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GEOTHERMAL RESOURCE, ENGINEERING AND ECONOMIC
FEASIBILITY STUDY FOR THE CITY OF OURAY, COLORADO

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Geothermal Resource, Engineering
and Economic Feasibility Study
for the City of Ouray, Colorado*

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ABSTRACT

A geothermal energy feasibility study has been performed for the City of Ouray, Colorado, to determine the potential economic development opportunities to the City. The resource assessment indicates the resource to be associated with the Ouray fault zone, the Leadville limestone formation, the high thermal gradient in the area of the San Juan mountains, and the recharge from precipitation in the adjacent mountains. Four engineering designs of alternative sizes, costs, applications, and years of start-up have been defined to offer the City a range of development scales. Life cycle cost analyses have been conducted for cases of both public and private ownership. All systems are found to be feasible on both economic and technical grounds.

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INTRODUCTION

The City of Ouray, Colorado, with partial financing from a DOE Appropriate Energy Technology Small Grant Award, has sponsored a geothermal resource, engineering and economic feasibility study. The purpose of the study project has been "to explore new ways for the City to use its geothermal energy for economic development and diversification." The overall geothermal project objectives have been (1) to create new tourism and commercial business opportunities, (2) to generate additional revenues for the City and its businesses, (3) to reduce energy costs for city and county buildings, for commercial businesses, and for residences, (4) to achieve year-round optimum use of geothermal energy, and (5) to preserve the rights and uses of geothermal springs and waters by parties already engaged in or entitled to use of geothermal energy.

RESOURCE ASSESSMENT ✓

Introduction: The Ouray geothermal resource was studied and evaluated by : 1) making a detailed analysis of existing geological, geophysical, geochemical and climatological information, 2) using LANDSAT imagery and aerial photos to delineate fracture systems that may guide subsurface flow of geothermal fluids, and 3) integrating the above data into a reasonable conceptual model of the geothermal system from which temperature, depth, subsurface extent and volume of resource can be estimated.

No attempt was made to summarize the voluminous literature pertaining to the Ouray area, but rather to focus on aspects of the geology that have a direct bearing on the geothermal assessment.

The principal published sources of information used in this evaluation are: 1) detailed geologic maps of the Ouray, Telluride and Wetterhorn Peak quadrangles, regional geologic maps of the Montrose and Durango 1 X 2 degree sheets, and the Colorado State Geologic Map, 2) geophysical maps of the regional gravity and magnetic fields, and the variation in Colorado of heat flow and geothermal gradient, 3) locations of seismic epicenters and young probably active faults, 4) climatological maps showing average annual temperature and precipitation, 5) syntheses of stratigraphic and structural studies pertinent to the Ouray area, and 6) studies by the Colorado Geological Survey of thermal springs and wells in the state, and preliminary geothermal appraisals of the Ouray area.

The report has benefited from unpublished information and discussions about the Ouray area with Kevin J. Carthy, Richard H. Pearl and Ted Zacharakis of the Colorado Geological Survey, Robert G. Young of Astro Oil and Minerals, Grand Junction, Colorado, and Nolan Doesken, climatologist at Colorado State University.

Geologic Setting: Ouray is located in a region of high heat flow, perhaps four times that of the world average (Zacharakis, 1981). Active faulting and a moderate to high level of seismic activity (Figure 1) also characterize the region. Faults less than 2 million years old on the Uncompahgre Plateau are only 22 miles northwest of and on strike with Ouray (Howard and others, 1978). A seismic study of the Ridgway fault zone 12 miles north of Ouray shows it to be seismically active (Sullivan and Martin, 1981). Recurrent movement along steep normal faults has dominated the structural pattern of southwest Colorado since Precambrian time and was a major influence on Phanerozoic sedimentation patterns and thicknesses (Tweto, 1980, Weimer, 1980). Ouray lies at the intersection of several major faults (Figure 2). The Ouray fault that is associated with the hot springs at Box Canyon is one of several faults of WNW to ENE trend that make up the complex, 3-mile wide Ouray Fault Zone (O.F.Z.) that is the boundary between the Ouray Graben and Sneffels Horst (Figures 3, 4, 5).

Paleogeographic reconstructions for late Paleozoic time indicate that the Ouray Graben is situated along the boundary between the Uncompahgre Uplift and the Paradox Basin (Figure 2). Faults of generally E-W trend have broken the earth's crust into several uplifted blocks (horsts) with intervening basins (grabens). Coarse-grained arkosic sediments eroded from the Uncompahgre Uplift were trapped in these basins (Figure 3). In the Ouray Graben these coarse sediments, named the Cutler Formation, are as much as 2000' thick and may be important geothermal aquifers. Strong deformation in early Triassic time was followed by deposition of fairly permeable Mesozoic sediments. The O.F.Z. was reactivated and intruded by dikes and plugs during late Cretaceous-Paleocene Laramide deformation. The enormous San Juan volcanic field erupted 35 to 22 million years ago and originally extended to beyond Ridgway. Three major volcanic vent areas are within 7 miles east, west, and south of Ouray, but the rocks are much too old to contain any residual magmatic heat. The main significance of the igneous rocks to the Ouray geothermal system is the pervasive fracturing that accompanied their forceful intrusion.

Late Miocene to the present time is characterized by extensional deformation and basaltic volcanism related to a general epeirogenic rise in elevation of much of western U.S. No igneous rocks of this latest episode are known to be present near Ouray. Reactivation of faults that intersect at Ouray has probably been important in promoting fracture permeability that maintains the

geothermal system.

Stratigraphy: Descriptions of the rock units given by Luedke and Burbank (1962), are conveniently summarized in Colorado Geological Survey Resource Series 15 (Zacharakis and others, 1981). Thickness and permeability of the rock units were compiled from these sources and are presented in Table 1. Qualitative estimates of permeability as low, moderate and high were made by Luedke and Burbank in the adjoining Telluride quadrangle and are assumed to be the same as at Ouray.

The Leadville Limestone (LL) contains breccia zones and solution channels that give it a high permeability that may locally have been enhanced by hydrothermal solutions associated with the two episodes of igneous activity. The LL also is an extensive groundwater aquifer. Of the 56 thermal springs and wells in Colorado that have been catalogued by Barrett and Pearl (1978), 6 of them including Ouray have the LL as their principal aquifer. Two of these, Dotsero and Glenwood, have very high rates of discharge, in excess of 10,000 gpm. The Cutler Formation is underlain by less permeable strata and probably functions as a perched aquifer. Several permeable sandstones of Mesozoic age, Kd through Trd, are groundwater aquifers that are hydrologically confined by the overlying impermeable Mancos Shale. This aquifer is too shallow in the Ouray Graben to function as a geothermal reservoir, however it does conduct groundwater northward across the graben thereby facilitating recharge of geothermal systems associated with the Ridgway fault zone.

The Ouray Geothermal System: The thermal springs at Ouray are probably the result of deep circulation of meteoric water in fractures and permeable sedimentary rocks of the Ouray Graben. The graben contains a maximum of 8800 feet of sedimentary rocks; about 3300 feet are aquifer zones (Table 1). Within the graben, groundwater flow is probably largely confined to the two main aquifer zones. But, in the basin margin fault zones fracture permeability permits downward recharge of the aquifers and upward flow of deep thermal waters, as at Ouray and Ridgway. Recharge is mostly from the San Juan Mountains along the south flank of the graben, through steep intersecting fractures of the Ouray and other fault zones. The geothermal gradient is sufficiently high to heat the deeply circulating groundwater. The flow path, from recharge to discharge area, is much shorter for the Ouray thermal water than for the water of the Ridgway area (Figure 5). The resulting difference in subsurface residence time of the waters of the two areas, is reflected in consistent differences of water chemistry and temperature. Orvis thermal water is more mineralized (2300 vs. 1650 ppm TDS) and has a higher geochemical reservoir temperature (78 C vs. 70 C) than Ouray thermal water (Barrett and Pearl, 1976, 1978) (Tables 2 and 3).

Temperature within the graben can be estimated from the depth of fill and the geothermal gradient. The total sedimentary-volcanic section above PE basement is a maximum of 8800 feet thick. The geothermal gradient is 400 C/km, (= 400 C/3000') which amounts to a temperature difference of 1170 C between the top and bottom of the section. Adding the average annual surface temperature of 70 C (Benci and McKee, 1977) gives 1240 C as the maximum expectable temperature at the bottom of the graben. The "average" temperature within the graben would be about half that or 660 C, which checks closely with the 690 C temperature of the Box Canyon Pool Spring at Ouray. The chalcedony-silica geothermometer yields a subsurface temperature of only 690 C to 710 C (Barrett and Pearl, 1978). This is very close to the surface temperature of Pool Spring and may mean that the thermal waters are ascending rapidly with little cooling or high-level dilution.

The depth of the LL in the 3-mile wide O.F.Z. can be determined from the geologic cross-section (Figure 6). The LL dips an average of 150 to the northwest, from where it is exposed at the surface south of Ouray down to a maximum depth of 300 feet beneath the valley floor near the mouth of Corbett Creek. Within the O.F.Z. are seven mapped faults, many dikes, veins, and innumerable fractures that impart a definite ENE grain to the topography that is apparent on aerial photos. This highly fractured area is probably an important recharge zone for the Ouray geothermal system. Subsurface flow through the fractures probably has a strong lateral component as well because of the extreme topographic relief. Recharge in the high Mt. Sneffels and Wetterhorn Peak areas would tend to migrate laterally toward the low Uncompahgre River Valley (Figure 7). The size of the recharge area is estimated to be about 20 square miles (a 2.6 mile wide fracture zone extending 7.7 miles from drainage divide to divide, east and west of the Uncompahgre Valley).

The rate of recharge can be estimated from the average annual precipitation, which is about 40 inches per year (U.S. Weather Bureau Map). This computes to 93 million cubic feet of water per year per square mile, or 177 cubic feet per minute per square mile. Since 1 cubic foot = 7.48 gallons, the precipitation rate is 1323.5 gallons per minute per square mile. Only part of this water actually recharges the Ouray geothermal system (Figure 5). We first assume that half of the precipitation is lost as runoff and evaporation; of the remaining 20 inches that infiltrates the fractured rocks of the recharge area, we assume half seeps laterally into the permeable Pc-Kd zone and half penetrates deeply to the Leadville Limestone aquifer; of the 10 inches that enter the Leadville, we assume that half migrates northward toward Ridgway and half flows updip toward Ouray. By this estimate only one eighth of the recharge, or about 3300 gallons per minute of hot water, is ascending beneath Ouray. The measured natural discharge from the thermal springs at Ouray ranges from 60 to 200

gpm. The greater part of the geothermal source is apparently leaking out of the system elsewhere. A considerable amount of hot water may be lost up bedrock fractures into shallow surficial deposits, becoming diluted with cold groundwater. The springs at Wiesbaden Motel, Ficco Springs, and the spring near the swimming pool all seem to be of this type, which would account for their low rates of flow (2-8 gpm) and low temperatures (22oC - 52oC; Zacharakis and others, 1981). The highest rate of flow (100 gpm) and highest temperatures (67oC - 69oC) are associated only with the springs flowing directly from the Leadville Limestone Bedrock. It seems reasonable that drilling through the cold saturated surficial deposits into the fractured bedrock would tap a hotter, more abundant water supply than is currently available.

It isn't possible to predict what effect drilling and pumping would have on the natural springs at Ouray. The permeability of the LL and fracture zones is unknown, hence the potential productivity of the system cannot be calculated. However, because the recharge rate is high, and the temperature and chemistry of the waters seem to indicate rapid ascent, the indications are favorable that the system may have the capacity to sustain a ten-fold increase in discharge without adversely affecting the existing springs.

The most promising drilling targets are intersecting fault zones and the LL. Mapped faults were photogeologically extrapolated and plotted on the enlarged map of the Ouray area (Figure 8) as well as the depth of the LL, to serve as a guide to drilling and development of the resource. Drilling and pumping is the only way to positively test the productivity of the system. Shallow wells should be drilled through the surficial deposits, which are at most 300' thick, to intercept concealed fault zones in the bedrock that might be leaking hot water. Fault intersections should be even more permeable. Holes up to 1000' deep would penetrate the LL. A hole drilled into the LL at the intersection of steep faults would be the best bet for a wildcat production well.

ENGINEERING DESIGNS

Four engineering designs have been evolved to provide a range of development and/or application options for the City of Ouray. The City may choose to initiate geothermal development with the smallest scale option and proceed sequentially to enlarged geothermal systems until a complete city-wide district heating system is achieved. Or the City may choose to start out with an intermediate size system and progress from that design. However, the City may also choose to proceed with design and construction of a full-scale city-wide geothermal system. The four engineering designs presented herein give the City the opportunity to examine at this time the engineering design factors, the capital costs, and the construction aspects of four alternative size systems. The

four engineering designs are briefly described here.

Case A: Space and Hot Water Heating of Public Buildings: The existing pipeline and geothermal waters from the Box Canyon Pool Spring to the Municipal Pool would be the source of hot water; no geothermal wells would be drilled. The existing pipeline would be tapped into at the base of Sixth Avenue and a portion of the Pool Spring water would be pumped up to the public buildings through a newly-installed insulated pipeline. The new pipeline system would serve the City Hall, the County Courthouse, the Museum, the School Gymnasium (not the Classroom Building), and the proposed Emergency Services Building. The discharge water would be returned through a parallel insulated pipeline to the Pool Spring Pipeline at the base of Sixth Avenue and added to the flow to the Municipal Pool (Figure 9).

The water in the existing pipeline is estimated to be 155o F and to flow at 200 gpm. Under the peak demand situation, 124 gpm at 155o F would be required to provide thermal energy to the five buildings. This 155o F geothermal water would be lowered in temperature to 120o F and returned to the pool pipeline at 115o F. The resultant water flowing to the pool would be 130.2o F at 200 gpm, which represents the "worst case" condition.

Fiberglass reinforced plastic (FRP) pipe was selected for the transmission line to deliver the geothermal resource to the several buildings. The supply and return FRP pipe would both be insulated so as to keep the water temperature as hot as possible for use in the swimming pool. The transmission line would range in diameter from 2" to 3".

The estimated cost of the transmission line is \$80,400 including installation. Two circulating pumps will be required to pump the fluids from the existing pipeline to the end users and back to the existing pipeline. The estimated cost of the circulating pumps is \$10,000. The total cost to retrofit the five buildings to geothermal energy is estimated to be \$21,800. The total capital costs for Case A including installations, contingency and engineering design is estimated to be \$112,200 in 1982 dollars (Table 4).

Case B: Same as Case A, Except with the Addition of Space and Hot Water Heating for the Municipal Bathhouse and a Prospective Year-Round Recreation Center: Case B is basically the same as Case A, except that it provides for year-round use of the Municipal Pool, which requires space heating and hot water for the existing Bathhouse; it also allocates water from the Box Canyon Pool Spring pipeline to provide space and hot water heating for a prospective new year-round Recreation Center, which would be located in the immediate vicinity of the Municipal Pool and Bathhouse. Capital costs for Case B include retrofit costs for the Bathhouse but not building or heating system costs for the Recreation Center; only

the energy load of the Recreation Center is incorporated into the design.

FRP pipe was again selected for the transmission line material. The cost for the installed transmission line is the same as in Case A. The additional retrofit cost for the Bathhouse and Recreation Center is estimated to be \$11,000. The total capital costs for Case B including installation, engineering design and contingencies is estimated to be \$123,200 (Table 5).

Case C: Main Street Commercial Strip, Including Public Buildings, Municipal Bathhouse and Recreation Center: Case C is designed to be a completely new geothermal system of geothermal wells and pipeline system. The design provides for two geothermal wells to be drilled at the northern edge of the City, to a well depth of 800 to 900 feet into the Leadville Limestone Formation. The two wells would be connected to a pipeline system which comes up Main Street and which has side-street branches in order to service most of the existing commercial businesses and motels. The Main Street pipeline would also connect with a major branch line to service the public buildings which are defined in Case A (Figure 10).

Estimating the geothermal resource to provide 175o F and 40 gpm per well, two wells would be required to meet the thermal needs for the above locations. The cost to develop the wells is estimated to be \$229,900. Well pumps will be required to pump the geothermal resource to the surface. At one per well, two will be required at a total estimated cost of \$33,880. Circulating pumps will be required to circulate the geothermal resources to the end users. Two circulating pumps will be required at a total estimated cost of \$15,920.

The total estimated cost to develop the wells and for the well and circulating pumps, including engineering design costs and contingencies, is \$279,700.

FRP pipe was again selected for the transmission line material. The supply and return lines will be insulated to keep the used water hot for use in the swimming pool. The size of the FRP pipe ranges from 6" diameter to 2" diameter. The total installed transmission line is estimated to cost \$.

The total transmission line costs including engineering design and contingencies is estimated to be \$287,500. The total capital costs for Case C, including retrofit of the five buildings in Case A and all engineering design and contingencies, is estimated to be \$600,000 in 1982 dollars (Table 6).

Case D: Year 2000 City-Wide District Heating System: Case D is an engineering design incorporating six geothermal wells at the north end of town and a pipeline array which would supply most of the residences, commercial establishments, and light industry in the

immediate area of the City in the Year 2000 (Figure 11). The Year 2000 energy demand estimate is approximately 233 billion BTU per year, which is based upon the 1979 estimated demand of 125 billion BTU (New Mexico Energy Institute, 19XX), escalated at 3 percent growth rate per year (Reference). Peak commercial and residential demands are estimated equally at 32.5 million BTUH each.

Estimating the geothermal resource to be available at 175o F and 400 gpm per well, six wells would be required to meet the city's thermal energy requirements. The cost to develop these six wells is estimated to be \$700,590. Well pumps will be required to pump the geothermal resource to the surface. At one per well, six will be required at a total estimated cost of \$108,900. Circulating pumps will be required to circulate the geothermal resource to the users. Six circulating pumps will be required at a total estimated cost of \$54,450. In addition to the six circulating pumps, two booster pumps will be required at a total estimated cost of \$11,060. The total estimated cost to develop the wells, for the well, circulating and booster pumps, including engineering design costs and contingencies, in 1982 dollars is \$875,000.

FRP pipe was again selected for the transmission line to deliver the geothermal fluids to the end users. The supply side of the transmission line will be insulated. Once the heat has been extracted from the geothermal fluids (down to 120oF) the used fluids will be discharged using uninsulated FRP pipe to the river at three discharge locations. The size of the FRP pipe to be used ranges from 10" diameter to 4" diameter. The cost of the FRP pipe for the well collection system (used to collect the fluids from the 6 wells to one main distribution line) is estimated to be \$159,720. The cost for the FRP pipe, including installation, for the distribution system is estimated to be \$1,715,280. The total estimated cost for the well collection system and the transmission line, including engineering design, installation, and contingencies, is estimated to be \$1,875,000 in 1982 dollars. The total capital costs for Case D is then computed to total \$2,750,000. This total cost includes all capital costs, installation costs, engineering design costs and contingencies to supply the City of Ouray with its projected thermal energy requirements for the Year 2000 (Table 7).

A summary of Cases A through D, of the facilities served, and of the fossil-fuel energy displaced by the geothermal systems is presented in Table 8.

ECONOMIC EVALUATIONS J

Summary of Costs: Table 5 summarizes the estimated exploration, capital equipment, working capital, and annual operating and maintenance costs for the four engineering designs. Also listed in Table 9 are the total BTU equivalents of fossil fuel to be

displaced by the geothermal systems, the total investment cost per MMBTU displaced, and the annual O&M cost per MMBTU displaced. The latter two sets of numbers suggest that significant economies of scale can be achieved with the larger geothermal systems.

Economic and Financial Assumptions: Escalation rates projected by the DOE Office of Policy and Evaluation for the period 1980 to 2000 have been assumed for the present life cycle cost analyses (Table 10). Propane and fuel oil prices (Ouray has no natural gas supply) are projected to increase at 11 percent per year through 1985 and again through 1990, diminish to 10 percent per year from 1990 to 1995, and then escalate at 9 percent per year thereafter. The general inflation rate is projected to increase annually at the rates of 9 percent, 8 percent, 7 percent and 6 percent, respectively, for the same periods. For the present economic evaluations, it is assumed that the geothermal energy price will be escalated at 1 percent over the general inflation rate. As this rate is less than the projected rates for the competing fuels, geothermal will offer additional cost savings relative to conventional fuels over the life of the project. Since the O&M costs include electricity costs as well as maintenance and other operating expenses, the assumed O&M escalation rate is a weighted average of expected electricity escalation and the general inflation rate: 11 percent, 9 percent, 8 percent, and 6 percent, respectively.

The financial assumptions for the private financing cases (Table 11) include an equity/debt ratio of 25 percent/75 percent, a loan duration of 15 years, and interest rates of 14 percent, 12 percent, and 10 percent on monies borrowed before 1985, between 1985-90, and after 1990, respectively. Various federal, state and local income and property taxes, tax credits, depletion allowances and depreciations are also assumed. A royalty of 10 percent on gross sales, payable by the private developer to the City of Ouray is used. DCFROR rates of 15 percent for Cases A and B and of 20 percent for Cases C and D are assumed; a larger DCFROR is used for Cases C and D because of the risk factor associated with the drilling of geothermal wells. Project durations of 20 years for Cases A, B and C and of 28 years (to the Year 2000) for Case D are used.

The projected investment schedules are also integrated into the economic analyses. They are critical to minimizing the cost of capital and to generating revenue as soon as system operation is practical. Cases A and B are proposed to be constructed in 1982 and put into operation in 1983. Case C defines exploration in 1983, construction in 1984, and operation in 1985. Case D starts with exploration in 1984 and is followed by three phases of construction/operation in 1985/1986, 1988/1989, and 1997/1998 (Table 12).

Results of Evaluations: Table 13 summarizes the results. In each

privately-financed case, the desired rate-of-return is specified and the first-year MMBTU-price to the Ouray consumer is calculated. For the publicly-financed case, the break-even price which meets all operating, maintenance, and bond indebtedness costs is determined. For comparison, Table 14 presents the expected costs of fuels currently in use in Ouray. It is seen that under all options, geothermal energy is highly competitive with propane and fuel oil. The highest first year geothermal price is Case A - Private at \$5.39/MMBTU in 1983. Propane fuel oil prices are expected to be \$10.10/MMBTU in that year. The previously projected effect of the economy of scale for Case D is confirmed here. At \$2.70/MMBTU in 1986, Case D is also competitive with coal, which is projected to cost \$3.63/MMBTU in that year. Year by year cash flows for the five options are presented in Tables 15-19.

Sensitivity Analysis: In the previous section, a DCFROR of 20% had been assumed for Cases C and D. This section examines the DCFROR as a variable (for these two cases) to determine its effect on the geothermal sales price. Figure 12 shows the effect of varying the Case C DCFROR from 15% to 25%. The resulting first year sales price is seen to vary from \$3.67 to \$4.62 per MMBTU. The same change in Case D produces a price spread of \$2.39 to \$3.05 per MMBTU (Figure 13).

CONCLUSIONS

The resource assessment of the Ouray geothermal resource has revealed that the reservoir is associated with the Leadville Limestone Formation within the Ouray graben, exists at depths from zero feet at the south edge of the City at the Box Canyon Pool Spring to about 900 feet at the north end near the Municipal Pool, has an estimated subsurface temperature of $^{\circ}\text{C}$ at the Pool location, and has a probable recharge rate of 3300 gpm. The four alternative engineering designs prepared for the City offer total investments ranging from \$129,000 to \$3,212,500, in 1982 dollars. Two designs (Cases A and B) provide for use of geothermal water already flowing through an old pipeline from the Box Canyon Pool Spring. The second two designs require the drilling of two and six geothermal wells, respectively, to supply quantities of geothermal energy for the present commercial sector only (Case C) and for the total community in the Year 2000 (Case D). Life cycle cost analyses clearly show that the geothermal options will be highly competitive with propane and fuel oil in the first year of operation, and that Case D will be competitive with coal in its first year of operation (1986). Therefore, from a technical and economic viewpoint, the development of geothermal energy by the City of Ouray can provide the bases for significant economic development and diversification in the years to come.

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Appendix

Addition of Heat Exchangers to Ouray Geothermal Engineering Designs

This appendix has been added to discuss the implementation of plate type heat exchangers in conjunction with Cases A, B, C and D, as outlined in Section . This is due to the presence of iron oxide in the geothermal waters, which potentially can deposit in the distribution pipelines.

Plate type heat exchangers are the preferred devices for isolating the geothermal waters from a closed-loop distribution pipeline system and from the heating equipment of the energy consumers. Plate type heat exchangers consist of a series of flat plates with a trough and dimple pattern pressed into the plates to increase the effective heat transfer area. They are a standard piece of plumbing and have been used widely in geothermal heating systems.

In Case A, a maximum of 145 gpm of geothermal water at 155oF would flow into the heat exchanger where its temperature would be lowered to 120oF. Fresh water in a closed-loop system would flow through the other side of the heat exchanger and have its temperature raised from 115oF to 150oF at a maximum flow of 145 gpm. Under the "worst case" condition, the water flowing to the pool would be reduced in temperature to 126oF at a flow of 200 gpm. The plate type heat exchanger required is estimated to cost \$14,000 (B-F Sales Engineering, Inc., Denver, Colorado).

In Case B, the same heat exchanger selected for Case A will be utilized to heat the public buildings. The water to the Bathhouse and the proposed recreation center under the "worst case" condition will be 126oF. This temperature is not felt to be adequate to allow the incorporation of an additional heat exchanger at the pool area. Therefore, it is recommended for this specific application that the geothermal water (126oF) be used directly to heat these facilities -- i.e. without the use of a heat exchanger.

In Case C, a maximum flow of 880 gpm of geothermal water at 175oF would flow into the heat exchanger, where its temperature would be lowered to 120oF. Fresh water in a closed-loop system would be heated from 115oF to 170oF at a maximum flow of 880 gpm. The plate type heat exchanger required is estimated to cost \$89,000.

In Case D, a maximum of 2400 gpm of geothermal water at 175oF would flow into the heat exchanger where its temperature would be lowered to 120oF. Fresh water in a closed-loop system would be heated from 115oF to 170oF at a maximum flow of 2400 gpm. The

plate type heat exchanger required is estimated to cost \$240,000.

In all cases where a heat exchanger is incorporated into the design(s), it will be necessary to recalculate the required sizes and costs of the circulating pumps. The addition of the heat exchangers results in requirements for increased gpm and Ft. Hd. of pumping capacity. In Cases C and D, the physical layout of the distribution pipeline system will also have to be modified because of the need for a closed-loop supply and return distribution system.

FIGURE 1- Geology of the Ouray area, adapted from Luedke and Burbank, 1962 and Barrett and Pearl, 1978.

Pennsylvanian and Cenozoic tectonic features. Pennsylvanian features shown with inclined lettering; Cenozoic features, with vertical lettering. Sawatch and Sangre de Cristo uplifts interpreted as Pennsylvanian tectonic features at general locations of similar Cenozoic features. Pennsylvanian faults: AC, Agate Creek; B, Borcas Pass; C, Crestone; CC, Curren Creek; CO, Cotopaxi; E, Elkhorn; FC, Freezeout Creek; G, Gore; GA, Gateway; M, Mosquito; PP, Pecos-Picuris; PV, Pleasant Valley; R, Ridgeway; S, Snowden; UP, Ute Pass; WR, Williams Range. Other geologic structures: SH, Sneffels horst; SP, South Park, WG, Wet Mountain Valley graben; SLV, San Luis Valley.

FIGURE 2- Late Paleozoic tectonic setting of Ouray area (DeVoto, 1980)

4A Pennsylvanian faults and paleogeography of northern San Juan Mountains, Colorado (Spoelhof, 1974). Large arrow is generalized sediment-transport direction.

4B Map showing Paleozoic paleotectonic elements on west and northwest flank of San Juan dome, Colorado. (Weimer, 1980)

FIGURE 3- Two versions of late Paleozoic tectonic elements

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Figure 4 Regional north-south section restored to base of Dolores Formation showing thinning of Paleozoic section and erosion of the Cutler Formation across top of paleotectonic elements. Symbols same as for Figure 3. Line of dots in Pc (Cutler Formation) is phantom horizon to show truncation at base of Dolores. (Weimer, 1980)

FIGURE 5- Schematic cross-section through Ouray graben emphasizing geologic features of geothermal importance

FIGURE 6 - Structural cross section BC along west wall of Uncompahgre River Valley. Section below valley floor is restored. O.F. is Ouray fault; symbols for formations are: P-x - Precambrian; D-M - Elbert, Ouray and Leadville; P - Molas and Hermosa; Pc - Cutler; Trd - Dolores; J - Jurassic; Kd - Dakota; Ti = Tertiary intrusion; * = approximate surface position of a core hole by Bear Creek Mining Company, drilled to a depth of about 2,000 ft (610 m).

Note complexity of 1.5 - 3 mile wide Ouray-fault zone; volcanics are omitted for simplicity. Adapted from Weimer, 1980

FIGURE 7 - Road section (not a true cross section) along U.S. Hwy 550 (line of dots) through Ouray graben. Note northward dip of pre-volcanic units and great thickness of volcanic rocks in the recharge area. (from Lee and others, 1976)

Figure 8. Ouray, Colorado Map of Geology and Thermal Springs.

— Mapped fault; bar + ball on downthrown side

..... Inferred fault

Geothermal Gradient
1.219°C / 188 ft.