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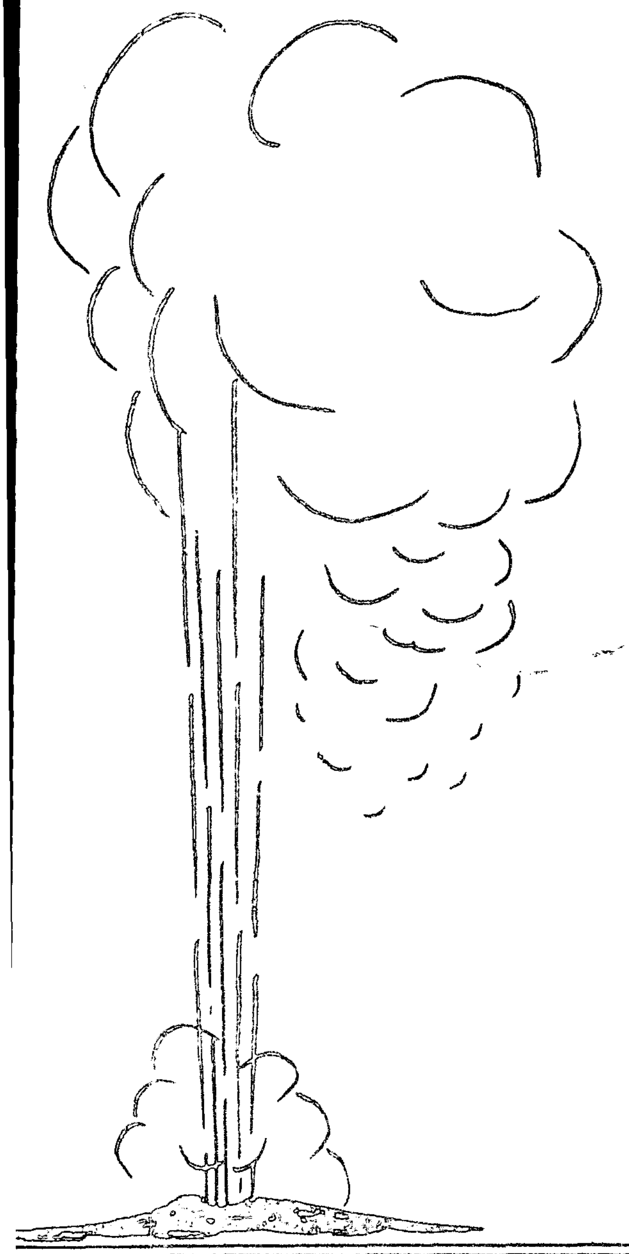

Engineering & Economic Studies
for Direct Application of Geothermal Energy

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

Phase I Report,
August 20, 1979 - December 31, 1979

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

January 4, 1980

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

PRC Toups Corporation
Orange, California

By
Glenn J. Spencer
M. Jane Cohen

U. S. DEPARTMENT OF ENERGY
Geothermal Energy

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Montana Bureau of Mines and Geology

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INTRODUCTION

This engineering and economic study is concerned with the question of using the natural heat of the earth, or geothermal energy, as an alternative to other energy sources such as oil and natural gas which are increasing in cost. This document represents a quarterly progress report on the effort directed to determine the availability of geothermal energy within the Fort Peck Indian Reservation, Montana (Figure 1), and the feasibility of beneficial use of this resource including engineering, economic and environmental considerations. The project is being carried out by the Tribal Research office, Assinboine and Sioux Tribes, Fort Peck Indian Reservation, Poplar, Montana under a contract to the United States Department of Energy. PRC Toups, the major subcontractor, is responsible for engineering and economic studies and the Council of Energy Resource Tribes (CERT) is providing support in the areas of environment and finance, the results of which will appear in the Final Report.

The existence of 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 to high temperature source near the town of Poplar, Montana, which is the location of the Tribal Headquarters for the Fort Peck Reservation. During the first phase of this project, additional data was collected to better characterize the nature of this geothermal resource and to analyze means of gaining access to it. As a result of this investigation, it has been learned that not only is there a potential geothermal resource in the region but that the producing oil wells north of the town of Poplar bring to the surface nearly 20,000 barrels a day (589 gal/min) of geothermal fluid in a temperature range of 185-200°F. Following oil separation, these fluids are disposed of by pumping into a deep groundwater aquifer. While beneficial uses may be found for these geothermal fluids, even higher temperatures (in excess of 260°F) may be found directly beneath the town of Poplar and the new residential development which is being planned in the area.

This project is primarily concerned with the use of geothermal energy for space heating and domestic hot water for the town of Poplar (Figure 2 and Photograph 1) and a new residential development of 250 homes which is planned for an area approximately 4 miles east of Poplar along U.S. Route 2 (Figure 2 and Photograph 2). A number of alternative engineering design approaches have been evaluated, and the cost of these systems has been compared to existing and expected heating costs.

During the course of the Phase I study, preliminary investigations were made into possible additional uses of the geothermal resource. Included in these addtional uses were agricultural (greenhouses) and aquacultural (prawn farms), as well as ethanol production. Ethanol, when mixed with gasoline, is popularly known as gasohol. The results of these preliminary investigations are presented as an appendix to this progress report.

Following the review of this document, the project will enter Phase II. During Phase II, specific engineering design approaches will be adopted and refined so that confident estimates of costs can be made. Also, the environmental, financial, and regulatory questions will be addressed.

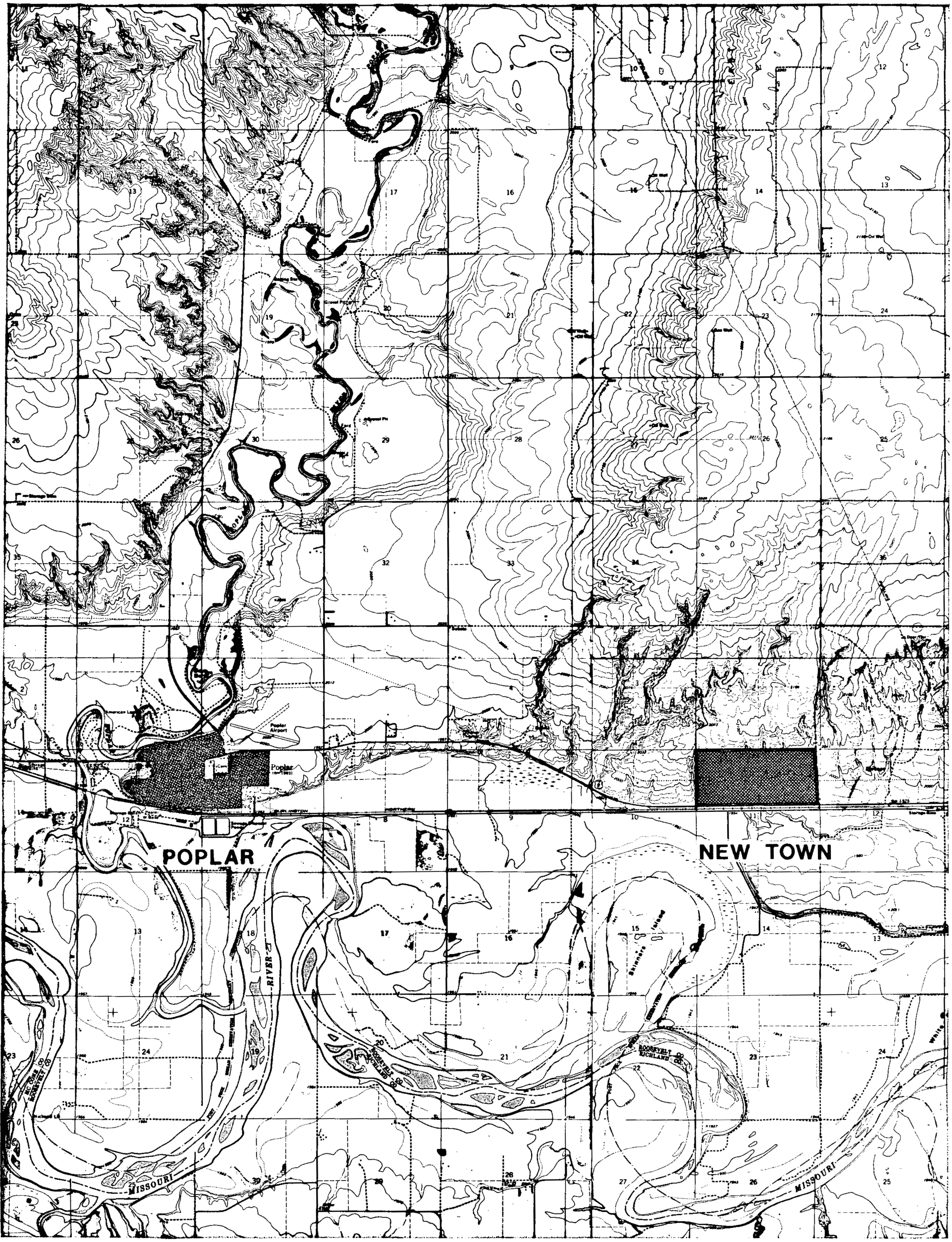
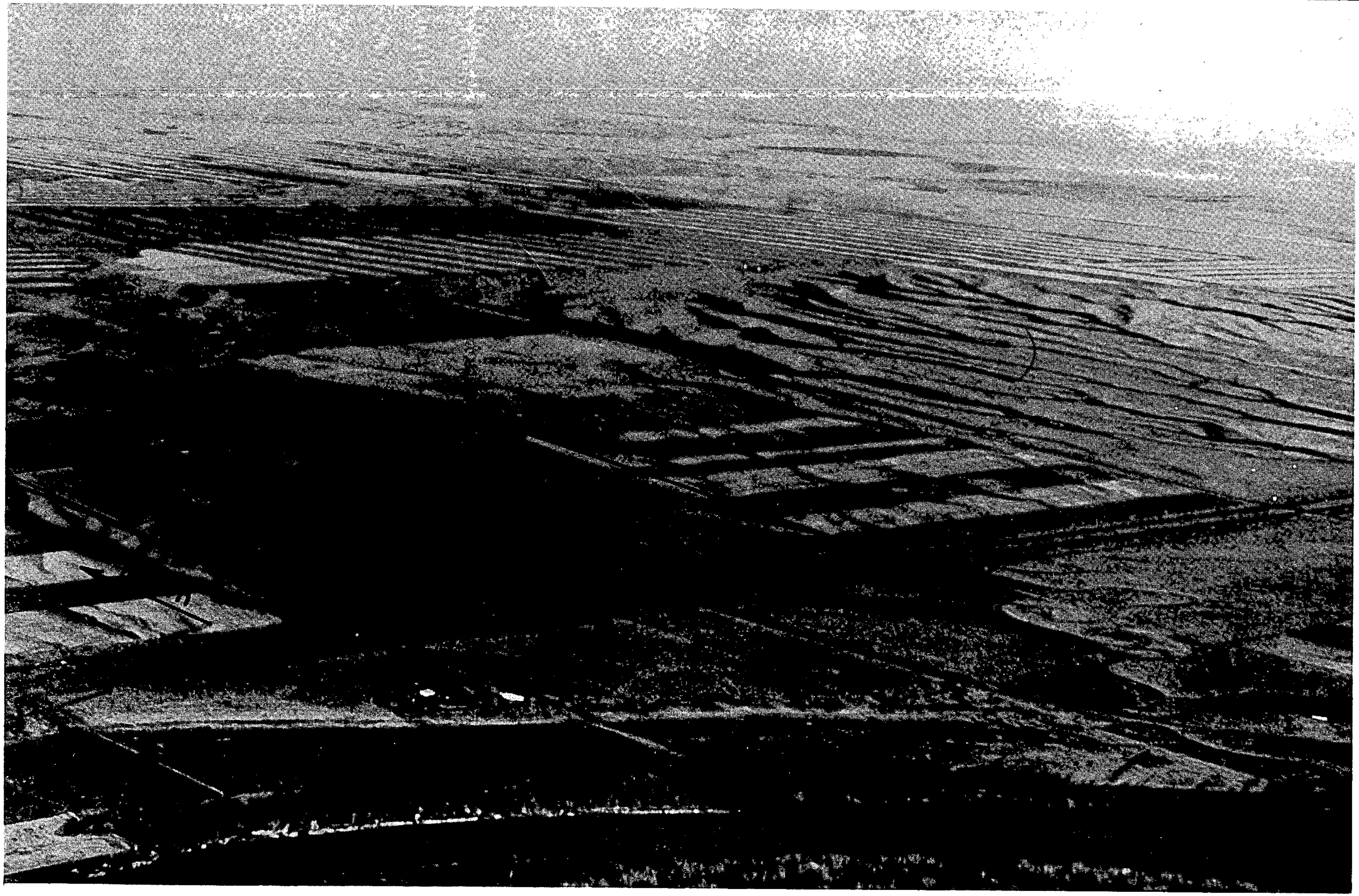


FIGURE 2 LOCATION OF POPLAR AND NEW TOWN

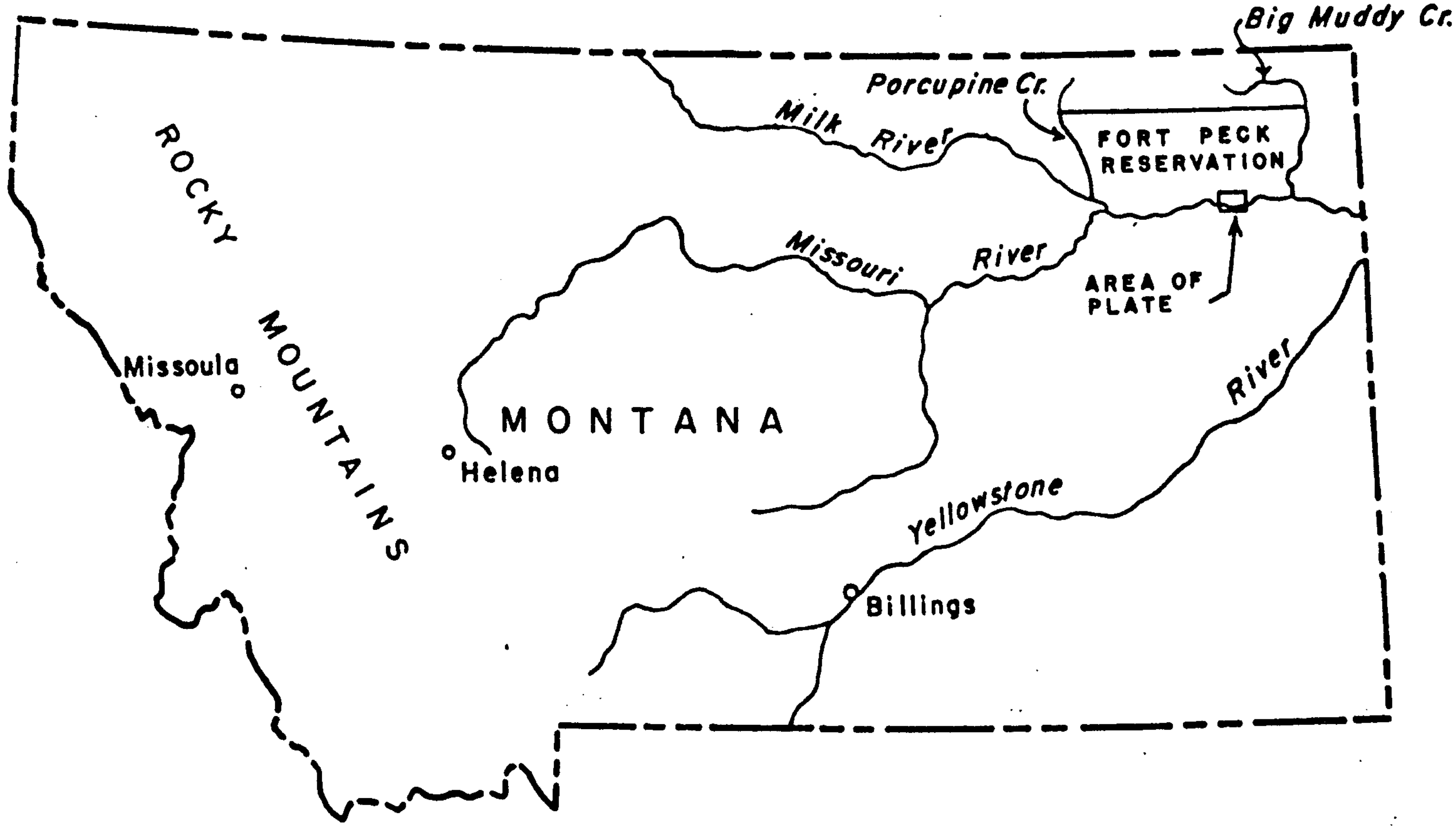
NORTHEAST VIEW OF POPLAR, MONTANA

PHOTOGRAPH I



PROPOSED HOUSING DEVELOPMENT SITE, EAST OF POPLAR, MONTANA

PHOTOGRAPH 2



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. 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.

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 accessbility 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 through purchase 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.

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 3. The low of $-63^{\circ}F$ 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.

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.

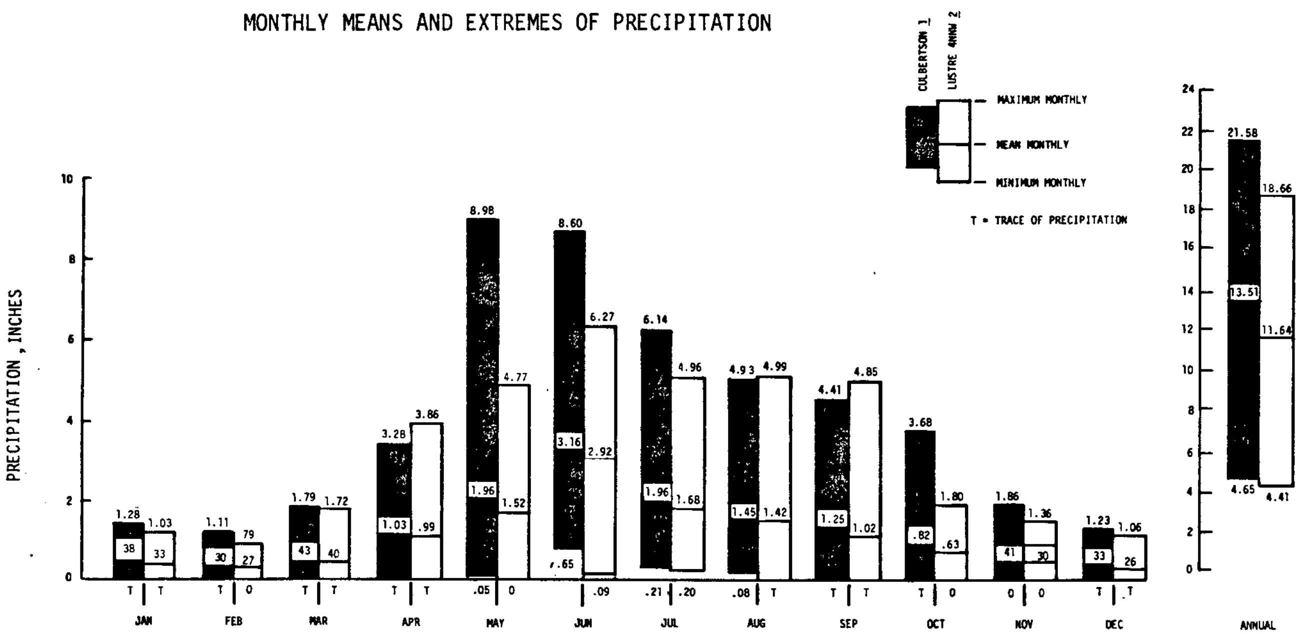
TABLE 2. LAND USE CLASS OF TRUST LANDS

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.

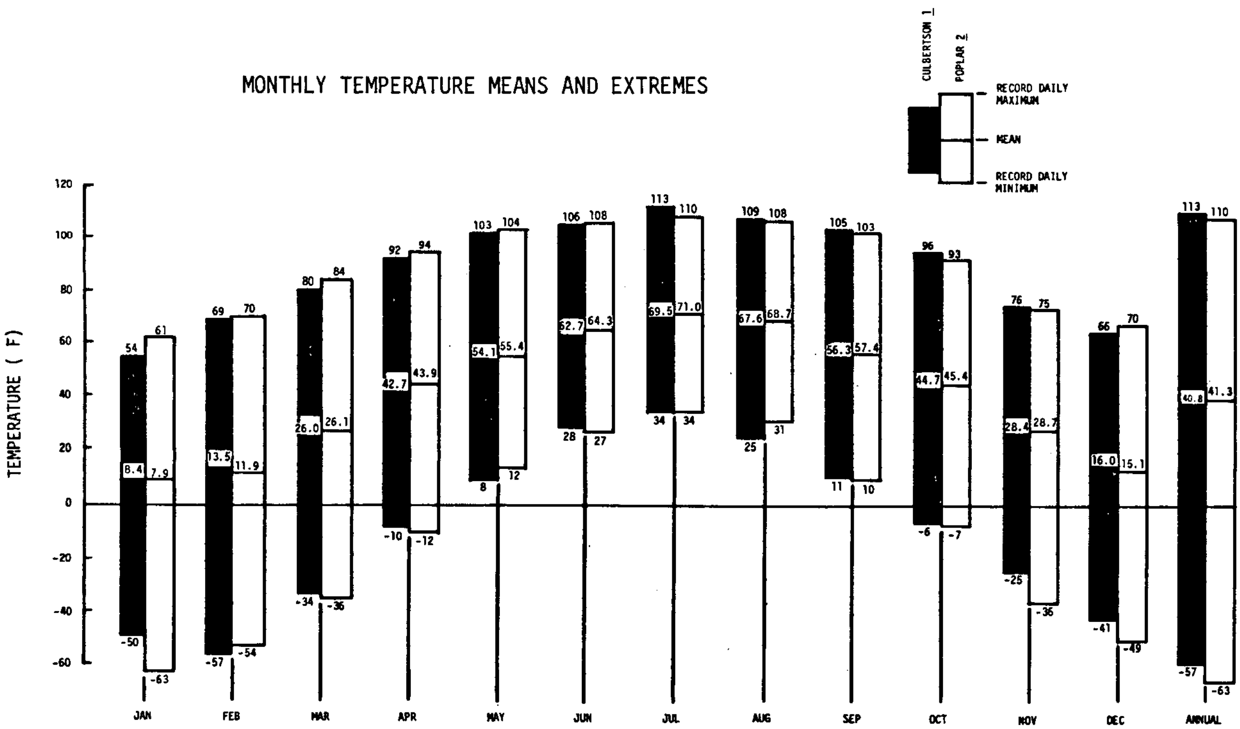
FIGURE 3 TEMPERATURE AND PRECIPITATION REPRESENTATIVE OF FORT PECK INDIAN RESERVATION

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. 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. The resource definition effort included the investigation of the near surface and subsurface geological conditions (due to their potential impact on resource accessibility and application), as well as the actual resource investigation. Since the existence of a geothermal resource within the Madison Formation had previously been detected, the primary emphasis of the resource investigation was to define further 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.)

NEAR SURFACE GEOLOGY

A summary description of the near-surface geology of the Fort Peck area is presented below. A more detailed discussion of these topics, including recommendations as to further investigation, is included in Appendix A. A geologic time scale, which may aid the reader in the interpretation of this discussion, appears in Appendix B.

GEOLOGIC SETTING

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 the 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. An arbitrary man-made boundary represents the northern limits of the reservation. (See Figure 1.)

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.(34) 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$\pm$ to 4$\pm$ miles wide (Figure I-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.

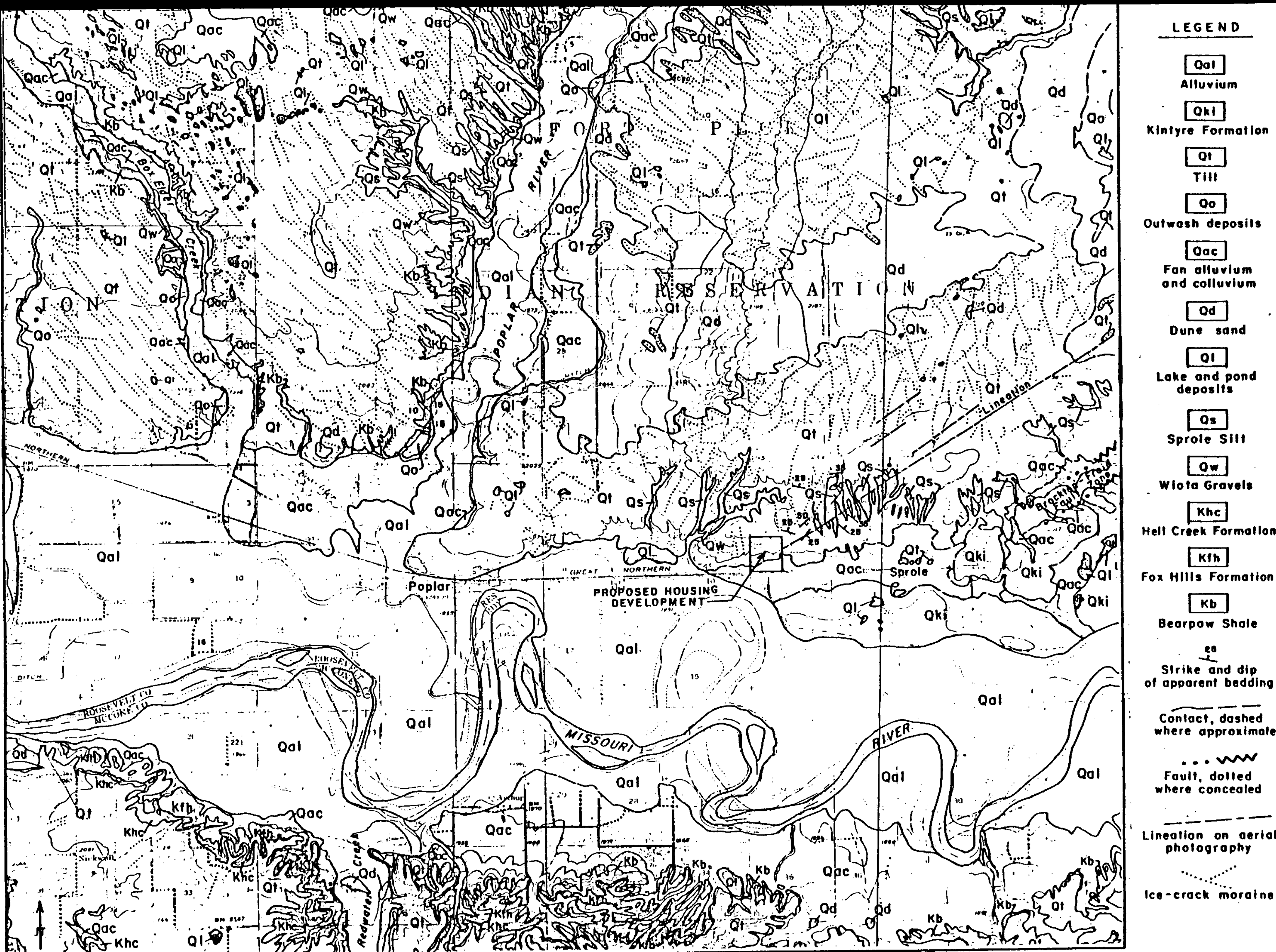


FIGURE I-1 GEOLOGIC MAP OF A PORTION OF THE FORT PECK INDIAN RESERVATION
(modified from R.B. Colton, 1963)

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± 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

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.

Soils

The soils and other surface deposits mantle the ground surface to varying depths, ranging up to several hundred feet thick.[8] 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, 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).

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. Bearpaw shale is exposed north of Poplar. (See Figure I-1).

The Hell Creek Formation is of continental freshwater origin and consists chiefly of gray to tan shales, siltstones, sandstones, and carbonaceous shales.[8] 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.[25] 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.[34]

SOIL STABILITY

Creep is the extremely slow and intermittant 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 (i.e. the town of Poplar and the proposed housing development site east of Poplar). This is primarily due to the lack of appreciable slope gradient sufficient to cause downslope movement.

SEISMICITY

Less is known about the earthquake history of the Western Mountain Region, which includes Montana, than any other section within the United States.[43] However, with the data that is known, the seismicity for the Poplar, Montana area appears to be relatively low.

A zone of normal faulting has been mapped between the towns of Brocktown and Froid.[9] As shown on Figure I-1, the western extent of this zone apparently extends southwest of Brockton into the eastern portion of the study area.[3] The Brockton-Froid fault is the only fault that has been mapped within the study area. This may be due, in part, to a lack of available outcrops or exposures within the subject area.

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 radial search from the town of Poplar, 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,[43] 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 comparatively small, with probable magnitudes of between 3 and 4. Based on the approximate location of these earthquakes, it is conceivable that they may be related to the Brockton-Froid fault zone.

According to Colton (U.S. Geological Survey) minor earthquakes felt in the Poplar area in 1935, 1943, 1944 and 1946 may have been related, at least in part, to the Brockton-Froid fault zone (personal communication). Based on his work,[6-9] Colton concludes that the Brockton-Froid fault zone is active (personal communication). However, there is no apparent evidence to associate this shaking with the Brockton-Froid fault zone. Slemmons (working for the U.S. Army Corps of Engineers) conducted an aerial examination of the entire fault zone from southwest of Brockton into North Dakota, and concluded that the Brockton-Froid fault zone was inactive.[29]

During the investigation for Fort Peck Dam,[29] Krinitzsky indicated that the Maximum Credible Earthquake for the Brockton-Froid fault zone ranged between Magnitude 6.0 and 7.2, which would subject the town of Poplar, as well as nearby areas, to strong seismic shaking. The larger mangnitude assumes that the Brockton-Froid fault zone is connected to the Weldon fault, which is located some 43± miles southwest of Poplar. (Note: Colton[6] does not continue the Brockton-Froid fault zone south of the Missouri River.) However, based on the existing seismic data, the possibility of an earthquake of that magnitude along the Brockton-Froid fault zone appears to be remote, at best.

STRUCTURE

Geologic structure locally within the area is controlled by the Poplar Dome and possibly the Brockton-Froid fault zone. Although workers disagree on the existence as well as activity of the Brockton-Froid fault zone, the work done by Colton[6-9] together with data developed during this study could suggest the existence of the 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.[36] Dips along the Greenhorn Formation (See Figure I-6) 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.[9]

Local dip fluctuations were also noted in some of the surficial materials, such as 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 3.) The bedding noted appears to be highly variable in dip direction and angle. Dips recorded range from 25± to 50± degrees (See Figure I-1). Based on available data and outcrops, it is uncertain as to whether these contorted beds are related to past glacial activity or fault activity (i.e. the Brockton-Froid fault zone).

SPROLE SILT EXPOSED IN ROAD CUT NORTHWEST OF SPROLE, MONTANA

PHOTOGRAPH 3

Brockton-Froid Fault Zone

Colton shows the Brockton-Froid fault zone to be a few thousand feet in width and about 30 miles in length.[29] He shows a fault zone consisting of at least two roughly parallel faults, with a graben or downdropped block between the faults.[8] These faults are shown to affect Pleistocene glacial deposits.[8] Furthermore, Colton and Bateman's structural contour map[9] shows offset of basement rock near Brockton of less than 100± feet to over 400± feet near Froid.[29]

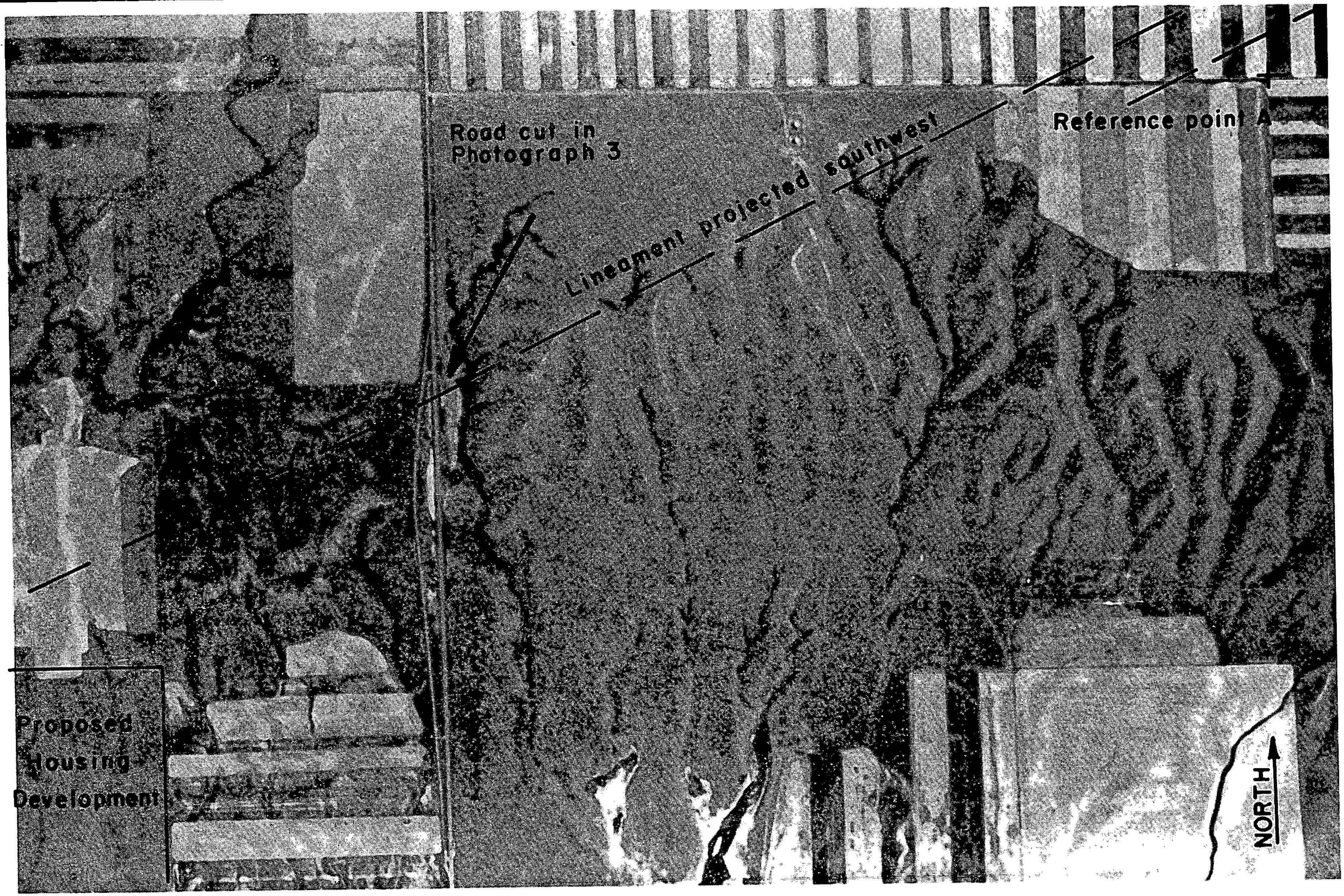
The existence of the Brockton-Froid fault zone is difficult to determine, due to a lack of outcrop exposures (i.e. road cuts, stream valleys, etc.). However, information developed as part of this study (irregular mineralization of the ground water and the shallow ground temperature configuration) suggest that the Brockton-Froid fault zone does exist.

In addition to the Brockton-Froid fault zone, Colton indicated the existence of several northeast-southwest-trending lineaments roughly parallel to the Brockton-Froid fault zone.[8] (Note: In addition to paralleling the fault zone, these lineaments also follow the same general trace of the last glacial ice sheet.)

As shown in Figure I-1, the longest of these lineaments intersects the previously mentioned road cuts northwest of Sprole. A projection of this lineament continues southwest beyond the road into the proposed housing development site. Photograph 4 shows this lineament in the cultivated field northeast of the road. The upper right corner of Photograph 5 shows the same lineament. It further shows

LINEAMENT IN CULTIVATED FIELD NORTHWEST OF SPROLE, MONTANA

PHOTOGRAPH 4



LINEAMENT LOCATED NORTHWEST OF SPROLE, MONTANA

PHOTOGRAPH 5

that a southwesterly projection of the subject lineament appears to intersect the northern portion of the proposed housing project.

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 is apparently not reaching the ground surface, as no hot springs were noted along the fault zone within the study area.

PRELIMINARY EVALUATION OF THE CHARACTERISTICS OF THE MADISON FORMATION

This report is a first-stage assessment of the aquifer characteristics of the Madison Group in the vicinity of Poplar, Montana. This is part of an investigation of the geothermal resources that occur in the area. The objective is to determine the production rate, quantity, and quality of hot water as an additional source of energy for direct application.

The results should be considered preliminary, as not all the available information was obtained and utilized in the time available. Nevertheless the results obtained to date are reasonable when compared with results from other studies of the Madison and similar lithologic formations. They indicate that: 1) significant amounts of hot water can be produced; and 2) direction and the need for further analysis to provide the most reliable expectations as to depth of production, rate, quantity, quality, etc. before a major investment in deep-hole drilling is warranted.

Although the present study concentrated on the Madison, some hydrologic-type information was also obtained on other formations that may be involved in geothermal resource production and management.

DESCRIPTION OF THE MADISON GROUP

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.[32]

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 subaereal erosion with the development of karst topography and resulting solution kreccias.

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.[32] 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 I-7). 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.[335]

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.

Hydrologic Aspects

Except locally, the Madison can be considered an aquifer of low porosity and permeability and high salinity. Water production rates range from a few gpm to more than 1000 gpm. Although significant variations occur, salinity is on the order of 150,000 ppm total dissolved solids.

Porosity and Permeability. Low range values of porosity and permeability can be expected to relate to granular texture, i.e., the sizes, shapes, and degree of interconnection of pore spaces among grains. Because of the fine-grained character of much of the limestone as deposited, the pore spaces would be small. Primary porosity might have been high initially, as is usually true of fine-grained deposits. However, since the time of deposition, primary porosity would have been reduced by compaction, recrystallization, and cementation. Primary permeability is always low in fine-grained deposits, but it would be somewhat greater in reef-type structures because of the coarser texture of the materials being deposited. In general it can be expected that porosity and permeability, and therefore productivity, in the dense limestone units of the Madison will be small.

Several factors provide increased (secondary) porosity and permeability within the Madison, and offer interesting possibilities for larger production, if their occurrence and distribution can be understood better. These factors 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 stated previously, some of the Madison has been subjected to subaereal erosion and karstification. Karst features are cavities dissolved by ground water. 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 is the dense fine-grained material.

Dolomitization provides another possibility. The transformation from calcite ($CACO_3$) to dolomite ($CaMG(CO_3)_2$) normally occurs with a decrease in volume. Thus, the dolomitized zones should have increased porosity and permeability.

Finally, 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.

In summary, although the Madison can be considered a formation of low porosity and permeability, there may be local areas within which these parameters are quite large, and from which large production rates may be obtainable.

Recharge, Piezometric Surface, and Temperature. 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. Migration of water in the Madison is therefore 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, and therefore the aquifers are increasingly artesian. At Poplar, there has not yet been sufficient study of available data 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 on 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.

The water in the Madison below much of the Poplar area ranges from about 150°F to at least 260°F in some wells, much above the temperatures expected as a result of the normal geothermal gradient. Proper identification of the source of the higher-than-normal temperatures in the Madison is also important in any long range plans for production. Possible sources are discussed later in this report.

Water Quality. The salinity of the Madison is high, on the order of 150,000 ppm total dissolved solids. Because the concentration is nearly an order of magnitude 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 major constituent is sodium chloride, and to a lesser extent sulfate and other constituents. 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.

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 I-2. Figure I-3 shows the location of the 47 wells near the town of Poplar for which the majority of the data used in this report was obtained. The shaded area in Figure I-4 delineates the oil producing zone. (Note: The well numbers shown on Figure I-3 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 in the time available for this phase 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.

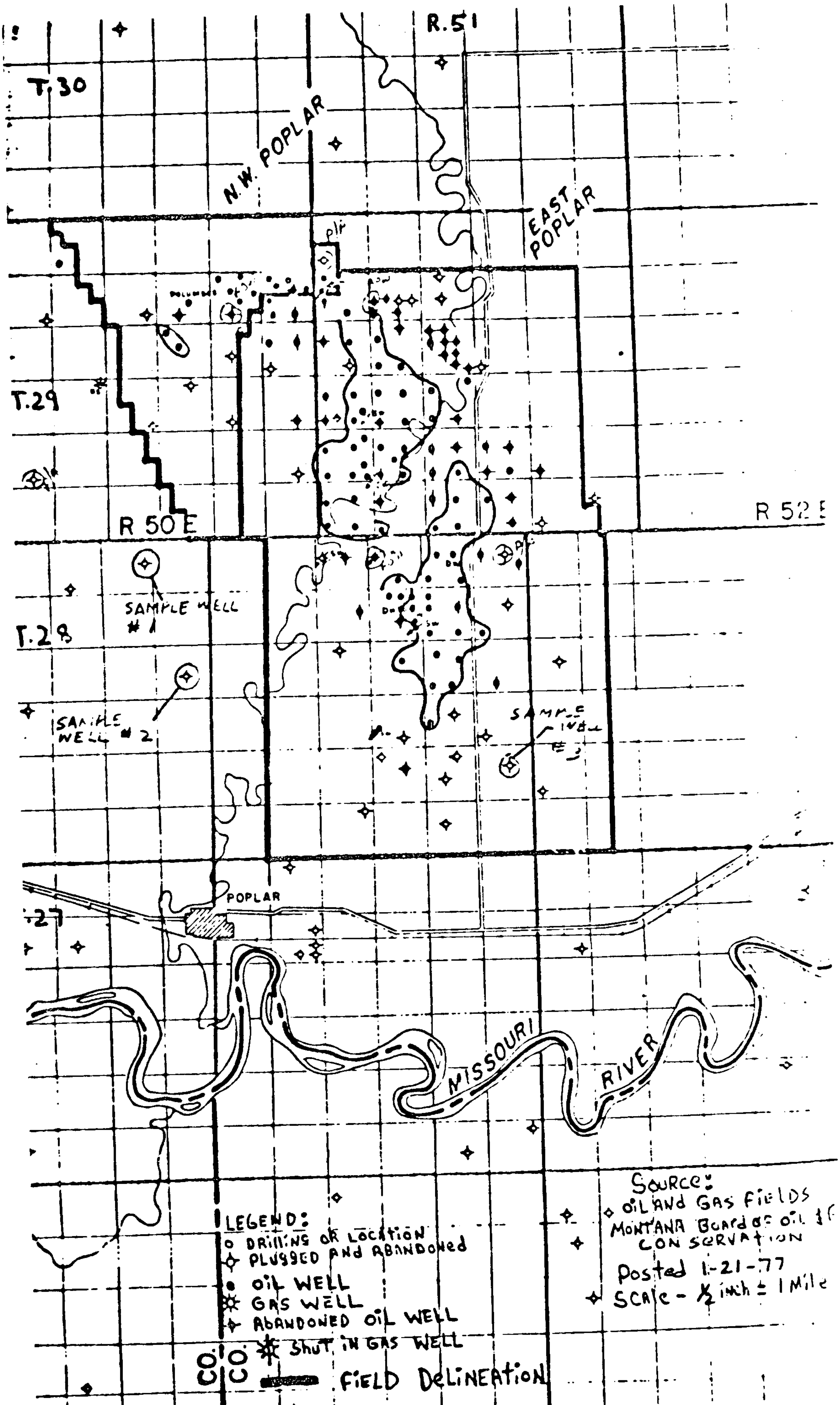
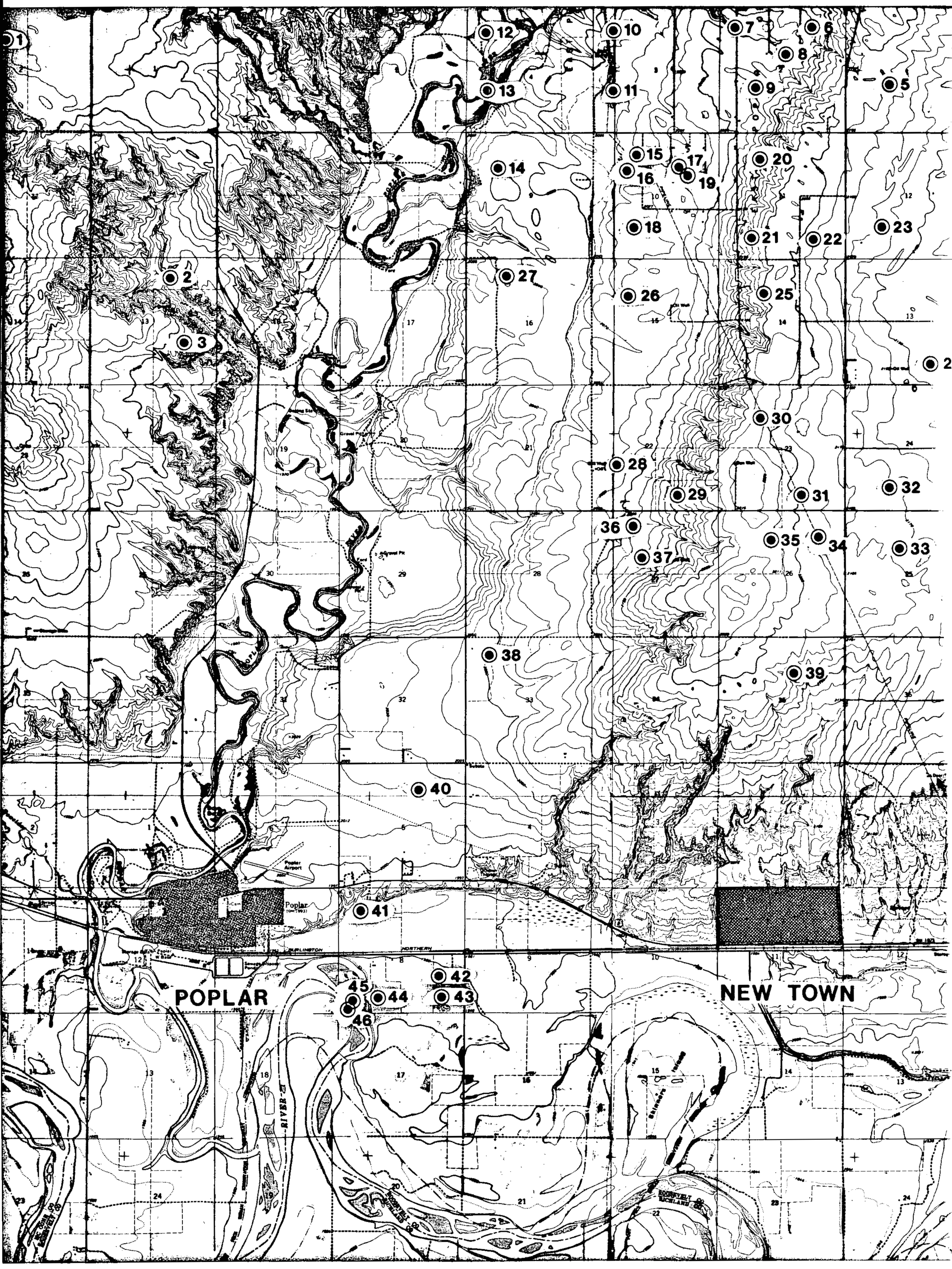


FIGURE I-2 POPLAR FIELD



◉ INDEX NUMBER

FIGURE I-3 LOCATION OF OIL WELLS USED IN ANALYSIS

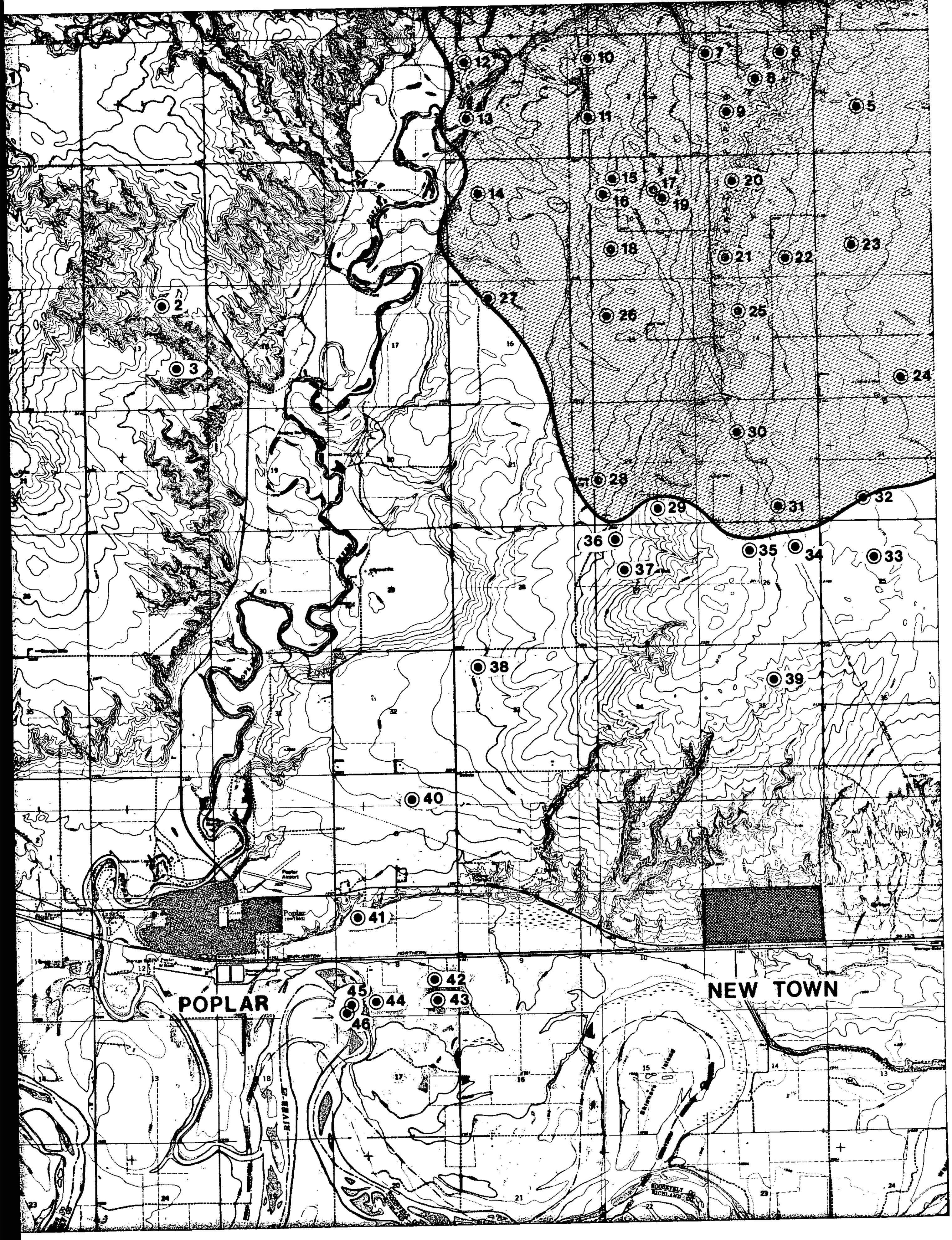


FIGURE I-4 DELINEATION OF OIL PRODUCING AREA

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

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^{o}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$\pm$ 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.

According to Murphy, the wells which produce the geothermal fluids are located in the southern portion of the field. Additional information has been requested which will allow the preparation of a layout of the field. Such a site plan would identify the 'geothermal' oil well, and the method of disposal. This, in turn, would allow further analysis as to the feasibility of utilizing this currently available, but unused heat source.

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.

RESULTS OF ANALYSES

Subsurface Geology

Well histories for the 47 wells shown on Figure I-2 were analyzed in order to further define the Madison Formation within the specific study area. Depth data from the histories for those wells are summarized in Table I-1. This data was used to define further 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 I-5. Figure I-6 presents a composite stratigraphic section in more detail for the Poplar area, which was developed on the basis of published literature. 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 these two figures.

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 I-7). Three cross sectional illustrations depict the erosional surface elevation of the top of the Madison in relation to the

TABLE I-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 #2	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 I-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	Delhi Petroleum 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
47	27-51-8	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) Ordivican
(g) McGowan

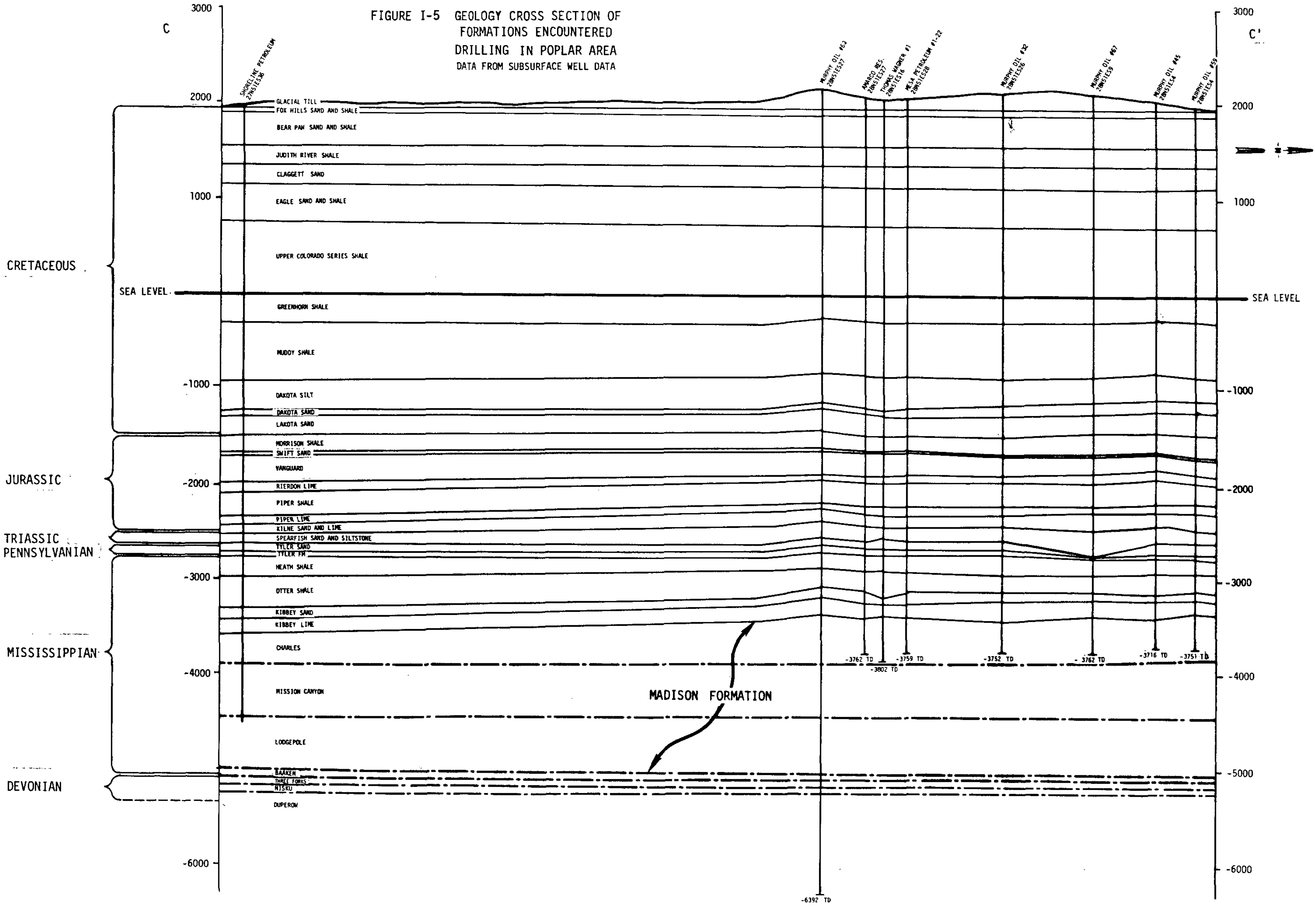


FIGURE I-5 GEOLOGY CROSS SECTION OF FORMATIONS ENCOUNTERED DRILLING IN POPLAR AREA
DATA FROM SUBSURFACE WELL DATA

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

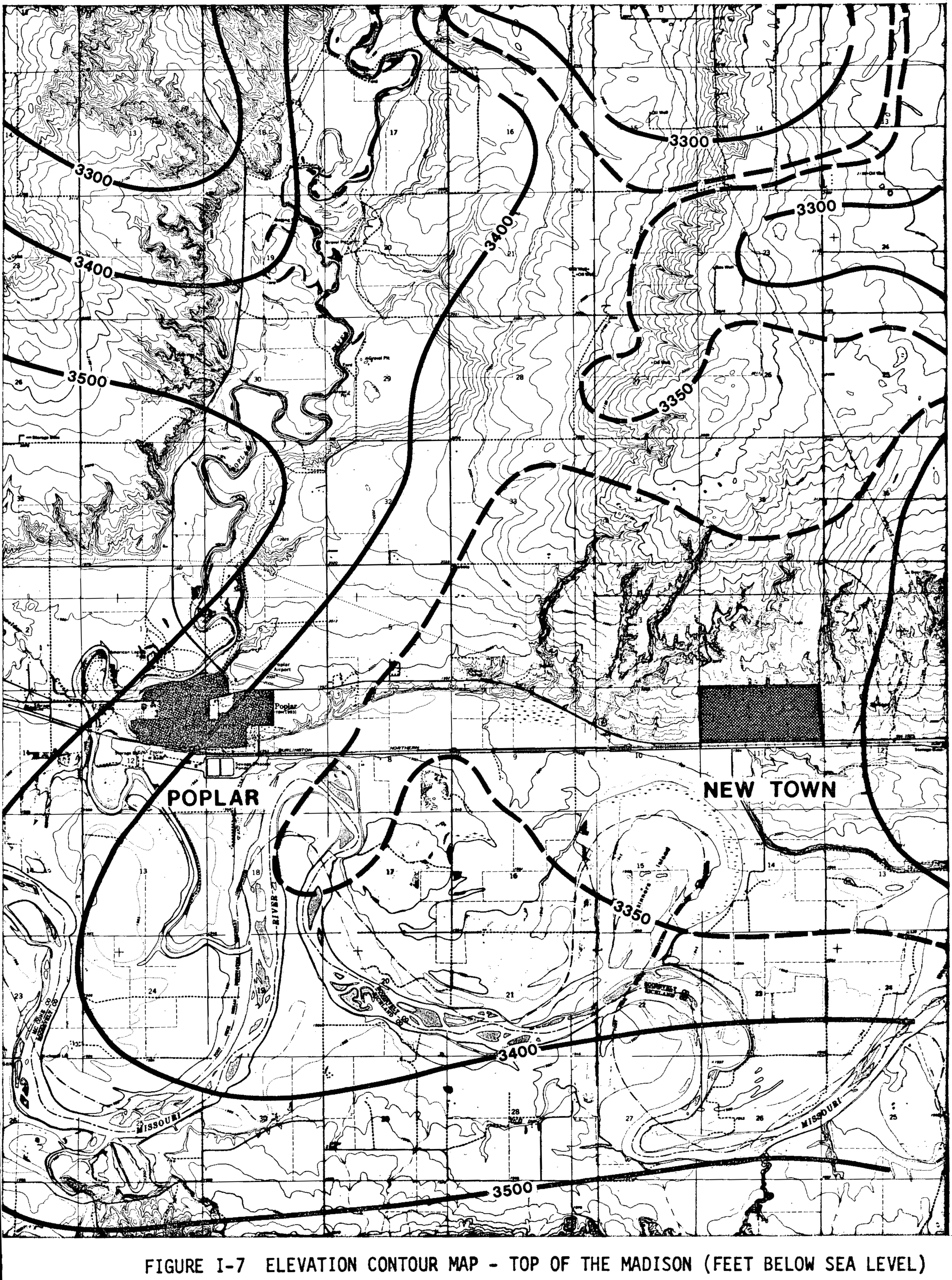


FIGURE I-7 ELEVATION CONTOUR MAP - TOP OF THE MADISON (FEET BELOW SEA LEVEL) ground-level elevation it underlies. The location of these cross sections are identified in Figure I-8, and the cross-sections are shown in Figure I-9. As shown in Figure I-9, the total drilling depth to the top of the Madison Formation from location to location within the area is 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 producable water of slightly lower temperatures.) As these formations are under an active water drive, reservoir pressures often allow fluid to flow initially to the surface on newly completed wells. Twenty-five years of production experience by local operators indicate most productive wells are placed on artificial lift after reservoir pressure lowers.

Porosity

Porosity values were derived from several different types of the 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 characeristics.[10, 14, 30]

Table I-2 presents some of the hydraulic parameters and other information derived from analyzing the well logs or provided with the well summary reports. Except

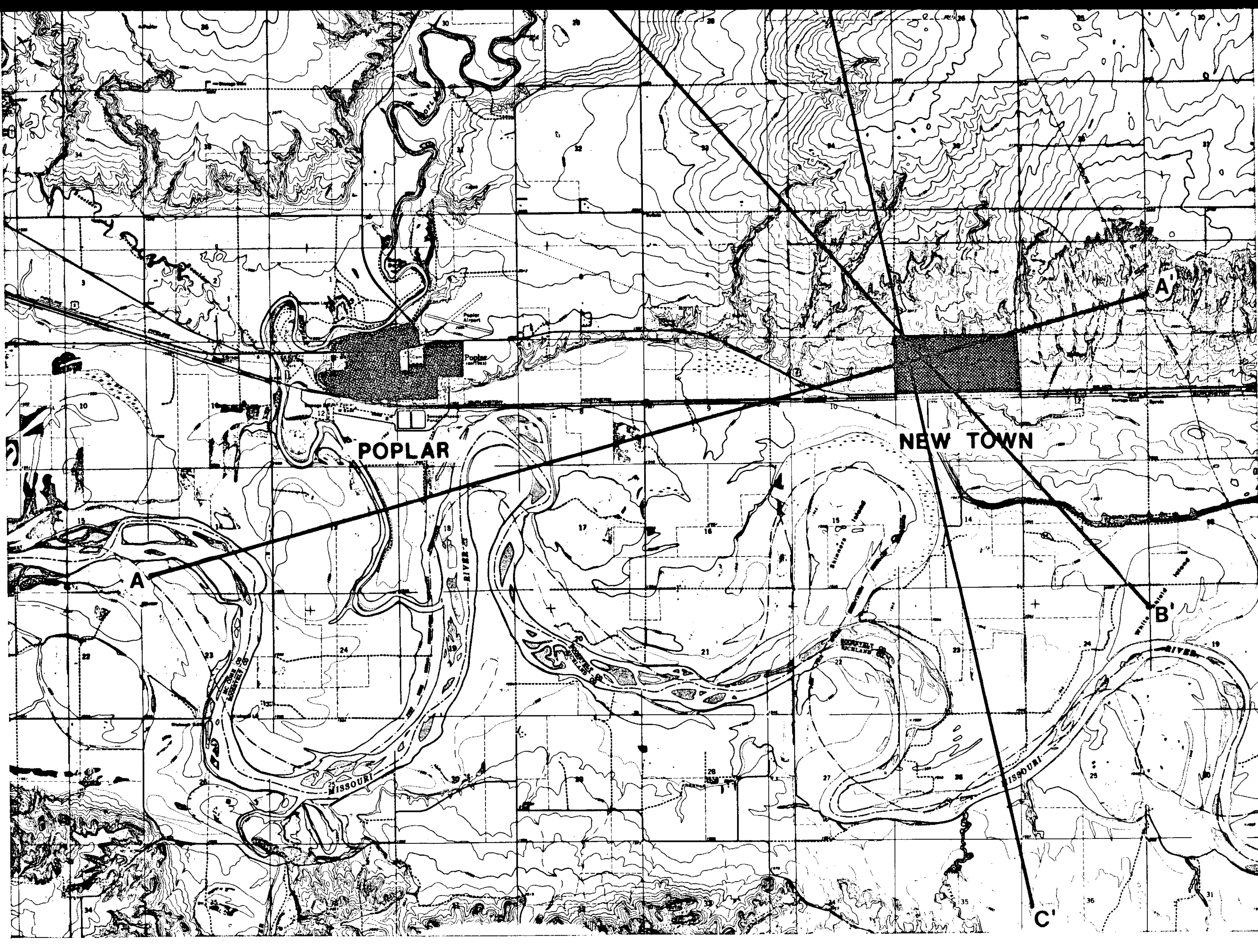


FIGURE I-8 IDENTIFICATION OF CROSS SECTIONS

FIGURE I-9 CROSS SECTIONS SHOWING EROSIONAL SURFACE OF MADISON FORMATION

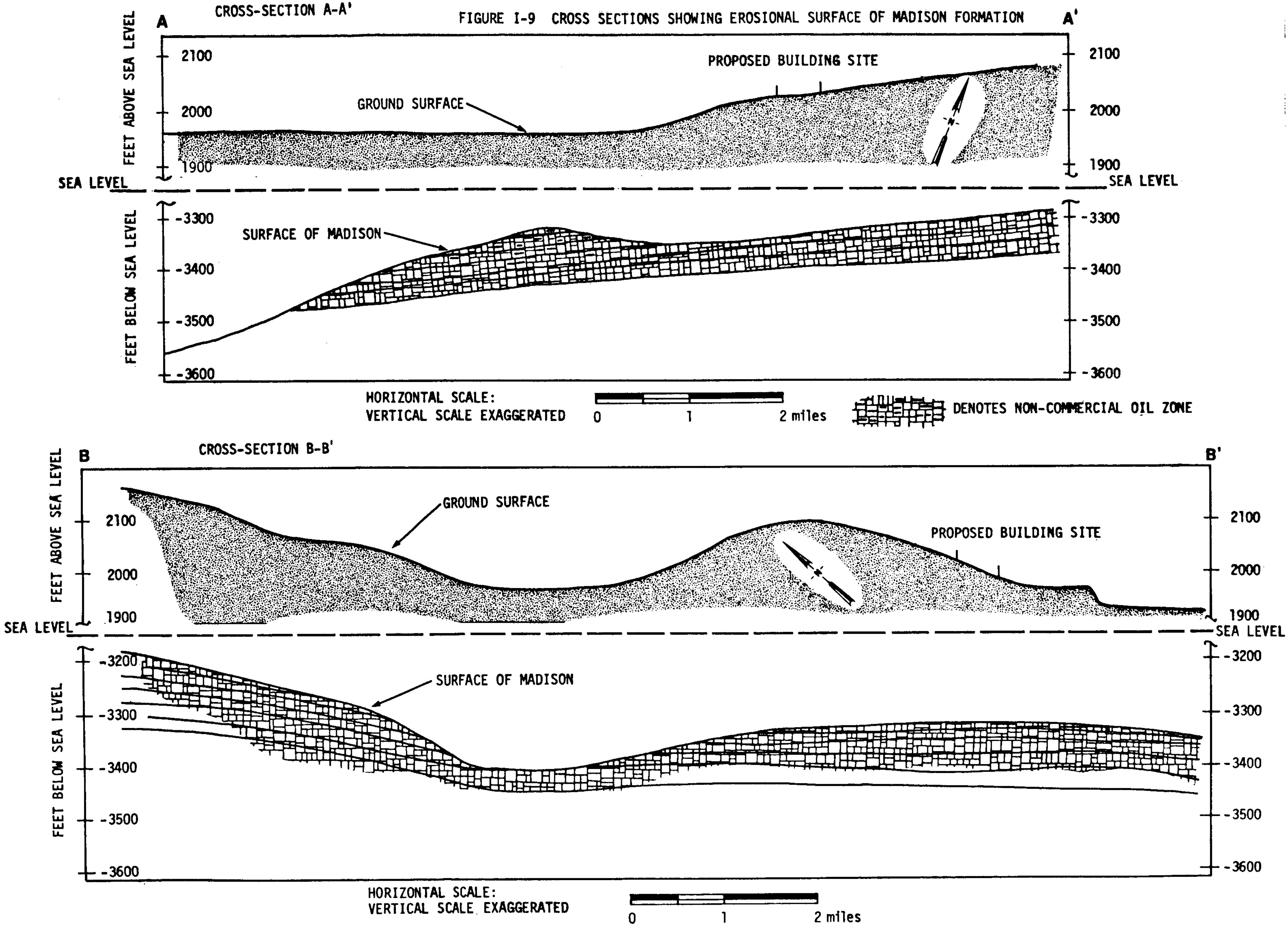
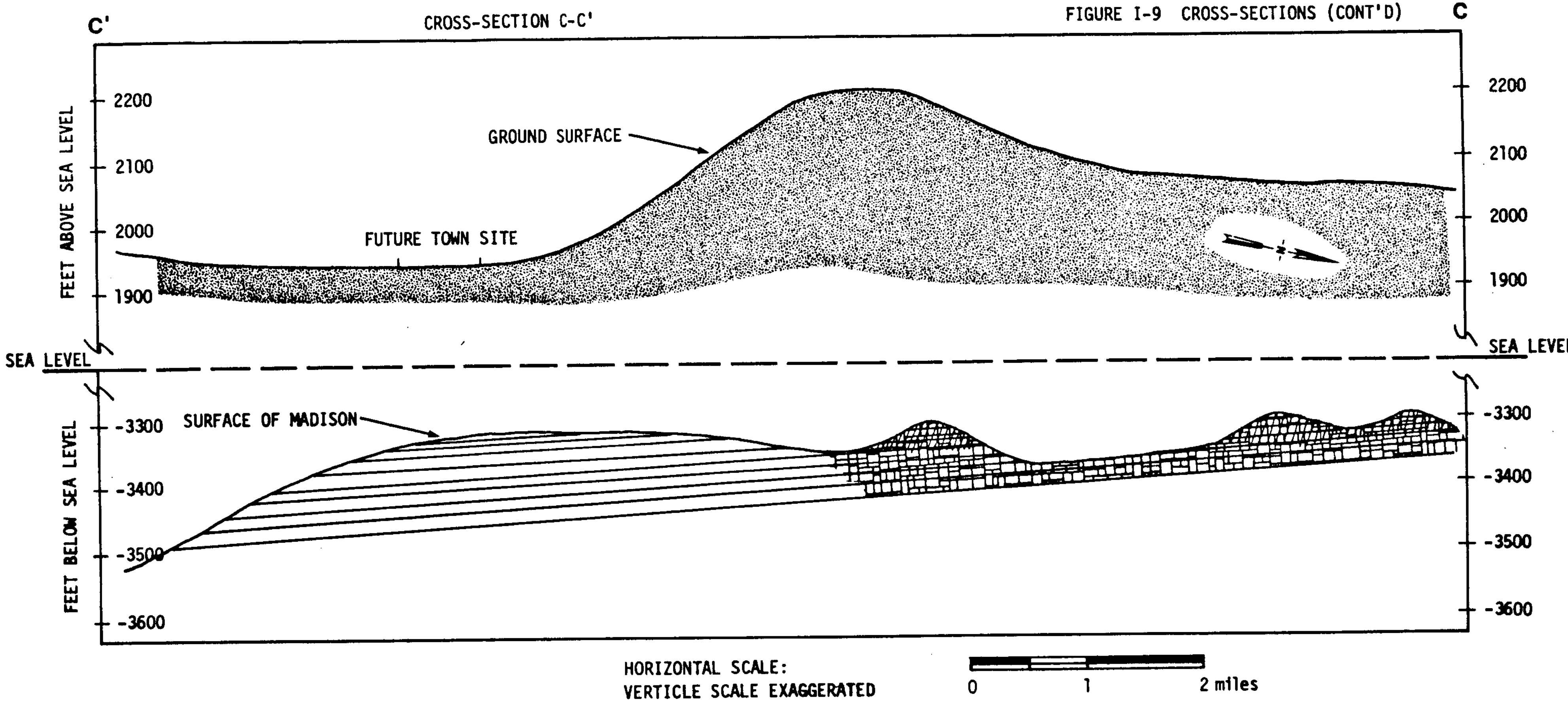
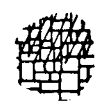


FIGURE I-9 CROSS-SECTIONS (CONT'D)




DENOTES OIL-BEARING ZONE

NORMAL LITHOLOGIC SEQUENCE IN POPLAR AREA

CRETACEOUS	GREENHORN	
JURASSIC	MORRISON	
	PIPER	
	NESSON	
TRIASSIC	SPEARFISH	
PENNSYLVANIAN	AMSDEN	
MISSISSIPPIAN	HEATH	
	KIBBEY	
MADISON FORMATION	CHARLES	"A" ZONE; "B-1" ZONE; "B-2" ZONE; "C" ZONE (MAIN PRODUCING ZONE IN POPLAR DOME AREA)
	MISSION CANYON	
	LODGEPOLE	
DEVONIAN	BAAKEN	
	THREE FORKS	
	NISKU	
	DUPEROW	

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

Well No.	Name	Location (Township) Range Section)	Derived From	Porosity (%) Range	Porosity (%) Average	Permeability (millidarcys) Range	Permeability (millidarcys) Average	Dept. Range (ft. below surface)	Interval ft	Total Depth (ft. below surface)	Bottomhole Temp (°F)
40	Danielson #1	27/51 5	long normal	1.8-4.7	3.2	-	.05	5350-6510	1160	6510	174 (250 max. at 5450')
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	2.0-6.2	4.1	-	.005	5290-5950	660	5950	149
			drill stem test		14.0						
39	Lockman #1	28/51 35	microlaterolog	2.5-11.0	6.8	.005-.05	-	5560-6020	460	6020	176
			sonic	6.0-16.0	11.0						
			sonic	4.0							
42	Ogleetal #1	27/51 8	sonic	4.0-16.0	10.0	-	10	5300-7200	1900	8940	243
			sonic	2.7	-	-	0.8				
22	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		
7	Murphy	28/51 11	core laboratory	-	10.0	0-200	-	5517-5530	13	-	-
			core laboratory	-	12.0	0-5	-	5795-5811	16		
15	Murphy	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 I-2. POROSITY VALUES DERIVED FROM WELL LOGS AND CORE ANALYSES; MADISON GROUP (CONTINUED)

Well No.	Name	Location (Township) Range Section)	Derived From	Porosity (%) Range	Porosity (%) Average	Permeability (millidarcys) Range	Permeability (millidarcys) Average	Dept. Range (Ft. Below Surface)	Interval Ft	Total Depth (Ft. Below Surface)	Bottomhole Temp (^{o}F)
18	Murphy	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		
17	Murphy	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		
3	Murphy	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	EPU #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

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 on empirical relationships.[26]

Table I-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.

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.[32] Mudge and Others report porosity of 11 percent for an 8-foot pay zone in the East Poplar field.[35]

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.[26, 39] 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 at hand.[11]

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 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 I-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-ft^2. The extremely high value of 5,000 millidarcys is equivalent to about 9 gal/day-ft^2 which is within the range of values found by Miller in southeastern Montana.(32) The spontaneous potential curve developed from the data for the Werner #1A, B well (desribed 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.(32) 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 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.

Table I-3 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 I-3. The range of values and the averages are reasonably similar to those found in the Madison in southeastern Montana by Miller[32] and elsewhere in Montana by Hopkins.[21] 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

TABLE I-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)
44	28/51 24	5632-5650	18	4.0	2.2
		5774-5782	8	4.0	72.6
		5757-5778	21	4.0	8.7
Morse #1	28/51 26	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
72	28/51 22	5842-5881	39	2.0	-0-
		5864-5872	8	4.0	4.7
		5706-5722	16	4.0	19.6
32	28/51 15	5497-5508	11	3.5	5.9
Murphy #22	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-
74	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 I-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
45	28/51 4	5471-5480	9	4.0	5.3
		5627-5639	12	4.0	10.6
59		5429-5438	9	4.0	1.8
		5593-5603	10	4.0	103.2
		5712-5736	24	4.0	7.5

TABLE I-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)
67		5480-5489	9	4.0	17.4
		5521-5540	19	4.0	16.8
		5781-5791	10	3.0	3.7
Murphy #18	28/51 2	5800-5810	10	1.4	-0-
East Poplar #1	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
Murphy #99	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

of the formations below the Madison, in this instance probably the Duperow, a Devonian formation predominently 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^{o}F to 210^{o}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 I-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 I-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.

TABLE I-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

Temperature

Bottom-hole temperatures from fifteen wells in the vicinity of Poplar and New Town were obtained from drill-stem tests. The temperatures and depths for these wells are listed in Table I-5. This data was utilized to derive the temperature contour map shown in Figure I-10. The data shown in Table I-5 show temperatures ranging from 150^{o}F to as high as 256^{o}F within a well depth range of 5,400 feet to 7,700 feet. Temperature was plotted as a function of temperature in an attempt to determine the relationship, if any, between the two (Figure I-11). As shown in Figure I-11, 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.

The temperature contouring suggests that the higher temperatures occur 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 I-7).

At a normal geothermal gradient of about 2^{o}F per 100 foot depth, bottom hole temperatures should be on the order of 150^{o}F at 5,000 foot depth, and 180^{o}F at 7,000 foot depth. Thus, many of the bottom-hole temperatures are higher than expected from the geothermal gradient alone.

One downhole temperature log available for this study (Danielson #1, 27/51 5) shows higher than expected temperatures throughout the logged interval

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

Well Location Map Number	Well	Depth (ft)	Temperature (^{o}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	Delhi #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
47	Shoreline #1	5,400 6,200	150 198

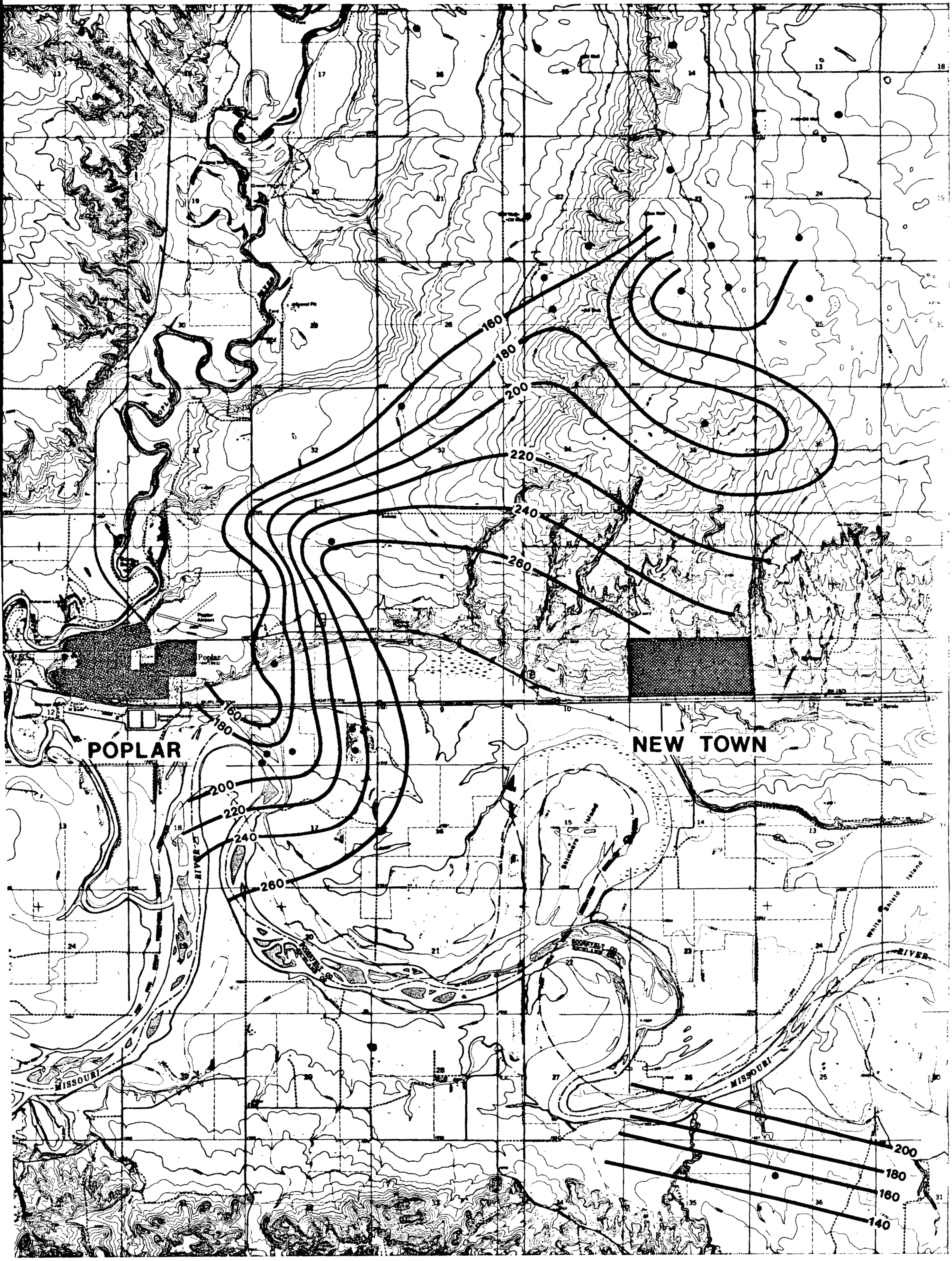


FIGURE I-10 BOTTOM HOLE TEMPERATURE CONTOURS

(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. This suggests lateral movement within individual zones rather than vertical mixing within the formations.

Water Quality

The primary water quality concern with the use of geothermal fluids is the effects the impurities contained within those fluids will have upon the equipment with which it comes in contact. A high level of impurities within the geothermal fluid can result in serious operating problems caused by deposit formation (scaling) and corrosion of metals.

Corrosion is an electrochemical process in which a difference in electrical potential develops between two metals or between different parts of a single metal. The extent of the corrosion is a function of electrical potential and also 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 I-6 presents some of the data from chemical analyses made available for some of the wells and produced water at Poplar. Total dissolved solids range widely, varying between about 59,000 to about 288,000 ppm. The average is about 102,000 ppm. All analyses show concentrations from about that of present sea water to as much as eight times the concentration of sea water. The brines 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.

Table I-7 compares two diverse water quality samples taken from two wells in the study area. The composition of these brines exhibit a marked difference in chemical constituent concentrations. Both brines, 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

TABLE I-6. SALINITY VALUES FOR OIL WELL BRINES AT POPLAR

Well Designation or Location	Formation	Total Dissolved Solids (ppm)	Chloride as Na Cl	Sulfate (ppm)	pH
Danielson #1	Madison	61,620	50,021	2,218	6.3
Danielson #1	Madison	288,120	276,471	1,946	5.2
28/51 7	Madison	180,000	173,458	2,567	6.2
Patch # 1	Madison	58,740	52,438	4,230	6.2
28/51 27	Madison	44,300	35,480	5,609	8.4
28/51 27	Madison	101,820	96,763	2,873	6.3
28/51 27	Nisku	113,560	108,859	1,144	6.1
28/51 27	Madison	34,640	19,997	8,831	8.5
28/51 27	Madison	52,020	46,446	2,938	6.8
28/51 27	Kibbey	130,992	130,630	2,099	6.0
28/51 27	Kibbey	140,800	130,630	2,099	6.0
28/51 27	Heath	65,240	61,283	1,456	6.7
Patch # 1	Madison	109,826	101,414	5,802	8.2
101	Madison	88,800	86,880	1,364	5.9
28/51 22	Madison	127,960	69,438	7,268	6.4
Trunk Battery, Sec. 22	-	63,500	60,100	2,000	7.2
Murphy #55, Sec. 2	-	72,100	69,100	2,000	7.5

TABLE I-7. COMPARISON OF TWO DIVERSE GEOTHERMAL BRINE CHEMICAL COMPOSITIONS FROM THE MADISON AQUIFER

	GEOLOGIC FORMATION	
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.

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.

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

	Sample A	Sample B
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 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. Based upon this preliminary data, it appears as if the brines within the Madison Formation exhibit a definite scaling potential.

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). Literature reports 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 brines 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. A large amount of work is currently being done on the scaling and corrison potential of various geothermal brines. During Phase II of this study, a literature search will be conducted summarizing the results of actual field testing geothermal brines, their chemical composition and their end effects (as to corrosion or scaling potential) and correlations drawn between those field tests and the geothermal fluid which may be available.

DISCUSSION OF RESULTS

The following paragraphs include a summary of the results, a discussion of possible explanations as to the origin of the geothermal resource (related to temperature), a discussion of the reliability of the results, and recommendations concerning additional analyses.

Summary

The present study shows that at Poplar 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. Although significant variations occur, water salinity is on the order of 150,000 ppm, mainly as a sodium chloride brine. Temperatures of water in the Madison are 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, nevertheless there is reason to expect that the 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.

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, by its thermal characteristics if correctly interpreted, and by irregular mineralization of the shallow ground water which sugggests 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.

Origin of the Geothermal Resource

There are several processes that can be used to explain why temperatures of water in the Madison are higher than would be expected from the normal geothermal gradient. None can be eliminated at this time, but some appear more likely than others.

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, would be more likely, 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. However, until a careful study is made, radioactivity as the principal heat source cannot be eliminated.

At this time, the preferred explanation 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 one down-hole temperature log available. It relates to the other indications that the Madison and other 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.

Reliability of Results

This study must be considered preliminary. Although the results agree well 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. Moreover, in the time available for the 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 thought most likely to produce oil rather than water. Furthermore, the tests were for periods of a few hours or less, which is much shorter than normally done for tests of aquifer yield. Actual rates of production of hot water from the present operators of the oil field have yet to be acquired; including--and vital to the objective of this project--what changes have been occurring over time. 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.

The results appear to be good enough, and the indications are sufficiently favorable that successful hot water production wells for direct use geothermal applications can reasonably be expected in the Poplar area. What 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. Of particular importance is the potential benefit of pumping with submersibles. Murphy Oil has recently run pumping tests which appear promising. The degree of risk can be reduced with further analysis of existing data.

Recommendations

For the reasons presented earlier in the discussion, it is recommended that some additional well data be acquired and that the analysis described in this report be continued in sufficient detail to refine the resource picture.

In addition to the Madison, other formations penetrated by the well logs should be studied in order to determine what potential exists that may provide the optimum combination of reservoir characteristics, heat, and depth. Included should be an assessment of the quantity of fluid in storage that can be produced. Finally, additional efforts should be made to learn from the experience gained by Murphy Oil, particularly in water treatment and pumping.

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 I-12. 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 possiblity 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

FIGURE I-12

THERMAL SURVEY

POPLAR, MONTANA

NOVEMBER 5, 1979

PRELIMINARY

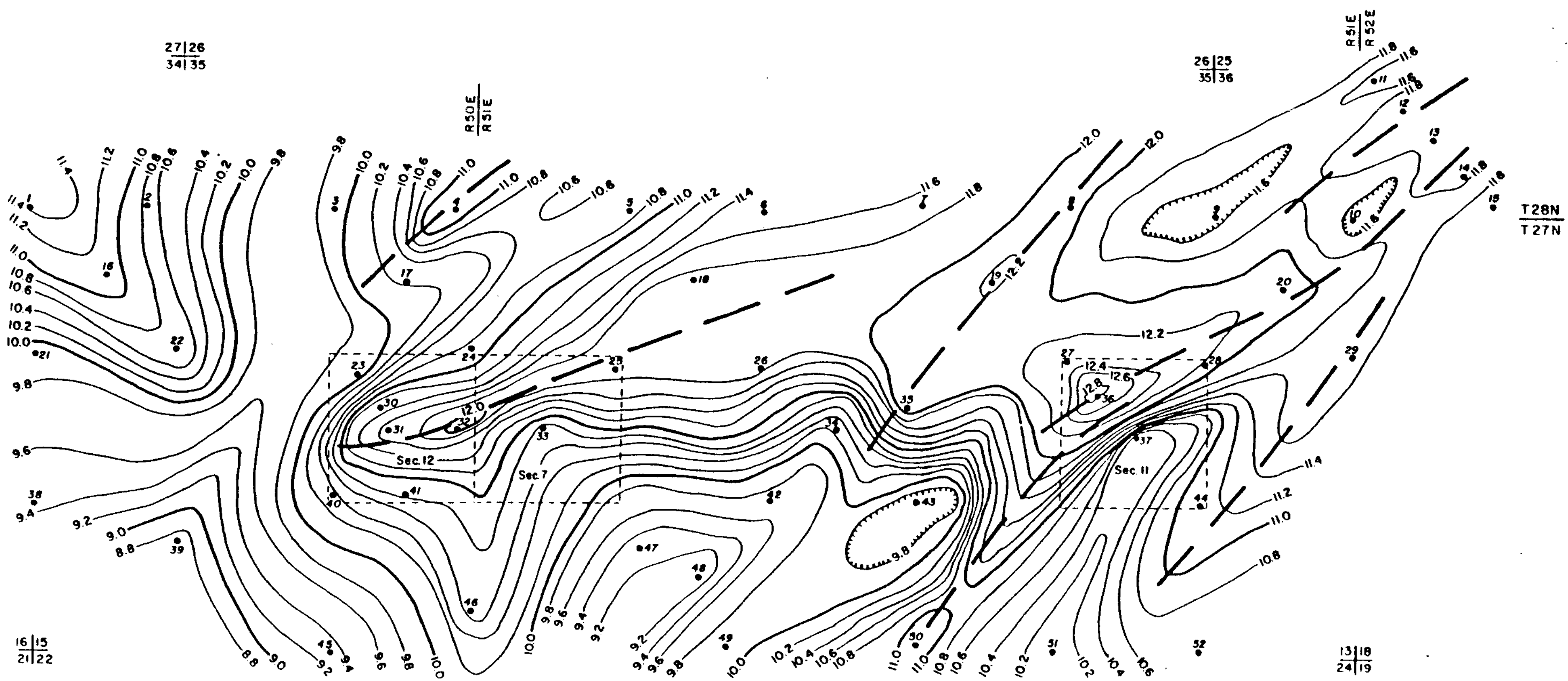
• PROBE LOCATION AND STATION NUMBER

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

INDICATED FAULTING (TENTATIVE)

0 0.5 1 MILES

N



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 [which would be expected to occur principally along faults and other fractures] 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 within a new housing site 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 on 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 I-13.

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, does underlie Poplar and vicinity. Depending on 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.

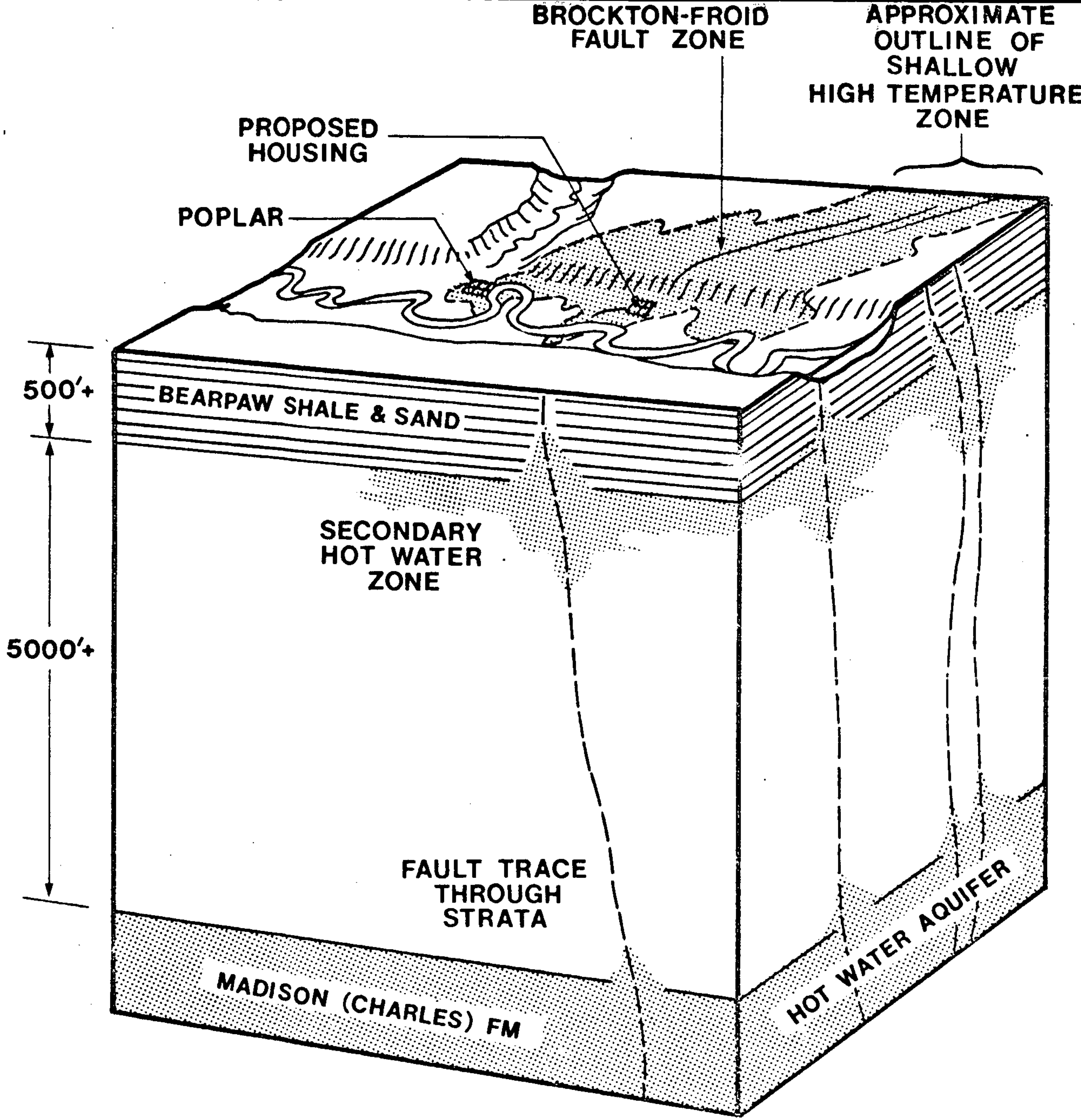


FIGURE I-13 DIAGRAMMATIC MODEL OF GEOTHERMAL RESERVOIR POPLAR, MONTANA

These conclusions, although encouraging, must be considered tentative. Further analysis is underway involving the relationship of the temperatures and their drift rates to detailed aspects of the superficial geologic setting, the structure and the ground water and surface hydrology.

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.

II. CONCEPTUAL DESIGN FOR RESOURCE APPLICATION

This section analyzes the overall economic feasibility of geothermal heating applications for the Poplar area. The analysis is based on use of geothermal heating systems for two representative heating districts: the Poplar central business district and school system, and the proposed new community development (New Town). These areas are representative of two diverse heating load densities. Economic feasibility for these two areas would be indicative of feasibility for Poplar and nearby communities. The locations of the existing and proposed communities is shown in Figure 2.

The analysis was performed in the following manner:

CONCEPTUAL DESIGN

(1) Develop space heating and water heating design load requirements for Poplar and New Town.

(2) Develop conceptual design parameters for Poplar and New Town based on the design heat load requirements and geothermal resource characteristics.

ECONOMIC ANALYSIS

(1) Prepare cost estimates based on the parameters defined in the conceptual design.

(2) Vary the conceptual design parameters to determine the sensitivity of the analysis to design assumptions and define potential cost savings areas for further study and refinement in Phase II.

(3) Compare the delivered geothermal energy costs to those of other energy sources as a measure of economic feasibility.

CONCEPTUAL DESIGN

DETERMINATION OF SPACE AND WATER HEATING DESIGN LOAD

The Poplar Central District heating subsystem would service the space heating and water heating needs of 30 non-residential buildings, 16 homes, and 3 schools, as shown in Figure II-1. The design load for this subsystem was determined to be 27.9 million BTU/hr, with an annual load of 62,800 MBTU (million BTU). (It should be noted that the study was restricted to those users within Poplar which had a high density heat load. If geothermal use is feasible for these users, the balance of the town will be evaluated in Phase II.)

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

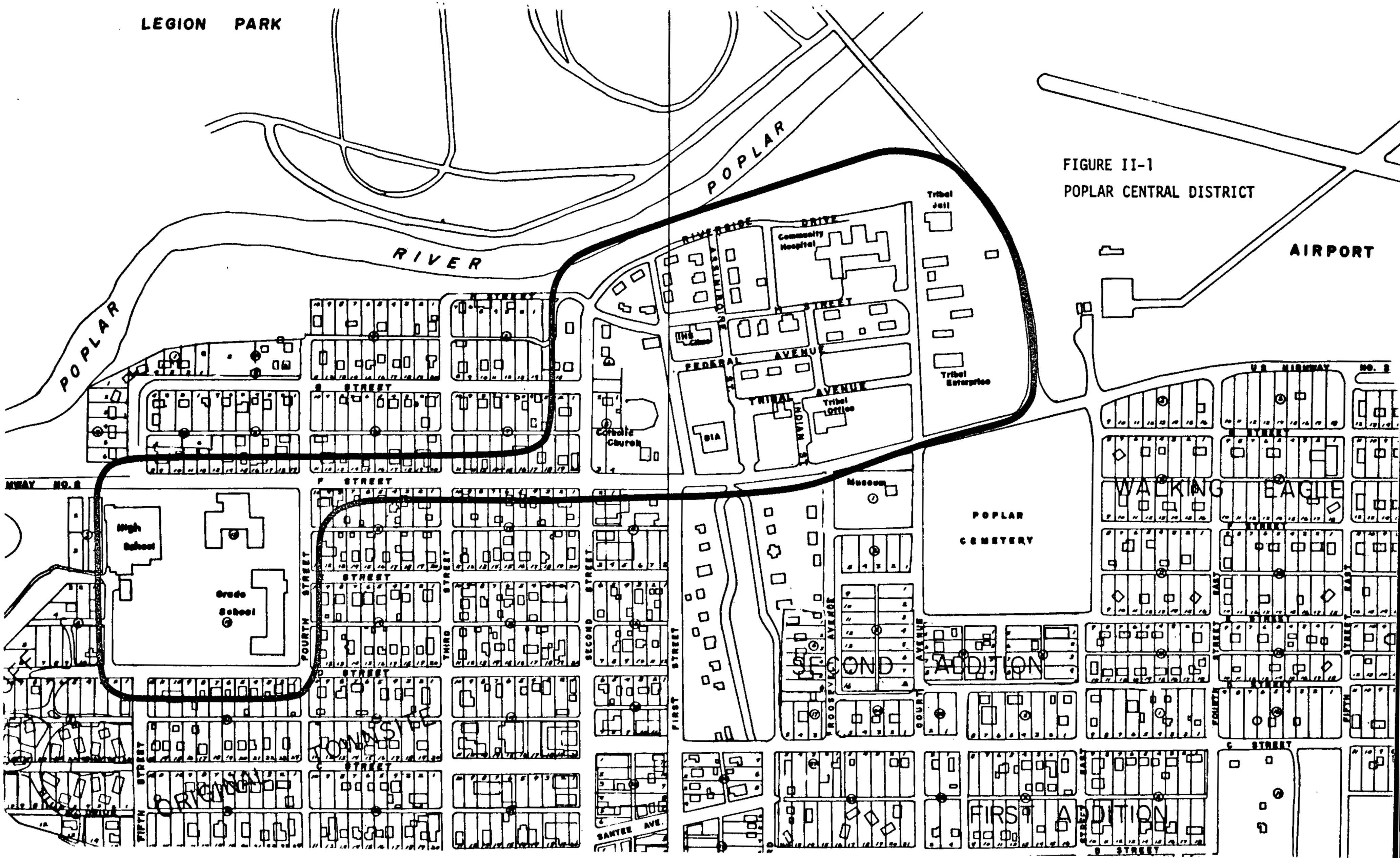


FIGURE II-1
POPLAR CENTRAL DISTRICT

district.[22,23] Weather data used in calculating the design load was for Glasgow, Montana, which is reasonably close to Poplar.[24] 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. A detailed breakdown of the space heating, domestic water heating, and design loads for the Poplar Central District are presented in Table II-1.

The new subdivision, New Town, will consist of 250 single family dwellings. Architectural plans for the new homes were utilized to compute the design space heating loads.[37] The total design load per dwelling is 83,000 BTU/hr. The total design heat load and annual load for New Town are 21 MBTU/hr and 62,800 MBTU/year, respectively. The heat load computations were based on 4 bedrooms per dwelling. The following weather design data for Glasgow, Montana was used: winter design temperature, -25^{o}F; January degree days, 1,711; annual degree days, 8,969.[40] The calculated design space heating load for each dwelling was 74,400 BTU/hr. The domestic water heating design load was determined to be 8,400 BTU/hr per residence. These calculations were based on the following assumptions: 6 persons per dwelling; 20 gallons/person/day; cold water entrance temperature, 40^{o}F; heated to 140^{o}F; water heater efficiency, 50 percent.

CONCEPTUAL SYSTEM DESIGN PARAMETERS

The system design and economic feasibility for the utilization of a geothermal resource is a function of the design interaction between three major factors:

TABLE II-1. ESTIMATED SPACE HEATING AND DOMESTIC WATER LOADS FOR THE POPLAR CENTRAL BUSINESS DISTRICT

Buildings	Design Load (BTU/hr) Space Heating	Design Load (BTU/hr) Domestic Water Heating	Design Load (BTU/hr) Total	Annual Load (MBTU) Space Heating	Annual Load (MBTU) Domestic Water Heating	Annual Load (MBTU) Total
Poplar Community Hospital	2,660,000	1,660,000	4,320,000	6,400	14,600	21,000
Fort Peck Tribal Building	670,000		670,000	1,600		1,600
Poplar Community Health Center	660,000	1,745,000	2,405,000	1,600	15,300	16,900
Bureau of Indian Affairs	900,000		900,000	2,100		2,100
Tribal Law and Order Building	700,000		700,000	1,700		1,700
Indian Health Service Building	925,000		925,000	2,200		2,200
Fort Peck Tribal Enterprise	350,000		350,000	800		800
Catholic Church	915,000		915,000	2,200		2,200
School District Buildings (3)	9,900,000		9,900,000	23,700		23,700
Other Buildings	5,600,000		5,600,000	13,400		13,400
Residences (16 total)	1,100,000	135,000	1,235,000	2,600	1,200	3,800
TOTALS	24,380,000	3,540,000	27,920,000	58,300	31,100	89,400

1) the nature of the resource application; 2) the characteristics of the geothermal resource and 3) the heat exchanger system. Table II-2 summarizes the items considered within each of the three areas in addition to: 1) the impact of each on general system design, 2) the specific system design considerations for Poplar and New Town, and 3) the resulting base case conceptual design parameters for this analysis.

The geothermal heating system is comprised of three major components:

- Resource Subsystem
- Heat Exchanger and Hot Water Transmission Pipeline Subsystem
- District Hot Water Distribution Subsystem

Resource Subsystem

The resource subsystem for each heating district is comprised of two production wells and one injection well together with pumps and associated piping between the wells and to the heat exchangers. The design parameters are listed in Table II-3. The production wells were spaced one-quarter mile apart. The cooled geothermal fluid would be injected below the Bearpaw to a depth of 1,000 feet with the injection well located near the heat exchanger.

The resource subsystem design was based on analysis of the geothermal fluid conditions in relation to the heat loads of Poplar and New Town as well as the heat

TABLE II-2. SUMMARY OF SYSTEM DESIGN CONSIDERATIONS AND CONCEPTUAL DESIGN PARAMETERS

DESIGN FACTOR	IMPACT ON SYSTEM DESIGN	POPLAR NEW TOWN DESIGN PARAMETERS	BASE CASE/CONCEPTUAL DESIGN PARAMETERS
RESOURCE APPLICATION			
Design Heat Load	Establishes hourly quantity of heat which heat exchanger must supply to distribution system.	Poplar Central District: 27.9 MBTU/HR New Town: 21 MBTU/HR	Heat provided to System: Poplar Central District-30 MBTU/HR New Town: 22 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 $15\text{-}20^{\circ}$ 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. May affect temperature of geothermal fluid.	Exact distances uncertain. Assume two alternate distances for cost comparison purposes.	Alternate pipeline lengths: 1/2 mile; 1-1/2 mile
Production Well Depth	Well cost increases with depth.	7,000 foot depth. Design to minimize number of wells.	2 wells required for each heating subsystem.
Fluid Temperature/ Production Well Flow Rate	Determines hourly quantity of useful heat which one well can supply to heat exchanger. Flow rate affects pipe diameter.	Fluid Temperature - 190°F Flow Rate - 500 gpm with submersible pumps	8" Diameter Pipe.
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 Total Flow Rate - 1,000 gpm. Equal flows on each side. Divide flow among three or more exchangers in parallel to provide reliability with minimum system redundancy cost.

TABLE II-3. RESOURCE SUBSYSTEM DESIGN PARAMETERS

PRODUCTION WELL DATA

Temperature at Wellhead - 190°F

Fluid Delivery Rate - 500 gpm w/submersible pumps

Well Depth - 7,000 feet

Well Life - 30 years

Well Spacing - 1/4 mile apart

Number of Wells - 2 per heating district

Location - 1/2 mile, 1.5 miles from heating district

DISPOSAL REQUIREMENTS

Injection - 100%

Injection Wells - 1 for every 2 production wells

Injection Depth - 1,000 feet (below Bearpaw)

Injection Pressure- 350 psi
Location - near heat exchanger

extraction efficiencies which could reasonably be obtained from the heat exchangers. Due to the variation in the available reservoir data, it was necessary to select reasonable values for resource conditions for the purposes of this analysis. A production well depth of 7,000 feet was assumed, with a wellhead fluid temperature of $190^{o}F$ and flow rate of 500 gallons per minute utilizing submersible pumps. The wellhead temperature of $190^{o}F$, together with the minimum useful hot water temperature and design heat loads for Poplar and New Town, dictated that a minimum of two wells be provided for each heating district. The 7,000-foot production well depth resulted in well costs which were significant enough to justify a heat exchanger subsystem which maximizes heat extraction and thus would require use of no more than two wells per district.

Heat Exchanger/Transmission Pipeline Subsystem

The heat exchanger subsystem was based on plate-type heat exchangers, which would allow for maximizing heat extraction from the geothermal fluid. The heat exchangers were located near the resource subsystem in order to minimize the length of piping from the wells to the heat exchanger which must be exposed to the anticipated corrosion and scaling problems from the geothermal fluid. The transmission pipeline scheme used a closed-loop system, with the hot water supply transported from the heat exchangers through the district heating subsystem, and the cooled water returned from the district to the heat exchanger. The total flow will be divided among several pumps in parallel such that each pump carries only a portion of the load.

TABLE II-5. EXAMPLES OF PLATE HEAT EXCHANGER DESIGNS WHICH COULD BE UTILIZED FOR POPLAR AND NEW TOWN

Maximum Flow Rate (gpm)	Surface Per Plate (Sq.Ft.)	Maximum Surface Area (Sq.Ft.)	Height	Width	Max. Length	Max. Dry Wt. (lbs.)	Plate Desi. Type
750	3.45	1,315	4'4"	1'4"	9'5"	3,450	P
750	3.45	1,073	4'4"	1'4"	9'10"	3,300	P
750	4.63	2,100	5'4"	2'8"	20'6"	11,000	M
1100	6.78	4,068	6'5"	2'5"	15'8"	11,000	M

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

*P - Herringbone
M - Mixed

Plate Materials:
304 S.S.
316 S.S.
Titanium
Incoloy 825™
Hastelloy™
Inconel™

The heat exchanger conceptual design data for Poplar and New Town are summarized on Table II-4. Since the characteristics of the geothermal fluid are uncertain, the calculations were based on 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. The flow will be divided among three or more heat exchangers in parallel in order to minimize the level of spare capacity required for system reliability. The heat exchangers were sized for 100 percent of system heat load demand. Table II-5 lists frame sizes and surface area available from one manufacturer which could be used to satisfy these requirements.[18]

The plate-type heat exchanger is, by its nature, well suited for the Poplar and New Town applications. Reliability can be built into the system without excess spare capacity. For example, selecting three units for parallel operation would allow for extra flow capability within the frame size selected. If one exchange requires repair, the remaining two can carry two-thirds of the design load, which will normally exceed the heating requirements of Poplar for all but three months of the year. A frame size could be selected such that each exchanger can accept 500 gpm of flow. Since a plate-type exchanger can be disassembled in a minimum period of time, it would therefore be possible to bypass the heat exchange system and transfer useable plates from the damaged exchanger to the remaining exchanger 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 II-2 and II-3), which should allow minimization of scale build-up and thus maintain the coefficient of heat transfer at a high level.[16] Further, with selection of a larger frame size, plates can be added for heat and growth.

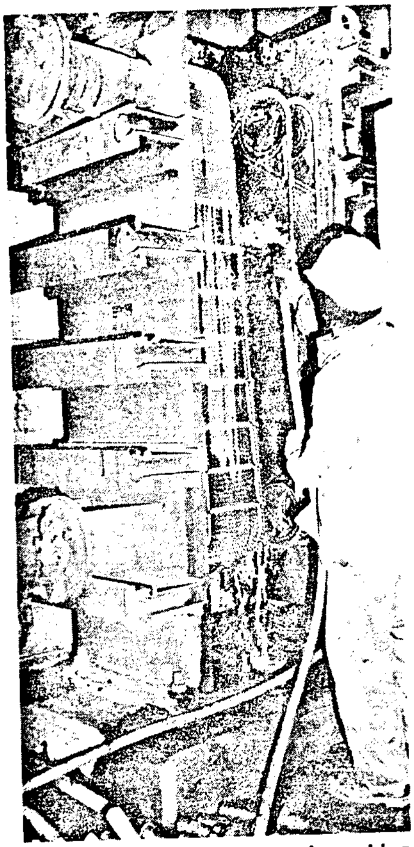
TABLE II-4. HEAT EXCHANGER CONCEPTUAL DESIGN DATA FOR POPLAR AND NEW TOWN

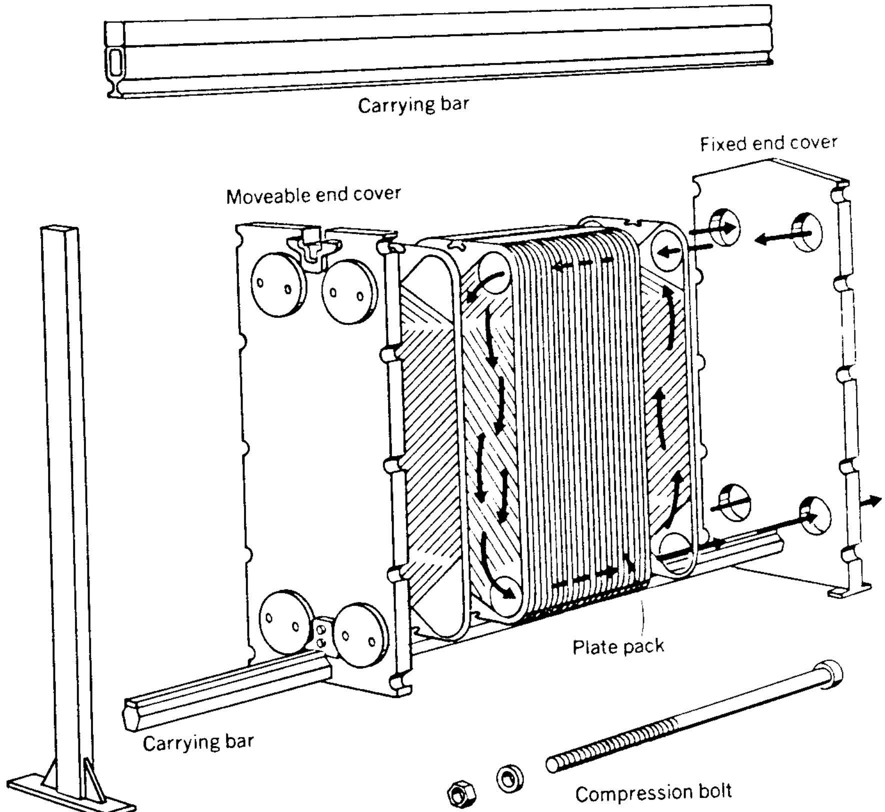
	POPLAR	NEW TOWN
Inlet/Exit Temperatures, ^{O}F (Δ T)	65^{O}	45^{O}
Fluid	190/125	190/145
Hot Water	115/180	125/170
Temperature Change, ^{O}F (Δ T)		
Fluid	65^{O}	45
Hot Water	65^{O}	45
LMTD ^{O}F (Δ Tm)	10	20
Flow Rate, gpm		
Fluid/Hot Water	1,000/1,000	1,000/1,000
Pressure Loss, PSI	25	12
LMTD Factor, F	0.92	0.970
Heat Transfer Coefficient (U)	700	700
Surface Area, ft^2 (A)	4650	1620
Heat Transferred, MBTU/hr (q)	30	22

Data Relationship Formulae for Water/Water Exchangers, 1:1 Flow Ratio

$q = (U)(F)(A)(\Delta T_m)$ (actual)

$q = (500)(gpm)(\Delta T)$ (maximum)





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 II-2 PLATE HEAT EXCHANGER CLEANING

FIGURE II-3 PLATE HEAT EXCHANGER MAINTENANCE

The heat exchanger material will be, at a minimum, 304 stainless steel to minimize corrosion. If required, heat exchanger material can be titanium. Use of the latter material would roughly double the cost of the exchangers, and would only be selected if necessary for significantly increased design life.

The transmission pipeline and pumps were designed to provide a 1,000 gpm flow to the district system, with 20 percent spare pumping capacity. The pipeline design utilized 8-inch diameter pipe, insulated and buried to minimize temperature drop and heat loss, with both the supply and return pipes occupying a single trench. The piping material will probably be reinforced fiberglass or a comparable material, with both pipes in an insulated PVC carrier, which is available as an off-the-shelf item. Since the exact well location is unknown, the conceptual design was based on two alternate pipeline distances: 0.5 mile and 1.5 miles.

District Heating Subsystem

The district heating subsystem layout developed for Poplar is shown in Figure II-4. The supply line used an 8-inch main. Pumping stations to maintain the flow rate through the subsystem were included in the design. The initial hot water delivery temperature to the subsystem was 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.

In order to utilize the heat under these design conditions, the subsystem will be designed as a series of "cascading" loops. Each loop will have a supply and return pipe. A building in a loop would remove water from the loop supply pipe and return

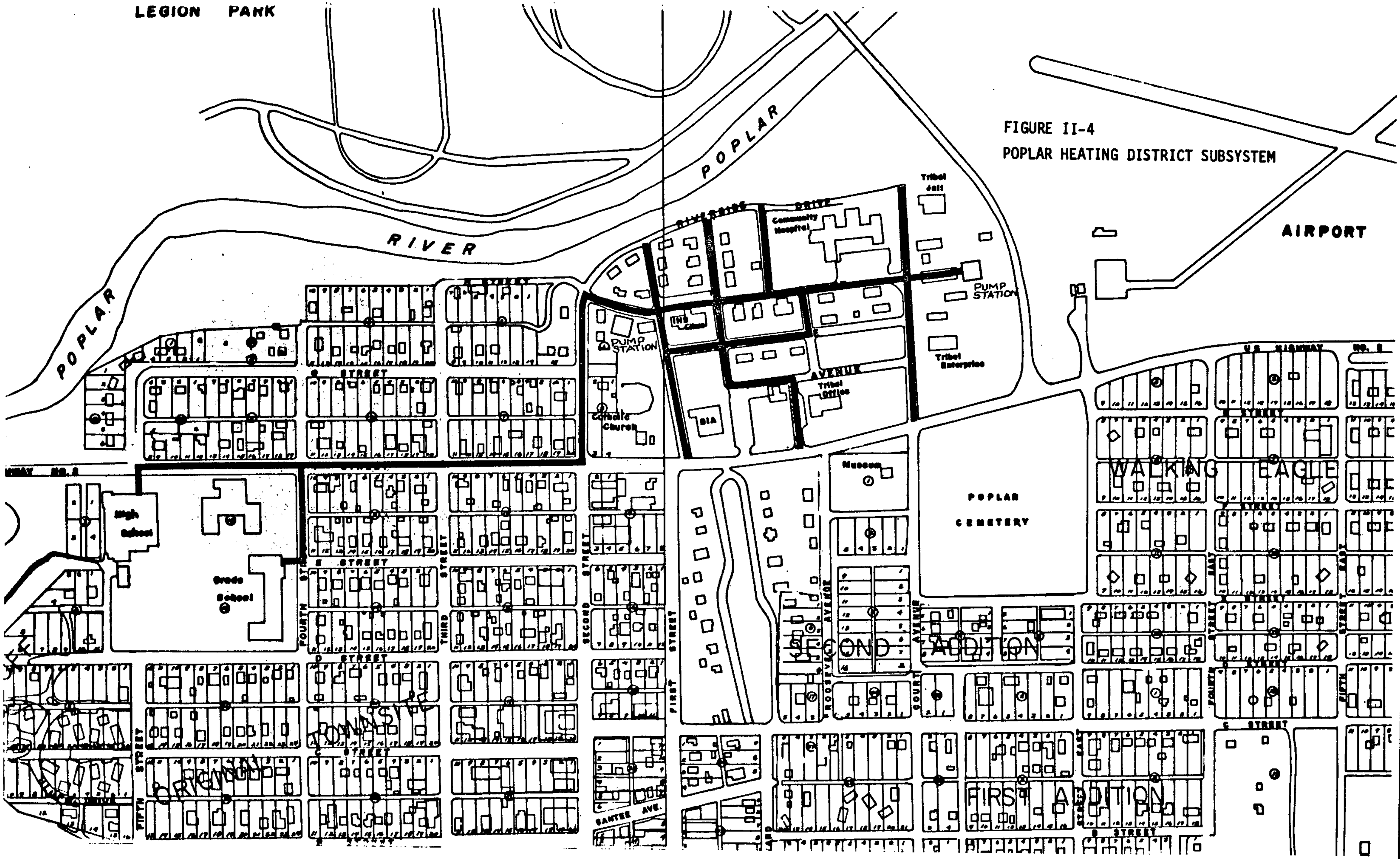


FIGURE II-4
POPLAR HEATING DISTRICT SUBSYSTEM
LEGION PARK
POPLAR RIVER
AIRPORT
RIVERSIDE DRIVE
Community Hospital
Tribal Jail
PUMP STATION
IHS Clinic
Tribal Enterprise
AVENUE
Tribal Office
BIA
Catholic Church
Museum
POPLAR CEMETERY
High School
Grade School
WALKING EAGLE
SECOND ADDITION
FIRST ADDITION
ORIGINAL TOWNSITE
FIRST STREET
SECOND STREET
THIRD STREET
FOURTH STREET
FIFTH STREET
E STREET
D STREET
C STREET
B STREET
SANTEE AVE.
ROOSEVELT AVENUE
COURT AVENUE
US HIGHWAY NO. 2

it to the loop return pipe. However, the loop return pipe will discharge into the subsystem supply main, until the point in the system where the temperature in the main has degraded to 130-140°F. At that point, the loops will discharge to the return main. Within this minimum cascading-loop operating temperature range, there should be no material difference in end-user system design and operating costs.[12]

ECONOMIC ANALYSIS

CONCEPTUAL COST ANALYSIS

Conceptual cost estimates were prepared for the Poplar and New Town heating system designs to serve as a basis for assessing the overall economic feasibility of a geothermal heating system for the Poplar area. Total capital costs were developed from individual cost estimates for the major system components. The system component costs were based on pricing information obtained from personal communications with equipment suppliers and cost data presented in published literature.[4,17,18,20,22,31] In the latter case, escalation factors were applied in order to approximate those costs in present-day dollars. The component costs from the various sources were then analyzed and compared for consistency as a measure of gauging the reasonableness of both the individual component and total system cost estimates. Evaluated costs were computed on the basis of an economic life of 30 years and 8 percent cost of money. The resulting capital costs, first year costs, and delivered energy costs, in fourth-quarter 1979 dollars, are summarized below:

	POPLAR		NEW TOWN	
	0.5-Mile Source Distance	1.5-Mile Source Distance	0.5-Mile Source Distance	1.5-Mile Source Distance
Capital Cost	$2,000,000.00	$2,445,000.00	$2,350,000.00	$2,795,000.00
First Year Cost	$ 300,000.00	$ 370,000.00	$ 340,000.00	$ 410,000.00
Delivered Energy Cost ($/MBTU)	$ 3.35	$ 4.15	$ 5.40	$ 6.50
Differential Energy Cost ($/MBTU)	BASE	$ 0.80	$ 2.05	$ 3.15

A system component breakdown of these costs is presented in Table II-6. The Resource Subsystem costs include production and injection wells, with associated pumps, valves, and piping between the wells and the heat exchanger. The Heat Exchanger Subsystem includes the heat exchangers, pumps, valves, and piping to and from the heating district. The District Subsystem costs are for the District distribution piping, pumps, valves, and customer connections. Contingency costs were factored into the component estimates. Engineering and Administration costs contribute approximately 10 percent of the total capital cost for the system.

The capital costs are based on $400,000 for each production well and $100,000 per injection well, which are consistent with drilling cost estimates, geology and drilling experience for that area. Pipine costs of $36.00 per foot were utilized for the 8-inch diameter pipe assuming two pipes in a common trench.

Customer connection costs of $1,200 and $1,800 per unit were used for residential and large buildings, respectively. The 10 percent total cost contribution for Engineering and Administration was considered a reasonable dollar value for that

TABLE II-6. CONCEPTUAL COST ESTIMATES FOR POPLAR AND NEW TOWN GEOTHERMAL HEATING SYSTEMS.

	POPLAR		NEW TOWN	
	0.5 Mile Resource Distance	1.5 Mile Resource Distance	0.5 Mile Resource Distance	1.5 Mile Resource Distance
CAPITAL COSTS				
Resource Subsystem	$1,105,000	$1,105,000	$1,105,000	$1,105,000
Heat Exchanger Subsystem	270,000	675,000	235,000	640,000
District Subsystem	415,000	415,000	770,000	770,000
Engineering & Administration	210,000	250,000	240,000	280,000
Total Capital Cost	$2,000,000	$2,445,000	$2,350,000	$2,795,000
FIRST YEAR COST				
Debt Service	$ 180,000	$ 220,000	$ 210,000	$ 250,000
Power Cost	40,000	53,000	40,000	55,000
Renewal, Replacement	40,000	50,000	50,000	60,000
Administration	40,000	45,000	40,000	45,000
Total First Year Cost	$ 300,000	$ 370,000	$ 340,000	$ 410,000
Delivered Cost, $/MBTU	$ 3.35	$ 4.15	$ 5.40	$ 6.50

component due to the proportion of the capital budget which would be used for drilling and off-the-shelf capital equipment items.

The first-year and delivered costs were calculated for a non-profit, cost-of-service pricing system. Power cost calculations were based on the estimated design motor requirements, load factor, and electricity costs for the Poplar area. Renewal and Replacement Costs and Administration costs were each developed on the basis of 2 percent of the capital budget, with adjustments, as appropriate to the resulting dollar value based on relative system size or complexity.

The differences in costs between these four cases illustrate: a) the cost of locating the production wells at increased distances from the source; b) differences in the cost of serving heat loads of high and low load density (large building (Poplar) vs. individual residences (New Town)); c) differences in heating district heat requirements for the same heat source capability (increased heat load per well and piping capital cost dollar). The cost impact of increasing the distance from 1/2 mile to 1 mile is $0.80/MBTU and $1.15/MBTU for Poplar and New Town, respectively. The combined effects of high heat load density and a high resource utilization (investment spread over higher annual heating demand) result in a cost savings of $1.15/MBTU for the Poplar heating district.

COST SENSITIVITY ANALYSIS

The conceptual design parameters defined in Table II-2 were varied in order to test the sensitivity of the delivered costs to the assumptions contained therein, and identify potential cost savings areas for further study in Phase II. The design concepts which were tested are as follows:

1. Design system to meet demand;

2. Design system for heat exchanger maximum efficiency condition (New Town only);

3. Design system for source temperature of 190°F;

4. Design system to minimize handling of geothermal fluid.

The variations to the above conditions which were tested are as follows:

1. Design system to maximize heat produced based on the minimum number of wells to satisfy base demand (Maximum Utilization);

2. Design system to minimize pipe cost between source and New Town;

3. Design system for higher resource temperatures, with maximum utilization of resource;

4. Locate heat exchanger at the heating district. Transport geothermal fluid from wellhead and inject near heat exchanger. Hot water loop through heating district only.

The impacts of these variations are summarized on Tables II-7, II-8, II-9, II-10, and II-11.

Maximize Output

The output was maximized by increasing the heat exchanger plate area to maximize the output from two wells. A comparison of applying the maximized output concept to the Base Cases (190°F, meet demand) shows that, for a relatively small increase in capital expenditures, more heat load can be served, thereby decreasing the cost per unit. The increased area in Poplar which could be served is shown in Figure II-5 (Area-1). The savings is most significant for New Town, where the design heat load was only 25 percent above that which could have been supplied by one well. In that case, an additional investment of $150,000 would produce enough heat to support a two-acre greenhouse, and at the same time, decrease the overall cost of service by $1.45/MBTU. (See Appendix C, Survey of Other Direct Applications.)

Minimize Pipe Cost

The base estimate for New Town was developed for the design concept of maximizing heat exchanger efficiency to meet the heating load. For a plate-type exchanger, this design concept dictates that the flows of hot and cold fluids be equal. However, the heat exchanger can deviate from the 1:1 flow ratio to .7/1 (minimum/maximum), with a reduction in efficiency. This analysis utilizes a .7/1 flow ratio, for a hot water flow rate of 700 gpm to minimize the size of the transmission pipeline from 8" to 6" diameter over a 1 1/2 mile distance from the

TABLE II-7. COMPARISON OF ECONOMIC EFFECTS OF VARYING DESIGN PARAMETERS FOR POPLAR CENTRAL DISTRICT

	CAPITAL COST ($)	ANNUAL COST	$/MBTU	DIFFERENTIAL BASE CASE	$/MBTU BASE CASE II
I. 190° Source					
Base Case 30 Million BTU/Hr .5 Mi to Source	$2,000,000	$300,000	$3.35	BASE	($0.65)
A. Full Utilization: .5 Mi to Source	$ 2,060,00	$310,000	$3.25	$0.10	($0.75)
B. 30 MM BTU/hr 1.5 Mi to Source	$2,445,000	$370,000	$4.15	$0.80	($0.15)
II. INCREASED SOURCE TEMPERATURE					
Full Utilization: 1.5 Mi to Source					
Base Case- 190°F	$2,505,000	$380,000	$4.00	$0.65	Base
A. 200°F	$2,650,000	$400,000	$3.75	$0.40	($0.25)
B. 210°F	$2,860,000	$430,000	$3.60	$0.25	($0.40)
C. 220°F	$2,900,000	$435,000	$3.35	0	($0.65)

TABLE II-8. IMPACTS OF VARYING DESIGN PARAMETERS FOR POPLAR CENTRAL DISTRICT

	HOURLY DEMAND (MBTU/HR)	ANNUAL LOAD (MBTU/YR)	ADDITIONAL STRUCTURES	UNIT COST FOR HEAT ($/MBTU)
190°F Source @ 0.5 Mile				
Base Case I: Design for Demand	27.9	89,400	BASE	$3.35
Case I-A Design for Well Production Capacity	31.0	95,400	35	$3.25
190°F-220°F @1.5 Mile				
Case I-B 190°F, Design for Demand	27.9	89,400	BASE	$4.15
Base Case II 190°F, Design for Well Production Capacity	31.0	95,400	35	$4.00
Case II-A 200°F, Design for Well Production Capacity	35.7	107,000	100	$3.75
Case II-B 210°F, Design for Well Production Capacity	40.5	119,000	155	$3.60
Case II-C 220F, Design for Well Production Capacity	45.2	131,000	210	$3.35

TABLE II-9. COMPARISON OF COST EFFECTS OF VARYING DESIGN PARAMETERS FOR NEW TOWN

		CAPITAL COST ($)	ANNUAL COST	$/MBTU	DIFFERENTIAL $/MBTU BASE CASE	BASE CASE II
I.	<u>190° SOURCE</u>					
	Base Case I: 21 Million BTU/Hr 0.5 Mi. to Source	$2,350,000	$340,000	$5.40	BASE	$0.70
	Case I-A Full Utilization 0.5 Mi. to Source	$2,510,000	$365,000	$3.95	($1.45)	($0.75)
	Case I-B 21 Million 3 BTU/hr 1,000 gpm/700 gpm Flow Ratio 1.5 Mi. to Source	$2,525,000	$355,000	$5.65	$0.25	$0.80
	Case I-C 21 Million BTU/Hr 1.5 Mi. to Source	$2,795,000	$410,000	$6.50	$1.10	$1.80
II.	<u>INCREASED SOURCE TEMPERATURE</u> Full Utilization 1-1/2 Mi. to Source					
	Base Case - 190°F	$2,970,000	$433,000	$4.70	($0.70)	BASE
	A - 200°F	$3,000,000	$434,000	$4.05	($1.35)	($0.65)
	B - 210°F	$3,205,000	$464,000	$3.80	($1.60)	($0.90)
	B-1 - 210°F (1 well)	$2,080,000	$293,000	$4.65	($0.75)	($0.05)
	C - 220°F	$3,350,000	$485,000	$3.55	($1.85)	($1.15)

TABLE II-10. IMPACTS OF VARYING DESIGN PARAMETERS FOR NEW TOWN

	HOURLY DEMAND (MBTU/HR)	ANNUAL LOAD (MBTU/YR)	ADDITIONAL STRUCTURES	UNIT COST FOR HEAT ($/MBTU)
<u>190°F Source @ 0.5 Mi</u>				
Base Case I: Design for Demand	21.0	62,800	BASE	$5.40
Case I-A Design for Well Production Capacity	31.0	92,400	Two-Acre Greenhouse	$3.95
Case I-B Design to Decrease Transmission Pipe Diameter	21.0	62,800	BASE	$5.65
<u>190°F - 220°F @ 1.5 Mi</u>				
Case I-C 190°F, Design for Demand	21.0	62,800	BASE	$6.50
Base Case II 190°F, Design for Well Production Capacity	31.0	92,400	Two-Acre Greenhouse	$4.70
Case II-A 200°F, Design for Well Production Capacity	35.7	107,000	Three-Acre Greenhouse	$4.05
Case II-B 210°F, Design for Well Production Capacity	40.5	122,000	Four-Acre Greenhouse	$3.80
Case II-B-1 210°F, Design for Well/Town, 1 Well, 500 gpm	21.0	62,800	BASE	$4.65
Case II-C 220°F, Design for Well Production Capacity	45.2	137,000	Five-Acre Greenhouse	$3.55

TABLE II-11. COST IMPACT OF TWO-PIPE TRANSMISSION PIPELINE SYSTEM FOR 1.5-MILE SOURCE DISTANCE

	2-Pipe System \$/MBTU	1-Pipe System \$/MBTU	Cost Differential \$/MBTU
POPLAR CASES			
I-B: 190°, 30 MBTU/hr	\$4.15	\$3.70	\$0.45
II-Base: 190°F	\$4.00	\$3.55	\$0.45
II-A: 200°F	\$3.75	\$3.35	\$0.40
II-B: 210°F	\$3.60	\$3.25	\$0.35
III-C: 220°F	\$3.35	\$3.05	\$0.30
NEW TOWN CASES			
I-C: 190°F, 21 MBTU/hr	\$6.50	\$5.85	\$0.65
II-Base Case: 190°F	\$4.70	\$4.25	\$0.45
II-A: 200°F	\$4.05	\$3.65	\$0.40
II-B: 210°F	\$3.80	\$3.45	\$0.35
II-C: 220°F	\$3.55	\$3.25	\$0.30

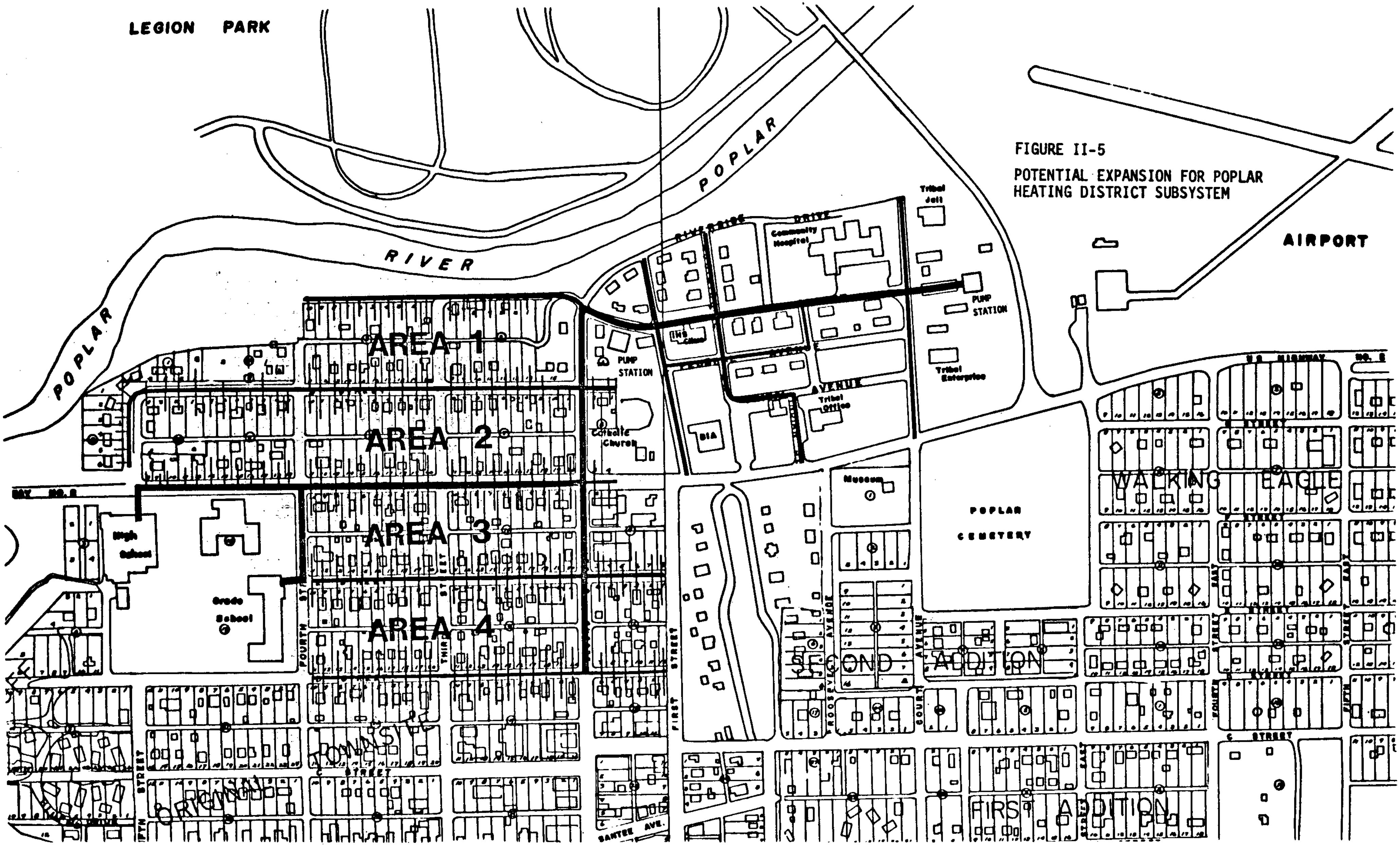


FIGURE II-5

POTENTIAL EXPANSION FOR POPLAR HEATING DISTRICT SUBSYSTEM heat source to the heating district. The result is a delivered cost of $5.65/MBTU, or a savings of $0.85/MBTU over the 8" pipe for that source distance. However, this cost savings is not as great as that of designing for maximum heat exchanger efficiency, and utilizing the excess heat for other heating applications.

Design for Higher Resource Temperatures

The geologic data suggest that a resource temperature of 190°F at the wellhead is a very conservative estimate, and that a source temperature of 220°F or more may be encountered. However, the distances from the resource to the heating districts could be approximately 1 1/2 miles or more. Therefore, an analysis of the estimated costs for developing a resource with two wells, on a maximum utilization basis, at a distance of 1.5 miles from Poplar and New Town was prepared for temperatures of 200°F, 210°F, and 220°F. The increased heating load which could be served as a result of the increase in resource temperature is shown in Tables II-8 and II-10. The potential expansion of the Poplar District heating subsystem is illustrated in Figure II-5 (200° - Area 1+2; 210° - Add Area 3; 220° - Add Area 4).

The analysis shows that although an increase in the temperature of the resource well significantly reduces the unit cost of service for a constant distance (a range of $0.25 to $0.65/MBTU for Poplar and $0.65 to $1.15 for New Town), the increase in heat extraction capability per well does not necessarily justify increasing pipeline distance in order to achieve a higher temperature. For example, for Poplar, the unit cost of heat from a 190°F source, full utilization located 1/2 mile from the heating district, is $3.35/MBTU. If increasing the distance from 1/2 to

1.5 miles would increase temperature, it would take a resource temperature of 220°F to overcome the piping cost differential and deliver the heat at $3.35/MBTU. For New Town, this "break-even point" is for roughly a 205-210°F resource. On the other hand, the ability to serve an increased number of buildings within the heating district without additional well cost could justify the increased unit cost (as compared to adding closer wells at less than maximum utilization to serve the incremental load).

For New Town, it was also determined that a resource temperature of 210°F would enable the heating district to be serviced by one well, with a 6" piping system. This is presented as Case II-B-2 on Table II-9. This shows that the unit costs could be decreased without adding additional buildings. However, the decrease would not be as great as that obtained with two wells serving New Town with additional heat uses, such as greenhouses.

Locate Heat Exchanger Near Heating District

The preceding cost analysis has shown that the overall cost is sensitive to the length of the transmission pipeline. Locating the heat exchanger near the production wells results in a two-pipe system between the resource and the heat load, which becomes a significant cost factor as distances increase. This concept was selected in order to minimize handling of the geothermal fluid and is considered to be a "worst-case" assumption based on the wider range in the fluid analyses. This analysis is based on transporting the geothermal fluid to the heating district, and injecting it (near the heat exchanger/near the heating district). The transmission pipeline system therefore becomes a single 8" pipe with the double-pipe system restricted to the heating district. The cost savings are presented in Table II-11. This shows that a savings of $0.30/MBTU to $0.45/MBTU could be realized for the maximum utilization cases. This savings, in turn, could enhance the attractiveness of increasing the distance between the production wells and the heating districts to attain higher resource temperatures. The feasibility of this arrangement will require further data as to the expected geothermal fluid characteristics and the feasibility of transporting the fluid in relation to corrosion and scaling problems. One method of fluid handling may be to treat the fluid at the wellhead. If this treatment could be achieved for less than the incremental pipe cost for a two-pipe hot water system, a one-pipe system could become an attractive alternative, particularly if higher resource temperatures could be located at distances in excess of 1.5 miles from the heating district.

Other Variables

Discount Rate, Economic Life

In performing this analysis, the annual costs were based on debt service at an 8 percent cost of money, with an economic life of 30 years. In order to assess the impact of these two assumptions, a comparison was made of this case with changing the economic life to 25 years and the discount rate to 10 percent. This was done for a representative capital cost of $2.5 million, and an annual heat load of 92,000 MBTU. The variations are summarized below.

	I=8% n=30 yrs	I=8% n=25 yrs	I=10% n=30 yrs	I=10% n=25 yrs
Increase from Base, $/MBTU	BASE	$.10	$0.35	$0.60

The discount rate is the more likely of the two variables to increase above the base case level. Ten percent could be considered a pessimistic case. Due to the annual dollars budgeted for renewal and replacement, which will escalate over time, an economic life of 30 years to the capital expenses is the more likely of the two values. Therefore, the expected value of the impact of a change from the I=8%, n=30 years would approximate $0.25/MBTU.

Load Factor

The system is designed to meet the peak heating demand for the heating district. However, this design hourly load only occurs during the winter heating season, and would not necessarily occur on any given day during the winter months. The cost of supplying the heat is spread over the annual heat load. The load factor is an expression of the amount of heat utilized during the year compared with the amount that would be available for consumption if the design heat load were generated and consumed over the entire year. For the Poplar and New Town space and water heating applications, the load factor is approximately 30%. Capital cost does not vary with load factor. Therefore, if the load factor could be increased, the annual heat (BTU) sales would increase, and the net result would be a decrease in the delivered cost of heat ($/MBTU) to the user.

Potential areas for further study would be to design for less than the high hourly demand and devise methods of supplementing during high use times (such as factoring in the use of fireplaces). Another possibility would be to use one well year round, store the heat in a shallow aquifer near the heating district, and withdraw the heat as required. This method could potentially produce a substantial decrease in capital costs (well, transmission pipeline size), and hence, a significant reduction in the delivered cost of energy to the user.

ECONOMIC EVALUATION

The range of first year delivered costs for geothermal energy from a 190°F resource for space and water heating purposes for Poplar was $3.25/MBTU to $4.15/MBTU. For New Town, this range was from $3.95 to $6.50/MBTU.

Natural gas and electricity are presently being used in Poplar for space heating and domestic water heating. The cost of natural gas is $1.80/MBTU, and the cost of electricity is about $9.50/MBTU.

The local natural gas utility has limited supplies and few available new gas connections. Since future natural gas supplies are uncertain, the costs of geothermal energy were also compared to home heating oil (which is comparable to a propane alternative), as well as electricity and natural gas. The current price of home heating oil was estimated to be $0.80/gallon, or $5.60/MBTU. On an efficiency-adjusted basis, the equivalent delivered cost is approximately $2.40/MBTU for natural gas, $9.50/MBTU for electricity and $8.60/MBTU for heating oil. These equivalent costs assume heating system efficiencies of 75%, 100%, and 65%, respectively.[17,44]

The present day costs of these alternatives are summarized below:

	$/MBTU
Geothermal	
Poplar	$3.05 - $4.15
New Town	$3.95 - $6.50
Natural Gas	$1.80
Efficiency Adjusted	$2.40
Electricity	$9.50
Heating Oil	$5.60
Efficiency Adjusted	$8.60

As shown above, on a first-year cost basis, geothermal is competitive with the alternatives to natural gas.

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 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 40 percent of the first year costs.

A recent study of energy price projections to the year 2000 compared price projections from various sources.[44] With 1975 as the starting point, the projections expected home heating oil to increase in a range of 2.5 to 4.5% annually above the inflation rate until 1990. Electricity was not expected to rise much faster than the inflation rate. One projection expected that natural gas would rise to a price equivalent with home heating oil.

Projections for the prices of home heating oil, electricity and natural gas were developed to the year 1990 based on Reference 18. The rate of inflation was assumed to be 7 percent per year. Home heating oil was assumed to rise only 1 percent per year above the annual inflation rate, since it has already incurred a substantial increase since the long-range projections were developed. Natural gas price projections were then developed on the basis that it will equal the projected heating oil price by 1990.[44] Electricity prices were projected to an increase of 7 percent per year.

Geothermal costs were escalated for the maximum and minimum values of the range of delivered costs and included with the following 1980 delivered costs: Poplar -- $3.35/MBTU and $4.00/MBTU; New Town - $4.70/MBTU, $5.40/MBTU and $6.50/MBTU. The projections were developed on the basis that the escalating components of the annual cost rise at a rate of 8%/year. The rate of 1 percent above overall inflation 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 II-6. The figure illustrates that, if the geothermal heating appplication system were installed today, the price of that energy in the future could become less than the alternatives.

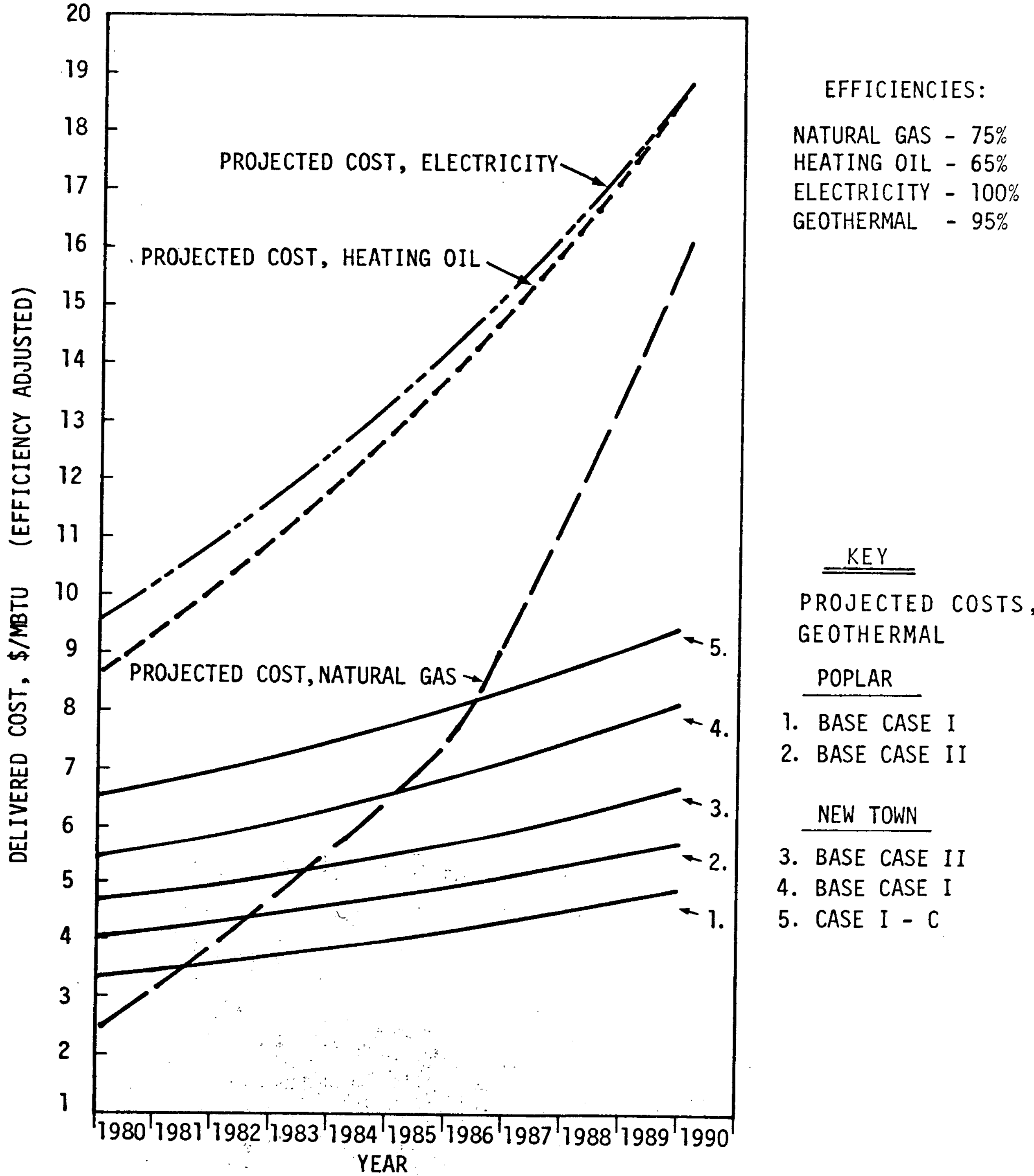


FIGURE II-6 COMPARISON OF EFFICIENCY ADJUSTED DELIVERED COST PROJECTIONS: GEOTHERMAL ENERGY, ELECTRICITY, HEATING OIL, NATURAL GAS. 1980 - 1990

In order to evaluate the future competitiveness of a geothermal system installed today with the projected prices of the alternates, equivalent uniform annual costs were computed for the yearly prices and efficiency-adjusted costs projected. These costs are tabulated below:

	$/MBTU
Geothermal	
Poplar	
Base Case I	$ 4.10
Base Case II	$ 4.80
New Town	
Base Case II	$ 5.60
Base Case I	$ 6.70
Case I-C	$ 7.90
Natural Gas	$ 5.30
Efficiency Adjusted	$ 7.05
Electricity	$14.00
Heating Oil	$ 8.70
Efficiency Adjusted	$13.35

The above tabulation shows that a geothermal energy system to provide heating applications for Poplar and the new development should be an economically feasible alternative energy supply within the expected delivered cost range.

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APPENDIX A

NEAR-SURFACE GEOLOGY

APPENDIX A

NEAR-SURFACE GEOLOGY

GEOLOGIC SETTING

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. An arbitrary man-made boundary represents the northern limits of the reservation. (See Figure 1.)

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.[(34)] Its present day landscape symbolizes an area that has undergone gentle, intermittant uplift, and successive invasions and retreats of Pleistocene ice sheets.

The most dominant physical feature within the study area is the meandering Missouri River sand, its flood plain which ranges from 2-1/2± to 4± miles wide (Figure I-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.

To the south, the nearly level Missouri River flood plain is bordered by gently sloping (50+ feet per mile), partially cultivated land. Continuing further south, this gently sloping area is replaced by highly dissected hills (i.e., badland topography) which are underlain by Cretaceous bedrock material. The average gradient of these hills is about 230± feet per mile, with local gradient as high as 400± feet per mile.

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.[34] In 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 across the Missouri River flood plain.

Although several tributary streams enter the Missouri River from the south, most of these streams are generally small; and few, if any, have perennial flows in excessively dry years. The largest tributary from the south is Redwater Creek (Figure I-1).

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 varing depths, ranging up to several hundred feet thick.[8] 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 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, 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 I-1.

NEAR SURFACE GEOLOGY

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.[25] 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.[34] 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.[8]

Fan Alluvium/Colluvium (Qac)

The fan alluvium and colluvium deposited, as defined by Colton,[8] 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.(8)

<u>Dune Sand (Qd)</u>

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.(34) Maximum thickness of these dune deposits is estimated to be approximately 20± feet.

<u>Lake/Pond (Ql)</u>

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.

<u>Kintyre Formation (Qki)</u>

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.[25] 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.[25] Located north of the Missouri River flood plain, the Kintyre Formation has a maximum thickness of approximately 150± feet.[8]

Glacial Till(Qt)

Glacial till mantles most of the upland areas within the study area (Figure I-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± to 20± feet, however, locally may be in excess of 100± 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 I-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.[25] Average thickness of these deposits is approximately 15± feet, however, may be as much as 60± feet.[25]

Sprole Silte (Qs)

Sprole silt is exposed in several small gullies in the northern and eastern portions of the study area (Figure I-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.[8] 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.[25] The Wiota Gravels often vary in nature from one location to another, and may consist of only the upper or lower parts or consist entirly of medium sand.[25] Although the Wiota Gravels appear to have much in common with modern stream deposits, the Wiota Gragvels are considererd to be Pleistocene preglacial fluvial deposits.[25] In most places, the thickness of this material ranges from 5+ to 55+ feet.[25] 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 I-1). This formation is of continental freshwater origin and consists chiefly of gray to tan shales, siltstones, sandstones, and carbonaceous shales.[8] The lower portion of the formation consists of at 50± feet to 100± feet of predominantly tan to rusty orangish brown, crossbedded sandstone.[8] 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.[34] Total thickness of this foundation varies locally, but it ranges up to 280± feet in the bluffs south of the Missouri River, between Poplar and Brockton.[25] 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± 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. 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± to 85± feet) of the Fox Hills Formation.[8,25] 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 conspicous rimrock that is characteristic of eroded Fox Hills sandstone.[34] Locally, the Fox Hills Formation reaches a thickness of as much as 120± feet.[8] Within the study area, surface exposures of the Fox Hills Formation are limited to the hilly area south of the Missouri River (See Figure I-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.[25] 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± to 2± inches thick), gypsum crystals and calcareous concretions.[34] Thickness of the Bearpaw shale is estimated to approximately 1,100± feet thick.[8] As shown on Figure I-6, the Bearpaw shale is approximately equivalent to the upper part of the Pierre shale.

MASS WASTING

Mass wasting refers to downslope movement of earth materials under the influences of gravity. Among the types of movement that can be included within the category of mass wasting are creep, landslide or slumping.

Creep is the imperceptably slow and intermittant 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 the two processes of mass wasting described above should be significant hazards to the proposed geothermal project (i.e., the town of Poplar and the proposed housing development site east of Poplar). This is primarily due to the lack of appreciable slope gradient sufficient to cause downslope movement.

STRUCTURE

The major bedrock units within the study area are characterized by broad, gently dipping beds which generally dip only a few tens of feet per mile. These units, however, have been somewhat affected by local folding and possible faulting. 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.[3] 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 Figure I-6) 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.[9]

Bedrock units exposed at the surface generally appear to be gently dipping, similar to the bedrock units and contoured by Colton and Bateman.[9] 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 I-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.[25] 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.[25] 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.[25] 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. As previously indicated, the Sprole silt was deposited in a lake formed when the ice advanced and clocked the Missouri River.[8] Deformation of the Sprole silt may have occured 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 3). The bedding noted appears to be highly variable in dip direction and angle. Dips recorded range from 25± to 50± degrees (See Figure I-1). Based on available data and outcrops, it is uncertain as to whether these contorted beds are related to past glacial activity or fault activity (i.e., the Brockton-Froid fault zone).

BROCKTON-FROID FAULT ZONE

A zone of normal faulting has been mapped between the towns of Brockton and Froid.[9] As shown on Figure I-1, the western extent of this zone apparently extends southwest of Brockton into the eastern portion of the study area.[8]

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.

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.[29] He shows a fault zone consisting of at least two roughly parallel faults, with a graben or downdropped block between the faults.[8] These faults are shown to affect Pleistocene glacial beds.[8] Furthermore, Colton and Bateman's structural contour map[9] shows offset of basement rock near Brockton of less than 100± feet to over 400± feet near Froid.[29]

In addition to his field data, Colton feels that minor earthquakes felt in the Poplar area in 1935, 1943, 1944 and 1946 may have been related, at least in part, to the Brockton-Froid fault zone (personal communication). Based on his work, Colton concludes that the Brockton-Froid fault zone is active (personal communication).

Others, however, disagree with Colton. Professor Slemmons (working for the Corps of Engineers) conducted an aerial examination of the entire fault zone from southwest of Brockton into North Dakota.[29] Using both early morning and late afternoon observations, several conspicuous lineaments apparently were recognized in Pleistocene glacial deposits. Ground checks made by Slemmons suggested that the lineaments were either old cattle trails or other cultural features. Slemmons concluded that the Brockton-Froid fault zone was inactive, as he felt that there were no significant Holocene scarps along this basement structure; roadcuts, stream banks and gravel quarries showed no evidence of faults in Pleistocene deposits.[29]

The existence of the Brockton-Froid fault zone within the study area is difficult to determine, due to a lack of outcrop exposures (i.e., road cuts, stream valleys, etc.). However, information developed as part of this study (hot water temperature gradients and shallow ground temperature gradients) suggest certain abnormalities that may support the possible existence of the Brockton-Froid fault zone.

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 is not apparently 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.[8] 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.[8] (Note: Although parallel to the Brockton-Froid fault zone, these lineaments also follow the same general trace of the last glacial ice sheet.[7])

As shown in Figure I-1, the longest of these lineaments intersects the previously mentioned road cuts northwest of Sprole. A projection of this lineament continues southwest beyond the road into the proposed housing development site. Photograph 4 shows this lineament in the cultivated field northeast of the road. The upper right corner of Photograph 5 shows the same lineament. It further shows that a southwesterly projection of the subject lineament appears to intersect the northern portion of the proposed housing project.

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 3). 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 3). 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 on available outcrop exposures. Additional investigation (i.e., subsurface exploration) would be necessary to solve this apparent enigma. As a minimum requirement, exploratory trenches should be excavated in the northern and eastern portions of the proposed housing development to determine the existence or nonexistence of faulting within the site.

Other smaller lineaments were also noted on aerial photographs and during the field reconnaissance. However, these features, for the most part, trend northwest-southeast and north-south, and appear to be glacially related. These features appear to coincide with the ice crack moraines mapped by Colton.(8) According to Colton, these ice crack moraines represent low ridges that were formed when debris fell into stagnant ice fractures. When the ice melted, this debris was left as small moraine ridges.(6,7)

SEISMICITY

Less is known about the earthquake history of the Western Mountain Region, which included Montana, than any other section within the United States.(43) 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 that was requested included a 60± miles radical search from the town of Poplar, 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,[43] 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 apparently small, with probable magnitudes of betwen 3 and 4. Based on 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). However, there is no apparent evidence to associate this shaking with the Brockton-Froid fault zone.

During the investigation for Fort Peck Dam,[29] 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[6] 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 on 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.

GEOLOGIC SUMMARY

The study area represents a region that has undergone gentle, intermittent uplift together with successive invasions and retreats of Pleistocene ice sheets. Earth materials within this 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.

Geologic structure locally within the area is controlled by the Poplar Dome and possibly the Brockton-Froid fault zone. Although workers disagree on the existence as well as activity of the Brockton-Froid fault zone, the work done by Colton(6-9) together with data developed during this study could suggest the possible existence of the fault zone. According to Krinitzky,(29) the Maximum Credible Earthquake for the fault zone ranges from Magnitude 6.0 to Magnitude 7.2. However, according to available earthquake data, an earthquake of these magnitudes along the Brockton-Froid fault zone appears to be very remote.

Relative to the geothermal resource, it is conceivable that the fault could be acting either as a barrier at depth or a vehicle along which hot water from deep beneath the surface can migrate upwards. However, if this is occurring, the hot water is apparently not reaching the ground surface. No hot springs were noted along the fault zone within the study area.

Several northeast-southwest trending lineaments exist north and roughly parallel to the Brockton-Froid fault zone. Colton[8] has suggested that these might be possible fault traces. One or more of these lineaments appears to intersect the northern portion of the proposed housing development site east of Poplar. Because of the location of these lineaments, relative to the project, it would be prudent to conduct subsurface exploration to determine the nature of the lineaments. Further exploration of the Brockton-Froid fault zone would also be advisable to verify the fault location within the study area.

APPENDIX B

THE GEOLOGIC TIME SCALE

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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			
Origin of Earth			4500

APPENDIX C

SURVEY OF OTHER DIRECT APPLICATIONS

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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 C.1 shows various direct applications (15, 19) 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 C-1 lists favorable greenhouse temperature ranges for selected vegetables.[28] A typical greenhouse was used to determine the design heating

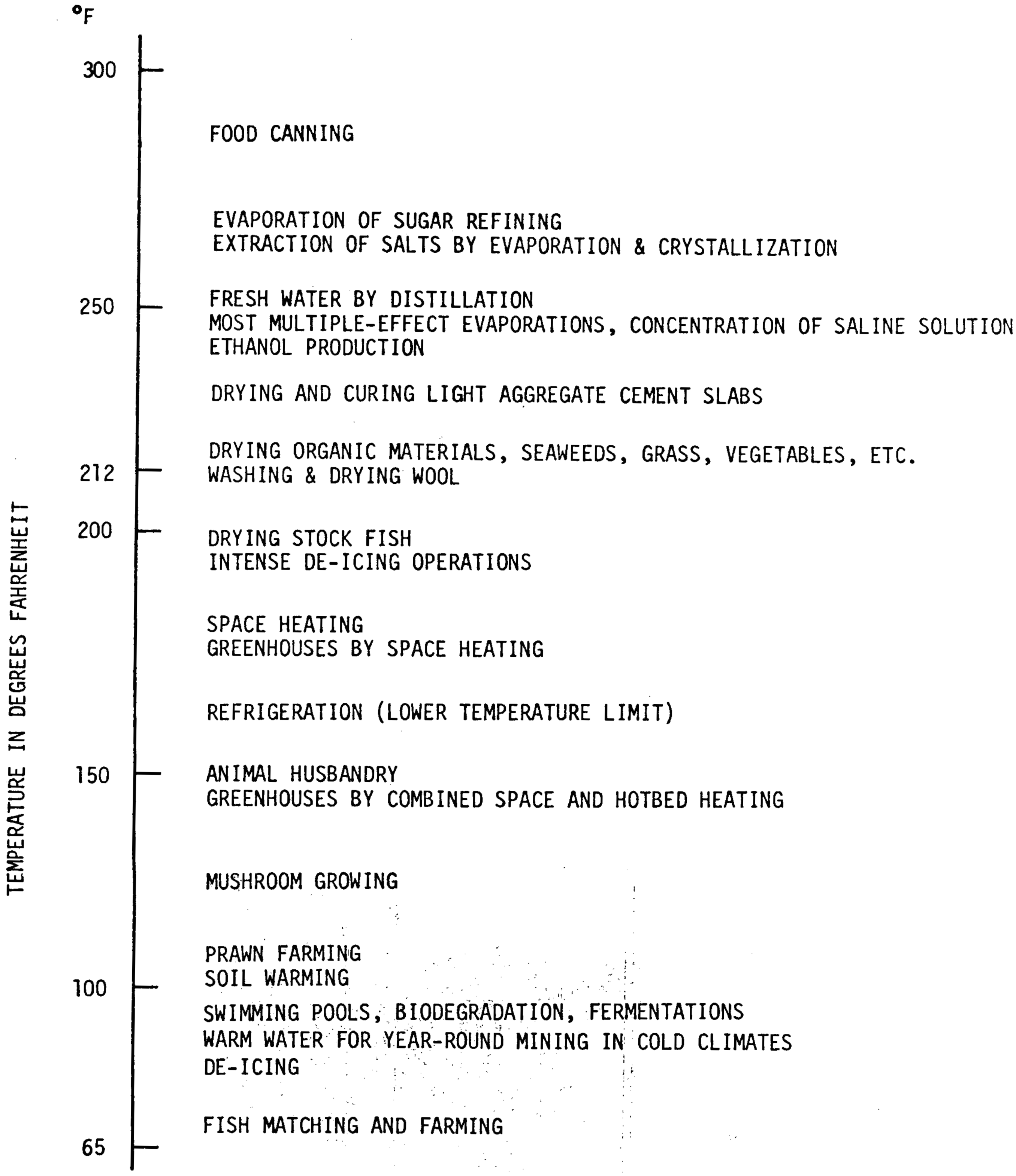

FIGURE C-1 DIRECT APPLICATIONS AVAILABLE FOR VARIOUS RESOURCE TEMPERATURE RANGES load, annual heating load, and other important factors. The typical greenhouse is 120 feet wide and 360 feet long, covering an area of 43,200 square feet. This one-acre greenhouse has an average wall height of 10 feet, a roof sloped at 5/12, and is heated to 65^oF. The heat transfer coefficient for the walls is 1.13 BTU/hr-ft^2 - ^oF. The heat transfer coefficient for the roof is 1.22 BTU/hr-ft^2 - ^oF.[27, 2]

TABLE C-1. TEMPERATURE RANGES FOR SELECTED PLANTS

	Asparagus	Tomatoes	Cucumbers	Lettuce
Temperature Range ^oF	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:

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

$$Q = 0.98\ MBTU/hr$$

The designheat loss through the roof was determined by:

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

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

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

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

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

where

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

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

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^{o}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^{o}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 C-2 presents the heat loads for the milking barn, milking cow barn, calf barn, and heifer and dry cow barn.

TABLE C-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, 18] The geothermal district heating systems could provide sufficient heat to maintain the barns in this temperature range.

PRAWN FARMS

Increasing pressure on naturally occuring 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 attentionin 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.[13] 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 [42] 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.[42]

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 to 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,[33] 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 ehtanol 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.