GPM is not classified under Montana water laws if no other party uses the water or if the liquids are reinjected into the stratum from which it was pumped (reinjection).

Zoning may affect Tribal development. If state zoning is effective within the area and has proscribed mining activities within townsites, Tribal controls to mitigate those zoning ordinances may result in conflicts. At this time, the zoning proscriptions are not known.

Finally, although not only a state concern, conflicting or overlapping leases are an issue, where oil or gas are drawn from the same rock horizon that contains geothermal waters. Under state law the prior resource production would have precedent; under Tribal development the question is whether the Tribe's effort can interfere with the present or ongoing production of oil and gas. Furthermore, associated questions on what happens to the geothermal fluids now pumped, how the fluids are disposed, and other drainage problems seem to remain unanswered. Maybe the lease terms for the producing wells should be renegotiated to conserve and manage the geothermal resources.

Federal Leases

Using the model of geothermal development outlined by the 1970 Geothermal Steam Act, the Fort Peck area of interest is not a Known Geothermal Resource Area (KGRA) (Ref. 41 CFR 3200). However, favorable data generated from electrical resistivity or other geophysical tools (such as microseismic, seismic ground noise, electromagnetic, and telluric methods) could compel the Supervisor (USGS) to change the Fort Peck classification to be a KGRA. This classification may become important since it relates to whether the geothermal resource can be leased by negotiation (if not classified) or by competitive bid (if designated as KGRA). The manner of leasing and its impact on Tribal lands cannot be predicted until a ruling is made by the Solicitor's Office concerning the applicability of the Geothermal Steam Act and regulations as defined in 30 CFR 270.

Recently, H.R. 740 has passed; it amends the Geothermal Steam Act by increasing the leasing acreage limit from 20,480 acres to 51,200 acres (under the Indian mineral leasing, the limitation is 2,560 acres). Senate action is expected to rule on a conditions lease option, acceleration of leases and permits, authorization of federal use, exemption of developed acreage from limits, free use for small-scale direct use applications, and relief from 10-year readjustment authority. Naturally the free use issue is one that could minimize the amount of accountability for the Tribes particularly if the financing is not in the form of a loan; however, the distinction between Tribal geothermal and the Geothermal Steam Act would need to be resolved first.

PROCEDURES FOR TRIBAL DEVELOPMENT OF GEOTHERMAL RESOURCES

Using the information identified in this analysis, institutional analysis, and the preceding impact analysis, a set of procedures was prepared for the approval process for developing the geothermal resources. Due to the uncertainties involved with the issues previously discussed such as regulatory jurisdiction, ownership, and resource classification, the procedure could not be realistically associated with a schedule at this time. These procedures are therefore presented in outline form to serve as a "check list" and are organized according to the chronological stages in the development. Further investigations by the Tribes and the Tribal legal counsel may show that some of the listed requirements may not apply. Specifically, those requirements of the state of Montana and their applicability to the development of this resource on Tribal lands needs further examination. Of particular importance to implementation will be resolution of such issues as 1) differentiation between private land owners and Indian land owners relative to resource use, and 2) legal classification of the geothermal fluid as a water or a mineral.

Many of these procedures are self-explanatory and can be used as a "check list".

- I. Definition of Governing Regulations on Tribal, In-Trust and Allottee Land.
 - A. Request a ruling from the BIA Solicitor's Office.
 - B. Determine overlap of state jurisdiction.
 - C. Obtain an independent legal interpretation of the BIA ruling.
- II. Withdrawal of Lands for Geothermal Development.
 - A. Determine land status in area of interest.
 - B. Determine ownership significance of patents, transfers, and acquisitions.
 - C. Identify existence contracts (vix: oil and gas leases) that could hinder or impact geothermal development.
 - D. Reserve, by Tribal resolution, Tribal and in-trust lands not influenced by existing contracts for future geothermal testing and/or development.

- E. Determine procedure for acquisition of either allottee, fee, or private lands.
- F. Obtain the BIA Field and Area Superintendent's approval for withdrawal and/or acquisition of lands.
- G. Identify existing water rights (surface and groundwater, location of wells and points of diversion).

III. Exploration: Target Definition.

- A. Geothermal exploration field reports may need to be filed with the Montana State Department of Natural Resources 60 days in advance of exploration activities. Preparation of a "long-range plan" describing the location, nature, and approximate dates of the exploration activities also may be required (see Appendix F, Montana Administrative Order No. 36-3-4).
- B. A prospecting permit must be secured from the BIA Field Superintendent prior to conducting geophysical and/or shallow drilling for thermal gradient determinations (25 CFR 171.27a). Surface resistivity and/or electromagnetic surveys may be excluded from this procedure if surface disturbance is minimal. Rotary drilling probably will require written permission from the BIA Supervisor. Plugging, well reporting, and reclamation requirements should be promulgated from the Supervisor's office. An environmental analysis may be required by the BIA that could include but not be limited to rate and endangered species surveys and archaeological surveys. Interaction (e.g., permits, reports) of state agencies such as the Oil and Gas Commission and the Montana State Department of Natural Resources should be identified by the Supervisor's office.
- C. Water sampling or pumpage greater than 100 gpm or test hole greater than 1,000 foot in depth (26-2.6(2)-560130) may require an application for beneficial water use from the Montana State Department of Natural Resources and Conservation (Form 600).
- D. A geophysical seismic operation that employs explosives requires filing a notice of intent with the appropriate county clerk and recorder and requires deposition of a surety bond with the Secretary of State to indemnify property owners. Reporting is required by the county clerk's office. Plugging and surface restoration may fall under the jurisdiction of the Montana Oil and Gas Commission. This could be handled by USGS or BIA if a Tribal-Agency cooperative agreement is developed.

IV. Developmental Drilling.

- A. A "Plan of Operations" will be required by the BIA Supervisor under either the regulations defined by 25 CFR 171.20 or 30 CFR 270.34

and approval will be needed from the Area Superintendent. A list of the probable subjects to be addressed within this plan is as follows:

1. Locations of drill target(s), support facilities, and access.
 2. Estimate of potential water yields and temperatures (may not be required until implementation stage).
 3. An environmental assessment of hazardous materials; surface and groundwater sources and hydrologic characteristics; water and air monitoring programs; prevention of commingling fresh-water with saline aquifers; potential damage to fish and wildlife; soil erosion; public safety; fire prevention; surface and noise disturbances related to but not limited to drilling and access; and overall environmental impacts on air, water, plants, and animals.
 4. Identification of waste disposal or treatment method.
 5. Easements to and from proposed drill site. This could involve the BLM, state, county, etc., depending on access requirements.
 6. A reclamation and abandonment plan in compliance with Geothermal Resources Operational Order No. 3.
 7. An Environmental Impact Statement may be required.
- B. Additionally, several state requirements and permits may be deemed applicable, namely:
1. A "Long-Range Exploration Plan" as outlined in 36-2.8.
 2. A water use permit that is similar to one submitted by the BLM in the Marysville geothermal area.
 3. A certificate of Environmental Compatibility as required by the Major Facility Siting Act of 1973.

V. Implementation and Facility Operations.

- A. Clarify or update the "Plan of Operations" (in Part IV, A) to include design specifications for direct utilization (i.e., space heating), economic feasibility and comparability to alternative energy sources, socioeconomic and environmental impacts, facilities management, and accountability. Submit to regulatory and potential funding agencies.
- B. Information concerning specifics on proposed deep tests probably will require the BIA Supervisor to file the "Details of Work" section in the

Plan of Operation (30 CFR 270.70). This application should be very specific about the types of equipment, proposed depth, estimated formation tops, estimated geothermal production zone, mineral by-products, casing types and weights, circulation media, blowout prevention material, intervals to be cored, types of down-the-hole logging, amount of cement and mud, intervals to be cased, and methodology for measuring the geothermal gradient. The "Details of Work" will need support maps illustrating the proposed hole location, structure, and hydrology.

- C. A permit application containing the specific methods and locations for spent water disposal, potential environmental impacts, and safeguards may be required by either the Montana Oil and Gas Commission (36.318(10)-S14480-3) via the Montana Pollutant Discharge Elimination System. The Federal Water Pollution Control Act as administered by National Environmental Policy Act (NEPA), however, may be the presiding authority for disposal applications if the state pollution safeguards or standards are deemed inappropriate for the Tribes (see Appendix M). Assuming a system design that is "closed" (water reinjected into the same or suitable alternate saline aquifer), there are advantages to state intervention through the Oil and Gas Commission and to controls established by EPA. A reinjection plan routed through this Oil and Gas Commission could be approved within 10 days unless there is a request for a public hearing. Reinjection of hot Madison-derived waters into the Madison Group, Dakota Sandstone, and Judith River Formation has been approved by the Commission for the past 25 years (nearest disposal well is 3 miles north of Poplar).
- D. An air pollution permit may be required by the Montana Board and State Department of Health and Environmental Sciences, administrators of the state's Clean Air Act (Title 69, Chapter 39, RCM 1947). However, the state's Clean Air Act does not list space heating plants and, therefore, may be inapplicable for this form of direct application. The federal Clean Air Act of 1970 was not specific about EPA's control over ambient emissions on Indian lands; however, a 1974 court order (39 Federal Register 235) provided that the Tribes could establish their own quality standards for "significant deterioration."

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APPENDIX A

**COMPOSITE STRATIGRAPHIC SECTION OF
THE FORT PECK RESERVATION**

FIGURE I-6
COMPOSITE STRATIGRAPHIC SECTION
OF THE
FORT PECK RESERVATION

ERA	PERIOD	SERIES	GROUP	FORMATION	AVERAGE THICKNESS(ft)	
Cenozoic	Quaternary	Recent		Alluvium*	0 - 130	
		Pleistocene		Glacial Deposits Wlota Gravel*	0 - 250	
	Tertiary	Early Pliocene To Late Miocene Paleocene		Unconformity Flaxville Gravel	0 - 100	
				Unconformity Fort Union Formation	1400±	
Mesozoic	Cretaceous	Latest Cretaceous	Montana Group	Hell Creek Formation*	220 - 280	
		Late Cretaceous		Unconformity		
				Fox Hills Sandstone *	85 - 120	
				Pierre Shale	Bearpaw Shale *	1095 - 1186
					Judith River Fm	90 - 136
					Clagget Shale	226 - 283
					Eagle Sandstone	695 - 770
					Telegraph Creek	
				Colorado Shale	Niobrara Shale	208 - 267
					Carlile Shale	200 - 232
					Greenhorn L.S.	181 - 218
					Belle Fourche Shl.	345 - 406
					Mowry Shale	
					Thermopolis Shale	27 - 54
					Skull Crk. Shale	152 - 197
					Dakota Sandstone	63 - 78
					First Cat Creek	72 - 205
				Kootenai Formation	Fuson Shale	253 - 416
					Lakota Sandstone	
	Jurassic		Ellis Group	Unconformity		
				Morrison(?) Formation	11 - 34	
				Swift Formation	373 - 415	
				Disconformity		
				Rierdon Formation	112 - 124	
	Triassic			Piper Formation	365 - 413	
				Unconformity		
		Spearfish Formation	21 - 134			
	Pennsylvanian			Unconformity		
				Amsden Formation	74 - 239	
Paleozoic	Mississippian	Big Snowy Group	Unconformity			
			Heath Shale	42 - 171		
			Otter Formation	129 - 172		
		Madison Group	Kibbey Sandstone	126 - 172		
			Charles Formation	605 - 755		
			Mission Canyon Limestone	490 - 680		
			Lodgepole Limestone	592 - 593		

* Deontes earth materials exposed on Figure I-1

Chart modified for References 8, 9 and 32

APPENDIX B

GEOLOGIC TIME SCALE

APPENDIX B
THE GEOLOGIC TIME SCALE

Era	Period	Epoch	Approximate Length of Time before Present (Millions of Years)
Cenozoic	Quaternary	Holocene (Recent)	.011
		Pleistocene	1.8-2
	Tertiary	Pliocene	5-7
		Miocene	24
		Oligocene	37
		Eocene	53
		Paleocene	65
		Mesozoic	Cretaceous	136-145
Jurassic	190-195		
Triassic	225		
Paleozoic	Permian	280	
	Pennsylvanian	325	
	Mississippian	345	
	Devonian	395	
	Silurian	430	
	Ordovician	500	
	Cambrian	570	
	Precambrian	4500	
Origin of Earth			4500

APPENDIX C

EARTH MATERIALS

APPENDIX C

EARTH MATERIALS

Earth material exposed within the study area can be divided into two general categories. Materials of the first group are soils and others surficial deposits of Quaternary age. These materials mantle the ground surface to varying depths, ranging up to several hundred feet thick.(7) Soils are relatively young deposits derived from underlying earth material. Because of their relatively recent origin and mode of accumulation, many of the soils tend to be rather loose, porous and either unconsolidated or poorly consolidated.

In addition to the surficial earth material commonly considered as soil or topsoil, other surficial material present include alluvium, colluvium, dune sand, land and pond deposits as well as assorted glacial deposits.

The second major category of earth material consists of bedrock units of Cretaceous age, which underlie the Quaternary surficial deposits. These materials are considerably older and generally more consolidated than the surficial material. Bedrock material exposed within the study area include the Hell Creek formation, The Fox Hills Formation, and the Bearpaw Shale. (Note: A geologic time scale is included as Appendix B.)

SOILS

Although the surficial soils have no effect on the geothermal resource, the physical properties of these soils may be of some engineering and design importance relative to construction and maintenance of building foundation, pipe lines, etc. Among the physical properties that often can affect construction are: soil drainage characteristics, permeability, shrink-well behavior and corrosivity.

The U.S. Department of Agriculture, Soil Conservation Service (SCS) is currently conducting a soil investigation in the Poplar, Montana area (personal communication with Edward Stein of the Wolf Point, SCS office). Although their survey is not yet completed, initial field data suggests that the town of Poplar is mantled by Williams and Zahill loams. These soils are typically well drained, greater than 5+ feet thick, and have low permeabilities. They are moderately expansive.

Corrosivity of these soils is low for concrete and high for uncoated steel (personal communication with Dennis Smitana, Wolf Point, SCS office). The following is a discussion of soil types shown in Figure II-1.

Alluvium (Qal)

Following the retreat of the last ice sheet, the Missouri River and its major tributaries have been accumulating moderately to well sorted unconsolidated clay, silt, sand and gravel in their valleys. Although the composition of the alluvium may be somewhat variable, most of the deposits in the upper portions of the

alluvium typically have a higher percentage of fine-grained materials than does the lower portion.(24) Individual layers or beds are generally lenticular and range in thickness from 1₊ to 4₊ feet. Laterally, these layers may extend up to several hundred feet.(32) Average thickness of the alluvium is on the order of 50₊ feet; but may be as much as 130₊ feet thick under the Missouri River flood plain.(7)

Fan Alluvium/Colluvium (Qac)

The fan alluvium and colluvium deposited, as defined by Colton,(7) are scattered throughout the study area. Accumulations of these generally poorly consolidated, often porous materials, result from a combined action of rainwash and mass wasting. These agents tend to move superficial material downslope in response to gravity and concentrate them in stream valleys, swales, along the base of steeper slopes or in other areas of gently sloping ground. The composition of these materials typically reflects the parent material from which they were derived. Therefore, these deposits tend to vary in composition from one location to another. Alluvium/colluvium deposits derived from the Bearpaw Shale tend to contain more clay, whereas those materials derived from the Hell Creek or Fox Hills formations consist chiefly of silt and sand. Deposits derived from till tend to range from pebbly to gravel clay. Thickness of the alluvium/colluvium deposits tend to vary from a few feet up to 20₊ feet.(7)

Dune Sand (Qd)

Sand dune deposits are located northeast of Poplar. The sand contained within these deposits is generally fine-grained, well-sorted, stratified and unconsolidated.

The sand material was deposited by the wind, probably from older glacial outwash deposits.(32) Maximum thickness of these dune deposits is estimated to be approximately 20₊ feet.

Lake/Pond (Ql)

Lake and pond deposits are limited to small, isolated pockets located north and east of Poplar. They consist of dark-gray clay and/or silty clay containing a few pebbles. Probably deposited in intermittent bodies of water by wind and/or water, these lake and pond deposits have an estimated maximum thickness of 16₊ feet.

Kintyre Formation (Qki)

The Kintyre Formation consists of fluviolacustrine (stream and lake) sediments which were probably deposited for the most part as stagnant ice in the old Missouri River Valley.(24) This formation consists of a basal olive-brown clay which is overlain by semi-consolidated buff to brown silt and very fine-grained sand interbedded with minor amounts of clay and silty clay.(24) Located north of the Missouri River flood plain, the Kintyre Formation has a maximum thickness of approximately 150₊ feet.(7)

Glacial Till(Qt)

Glacial till mantles most of the upland areas within the study area (Figure II-1). Both the town of Poplar and the proposed housing development site east of Poplar are underlain by this material. The till consists of a moderately to well-

compacted, heterogeneous mixture of clay with lesser amounts of silt, and, pebbles, cobbles and boulders which were deposited as unsorted debris by glacial ice. Because of the method of deposition, the till is typically unsorted and unstratified. Average thickness of the till commonly ranges from 10 $\pm$ to 20 $\pm$ feet, however, locally may be in excess of 100 $\pm$ feet thick. Stratigraphically, the till unconformably overlies the Sprole Silt, the Hell Creek Formation and the Bearpaw Shale.

Outwash Deposits (Qo)

Outwash deposits are located chiefly along drainage courses in the northern portion of the study area (Figure II-1). Typically, these deposits consist of sandy gravel and silt, are limited in areal extent, and generally overlie till deposits. Basically, the outwash deposits represent remnants of larger glacial-outwash deposits that once filled the floors of modern drainage valleys. However, a change in the stream regimen in postglacial time resulted in the erosion and dissection of these deposits, leaving the discontinuous terrace remnants of outwash deposits that are in existence today.(24) Average thickness of these deposits is approximately 15 $\pm$ feet, however, may be as much as 60 $\pm$ feet.(24)

Sprole Silte (Qs)

Sprole silt is exposed in several small gullies in the northern and eastern portions of the study area (Figure II-1). This unit consists chiefly of bedded to massive silt. The silt is yellowish gray, brown or reddish brown, clayey, plastic, often thin bedded and locally limonitic. The lower half of the unit consists of well-stratified

silt and clay, and contains pebbles. Bedding is less pronounced or more massive in the upper half of the unit. This Sprole silt was probably deposited in a lake formed when the ice advanced and blocked the Missouri River.(6) Locally, the Sprole silt overlies the Wiota Gravels, and is estimated to be approximately 60+ to 100+ feet thick.

Wiota Gravels (Qw)

Wiota Gravels are limited to a few isolated pockets in the northern portion of the study area. Most outcrops of this unit are located high on the sides of small drainage gullies. The Wiota Gravels consist of sand, silt, clay and gravel. Generally, the lower portion of the unit consists of moderately well-stratified, sandy gravel containing numerous lenses of medium-grained sand. The upper part of the unit is composed of silt and fine to medium-grained sand with intercolated clay lenses.(24) The Wiota Gravels often vary in nature from one location to another, and may consist of only the upper or lower parts or consist entirely of medium sand.(24) Although the Wiota Gravels appear to have much in common with modern stream deposits, the Wiota Gravels are considered to be Pleistocene preglacial fluvial deposits.(24) In most places, the thickness of this material ranges from 5+ to 55+ feet.(24) Within the study area, the Wiota Gravels unconformably overlie Bearpaw Shale.

BEDROCK MATERIALS

Hell Creek Formation (Khc)

The Hell Creek Formation of late Cretaceous age is located south of the Missouri River (Figure II-1). This formation is of continental freshwater origin and consists chiefly of gray to tan shales, siltstones, sandstones, and carbonaceous shales.(7) The lower portion of the formation consists of at 50 $\pm$ feet to 100 $\pm$ feet of predominantly tan to rusty orangish brown, crossbedded sandstone.(7) This basal sandstone is differentially cemented with calcium carbonate, and the cemented zones tend to form hard ledgeforming rock. Lenses of sandstone found higher in the formation (i.e., interbedded with clays, silts and soft silty sands) often cap hills eroded in the Hell Creek Formation.(32) Total thickness of this foundation varies locally, but it ranges up to 280 $\pm$ feet in the bluffs south of the Missouri River, between Poplar and Brockton.(24) Locally the Hell Creek Formation unconformably overlies the Fox Hills Formation.

Fox Hills Formation (Khf)

The Fox Hills Formation is of late Cretaceous age and consists of an assemblage of transitional marine claystone, siltstones, and sandstones. The lower portion (i.e., 35 $\pm$ to 60 $\pm$ feet) of the formation is composed of thin beds of alternating gray claystone, siltstone and yellow, very fine-grained sandstone. The finer-grained beds are located predominantly near the base of the formation when they are transitional with the older, underlying Bearpaw Shale. A thinly bedded to massive bedded yellow, very fine-grained sandstone together with subordinate amounts of

lenticular thinly bedded gray shale and siltstone comprise the upper portion (i.e., 35 $\pm$ to 85 $\pm$ feet) of the Fox Hills Formation.(7,24) These upper beds vary in thickness and are differentially cemented with calcium carbonate. Lenticular shaped calcium carbonate cemented concretions commonly exist within the upper sandstone unit. These concretions form a conspicuous rimrock that is characteristic of eroded Fox Hills sandstone.(32) Locally, the Fox Hills Formation reaches a thickness of as much as 120 $\pm$ feet.(7) Within the study area, surface exposures of the Fox Hills Formation are limited to the hilly area south of the Missouri River (See Figure II-1).

Bearpaw Shale

The Bearpaw shale of late Cretaceous age is the oldest bedrock unit exposed within the study area. It consists of a marine, dark-gray to black clayey shale that is somewhat sandy in the upper part, where the transition between the Bearpaw shale and the overlying Fox Hills Formation is gradational.(24) Typically, the Bearpaw shale is expansive and when exposed to surface weathering, is subject to air slaking. Furthermore, it is notorious for landsliding. In addition to shale, the Bearpaw contains distinct benonite layers (1/4 $\pm$ to 2 $\pm$ inches thick), gypsum crystals and calcareous concretions.(32) Thickness of the Bearpaw shale is estimated to approximately 1,100 $\pm$ feet thick.(7) As shown on Appendix A, the Bearpaw shale is approximately equivalent to the upper part of the Pierre shale.

APPENDIX D

SYMBOL KEY

APPENDIX D

Butterfly valve

Manual flow controller

HANDS/OFF/AUTO

Equipment control (pumps)

Pressure relief valve

Pressure reducing valve

Plate type heat exchanger

To transfer heat from one medium to another without direct contact

Pump

Prime mover

Air compressor

To maintain a preset pressure in the expansion tank

Computer

Takes flow signal from flow transmitter (4-20MA) and $\Delta T(^{\circ}F)$ from subtractor and computes the BTU/hr usage

Subtractor

Takes difference of temperature from two (2) sources and transmits 4-20 MA signal proportional to the difference for computer input

APPENDIX D

<u>SYMBOL</u>	<u>NOMENCLATURE</u>	<u>PURPOSE</u>
	Pressure gauge (#1 in 2)	Pressure indication
	Temperature transmitter (°F) Panel mounted	Transmits a 4-20 MA signal logic box or meter recorder
	Temperature gauge (°F)	Temperature indication
	Flow indicator and transmitter with differential type flow tube. Panel mounted (GPM)	Transmitter section sends 4-20 MA signal proportional to flow (GPM). This signal can be used for remote indication or control
	Flow indicator (GPM) Local display	Flow indication
	Level switch, ON/OFF	For pump control to maintain desired level in tank
	Temperature indicator and controller (°F) Panel mounted	Sends 4-20 MA signal proportional to temperature reading and modulates flow of geothermal water through heat exchanger by the use of an electrical operated flow control valve with electric positioner

APPENDIX E

**DRILLING CONTRACT BID FOR
WELL NEAR POPLAR**

CENTURY DRILLING COMPANY

Drilling the Northern Rocky Mountain Area

March 14, 1980

Bruce Barron
Strata-Analysts
4211 West First St.
Santa Ana, California 92703

Attn: Bruce Barron

Enclosed, please find two copies of the contract on the well to be drilled in Roosevelt County, Montana. If we are the successful bidder, please sign one copy and return it to this office at your earliest convenience.

Also enclosed is a Century Drilling Company brochure with all the pertinent information about Rig #1 and Rig #3 which will be available for the drilling of your well.

If you have any questions, please feel free to call.

CENTURY DRILLING COMPANY

By:
Donald Donahue
Field Superintendent

Don Donahue

DD/wf
Encl:

CENTURY DRILLING COMPANY
P.O. BOX 0
Shelby, Montana 59474

THIS DRILLING CONTRACT, made and entered into this 14th day of
March, 1980, by and between BRUCE BARRON of
4211 West First St.
Santa Ana, California 92703, hereinafter referred to as "Operator"
and CENTURY DRILLING COMPANY, a Montana Corporation, 125 Main Street, Shelby,
Montana, hereinafter referred to as "Contractor."

W I T N E S S E T H :

THAT WHEREAS, Operator desires to employ Contractor as an independent
contractor to drill a well for oil and/or gas hereinafter referred to in the
form, time and manner provided, to be located in the _____ of Section
____, Township _____, Range _____, Roosevelt County, Montana.
The said well to be designated as _____.

1.

NOW, THEREFORE, on or before August 15, 1980 Contractor shall commence
actual drilling of said well, and thereafter shall prosecute the drilling of
same with due diligence to a sufficient depth to penetrate the Madison
formation, or 6000' depth, whichever is the lesser depth; with hole to suf-
ficient size and condition to permit the setting of 5-1/2 inch production casing.
Operator shall have the right to complete said well at a lesser depth if com-
mercial production is encountered. It is agreed by both parties that time is
of the essence of this contract.

2.

Contractor shall furnish all labor, materials, supplies, equipment and
other items applicable under Schedule "A" attached hereto which are necessary
to drill said well. Contractor represents that his tools and equipment are
in good and usable condition, and agrees to drill the well in a workmanlike
manner in accordance with approved oil field practices and in strict conformity
with applicable federal, state and local laws, orders, rules and regulations.
In the performance of the work herein contemplated, Contractor is an independent

contractor with authority to control and direct performance of the details of the work, Operator being interested only in results obtained; however, the work contemplated herein shall meet the approval of Operator and be subject to the general right of inspection and supervision herein provided to Operator to assure the satisfactory completion thereof.

3.

Contractor agrees to assume full liability for, and hold operator harmless against, all claims whatsoever arising as a result of blowouts, explosions or accidents incident to drilling operations conducted by Contractor hereunder, and further agrees to indemnify and forever save from harm and expense said Operator and its successors and assigns, from all claims, demands and causes of action of any nature for personal injuries or death arising in favor of third parties or employees of Contractor, and agrees to maintain at its expense sufficient insurance, in full compliance with the laws of the state in which said well is being drilled, and will furnish Operator with evidence of same wherein Operator will be named as one of the insured. Contractor further agrees to indemnify and forever save Operator harmless from and against all labor and materialmen's liens which may arise from Contractor's operations covered herein.

4.

Operator shall provide or furnish the applicable items of materials, equipment and services as shown on the attached Schedule "A".

5.

All work performed at the request of Operator which is in addition to work specifically included hereunder shall be paid for at applicable daywork rates as shown under Schedule "A". When operations are conducted on a daywork basis, Operator shall have full and exclusive control, and, notwithstanding Article 3, Operator shall assume liability for Contractor's equipment, as well as Owner's equipment. In the event the hole should be lost or damaged while Contractor is working for Operator on a daywork basis, or as a result of said daywork, Owner shall be responsible for any such loss or damage.

6.

As consideration for the work performed hereunder in accordance with Schedule "A", Operator agrees to pay within THIRTY (30) days of receipt of invoice and Contractor agrees to accept the sum of DAYWORK plus amounts accruing under special provisions on attached Schedule "A" and work performed on a daywork basis. When invoice is not paid within the net period defined above, the account will begin to accrue an interest charge at the rate of 10% per annum.

7.

Neither Operator nor Contractor shall be liable to the other for any delays or damages or any failure to act due, occasioned, or caused by reason of federal or state laws or the rules, regulations, or orders of any public body or official purporting to exercise authority or control respecting the operation covered hereby, including the use of tools and equipment, or due, occasioned, or caused by strikes, action of the elements, or causes beyond the control of the parties affected hereby and delays due to the above causes, or any of them shall not be deemed to be a breach of or failure to perform under this agreement.

8.

all information obtained by the Contractor in the conduct of drilling operations on this well, including but not limited to, depth, formation penetrated, the results of any drill stem testing, logging, coring, sample collecting, running of production casing, shall be considered confidential, privileged information, and shall not be divulged by Contractor or his supervisory employees to any person, firm or corporation other than Owner's representatives.

THIS AGREEMENT shall be binding upon the parties hereto, their heirs, executors, administrators, successors and assigns.

IN WITNESS WHEREOF, this Contract is executed by the parties hereto the day and year first above written.

OPERATOR:

BRUCE BARRON

BY: _____

(Title)

CONTRACTOR:

CENTURY DRILLING COMPANY

BY: Donahue

(Title) Field Superintendent

SCHEDULE "A"

DRILLING BID SPECIFICATIONS

Attached to and made part of that certain Drilling Contract dated March 14, 1980, by and between BRUCE BARRON as Operator, and CENTURY DRILLING COMPANY, as Contractor, indicating those items of service, cost and equipment to be provided by the parties hereto and expressing the intent of both the Operator and the Contractor.

Well Name _____ Field or Area Poplar
 Location Roosevelt County, Montana
 Contract T.D. 6000' Target Zones Madison

SERVICE OR ITEMS TO BE FURNISHED BY;	OPR.	CONTR.	REMARKS
1. <u>Roads and Location</u>	<u>X</u>		
2. <u>Right-of-Way</u>	<u>X</u>		
3. <u>Maintenance of Access Roads</u>	<u>X</u>		
4. <u>Dirt Work for Pits</u>	<u>X</u>		
5. <u>Complete Rotary Drilling Rig, Fuel, Wash, Labor, Supervision and insurance.</u>		<u>X</u>	<u>At Daywork Rates</u>
6. <u>BOP Stack, Hydraulic Accumulator, Remote Closing Unit, Kill and Choke Manifold</u>		<u>X</u>	<u>Test @ 500# for 15 Min.</u>
7. <u>Surface Casing</u>	<u>X</u>		
a. <u>Rig Time</u>	<u>X</u>		
b. <u>Haul Surface Casing</u>	<u>X</u>		
c. <u>Weld Surface Casing</u>	<u>X</u>		
d. <u>Cement and Cementing Service</u>	<u>X</u>		
8. <u>Water at source & transportation</u>	<u>X</u>		
9. <u>Mud and mud additives, including lost circulation materials and services</u>	<u>X</u>		
10. <u>Oil as Mud Additive</u>	<u>X</u>		
11. <u>Drill 7-7/8 hole under surface casing</u>		<u>X</u>	<u>At daywork rates</u>
12. <u>Drilling past Contract T.D.</u>	<u>X</u>		
13. <u>Logs:</u>			
a. <u>Third Party Service</u>	<u>X</u>		
b. <u>Rig Time</u>	<u>X</u>		
14. <u>Drill Stem Tests:</u>			
a. <u>Third Party Service</u>	<u>X</u>		
b. <u>Rig Time</u>	<u>X</u>		
15. <u>Coring:</u>			
a. <u>Third Party Service</u>	<u>X</u>		
b. <u>Rig Time</u>	<u>X</u>		
16. <u>Circulating for samples and/or waiting on Operator's Orders and/or Equipment</u>	<u>X</u>		

17. <u>Rig Time for Running Oil String</u>	X		
18. <u>Power Tongs and/or extra labor for running oil string</u>	X		
19. <u>Cement and Cementing service for oil string</u>	X		
20. <u>Rig Time While Waiting on Cement:</u>			
a. <u>Surface Casing</u>	X		
b. <u>Oil String</u>	X		
21. <u>Cement and Cementing Service for plugging hole</u>	X		
22. <u>Rig Time for Plugging Hole</u>	X		
23. <u>Cleaning location, covering pits</u>	X		
24. <u>Dry Hole Marker</u>	X		
25. <u>Rig Move:</u>			
a. <u>On Location</u>	X		
b. <u>Off Location</u>	X		
26. <u>Bits, special for drilling igneous formation, etc.</u>	X		
27. <u>Cumulative rig time to combat lost circulation, blowout, water flow or impenetrable formations</u>	X		
28. <u>Crew mileage & subsistence</u>	X		

SPECIAL PROVISIONS:

1. For cores and/or drill stem tests not included above, Contractor shall provide same on a turnkey basis as follows:

Testing:	Each Successful Single Packer DST	\$	
	Each Successful Double Packer DST	\$	OPERATOR
	Each Misrun	\$	

The above turnkey prices include the base charge, safety joint and jars if required in the opinion of the Contractor. All additional equipment and/or services in conjunction therewith will be charged to the Operator at cost.

Coring:	Each Trip for Core Barrel	\$	
	Each Foot of Hole Cored	\$	OPERATOR
	Minimum Charge per Core	\$	
	Bits for Reaming	\$	

2. All Hookwall, Straddle or Lynes Tests to be on Daywork basis only.
3. In the event of lost circulation, blowout, water flow, or drilling igneous rock, wherein Operator must furnish rig time and materials (mud additives, including water) used to combat same in excess of 0 hours, and as a result thereof Operator desires to terminate efforts to combat and remedy same, then the payment due Contractor from Operator under this contract shall be Contractor's actual costs for outside services and materials used; plug rig time used calculated at the below listed daywork rates plus 15%. \$350.00
If boiler is required the daily rate including fuel shall be \$225.00 per day.

Footage bid \$ N/A Turnkey Bid as per Schedule "A" \$ N/A

DAYWORK RATES:	While Drill Pipe is in use:	\$ 3,960.00	per day
	While Drill Pipe is not in use:	\$ 3,960.00	per day
	Standby with Full Crews:	\$ 3,960.00	per day
	Standby with Watchman Only:	\$ 3,660.00	per day

APPROVED AND ACCEPTED:

Operator: _____

Contractor: _____

APPENDIX F

CODIFIED NAVAJO TRIBAL UTILITY AUTHORITY CHARTER

124 § 1

PUBLIC UTILITIES

Ch. 1

§ 1. History

The Navajo Tribal Utility Authority was created by the Tribal Council on January 22, 1959, in order to bring electric power to Shiprock, New Mexico. The Authority has expanded into natural gas, water, and sewer utility operations, as well as increasing its electric services.

By Council Resolution CN-61-59, the Navajo Tribal Utility Authority was authorized to acquire, construct, operate and maintain utility systems throughout the Navajo Reservation. Since then the Authority has extended the benefits of reliable utility services to substantial portions of the Reservation. The rapid growth of Navajo Tribal Authority in five years' time has occasioned certain management problems which this chapter is designed to remedy.

HISTORY

Source. Advisory Committee Res. ACN-149-65, as amended by Res. ACD-158-65, passed Dec. 13, 1965, and ACJA-8-66, passed Jan. 28, 1966.

Reorganization of Tribal Utility Authority. Advisory Committee Res. ACJN-82-65, passed June 10, 1965, acting on the authority granted by CAP-46-65, adopted a series of bylaws for the Utility which were rescinded by Advisory Committee Res. ACN-149-65, passed Nov. 3, 1965, and a revised Plan of Operation was submitted for approval to the Commissioner of Indian Affairs.

Advisory Committee Res. ACN-149-65 was amended by Advisory Committee Res. ACD-158-65, passed Dec. 13, 1965, and a further revision of the Plan of Operation was submitted for approval to the Commissioner of Indian Affairs.

Advisory Committee Res. ACJA-8-66, § 1, passed Jan. 28, 1966, confirmed ACD-158-65 and revised Plan of Operation attached thereto. ACJA-8-66, § 2, acknowledged commissioner's letter of approval dated Jan. 13, 1966.

ACJA-8-66, § 3, provided: "The Enterprise Application and Agreement and approval of same by the Commissioner for the Navajo Tribal Utility Authority to enterprise status is hereby further confirmed and staff members of the Utility Authority are directed to proceed with all necessary steps and measures for conversion to enterprise status at the earliest possible date."

Execution of contracts. Prior to the reorganization of the Utility, the Chairman of the Tribal Council was authorized to execute "all contracts necessary to the efficient operation of, and rendering of services by", the Utility, and was authorized to delegate execution of service agreements and contracts, where reasonable annual charges did not exceed \$1,000, to the several managers of the Utility by Tribal Council Res. CAP-42-65, passed Apr. 22, 1965.

Accounting procedure. Prior to the reorganization of the Utility, Advisory Committee Res. ACJN-78-65, passed June 9, 1965, and Tribal Council Res. CJY-55-65, passed July 20, 1965, directed that all books, records, and accounting transactions be handled as if enterprise status had been approved, from July 1, 1965, until the adoption of a Plan of Operation for the Utility.

Transfer of existing facilities. Plan of Operation, § XI, provided: "The existing plant and facilities of the Navajo Tribal Utility Authority, including all electric, natural gas, water and sewer systems now in operation or under construction, as of the effective date hereof (which totaled \$8,746,553.23, as of June 30, 1964), are to be transferred to the Enterprise and accounted for in accordance with applicable regulations and statutes. Additional funds for capital

Ch. 1

TRIAL UTILITY AUTHORITY

T.21 § 3

expenditure for construction of further facilities, as recommended by the Management Board may be supplied from Tribal funds on approval of the Navajo Tribal Council and the Secretary of the Interior or his authorized representative, or from outside sources with the approval of the Advisory Committee and the Secretary of the Interior or his authorized representative."

Advisory Committee Res. ACD-245-66, passed Dec. 13, 1966, authorized transfer of all Fort Defiance, Arizona, Water and Sewerage facilities and appurtenances thereto of P.L. 86-121 Project No. WI-61-320 to Tribal Utility Authority, subject to acceptance of Management Board.

Power supply lease and agreement. Tribal Council Res. CJY-46-60, passed July 21, 1960, authorized lease of plant site for generating power and agreement for supply of power with Arizona Public Service Company. Tribal Council Res. CF-18-66, passed Feb. 23, 1966, Advisory Committee Res. ACMY-81-66, passed May 27, 1966, and Res. ACMY-79-66, passed May 27, 1966, authorized and approved supplemental lease and agreement.

Repayment schedule. Plan of Operation, § XII, provided: "The Tribal Council shall determine whether the whole or any part of the Tribal funds advanced or facilities transferred to this Enterprise shall be regarded as fixed investment. The portion of Tribal funds, if any, advanced to the Enterprise on a loan basis, shall bear interest at a rate to be agreed upon and the amount thereof shall be repaid at the times and in the manner fixed by agreement."

Accumulated sick leave. Advisory Committee Res. ACJN-79-65, §§ 1, 2, passed June 9, 1965, authorized the Tribal Utility to pay accumulated annual leave and establish and transfer funds for accumulated sick leave, but payment to be made only on the Utility's becoming a Tribal enterprise.

Authority. Plan of Operation, § XVIII, provided: "Tribal Council Resolutions CJA-14-59, CN-61-59, CMY-22-60, CD-61-61, and CAP-46-65 contain the authority for development of the Navajo Tribal Utility Authority."

Organization chart. Plan of Operation, § XIX, contained a prepared organization chart to "be changed as the General Manager and Management Board require".

§ 2. Name, location and place of business

(a) Navajo Tribal Utility Authority.

(b) The principal place of business and the office of the Enterprise shall be at Window Rock, Arizona, and the post-office address of the principal office is Post-Office Box 68, Window Rock, Arizona.

(c) The Enterprise may also have offices at such other place or places as the Management Board may from time to time direct, or as the operation of the Enterprise shall require.

HISTORY

Source. Advisory Committee Res. ACN-149-65, as amended by Res. ACD-158-65, passed Dec. 13, 1965.

§ 3. Seal

The seal of this Enterprise shall consist of two concentric circles between which shall be the name of the Enterprise and the word "seal", and in the center shall be the words, "An Enterprise of the Navajo Tribe".

HISTORY

Source: Advisory Committee Res. ACN-149-65, as amended by Res. ACD-158-65, passed Dec. 13, 1965.

§ 4. Duration

The duration of the Enterprise is perpetual.

HISTORY

Source: Advisory Committee Res. ACN-149-65, as amended by Res. ACD-158-65, passed Dec. 13, 1965.

§ 5. Purposes

(a) *General.* The purposes for which the Navajo Tribal Utility Authority is organized are as follows:

(1) To operate, maintain, and promote existing utility systems furnishing electric, gas, water, and sewer utility services on the Navajo Indian Reservation.

(2) To expand and execute such extensions of existing utility systems as are efficient and feasible.

(3) To plan for, provide and furnish utility services to all areas of the Navajo Reservation, where such services are determined to be feasible and economic.

(4) To carry out the purposes and intent of the Act of April 19, 1950, Public Law 474, 81st Congress, the Navajo-Hopi Rehabilitation Act.

(5) To promote the use of utility services where available in order to improve the health and welfare of the residents of the Navajo Indian Reservation.

(6) To provide a fair return to the Tribe on its investment consistent with the furnishing of utility services at low cost to residents of the Navajo Indian Reservation and with the employment of Navajo people in the operation of the Enterprise.

(b) *Ancillary.* To do everything necessary, proper, advisable, or convenient for the accomplishment of the purposes hereinabove set forth, and do all things incidental thereto or connected therewith, which are not forbidden by law, or this chapter for the Enterprise.

HISTORY

Source: Advisory Committee Res. ACN-149-65, as amended by Res. ACD-158-65, passed Dec. 13, 1965.

§ 6. Control of operations

It is intended that control and operation of this Enterprise shall be patterned as closely as is feasible on the lines of a chartered public

service corporation of similar magnitude with a Management Board comparable to a Board of Directors of such a corporation.

HISTORY

Source: Advisory Committee Res. ACN-149-65, as amended by Res. ACD-158-65, passed Dec. 13, 1965.

§ 7. Management Board; purpose; duties and powers

(a) *Direction of purposes and exercise of powers by Management Board.* Subject to applicable Federal and Tribal Laws and Regulations, the Management Board shall, direct the purposes and exercise the following powers and duties:

(1) The Management Board of the Navajo Tribal Utility Authority is delegated authority and responsibility for the management and operation of the Enterprise.

(2) The Management Board is authorized to direct the operations to accomplish the purposes set forth in 21 N.T.C. § 5 and to exercise the powers set forth in subsection (b) below without previous authorization or subsequent approval and all parties dealing with the Authority shall have the right to rely upon any action taken by the Management Board pursuant to such authorization.

(3) The Management Board shall exercise full power and shall be responsible for the custody and management, operation, inventory, and maintenance of all utilities and facilities, the planning, constructing and operating of all new facilities, and the taking of any and all usual, necessary and convenient actions incidental thereto including, should it be deemed advisable or desirable, the borrowing of funds, and the making of contracts or commitments necessary to the functioning of the organization.

(4) The Management Board shall function in much the same capacity as an elected Board of Directors of a chartered public service corporation, and shall be responsible for making investment decisions, subject to the limitations contained herein or in any advance of funds; for the establishment and maintenance of effective operating policies; the selection of management personnel except that the person selected as the General Manager shall be approved by the Tribal Council; and for continuous supervision of performance.

(5) It shall be expected to exercise its authorized powers in the best interests of the Navajo Tribe within the limits of responsible business judgment and with the stipulation that it shall not incur contract obligations in excess of the ability of the Enterprise to make payment on due date.

(6) It shall select from its own membership a Chairman of the Board and other officers; and it shall adopt such rules as it may determine necessary for the orderly conduct of its business.

(7) Minutes of each meeting shall be made available promptly after each meeting, to the Advisory Committee of the Tribal Council, the General Superintendent and such other officials as may be designated from time to time.

(8) Members shall be reimbursed for expenses incurred in attending its meetings, and the Board may, at its discretion, propose a fee to be paid to its members (subject to approval of the Advisory Committee of the Tribal Council) on a per-meeting attended or an annual basis.

(9) The Chairman of the Board shall make a formal report to the Tribal Council and the Advisory Committee of the Tribal Council not less often than annually and in such report, shall include a summary of the budget which the Management Board has approved for the coming fiscal year.

(10) It shall establish purchasing policies and procedures, giving usual and essential latitude to the General Manager and his delegated employees, but establishing limitations on amounts which may be expended without specific approval of the Board.

(11) No contract or other transaction between the Navajo Tribal Utility Authority and any one of the members of the Management Board, or between Navajo Tribal Utility Authority and any corporation, partnership, firm or other legal entity in which one or more of the Management Board has an interest directly or indirectly shall be valid, for any purpose, unless the entire interest of the Director or Directors in such corporation, firm or other legal entity is fully disclosed to the Management Board and the proposed contract or transaction shall be approved, ratified or confirmed by the affirmative vote of at least a majority of the entire Management Board who are not so interested.

(12) The Management Board, in its discretion, may submit any such contract or act for approval or ratification at any regularly called or noticed meeting of the Advisory Committee of the Tribal Council; and any contract or act that shall be approved or ratified by the vote of the majority of the Advisory Committee of the Tribal Council shall be valid and binding upon the parties.

(13) The Management Board shall submit any contract or act wherein a Tribal Officer or employee may have an interest directly or indirectly in the matter or transaction to any regularly called or

noticed meeting of the Advisory Committee of the Tribal Council for approval. Any contract or act that shall be approved or ratified by the vote of the majority of the Advisory Committee of the Tribal Council shall be valid and binding upon the parties.

(b) *Enumerated powers.* Subject to Tribal approval where required, and applicable Tribal and Federal laws and regulations, and solely in furtherance of the limited purposes set forth in 21 N.T.C. § 5, the Management Board shall have the following powers:

(1) *Facilities.* The Management Board shall exercise full authority and shall be responsible for the custody, management and operation of all utility property and facilities owned and operated by the Navajo Tribe, including such expansions and enlargements thereof as shall be authorized; for the planning, construction and operation of additional utility facilities including the negotiation and execution of engineering and construction contracts and for taking of any and all usual, necessary, and convenient actions incident thereto.

(2) *Capacity to act.* To have the capacity to act and to direct the officers of the Enterprise to act in the same capacity as that of natural persons, but to have authority to perform only such acts as are necessary, convenient or expedient to accomplish the purposes set forth in 21 N.T.C. § 5, and such as are not repugnant to laws and regulations applicable to this Enterprise.

(3) *To appoint officers and agents.* To elect or appoint officers, agents, engineers, auditors, and such professional consultants as in the opinion of the Board or Advisory Committee may be needed from time to time, and to define their duties and fix their compensation; provided, however, that unless the Advisory Committee shall consent and approve otherwise, the auditors shall be the firm of accountants employed by the Navajo Tribe; and provided further, that the selection of a General Manager shall be approved by the Tribal Council. The Management Board, at Enterprise expense, shall require the bonding of all officers, agents or employees responsible for the handling or safeguarding of funds, property or other assets of the Enterprise.

(4) *To act as agent.* To act in any state, territory, district, or possession of the United States, or in any foreign country for and on behalf of the Tribal Enterprise.

(5) *To deal in real property.* To negotiate the acquisition of (by purchase, exchange, lease, hire or otherwise), utilize, improve, manage, operate, and to negotiate the sale, lease, or mortgage of,

either alone or in conjunction with others, real estate of every kind, character and description and any interest therein, necessary or incidental to the purposes set forth in 21 N.T.C. § 5 except as prohibited by law. Title to all such real property shall be taken in the name of the Navajo Tribe of Indians and title to all trust or restricted real property shall be and remain in its trust or restricted status.

(6) *To deal in personal property, generally.* To acquire (by purchase, exchange, lease, hire or otherwise), hold, own, manage, operate, mortgage, pledge, hypothecate, exchange, sell, deal in and dispose of, either alone or in conjunction with others, personal property, and interest therein and commodities of every kind, character and description necessary or incidental to the purposes set forth in 21 N.T.C. § 5.

(7) *To deal in inventions, copyrights, and trademarks.* To acquire (by application, assignment, purchase, exchange, lease, hire or otherwise), hold, own, use, license, lease, and sell, either alone or in conjunction with others, the absolute or any partial or qualified interest in and to inventions, improvements, letters patent and applications therefor, licenses, formulas, privileges, processes, copyrights and applications therefor, trademarks and applications therefor, and trade names, and that title of all such acquisitions shall be taken in the name of the Navajo Tribe of Indians.

(8) *To execute guaranties.* To make any guaranty respecting indebtedness, interest, contracts or other obligations lawfully entered into by or on behalf of the Enterprise, to the extent that such guaranty is made in pursuance of the purposes set forth in 21 N.T.C. § 5, provided, that no such guaranty in excess of \$200,000 shall be made without the prior written approval of the Advisory Committee.

(9) *Depository.* To designate and approve all depositories used for the deposit of funds of the Enterprise.

(10) *To make contracts.* To enter into, make, perform and carry out or cancel and rescind, contracts for any lawful purpose pertaining to its business necessary or incidental to the purposes set forth in 21 N.T.C. § 5, including the negotiation of contracts subject to R.S. § 2103, 25 U.S.C. § 81 (1964), which shall, as therein provided, become effective only upon the approval of the Secretary of the Interior.

(11) *To approve budgets.* To give initial approval to annual Enterprise budgets, and to take final approval action with reference to the use of funds under the exclusive control of the Enterprise for operating and capital addition purposes.

(c) *Ancillary powers.* To have and exercise all powers necessary or convenient to effect any or all of the purposes for which the Authority is organized.

(d) *No construction of powers as purposes.* The powers enumerated herein shall not be construed as purposes but the Navajo Tribal Utility Authority shall have and exercise such powers solely in furtherance of, but not in addition to, the limited purposes set forth in 21 N.T.C. § 5.

HISTORY

Source. Advisory Committee Res. ACN-149-65, as amended by Res. ACD-153-65, passed Dec. 13, 1965, and ACJA-8-66, passed Jan. 28, 1966.

Amendments—1966. ACJA-8-66, § 2, amended subsec. (b)(10) generally.

Delegation to act. Advisory Committee Res. ACMA-21-66, § 5, passed Mar. 14, 1966, delegated approved Management Board to act in all matters incidental and pursuant to Tribal Council Res. CAP-46-65 and its approved Plan of Operation.

Compensation. Advisory Committee Res. ACMY-74-66 provided: "(1) The Advisory Committee of the Navajo Tribal Council does hereby approve as provided in the approved Plan of Operation, beginning with the 14th day of March, 1966, and until otherwise provided by an approved resolution of the Management Board of the Navajo Tribal Utility Authority Enterprise, each and every person who shall have been duly elected to and shall hold office of Director of this Enterprise shall be entitled to receive as compensation for his services as such Director, the sum of \$2,400.00 per year, to be paid in monthly installments of \$200.00 on the last day of each and every month.

"(2) Members of the Management Board of the Navajo Tribal Utility Authority shall, while in travel status in furtherance of the business of the Enterprise, be reimbursed for their actual and necessary travel expenses. Reimbursement therefor shall be made on Voucher Check issued upon presentation of statements showing the nature, purpose and extent thereof.

"(3) Any changes for the compensation of members of the Management Board for Navajo Tribal Utility Authority shall be subject to the approval of the Advisory Committee of the Navajo Tribal Council as contained in the approved Plan of Operation."

Consignment of supply contracts. Advisory Committee Res. ACAU-152-66, passed Aug. 10, 1966, consigned the following utility supply contracts to the Tribal Utility Authority:

1. Arizona Public Service Wholesale Power Supply Contract, dated Dec. 1, 1960.
2. Public Service Company of New Mexico, Electrical Service Agreement, dated July 19, 1962.
3. El Paso Natural Gas Company, Natural Gas Service Agreement, dated Feb. 15, 1963.
4. Continental Oil Company, Natural Gas Service Agreement, dated Jan. 28, 1963.

Confirmation and ratification of adoption of safety codes and rules. Advisory Committee Res. ACAU-164-66, passed Aug. 30, 1966, confirmed and ratified resolution No. NTUA-25-66 of the Tribal Utility Authority which adopted specific safety codes and rules.

Applications to put utility lines across rights of way. Advisory Committee Res. ACN-19-71 provided: "The Chairman of the Navajo Tribal Council or his designee is hereby authorized to execute any and all applications or other documents on behalf of the Navajo Tribe of Indians, for the purpose of securing permission to place utility lines across rights of way or easements within the Navajo Nation."

§ 8. Indemnification of officers, employees and members of the Management Board

The Navajo Tribal Utility Authority shall indemnify any officer, employee or member of the Management Board or former officer, employee or member of the Management Board of the Navajo Tribal Utility Authority, or any person who may have served at its request as an officer, employee or member of the Management Board, against reasonable expenses actually and necessarily incurred by him in connection with the defense of any action, suit or proceeding in which he is made a party by reason of being, or having been such officer, employee or member of the Management Board except in relation to matters as to which he shall be adjudged in such action, suit or proceeding to be liable for negligence or misconduct in the performance of duty; or except in relation to matters in which such employee was acting beyond the scope of his employment. The Navajo Tribal Utility Authority shall also reimburse to any officer, employee or member of the Management Board reasonable costs of settlements of any such action, suit or proceeding if it shall be found by a majority of the Management Board other than Directors involved in the matter of controversy (whether or not a quorum exists), that it is in the best interest of the Navajo Tribal Utility Authority and the Navajo Tribe that such settlement be made and that such officer, employee or member of the Management Board was not guilty of negligence or misconduct. Such rights of indemnification and reimbursement shall not be deemed exclusive of any other rights which such officer, employee, or member of the Management Board may be entitled to receive.

HISTORY

Source. Advisory Committee Res. ACN-149-65, as amended by Res. ACD-158-65, passed Dec. 13, 1965.

§ 9. Membership of Board; qualification; term of office

(a) *Number.* The Management Board shall consist of seven persons, all of whom shall be appointed by the Advisory Committee of the Tribal Council.

(b) *Qualification.* The members of the Management Board shall be called Directors, and shall have the following qualifications:

(1) Four of the Directors shall be members of the Tribe who speak English with fluency and who have sufficient education and experience to qualify them for learning utility business practices and procedures and making sound judgments.

(2) Four Directors shall be persons having not less than ten years' experience in business management of substantial character and at least two of such persons shall have had such experience in the management and operation of a utility business.

(3) No employee in the Bureau of Indian Affairs shall be a member of the Board.

(c) *Term of office.* Directors shall be elected for the following terms of office and shall hold office until the qualification and selection of their successors:

(1) The initial Management Board shall be appointed for a period of one year or until their successors have been appointed and qualified. Directors shall be eligible for reappointment.

(2) Beginning the second year, the Directors shall be selected and designated by the Advisory Committee in three groups, the first group of three to serve one year, the second group of two to serve for two years, and the third group of two to serve for three years. Thereafter, all terms shall be for three years.

(3) Vacancies in the Management Board may be filled by the Advisory Committee for the unexpired term of the vacant office.

HISTORY

Source. Advisory Committee Res. ACN-149-65, as amended by Res. ACD-158-65, passed Dec. 13, 1965.

Advisory Committee Res. ACS-194-68, § 2, passed Sept. 16, 1968.

Amendments—1968. ACS-194-68, § 2, amended this section by substituting "Four of the Directors" for "Three of the Directors" in subsection (1) of paragraph (b).

Appointment of members. The following resolutions appointed members of the Management Board of the Navajo Tribal Utility Authority and designated the expiration dates of the term of such members:

ACS-301-69, §§ 1, 2, passed Sept. 3, 1969.

ACS-194-68, §§ 3, 4, 5, passed Sept. 16, 1968.

ACJ-2-68, passed Jan. 5, 1968.

ACMA-21-66, §§ 2, 3, passed Mar. 14, 1966.

§ 10. Meetings of Board

(a) *Annual meeting.* The annual meeting of the Management Board shall be held at 10:30 a.m. on the second Wednesday of

Applications to put utility lines across rights of way. Advisory Committee Res. CJA-13-71 provided: "The Chairman of the Navajo Tribal Council or his designee is hereby authorized to execute any and all applications or other documents on behalf of the Navajo Tribe of Indians, for the purpose of securing permission to place utility lines across rights of way or encumbrances within the Navajo Nation."

§ 8. Indemnification of officers, employees and members of the Management Board

The Navajo Tribal Utility Authority shall indemnify any officer, employee or member of the Management Board or former officer, employee or member of the Management Board of the Navajo Tribal Utility Authority, or any person who may have served at its request as an officer, employee or member of the Management Board, against reasonable expenses actually and necessarily incurred by him in connection with the defense of any action, suit or proceeding in which he is made a party by reason of being, or having been such officer, employee or member of the Management Board except in relation to matters as to which he shall be adjudged in such action, suit or proceeding to be liable for negligence or misconduct in the performance of duty; or except in relation to matters in which such employee was acting beyond the scope of his employment. The Navajo Tribal Utility Authority shall also reimburse to any officer, employee or member of the Management Board reasonable costs of settlements of any such action, suit or proceeding if it shall be found by a majority of the Management Board other than Directors involved in the matter of controversy (whether or not a quorum exists), that it is in the best interest of the Navajo Tribal Utility Authority and the Navajo Tribe that such settlement be made and that such officer, employee or member of the Management Board was not guilty of negligence or misconduct. Such rights of indemnification and reimbursement shall not be deemed exclusive of any other rights which such officer, employee, or member of the Management Board may be entitled to receive.

HISTORY

Source. Advisory Committee Res. ACN-149-65, as amended by Res. ACD-158-65, passed Dec. 13, 1965.

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(b) *Qualification.* The members of the Management Board shall be called Directors, and shall have the following qualifications:

(1) Four of the Directors shall be members of the Tribe who speak English with fluency and who have sufficient education and experience to qualify them for learning utility business practices and procedures and making sound judgments.

(2) Four Directors shall be persons having not less than ten years' experience in business management of substantial character and at least two of such persons shall have had such experience in the management and operation of a utility business.

(3) No employee in the Bureau of Indian Affairs shall be a member of the Board.

(c) *Term of office.* Directors shall be elected for the following terms of office and shall hold office until the qualification and selection of their successors:

(1) The initial Management Board shall be appointed for a period of one year or until their successors have been appointed and qualified. Directors shall be eligible for reappointment.

(2) Beginning the second year, the Directors shall be selected and designated by the Advisory Committee in three groups, the first group of three to serve one year, the second group of two to serve for two years, and the third group of two to serve for three years. Thereafter, all terms shall be for three years.

(3) Vacancies in the Management Board may be filled by the Advisory Committee for the unexpired term of the vacant office.

HISTORY

Source. Advisory Committee Res. ACN-149-65, as amended by Res. ACD-158-65, passed Dec. 13, 1965.

Advisory Committee Res. ACS-194-68, § 2, passed Sept. 16, 1968.

Amendments—1968. ACS-194-68, § 2, amended this section by substituting "Four of the Directors" for "Three of the Directors" in subsection (1) of paragraph (b).

Appointment of members. The following resolutions appointed members of the Management Board of the Navajo Tribal Utility Authority and designated the expiration dates of the term of such members:

ACS-301-69, §§ 1, 2, passed Sept. 3, 1969.

ACS-194-68, §§ 3, 4, 5, passed Sept. 16, 1968.

ACJ-2-68, passed Jan. 5, 1968.

ACMA-21-66, §§ 2, 3, passed Mar. 14, 1966.

§ 10. Meetings of Board

(a) *Annual meeting.* The annual meeting of the Management Board shall be held at 10:30 a.m. on the second Wednesday of

October at the principal place of business, or at such other place as the Board shall fix, commencing with 1966. No notices shall be required for annual meetings.

(b) *Regular meetings.* The Management Board shall meet at least quarterly upon notice fixing the time and place.

(c) *Special meetings.* Special meetings of the Board may be held upon notice given by the Chairman, or Secretary, or by any three members of the Board, at such place as the Board shall direct or as shall be fixed by the notice.

(d) *Notice.*

(1) Notice of meetings stating the time and date, shall be given in writing by letter, telegram or radiogram properly addressed to each member according to the latest available Enterprise records, not later than five days nor more than 30 days immediately preceding the meeting excluding the day of the meeting.

(2) Notice may be waived in writing signed by the member or members entitled to such notices; whether before or after the time stated therein, and such waiver shall be deemed equivalent to the giving of such notice. Attendance of any member at the special meeting shall constitute a waiver of notice.

(e) *Quorum.* Five members of the Management Board shall constitute a quorum for the transaction of any business. The act of the majority of the members present and voting at a meeting at which a quorum is present shall be the act of the Board.

HISTORY

Source. Advisory Committee Res. ACN-149-65, as amended by Res. ACD-158-65, passed Dec. 13, 1965.

First meeting. Advisory Committee Res. ACMA-21-66, § 4, passed Mar. 14, 1966, called first meeting of Management Board to be held on a date to be fixed by Acting General Manager within 30 days of approval of resolution.

11. Executive Committee

(a) *Designation of committee.* The Management Board, by resolution duly adopted, may designate four members of the Board, two of whom shall be members of the Tribe, to constitute an Executive Committee. Following such designation of Executive Committee membership or a modification thereof, the Management Board shall give prompt notice in writing to the Advisory Committee and the General Superintendent of the members thereof. The designation of such Executive Committee and the delegation of the authority herein granted, shall not operate to relieve the Management Board, or members thereof, of any responsibility imposed upon it, or him, by law

or this Plan of Operation. No member of the Executive Committee shall continue to be a member thereof after he ceases to be a member of the Management Board. The Management Board shall have the power at any time to increase the number of members of the Executive Committee, to fill vacancies thereon, to change any member thereof, and to change the functions or to terminate the existence thereof.

(b) *Powers of the Executive Committee.* During the intervals between meetings of the Management Board, and subject to such limitations as may be required by resolution of the Management Board, the Executive Committee shall have and may exercise such authority as may be delegated by the Board.

All minutes of meetings of the Executive Committee shall be submitted to the next succeeding meeting of the Management Board for approval, but failure to submit the same or to receive the approval thereof shall not invalidate any completed or uncompleted action taken by the Enterprise upon authorization of the Executive Committee prior to the time at which the same was submitted as above provided.

(c) *Procedure, meetings.* A Chairman of the Executive Committee shall be elected by the Management Board from among the members of the Executive Committee and shall preside at meetings of the Executive Committee and perform all duties incident to the office of the Chairman of the Executive Committee, and such other duties as, from time to time, may be assigned to him by the Management Board or the Executive Committee. The Secretary of the Enterprise shall keep a record of the acts of the Executive Committee and its proceedings. In the absence of the Secretary, the Chairman of the Management Board shall designate a person to act in said capacity.

(d) *No individual authority.* The members of the Executive Committee shall act only as a committee, and the individual members shall have no power as individuals.

(e) *Notice.* Notices of all meetings of the Executive Committee shall be given by the Chairman, the Secretary, or any member thereof, in the manner provided in 21 N.T.C. § 10 (d), and may be waived as therein provided.

(f) *Quorum.* The presence of not less than three members shall be necessary to constitute a quorum for the transaction of business and the act of the majority of the members present and voting at a meeting at which a quorum is present shall be the act of the Committee.

HISTORY

Source. Advisory Committee Res. ACN-149-65, as amended by Res. ACD-158-65, passed Dec. 13, 1965.

§ 12. Principal officers

The principal officers of the Enterprise shall consist of the following:

(1) Chairman of the Management Board and Chairman of the Executive Committee, which positions may be, but need not be, held by the same person.

(2) Secretary and a Treasurer, who need not be members of the Management Board or of the Executive Committee.

(3) General Manager, who shall not be a member of the Management Board.

(4) In the discretion of the Board, there may be a Vice-Chairman of the Board, Assistant Secretary, and Assistant Treasurer. Any two of these positions may be held by the same person.

HISTORY

Source. Advisory Committee Res. ACN-149-65, as amended by Res. ACD-158-65, passed Dec. 13, 1965.

§ 13. Powers and duties

All officers and agents of the Enterprise shall have the following duties and such other duties as may be determined by resolution of the Management Board, not inconsistent with this chapter:

(1) *The Chairman of the Board.* The Chairman of the Management Board shall be chosen from among the members of the Board, shall preside at all meetings of the Board if present, and shall, in general, perform all duties incident to the office of the Chairman of the Board and such other duties as, from time to time, may be assigned to him by the Management Board. If a Vice Chairman is elected, he shall act in the capacity of the Chairman in the absence of the latter, and shall discharge any other duties designated by the Chairman.

(2) *The Secretary.* The Secretary shall keep, or cause to be kept, the minutes of the meeting of the Management Board and the Executive Committee. He shall see that all notices are duly given in accordance with provisions of this chapter. He shall be custodian of the seal and records, and in general, shall perform all duties incident to the office of the Secretary, and such other duties as may, from time to time, be assigned to him by the Management Board, the Chairman, or the Executive Committee.

(3) *The Treasurer.* The Treasurer shall be the financial officer of the Enterprise and shall have charge and custody of, and be responsible for, all funds of the Enterprise, and shall deposit such funds in such banks, trust companies, or other depositories as shall have been approved by the Management Board. He shall receive and give receipts for monies due and payable to the Enterprise from any source whatsoever; and, in general, shall perform all duties incident to the office of the Treasurer and such other duties as, from time to time, may be assigned to him by the Management Board, the Chairman, or the Executive Committee. The Treasurer shall render to the Chairman and the Board, whenever the same may be required, an account of all his transactions as Treasurer and of the financial condition of the Enterprise. He shall, at the expense of the Authority, give a bond for the faithful performance and discharge of his duties in such amount, so conditioned, and with such surety or sureties as the Management Board may require.

(4) *General Manager.* The General Manager shall be principal operating executive of the Enterprise and shall have direction of all parts of the actual operations. He shall be responsible to the Management Board as a principal operating executive of a public service corporation normally would be. He shall render reports to the Board and perform all other functions and duties specified in 21 N.T.C. § 18 for the General Manager.

HISTORY

Source. Advisory Committee Res. ACN-149-65, as amended by Res. ACD-158-65, passed Dec. 13, 1965.

§ 14. Election; term of office; qualification

The officers with the exception of the General Manager, shall be chosen annually by the Management Board at its annual meeting, or as soon after such annual meeting as newly appointed Directors shall have qualified. Each officer shall hold office until his successor is chosen and qualified, or until his death, or until he shall have resigned, or shall have been removed in the manner provided herein.

HISTORY

Source. Advisory Committee Res. ACN-149-65, as amended by Res. ACD-158-65, passed Dec. 13, 1965.

§ 15. —Removal

Any officer or agent elected or appointed by the Board may be removed by the Management Board whenever, in its judgment, the best interest of the Enterprise will be served thereby, but in the

absence of dereliction in duty, negligence or malfeasance in office, or any other good cause shown, such removal shall be without prejudice to the contract rights, if any, of the persons who are removed; provided, however, the General Manager may be removed only pursuant to any approved contract provisions.

HISTORY

Source. Advisory Committee Res. ACN-149-65, as amended by Res. ACD-158-65, passed Dec. 13, 1965.

§ 16. —Resignations; vacancies

Any officer may resign at any time by giving written notice to the Management Board, or to the Chairman, or Secretary, such resignation shall take effect at the time specified therein, and, unless otherwise specified therein, the acceptance of such resignation shall not be necessary to make it effective. Any vacancy in any office because of death, resignation, removal, or any other cause shall be filled for the unexpired portion of the term in the manner prescribed herein for election or appointment to such office.

HISTORY

Source. Advisory Committee Res. ACN-149-65, as amended by Res. ACD-158-65, passed Dec. 13, 1965.

§ 17. Other officers and agents

The Management Board may appoint such other officers and agents as it deems necessary or expedient, and may determine the duties of them, as well as the terms of their holding office.

HISTORY

Source. Advisory Committee Res. ACN-149-65, as amended by Res. ACD-158-65, passed Dec. 13, 1965.

§ 18. General Manager; functions; duties

(a) The General Manager shall be employed under a written employment contract subject to approval by the Tribal Council and the Secretary of the Interior or his authorized representative, and shall be responsible to the Management Board.

(b) The function of a General Manager shall be analogous to that of the president of a public service corporation. He shall, among other things, execute the general policies formulated by the Management Board and organize the operation of the Enterprise into departments each with its own specific duties and responsibilities.

(c) He shall exercise his best judgment in the determination of

the ways and means by which general policy set forth by the Management Board is to be effectuated.

(d) He shall be the active, operating executive of the Enterprise and shall prepare plans and annual budgets; and make suggestions as to policies and any proposals for improvements.

(e) He shall have the full authority and control over all employees of the Enterprise and shall be responsible for all department heads or other executives carrying out their assignments.

(f) He shall be responsible for the general supervision of the performance of staff in respect to all such matters as conformance to approved budgets, standards, program inspection, cost control, employee relations and in-service training.

(g) He shall render regular reports to the Board and perform all other functions and duties specified in this chapter.

(h) He shall be furnished with ample transportation and shall be reimbursed for any personal expenses he may incur in carrying out his responsibilities.

(i) The General Manager shall employ competent department heads for the usual functional responsibilities for each department.

HISTORY

Source. Advisory Committee Res. ACN-149-65, as amended by Res. ACD-158-65, passed Dec. 13, 1965.

§ 19. Accounting; fiscal year

A modern accounting system shall be established and installed by a reputable consulting firm in conformity with accounting principles generally accepted in the utility operation field. Financial and operating statements shall be provided to the Chairman of the Tribal Council, Navajo Agency General Superintendent and the Management Board not less often than quarterly. The accounting system shall insure the availability of information as may be necessary to comply with Federal, State, and Tribal regulatory requirements. Use of automatic data processing shall be encouraged wherever possible. The fiscal year of the Authority shall be July 1 to June 30th.

HISTORY

Source. Advisory Committee Res. ACN-149-65, as amended by Res. ACD-158-65, passed Dec. 13, 1965.

§ 20. Records; inspection; audits

The books, records and property of the Authority shall be available for inspection at all reasonable times by authorized representatives

of the Navajo Tribe, and upon notice to the Advisory Committee of the Navajo Tribal Council, by representatives of the Secretary of the Interior. The accounts and records of the Authority shall be audited at the close of each fiscal year in accordance with the provisions of 21 N.T.C. § 7(b). Copies of such Audit Reports shall be furnished to the parties receiving copies of the financial and operating statements and to the Advisory Committee of the Tribal Council.

HISTORY

Source. Advisory Committee Res. ACN-149-65, as amended by Res. ACD-158-65, passed Dec. 13, 1965, and ACJA-8-66, passed Jan. 28, 1966.

Amendments—1966. ACJA-8-66, § 2, added the words “, and upon notice to the Advisory Committee of the Navajo Tribal Council, by representatives of the Secretary of the Interior” to the first sentence of this section.

§ 21. Insurance

Insurance, including liability, adequate and sufficient to protect the interests of the United States and the Tribe from losses by fire or other disaster shall be carried on all property of the Enterprise.

HISTORY

Source. Advisory Committee Res. ACN-149-65, as amended by Res. ACD-158-65, passed Dec. 13, 1965.

§ 22. Rates and charges

(a) All rates and charges for utility services shall be adopted by the Management Board after formal public hearing for which adequate notice as the Board may determine has been given.

(b) The Management Board may, in their sole discretion, negotiate with large users of a particular utility service for special rates and charges, provided, however, that such negotiated rates shall be demonstrated to be fair and equitable to all other customers or users of the Navajo Tribal Utility Authority services.

(c) Procedures shall be established by the Advisory Committee of the Tribal Council to provide for appeals of rate decisions to an impartial review board composed of specialists on utility rates.

HISTORY

Source. Advisory Committee Res. ACN-149-65, as amended by Res. ACD-158-65, passed Dec. 13, 1965.

Confirmation and ratification of Tariff Rules and Regulations. Advisory Committee Res. ACJN-95-66, passed June 15, 1966, confirmed and ratified all provisions included in Tribal Utility Authority's Tariff Rules and Regulations.

APPENDIX G

DIRECT APPLICATIONS

APPENDIX G

SURVEY OF OTHER DIRECT APPLICATIONS

The primary emphasis of the study is to assess the engineering and economic feasibility of utilizing the geothermal resource for space heating applications in the Poplar, Montana area. However, additional factors, such as (a) the potential for higher resource temperatures than earlier anticipated, (b) the economics to be gained from maximizing resource utilization, and (c) the potential availability of the 18-20,000 barrels/day (525 gpm) of hot water which is currently a wasted by-product of the oil field production, suggested that complementary applications should also be surveyed. Figure G-1 shows various direct applications (14, 18) associated with their resource temperature ranges. Some of the potentially attractive applications for the Fort Peck area are listed below.

- o Greenhouse Heating
- o Dairy Farming
- o Prawn Farming
- o Ethanol Productions

GREENHOUSE HEATING

Greenhouses utilizing heat in the temperature ranges available should be able to grow crops such as tomatoes, lettuce, cucumbers, asparagus, and mushrooms. Table G-1 lists favorable greenhouse temperature ranges for selected vegetables.⁽²⁷⁾ A typical greenhouse was used to determine the design heating

FIGURE G DIRECT APPLICATIONS AVAILABLE FOR VARIOUS RESOURCE TEMPERATURE RANGES

load, annual heating load, and other important factors. The typical greenhouse is 120 feet wide and 360 feet long, covering an area of 43,200 square feet. This one-acre greenhouse has an average wall height of 10 feet, a roof sloped at 5/12, and is heated to 65°F. The heat transfer coefficient for the walls is 1.13 BTU/hr-ft² - °F. The heat transfer coefficient for the roof is 1.22 BTU/hr-ft² - °F. (26, 2)

TABLE G-1. TEMPERATURE RANGES FOR SELECTED PLANTS

	Asparagus	Tomatoes	Cucumbers	Lettuce
Temperature Range °F	55 to 64	64 to 72	68 to 75	50 to 68

Space heating requirements for a one-acre greenhouse located in the Poplar area were determined to be 6.12M Btu/hr, as follows:

$$Q = UA = \frac{1.13 \text{ BTU}}{\text{hr-ft}^2\text{-}^\circ\text{F}} (9,600 \text{ ft}^2) (65 - (-25)^\circ\text{F})$$

$$Q = 0.98 \text{ MBTU/hr}$$

The design heat loss through the roof was determined by:

$$Q = UA = \frac{1.22 \text{ BTU}}{\text{hr-ft}^2\text{-}^\circ\text{F}} (46,800 \text{ ft}^2) (65 - (-25)^\circ\text{F})$$

$$Q = 5.14 \text{ MBTU/hr}$$

The annual heating load (AHL) would be 14,800 MBTU. It was determined by:

$$\text{AHL} = (\text{HL})(\text{dd}) = (1,650,000 \text{ BTU/dd})(8,969 \text{ dd})$$

$$\text{AHL} = 14,800 \text{ MBTU,}$$

where

$$\text{HL} = \frac{(6.16 \text{ MBTU/hr})(24 \text{ hr/day})}{65 - (-25)^{\circ}\text{F}}$$

$$\text{HL} = 1,650,000 \text{ BTU/dd.}$$

If a larger greenhouse area were used, the heating load per acre would decrease due to a decrease in wall space that would be realized over two smaller greenhouses. Thus the geothermal heat which could be available from the oil field production could support a greenhouse area of 5 to 6 acres.

DAIRY FARMING

The resource temperature is within the range of that which would be required to support a dairy farm, including the process of pasteurization. As an example, a system to which hot water traveling through a heat-exchanger at the rate of 100 gallons per minute is utilized to heat 800 gallons per hour of milk to 172°F for 15 seconds as required for pasteurization is already in operation in Oregon.⁽³⁾

The space heating requirements of sample dairy containing 200 milking cows were calculated.⁽¹⁾ The dairy would have four major buildings, as shown below, and contain over 400 animals.

- o Milking barn;
- o Milking cow barn;
- o Calf barn;
- o Heifer and dry cow barn.

The design heat load and annual heat load for the dairy were based on R-10 insulation in the wall and R-20 insulation in the ceilings. The space heating requirements for the dairy were based on Glasgow weather data and a barn temperature of 65°F. For design purposes, the space heating requirements for the dairy were determined to be 450,000 BTU/hr for the design load and 1,100 MBTU per year for the annual heating load. Table G-2 presents the heat loads for the milking barn, milking cow barn, calf barn, and heifer and dry cow barn.

TABLE G-2. HEAT LOADS FOR THE DAIRY'S FOUR MAJOR BUILDINGS

Barn	Size	Area	Design Space Heating Load	Annual Space Heating Load
Milking Barn	41 ft by 97 ft	3,977 ft ²	47,700 BTU/hr	114 MBTU
Milking Cow Barn	84 ft by 237 ft	19,908 ft ²	193,600 BTU/hr	463 MBTU
Calf Barn	84 ft by 77 ft	6,468 ft ²	81,300 BTU/hr	194 MBTU
Heifer and Dry Cow Barn	84 ft by 134 ft	11,256 ft ²	121,300 BTU/hr	290 MBTU
Total			443,900 BTU/hr	1,061 MBTU

Various studies have also shown that farm animals need less feed for growing and are more productive when the barns are maintained at temperatures ranging from 60°F to 75°F.^(1, 17) The geothermal district heating systems could provide sufficient heat to maintain the barns in this temperature range.

PRAWN FARMS

Increasing pressure on naturally occurring aquatic food resources has led to an expanding interest in aquaculture, or the raising of aquatic animals under controlled conditions. Without detailing the history of their development, it is noted that one particular species which has attracted attention in aquaculture is the Giant Indonesian Prawn, or Macrobrachium Rosenbergii.

A number of projects are under way to demonstrate the use of geothermal energy in the growing of prawns.⁽¹²⁾ At temperatures of 80 to 85°F, yields of these animals are on the order of 2,000 lbs per acre. At a whole sale price of \$5.00 per pound, one acre of prawns can gross up to \$10,000 annually.

On one 50-acre geothermal farm in California⁽⁴⁰⁾ the equivalent energy demand for raising prawns is on the order of 170 billion BTU per year. In that area, the equivalent energy savings amounts to \$560,000 per year (at \$2/MMBTU and 60 percent boiler efficiency).

Figures for energy requirements for prawn farms in this region of Montana will depend on factors such as external temperatures and wind chilling. Preliminary discussion with specialists in this field indicate that advanced growing methods to

increase production, coupled with a design which calls for covering growing ponds, may provide a combination which is economically viable. Additional studies are required however before any detailed conclusions can be reached.

It should be noted that any study of prawn growing should consider the concomittant raising of other products such as mosquito fish (gambosia) and hyasinth.⁽⁴⁰⁾

ETHANOL PRODUCTION

The possible application of geothermal energy for the production of ethanol is an interesting prospect for the Fort Peck Indian Reservation. Ethanol or ethyl alcohol when mixed with gasoline is commonly referred to as gasahol. Ethanol can be produced from farm products such as wheat and barley through fermentation and distillation. Based on a study now being performed for the U.S. Department of Energy by Beichtel National, Inc., an ethanol facility with a total capacity or output of 20 million gallons a year could be supported by a geothermal facility equivalent to that designed for the towns of Poplar and New town, if the resource temperature is found at 280°F.

Based on a study by the Stanford Research Institute,⁽³¹⁾ one can expect to produce from 90 to 95 gallons of ethanol from a ton of grain (approximately 36 bushels). If the price of grain can be assumed to range from about \$2.20 to \$2.60 per bushel, then the range of material cost is equivalent to \$.80 to \$1.00 per gallon. At \$1.00 per gallon, this equivalent to about \$12.00 per million BTU. The processing of the grain in this manner produces not only ethanol but also dried spent grains

know as brewer's dried grain. This can be used as a source of protein such as in cattle feed and can perhaps yield a revenue of approximately \$120 per ton. Thus, the major variable beyond the cost of grain which will determine the marketability of a product is the processing or conversion cost into ethanol, including energy cost.

While the data are a very preliminary, it would appear that a 20 million gallon per year ethanol plant could consume the grain output of approximately 160,000+ acres in this region. (This assumes 120 gal ethanol/acre) Many questions need to be addressed before any conclusion can be made regarding ethanol productions using geothermal energy. These include the extent nature of the geothermal resource, the capacity of farm land in the region, the availability of other resources, such as water, and the handling of wastewater and sludge. If an ethanol production facility does appear to be feasible then careful consideration should be given to intergrating it into the overall Fort Peck geothermal development plan.