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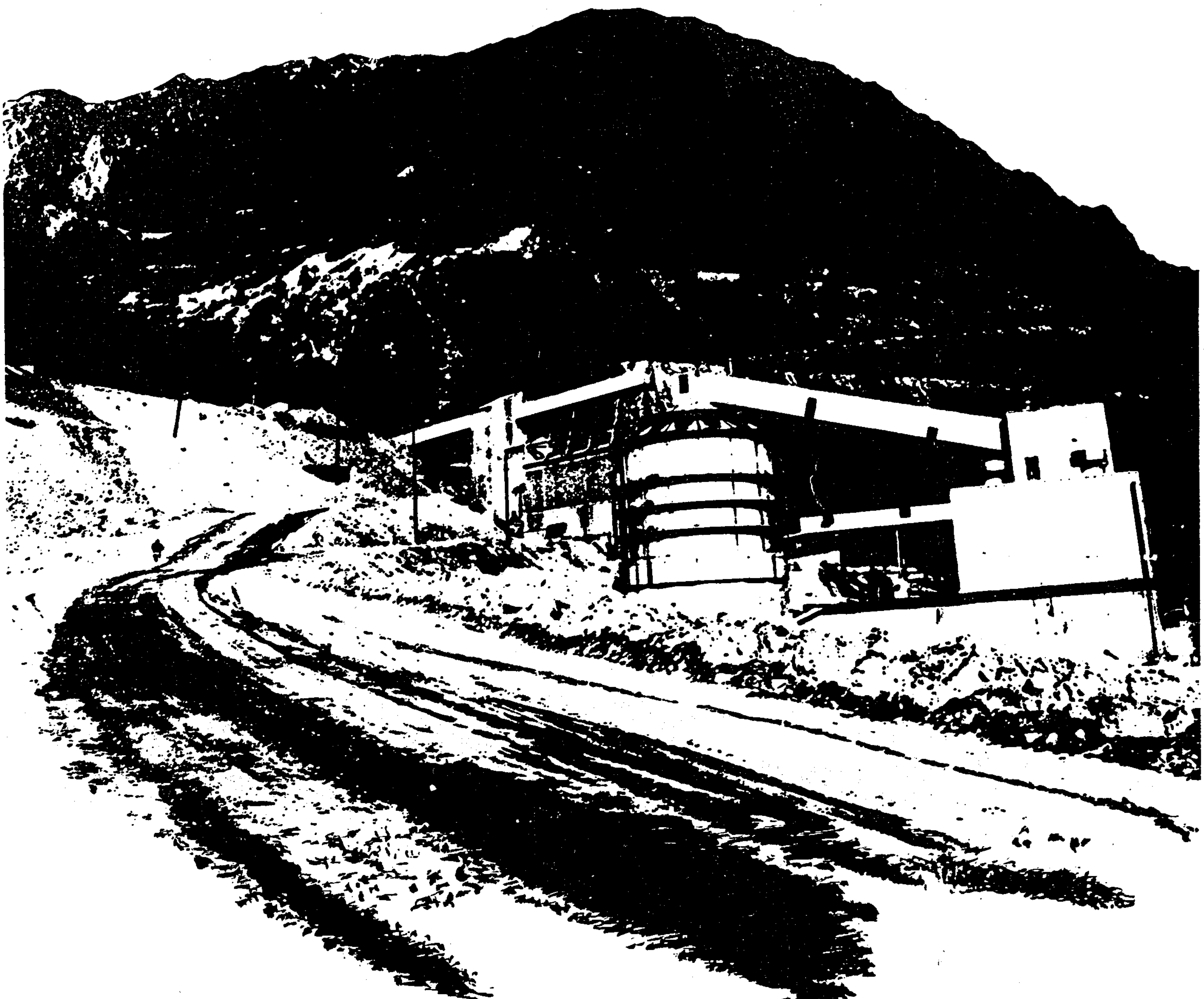
THE UTILIZATION OF GEOTHERMAL ENERGY IN THE MINING AND PROCESSING OF TUNGSTEN ORE



WESTEC Services, Inc.

Second Quarterly Report June 1980

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UTILIZATION OF GEOTHERMAL ENERGY IN THE MINING AND PROCESSING OF TUNGSTEN ORE

2nd Quarterly Report

Prepared By

M.V. Erickson
C.A. Willens
K.M. Walter
R.L. Carrico
G.D. Lowe
S.B. Lacy

WESTEC Services, Inc.
3211 Fifth Avenue
San Diego, California 92103

Prepared For:

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SECTION 1

INTRODUCTION

1.1 STATEMENT OF OBJECTIVES

1.1.1 Overall Objectives

The overall objective of this study is to determine the engineering, economic and environmental feasibility of the utilization of low and moderate temperature geothermal heat from an area designated as valuable prospectively for geothermal resources in the mining and processing of tungsten ore at the Union Carbide - Metals Division facility near Bishop, California. A secondary objective is the development of engineering techniques in the direct use application of geothermal energy in anticipation that these techniques could be translated to other geothermal resource areas and applications.

1.1.2 Specific Objectives

The specific objectives of this study are as follows:

a) Prepare a preliminary geophysical evaluation of the geothermal resource within transportable range of the Union Carbide - Metals Division tungsten mining and processing complex at Pine Creek.

b) Develop a specific plan for early resource confirmation including a discussion of exploration techniques, reservoir parameters and well drilling and testing.

c) Conduct an engineering evaluation of the Pine Creek tungsten complex to identify those processes and systems which could directly utilize geothermal heat as a substitute for fossil fuel.

d) Conduct heat balance studies of the entire mill and mine to establish the technical feasibility of substituting geothermal heat for those mineral processing functions identified as compatible with the geothermal resource.

e) Determine the heat transfer methods for converting geothermal heat to process heat for those mineral processing functions identified as compatible with the geothermal resource.

f) Prepare cost estimates in terms of plant modification (capitalization) and operating costs for each alternative heat transfer approach considered to be technically feasible.

g) Determine the specific benefits of geothermal heat utilization in terms of reduced fossil fuel and electricity consumption and associated reduced energy costs.

h) Determine feasible approaches for transporting geothermal heat to the Pine Creek tungsten complex.

i) Determine the costs of transporting geothermal heat to the Pine Creek tungsten complex based on the selected heat delivery approaches.

j) Develop a conceptual design of a geothermal energy system that could supply process steam to the Pine Creek tungsten operation and if appropriate, concurrent generation of electrical power for plant use, utilizing parameters implied by the potential resource.

k) Provide an economic analysis of such a conceptual design comparing present and future conventional fuel costs, reduced fossil fuel and electricity costs, costs of mill modifications, and comparison of other unconventional alternatives, such as low-head hydro.

l) Provide an analysis of environmental and institutional factors related to such a geothermal application.

m) Provide a final report which addresses the feasibility of utilizing geothermal energy at the Pine Creek tungsten complex. If it is determined to be technically, economically and environmentally feasible to utilize geothermal heat, provide a specific plan of pilot experiments and/or detailed engineering requirements to accomplish this objective.

1.2 SCOPE OF SECOND QUARTERLY REPORT

This second quarterly report contains the completed geochemical analysis of groundwater in the Pine Creek area for evaluation of the geothermal potential of this location. Also included is an environmental constraints analysis of Pine Creek noting any potential environmental problems if a geothermal system was developed onsite. Design of a geothermal system is discussed for site-specific applications and is discussed in detail with equipment recommendations and material specifications. A preliminary financial, economic, and institutional assessment of geothermal system located totally on Union Carbide property at Pine Creek is included in this report.

1.3 CONCLUSIONS AND RECOMMENDATIONS

Initial economic and technical evaluation indicates that geothermal resource development on the project site may not be possible. The initial geochemical analysis concludes that in order to obtain fluid within the specified temperature range for space heating, the production wells would need to be drilled to a depth of 5.7 kilometers. Drilling to this depth for low temperature fluid is considered to be a high risk, low return project and is not recommended. A specific plan for resource confirmation at the project site is presented in Appendix B.

Since initial geochemical analysis indicates a geothermal reservoir with a significant energy potential may not exist beneath the Pine Creek tungsten complex, other alternative energy sources are being examined. The Mono-Long Valley KGRA is approximately 30 miles from the project site and successful wells have been drilled in this area. Analysis for transporting fluid from this geothermal resource will be completed in the final project report. An initial discussion of transporting fluid from the Mono-Long Valley KGRA is presented in this report. The potential for utilization of hot dry rock energy extraction techniques will also be examined as an alternative to the alternate site concept.

1.4 BACKGROUND: UNION CARBIDE CORPORATION — METALS DIVISION, BISHOP, CALIFORNIA OPERATIONS

1.4.1 General

Tungsten, one of the hardest of all metals and one of the strongest in tensile strength at high temperatures, has great industrial and national security value. Tungsten carbide is used for producing tools with extraordinary cutting ability. Tungsten is also an alloying component for steel, adding hardness. The compounds of tungsten are used in making automobile parts, fireproof cloth, pigments, X-ray screens, electric light bulbs, cutlery, electronic components, and dental and surgical instruments, as well as parts for lasers and military munitions.

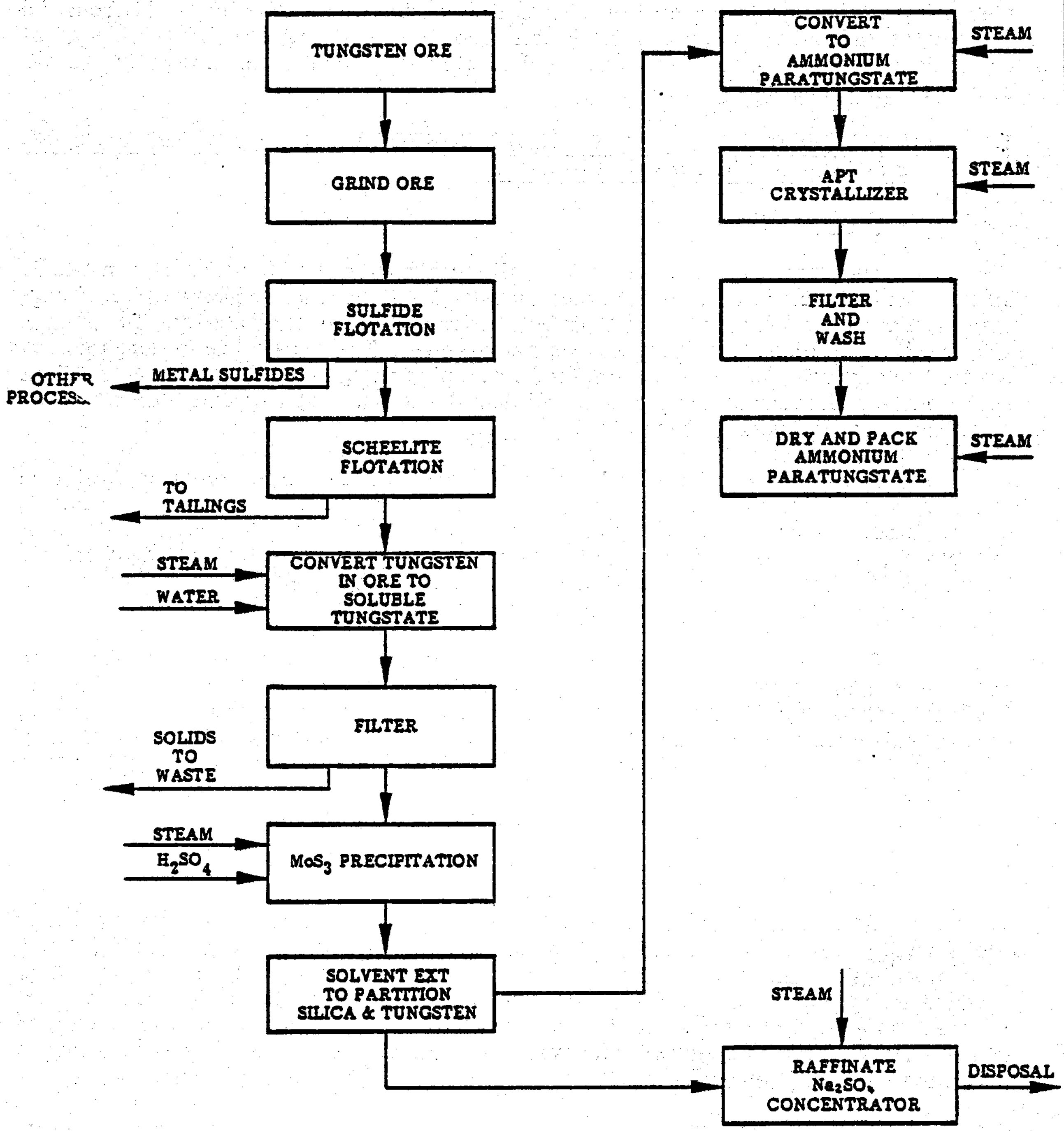
More than a third of all tungsten ore in the United States is in California and Nevada. The largest mine, which is located near Bishop in Inyo County, California, has been operated by Union Carbide since 1937, providing the nation with its most important single source of the essential metal and the County with its largest private industry. More than 400 people (miners, skilled tradesmen, engineers, mill operators, and geologists) work at the Union Carbide Corporation's Bishop operation.

Beneath the Sierra Nevada Mountains, Union Carbide miners have excavated miles of tunnels which are connected by vertical shafts rising from the 2470 m to 3540 m level to the 3540 m level (8100 ft to 11,600 ft). Ore from the mine is crushed, ground and chemically processed to a white sugar-like powder known as ammonium paratungstate. This is the main product Union Carbide ships from its Bishop operations. In addition to the principal tungsten mining, some molybdenum, an alloying metal, and copper also are mined, as well as small quantities of silver and gold.

1.4.2 Ammonium Paratungstate Process

Union Carbide owns patent rights to the ammonium paratungstate (APT) process (U.S. Patent Nos. 2,963,342 and 2,963,343). The APT process consists of a series of physical and chemical operations to extract tungsten from the raw ore and to produce a dry, solid product (see Figure 1-1). The raw ore from the mine is first crushed and ground to a small mesh size. The ground ore is then subjected to a series of aqueous flotations with chemical additives to remove heavy metal sulfides, resulting in a solution with a higher concentration of scheelite (tungsten bearing mineral).

The scheelite concentrate is then mixed with soda ash and water before being pressure digested in an autoclave. This operation puts the tungsten in solution so that it can be separated from the gangue (waste material) by filtration. This solution is filtered and the solids are sent to waste.



SCHEMATIC FOR THE PROCESSING OF TUNGSTEN ORE

FIGURE 1-1

The tungsten-rich solution then goes through a series of proprietary solvent extraction operations which converts the tungsten to ammonium tungstate. This solution is processed in a crystallizer to produce solid ammonium paratungstate. The wet solids are then dried and packaged for shipment.

1.5 ENERGY UTILIZATION SURVEY

1.5.1 Introduction

A detailed engineering survey of the mill was conducted to identify which processes could potentially utilize geothermal heat as a substitute for fossil fuel generated heat. The survey concentrated on development of a model for the mill steam usage, since the primary opportunity to substitute geothermal heat for fossil fuel energy will be in the reduction of fired steam production.

1.5.2 Present Energy Consumption

The Pine Creek tungsten complex relies solely on purchased electricity for prime movers and fuel oil for the production of process steam. A survey was completed of current energy consumption at the Pine Creek tungsten complex to evaluate the potential for utilizing geothermal energy.

1.5.2.1 Electrical Consumption

Electricity for Union Carbide's tungsten complex is produced at a hydroelectric power generation plant approximately twenty-eight miles from Union Carbide's facilities and purchased from Southern California Edison (SCE). Power from the SCE plant is carried via a 55,000 V transmission line and is transformed onsite to 12,480 V for delivery.

Large pieces of rotating machinery including ball and rod mills, compressors and pumps are used in the mill for the processing of tungsten ore. An electrical use survey at the Pine Creek tungsten complex, listing major pieces of equipment and their electrical requirements, is shown in Table 1-1. Approximately 36 million kilowatt hours are required for the continuous operation of the mill at a cost of 3.7 cents per kilowatt hour. SCE has two rate increases pending which could result in large utility cost increases to industrial users such as Union Carbide. These rate changes would be reflected in the Energy Cost Adjustment Charges which might result in an increase of sixteen percent before 1981. This projected increase would result in electrical power costs of 4.3 cents per kilowatt hour for Union Carbide. The feasibility of electrical production onsite will be investigated for unconventional alternatives such as geothermal or small scale hydro generation facilities to reduce purchased power requirements.

1.5.2.2 Steam Consumption

Large amounts of steam and clean water are needed for processing tungsten ore to the end product, ammonium paratungstate. The mine cuts across several water bearing fractures which results in a drainage of 442-505 liters/sec (7-8000 GPM) that collects at the lowest level of the mine. From there it is pumped to a water clarifier which supplies water for process use and the water required for process steam.

Table 1-1

UNION CARBIDE ELECTRICAL SURVEY SUMMARY

EQUIPMENT	AMPS	VOLTS	KVA	KW
B&W Boiler M.C.C. 107 Main	70	460	56	46
B&W Boiler Fan 100 HP	62	460	49	41
Agitators, Filters, M.C.C. 108 Main	50	465	40	24
Digester M.C.C. 109 Main	29	465	23	13
Digester M.C.C. 15 HP	3	465	2.4	.6
Boilers M.C.C. 110 Main	115	465	92	79
Boilers Water Pump 40 HP	265	465	21	19
Boilers Water Pump 60 HP	55	465	44	38
Edwards Roaster M.C.C. 111 Main	140	465	113	106
Edwards Roaster Scrubber Fan	45	465	36	35
Stripper Column Fan 75 HP	48.5	465	39	32
Raffinate Main	400	465	322	261
Crystalizing Circulation Pump 60 HP	67	465	54	40
Evap. Pump Dr. 75 HP	50	465	33	33
Water Reclaimer 60 HP	66	465	53	47
Slurry Agitation Dr. 60 HP	50	465	40	33
Batch Mixing M.C.C. 112 Main	130	465	105	78
30 Transfer Pump	38	460	30	25
Agitator M.C.C. 114 Main	92	460	73	51
Agitator 40 HP	16	465	7	2
Batch Mix 40 HP	35	465	28	22
Main 3000 AMP	1320	470	1075	784
APT Main, 600 AMP (3 M.C.C.'s)	135	465	109	71
Crusher Area one M.C.C.	80	470	65	57
Crusher Area two M.C.C.	100	470	81	73
Crusher Area Jaw Crusher 150 HP	110	470	88	88
Crusher Area Cone Crusher 150 HP	140	470	112	95
Ball & Rod Mill M.C.C. #2 Main	300	460	239	186
Cyclone Feed Pump #1	140	460	112	97
Cyclone Feed Pump #2	140	460	112	97
Floats 20 Hp (9 units)	14	460	11	8
Floats M.C.C. #3 Main	230	465	185	128
Floats M.C.C. #4 Main	210	440	160	112
Floats 20 HP (9 Units)	14	460	11	8
Air Blower 25 HP	14	460	11	9
M.C.C. 101 Main	85	465	68	40
Wolframite M.C.C. 102 Main	270	465	218	180
6x5 Ball Mill 100 HP	110	465	89	75
5x6 Ball Mill 60 HP	80	465	64	46
M.C.C. 106 Main	200	465	161	97
Air Compressor	110	470	80	80
Air Compressor 125 Hp	135	465	63	53
Vacuum Pumps 30 HP (4)	22	465	18	14
Floats 20 HP (10 units)	22	465	18	12

Three oil fired boilers provide process steam to the Pine Creek tungsten complex. Steam consumption to the mill is supplied through a 240 psi steam header with pressure reducing stations to throttle the steam to the pressure levels required for various process stages. Seventy-two percent (46,000 lb/hr) of the produced steam is used for direct injection into the ore process stream. The steam is injected for three reasons:

- To provide the heat required to carry out the chemical reactions.
- To provide dilution of the process stream.
- Due to the corrosive nature and the fouling tendencies of the slurries being processed, direct injection is economical.

A general schematic for mill steam usage as related to the Ammonium Paratungstate (APT) process is shown in Figure 1-2.

Raffinate, a byproduct of the APT process, is treated in a highly energy intensive process that removes and concentrates sodium sulfate prior to disposal. The process does not require direct steam injection (see Figure 1-3) but uses nearly twenty percent of the mill's produced steam for waste treatment.

The steam usage in the Pine Creek complex was evaluated to determine where geothermal fluid could replace fuel oil as an energy input. Because the processing of tungsten ore is highly energy intensive, a reduction in fuel oil required per pound of steam produced could result in substantial savings.

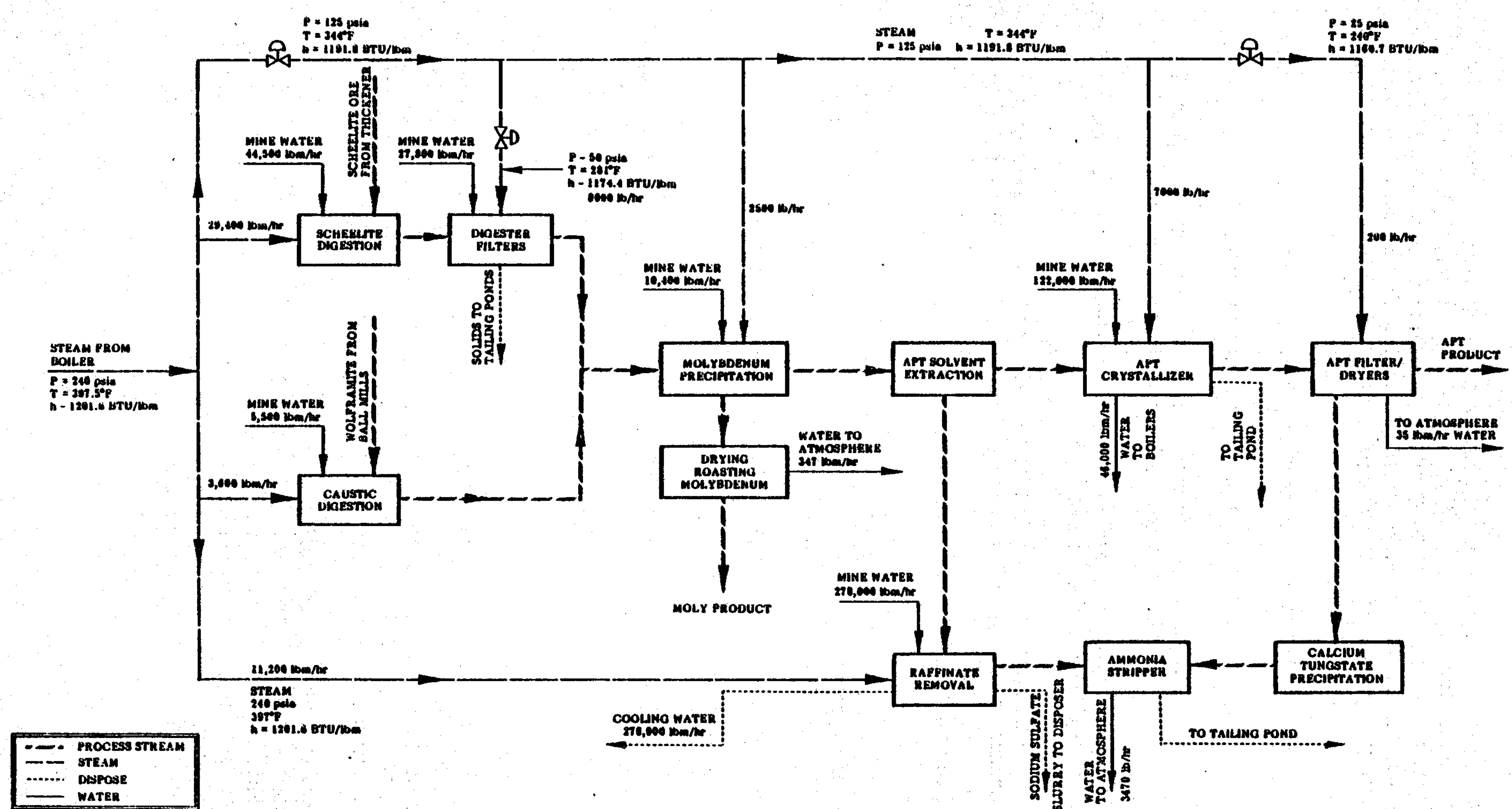
1.6 Geothermal Applications at the Pine Creek Tungsten Complex

1.6.1 Introduction

Energy is available in geothermal brine as heat. Therefore, applications for geothermal energy utilization will be analyzed in terms of economic and technical feasibility of direct or indirect heat conversion. End uses were evaluated for geothermal application based on the present source of energy use, its impact on the total energy consumption, its adaptability to using geothermal brine with available equipment, and its practicality for adapting to geothermal energy.

Process steam for the Pine Creek tungsten complex is presently supplied through a 240 psia steam header. As a large portion of this steam is directly injected into the process stream, geothermal brine cannot be used for direct applications in the ammonium paratungstate process because the predicted reservoir temperature is cooler than the required temperature for direct injection of 203C (397F).

The highest potential for geothermal applications will be in utilizing brine through heat exchangers to preheat water to the boilers, to provide space heating, and to heat additives prior to their introduction into the process stream. Geothermal fluid is expected to be relatively clean because of the geology of the area; therefore scaling is projected to be minimal and reinjection temperature will be limited by heat extraction efficiency instead of factors relating to solid deposition from the geothermal fluid.



MODEL FOR MILL STEAM USAGE

FIGURE 1-2

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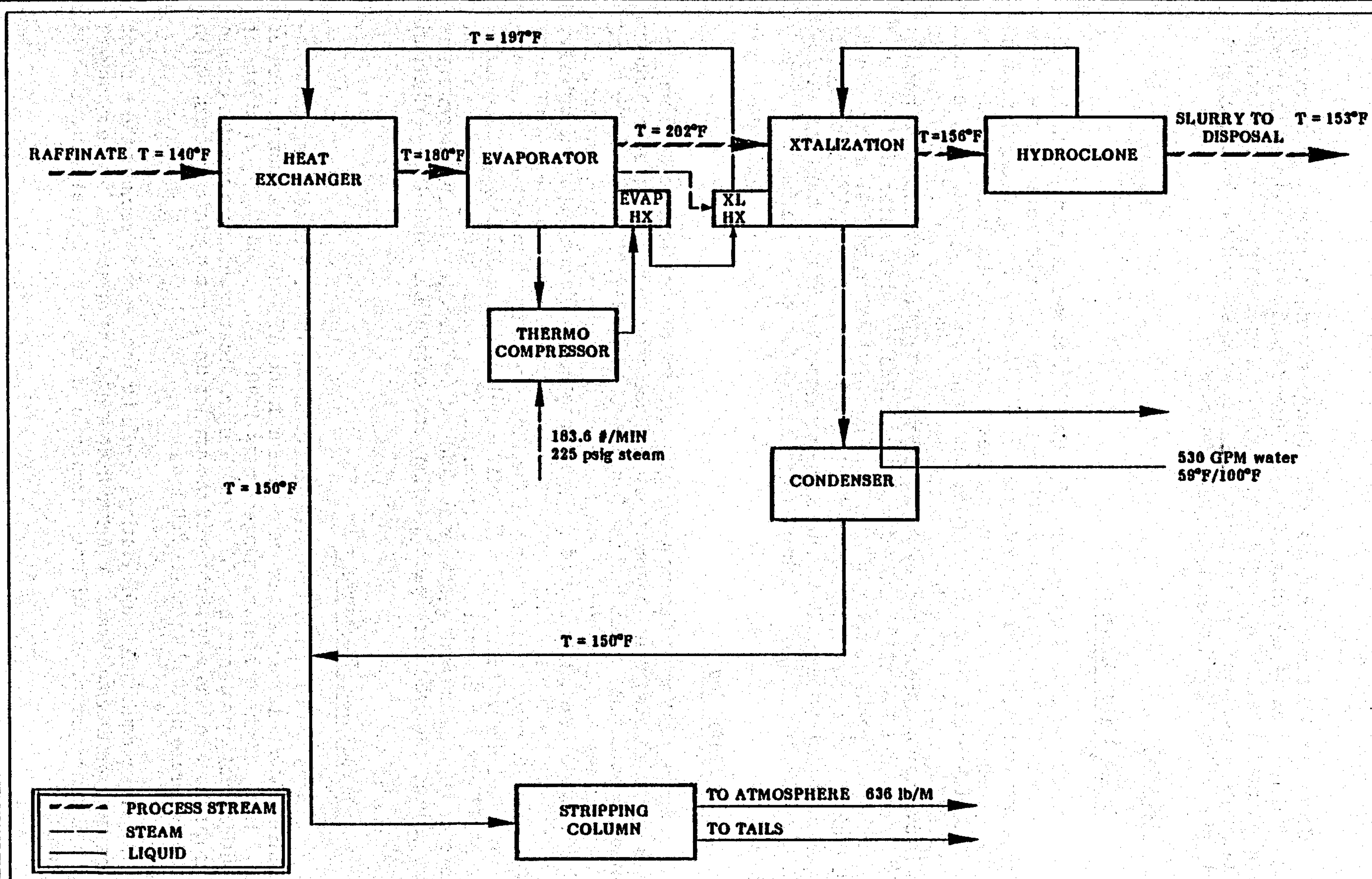


RAFFINATE TREATMENT

FIGURE 1-3

Cascading heat requirements will improve system efficiency by utilizing a large portion of the heat contained in the brine before disposal. Portions of the plant energy cycle which already use indirect heating via heat exchangers were examined for the feasibility of replacement with alternate heat exchangers using a lower temperature fluid while maintaining the same heat transfer rate.

1.6.2 End Uses

1.6.2.1 Boiler Water Preheat

Using the data supplied by Union Carbide, it was determined that a substantial decrease in fuel consumption would occur if the incoming water to the boiler feedwater pumps was preheated via geothermal fluid. If make up water from the mine at 4C (40F) is preheated in a counterflow heat exchanger, an inlet temperature to the boiler of 85C (185F) can be obtained saving 140 Btu/lb water. Currently, 72 percent (5.0×10^5 liters/day; 1.32×10^5 gal/day) of the water entering the boiler is preheated to 60C (140F) by passing through the APT crystallizer. With the remaining 28 percent (2.0×10^5 liters/day; 5.3×10^4 gal/day) of the incoming mine water to the boiler utilizing geothermal preheat, 2.9×10^6 Btu/hr of conventional fossil fuel energy can be replaced. This is a thirteen percent reduction in the amount of energy supplied by fuel oil for the make up water. The brine exit temperature can be between 82-93C (180-200F), making it possible to extract more energy for space heating or alternate uses.

1.6.2.2 Space Heating

Space heating is the most versatile use for the heat extracted from geothermal fluid. High reservoir temperatures are not required nor is the technology complicated. Geothermal water ranging from 48-114C (118-237F) is currently being used to heat homes and commercial establishments in Klamath Falls, Oregon, and Reykjavik, Iceland. The water is used for space heating by circulating it through very large radiators, or by transferring the heat to a closed system supplied with clean municipal water. Current space heating at the Pine Creek tungsten complex is accomplished with a fuel oil-fired furnace for the office buildings, and 2720 kg/hr (6000 lb/hr) of steam at 240 psia for the mill and change room. This space heating requirement can be replaced or augmented with geothermal fluid via a different distribution system as the temperatures required for space heating are compatible with the geothermal resource.

1.6.2.3 Current Heat Exchangers

There are currently two heat exchangers at the Pine Creek tungsten complex that utilize steam to heat the process stream in the APT crystallization portion of the cycle. Each of these heat exchangers uses 1590 kg/hr (3500 lb/hr) of steam at 130 psi, with a heat transfer rate of 3.1×10^6 Btu/hr. Heat exchangers are also used in processing raffinate, a waste byproduct of the ammonium paratungstate process, which use steam at the rate of 5080 kg/hr (11,200 lb/hr).

Major equipment modifications would be necessary to replace the current exchangers using geothermal heat. A larger heat exchanger or several heat exchangers in series will be required, but will be acceptable if the overall heat transfer rate remains constant.

Scaling is expected to be a minimal problem as initial water analysis and a geologic review of the area indicate that there will be a low percentage of dissolved solids in the geothermal fluid because of the expected reservoir temperature and the geology of the area. If the heat in the geothermal fluid is extracted prior to entry to the tungsten mill, the problems associated with geothermal heat extraction such as solid deposition can be confined to one location.

months of December, January, February and March (the four coldest months of the year for this location) is -4.3C (24.2F). This corresponds to a mean daily minimum dry-bulb temperature of -14.6C (5.7F) at Pine Creek for the winter months.

2.3 GEOTHERMAL FLUID PRODUCTION/REINJECTION

A typical production well with a downhole submersible pump and a reinjection well required for a geothermal system are shown in Figures 2-1 and 2-2. The production well at Pine Creek would be drilled to a depth of 5700 m (1737 ft) and lined with cement casing to a depth of 2130 m (6890 ft). At this depth, the expected wellhead temperature is 121C (250F). To supply the geothermal energy needed to replace conventional energy sources for space heating, domestic hot water, and to preheat a portion of the boiler water, estimated at 4.5 x 10^{10} Btu/yr or 1.52 x 10^7 Btu/hr, a geothermal fluid flow of 30 liters per second (450 gpm) is required. This value is based on extraction of all of the heat in the brine between the temperatures of 116C and 77C (240-170F).

This flow rate would require the use of a pump in the geothermal supply system. A downhole, totally submersible pump has been decided on for this application. Downhole pumps are currently being modified to withstand the normally corrosive environment of the geothermal brine and are being tested at East Mesa, California and Raft River, Idaho to determine endurance limits and operating procedures.

Because the Pine Creek resource has a relatively low temperature, flashing the brine to make steam for the industrial processes is not an economical process. For example, approximately 34 pounds of geothermal brine at 116C (240F) would be needed in a flash tank at atmospheric pressure to produce one pound of steam. This limits the heat extraction from the geothermal fluid to heating, via heat exchangers, a second fluid that is compatible with system components. For this application water will be used as the secondary fluid, which will be circulated through heating coils for space heating, enter a storage tank which will provide domestic hot water and provide feedwater for the boiler feed pumps.

After the geothermal brine passes through a series of heat exchangers, it is discharged through the reinjection line through the injection well into a compatible aquifer. A centrifugal reinjection pump will be used, if required, to pressurize the reinjection line to provide adequate flow into the reinjection well at a depth of 2450 m (8000 ft).

Because of the surrounding geology, water from the geothermal reservoir is expected to be relatively clean, containing low total dissolved solids. Therefore, scaling and solid deposition on piping and process equipment should be a minimal problem. The brine reinjection temperature will be limited by the efficiency of extracting heat from the geothermal fluid in the shell and tube exchangers.

2.4 GEOTHERMAL HEAT EXTRACTION

The geothermal energy required to totally replace the space heating, domestic water heating and to preheat boiler feedwater is estimated at peak load to be 1.52 x 10^7 Btu/yr, which would require approximately 450 gpm of geothermal brine if all the

SECTION 2

GENERAL ENGINEERING EVALUATION

2.1 INTRODUCTION

The energy use survey of the Pine Creek tungsten complex identified three major areas for utilizing geothermal heat to replace or augment fossil fuel energy consumption. Because of the initial reservoir evaluation, which indicated a low resource temperature, electrical generation was excluded from consideration and all uses involved direct heat applications of the geothermal fluid. The three areas considered most compatible with a low resource temperature at the tungsten complex are space heating, domestic hot water heating and preheat of the industrial water prior to entering the boiler feedwater pumps.

2.2 WEATHER ANALYSIS

2.2.1 Introduction

Climatological data has been compiled on a month-by-month basis for the town of Bishop, California (elevation 1252 m, 4108 ft) since 1944. The offices and the tungsten processing mill of the Pine Creek tungsten complex are 20 miles northwest of Bishop in the Sierra Nevada mountains at an elevation of 2380 m (7800 ft). Current monitoring at Pine Creek consists only of air quality analysis performed for environmental agencies; data for specific weather analysis (temperature and precipitation) are not collected.

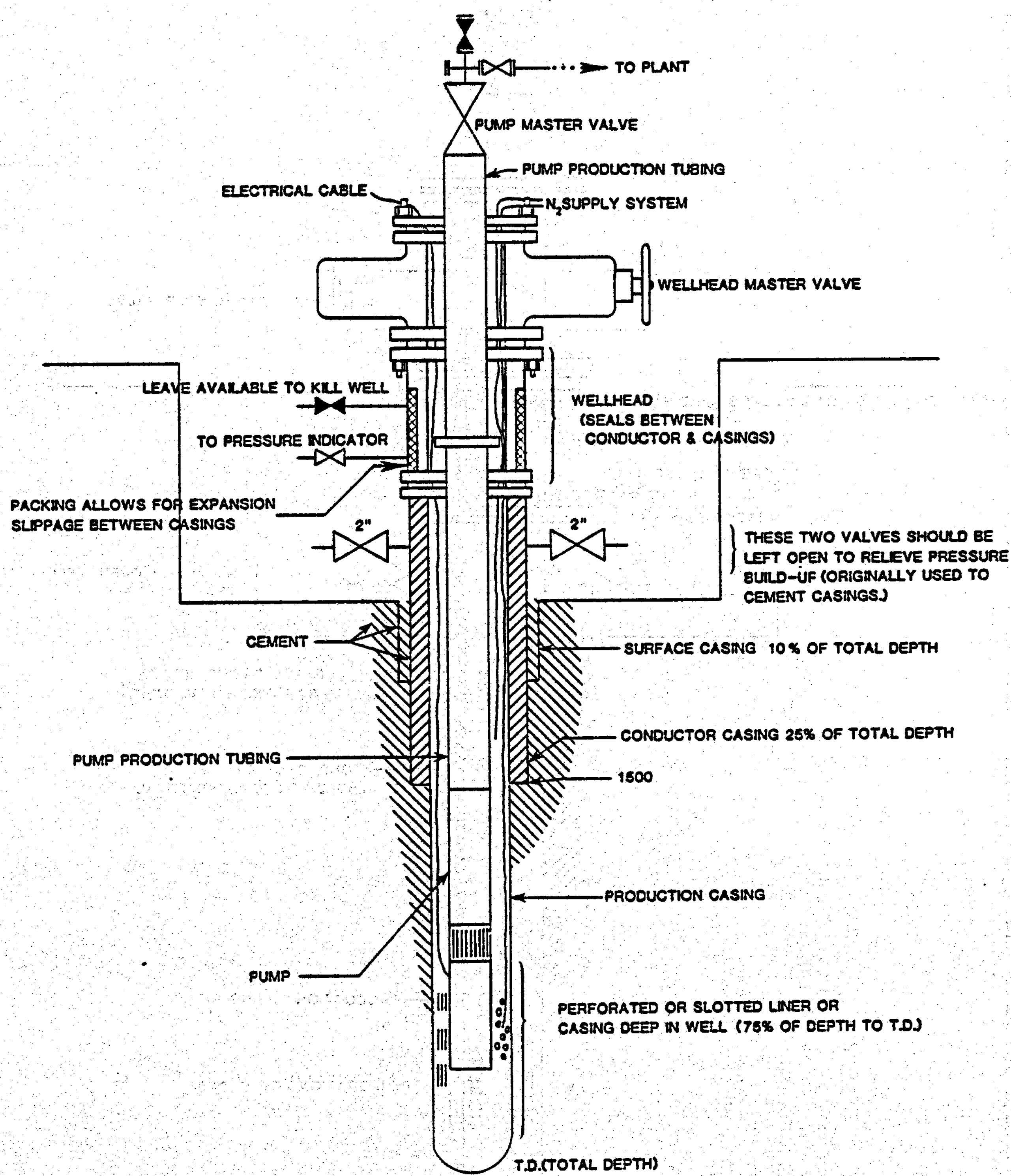
2.2.2 Adjustment for Elevation Change

The weather data from Bishop has been adjusted in accordance with ASHRAE's (1977) rule for determination of heating load using climatic conditions. For interpolation of weather data, ASHRAE suggests that an approximate adjustment for higher elevations is to decrease the values of wet bulb and dry bulb temperatures by the following increments:

Dry bulb temperature: 1 degree F per 200 ft
Wet bulb temperature: 1 degree F per 500 ft

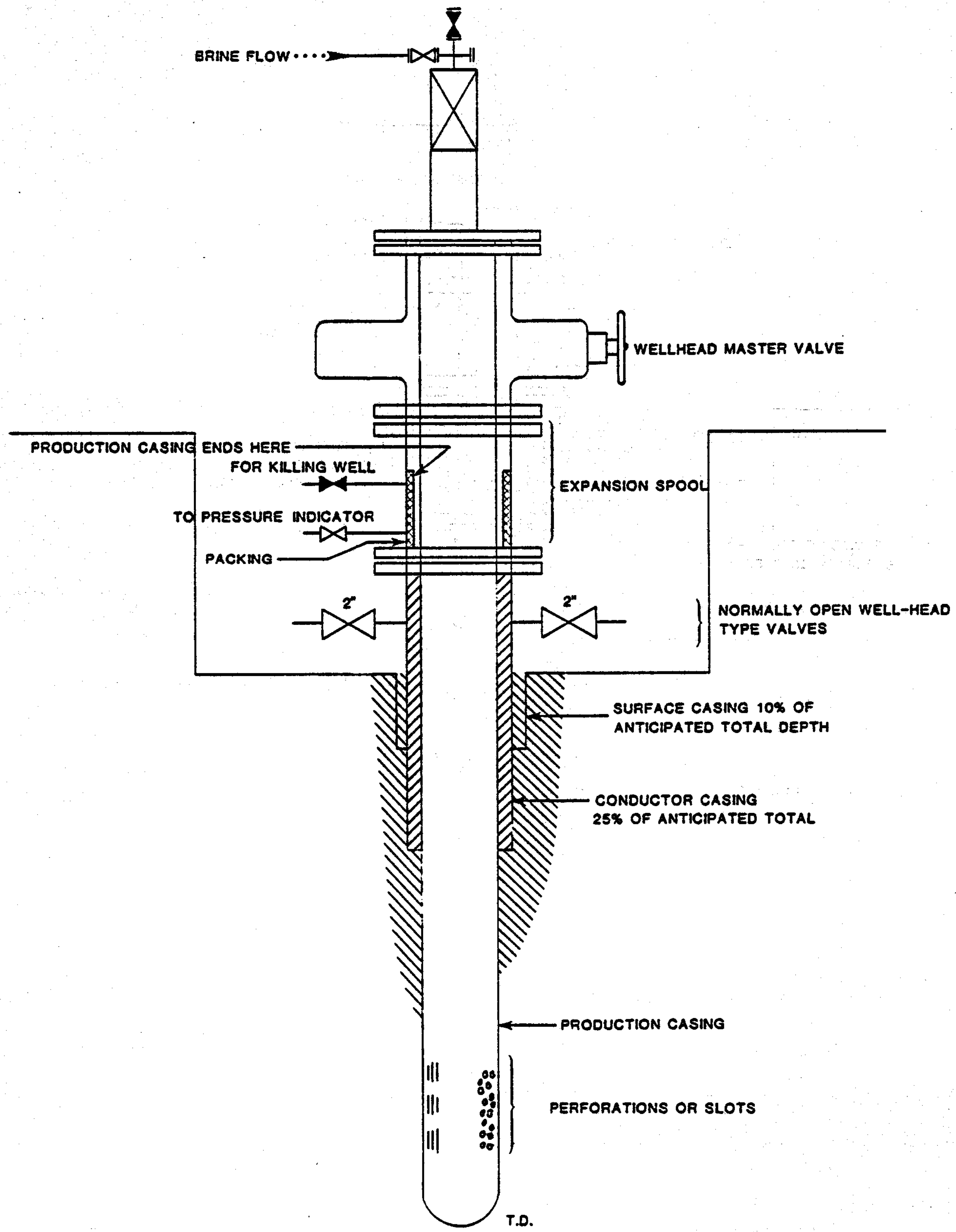
Bishop averages 4192 heating degree days and 1075 cooling degree days per year based on the traditional 65F (18.3C) base temperature. The annual average temperature for Bishop is 13.2C (55.9F)(U.S. Department of Commerce, 1978). Using the ASHRAE adjustments, an offset of 10.2C (18.5F) for the dry bulb temperature is taken for the location at Pine Creek which would result in a mean annual temperature of 3C (37.4F). This corresponds well with information obtained from personnel at the project site that stated the average annual temperature for the Pine Creek tungsten complex is 4C.

The largest demand for space conditioning will be heating, as seen by the above weather data. The mean daily minimum dry-bulb temperature for Bishop for the



PRODUCTION WELL WITH DOWNHOLE PUMP

FIGURE 2-1



INJECTION WELL

FIGURE 2-2

heat was utilized in the geothermal fluid from 116C to 77C (240-170F). This heat extraction will be accomplished with shell and tube heat exchangers in a binary system with clarified mine water absorbing the heat on the shell side.

2.4.1 Heat Delivery Methods

There are many ways to deliver the heat contained in the geothermal brine to the point of use. The most direct method would be use of the brine itself in the areas designated as having the highest potential for end use in the Pine Creek tungsten complex. This method has the advantage of being the most efficient heat transfer method and the potential for utilizing the greatest amount of energy contained in the brine. Transporting brine throughout the distribution system has some inherent problems. Although any geothermal fluid found in the area is predicted to be low in total dissolved solids, trace elements and dissolved gases in the fluid could cause problems in the equipment due to scaling or corrosion and in the tungsten process itself due to its sensitivity to contaminants.

Because of the problems associated with direct use of the geothermal fluid, heat exchangers will be used to transfer the heat to water taken directly from the water clarifier at the tungsten mining complex. The mine cuts across several water bearing fractures which results in a drainage of 7-8000 gpm that collects at the lowest level of the mine from where it is pumped to a water clarifier. A portion of the clarified water is used for process steam, flotation for heavy metal and scheelite separation and in other phases of tungsten ore processing. The remaining clean water is discharged into Morgan Creek.

Only minor piping changes would be required to introduce the geothermal energy system into the industrial piping at the Pine Creek tungsten complex. The normal flow of the discharge from the water clarifier to the tungsten mill will be directed through a heat exchanger for preheating industrial water to the boiler feedwater pumps.

2.4.2 Piping System

Heat for the Pine Creek complex is required for process applications and also for space heat and domestic hot water use. Mine runoff water heated in the boiler is for the most part consumed in the mill process, with only a relatively small amount rejected to the tailings pond. The hot water rejected from low temperature process applications could be used for space heating the office buildings and for heating the domestic supply water.

Heat for the Pine Creek complex would have to be transported from the geothermal resource to the mill area. If it is assumed that the geothermal plant is on the grounds of the mill then heat transportation would be a short distance (a few hundred yards at most).

The design for the Pine Creek mill will make use of a two-pipe hot water system. This system would entail one supply pipe of hot water for preheated boiler supply and low temperature process applications, and one return pipe of rejected water from low temperature process applications and office buildings use.

Figure 2-3 is a diagram showing a schematic of the two-pipe hot water system. The geothermal brine exchanges heat with the water taken from the tungsten mine. This geothermally preheated mine water is used to provide feedwater for the existing mill boiler and also for low temperature process applications. Hot water from the low temperature processes can be cascaded to provide space heat and to heat domestic water. The heat remaining in this water would be returned to the geothermal facility to be used to preheat mine makeup water prior to entering the heat exchanger.

2.4.3 Storage

In large scale district distribution systems, daily demand fluctuations are a regular occurrence. To provide a ready supply of fluid for the daily peak demands, storage tanks are employed.

Although the steam demand for the Pine Creek tungsten process is rather constant, heat demands for other end uses are prone to daily fluctuations. Both process heat for the mill and space heat for the office buildings may require daily changes in heat demand. Thus a storage tank will be employed to handle demand fluctuations of the geothermally heated hot water on a day-to-day basis. An insulated storage tank will provide a reservoir of hot water for increases in demand whenever they may occur.

2.4.4 Materials Evaluation

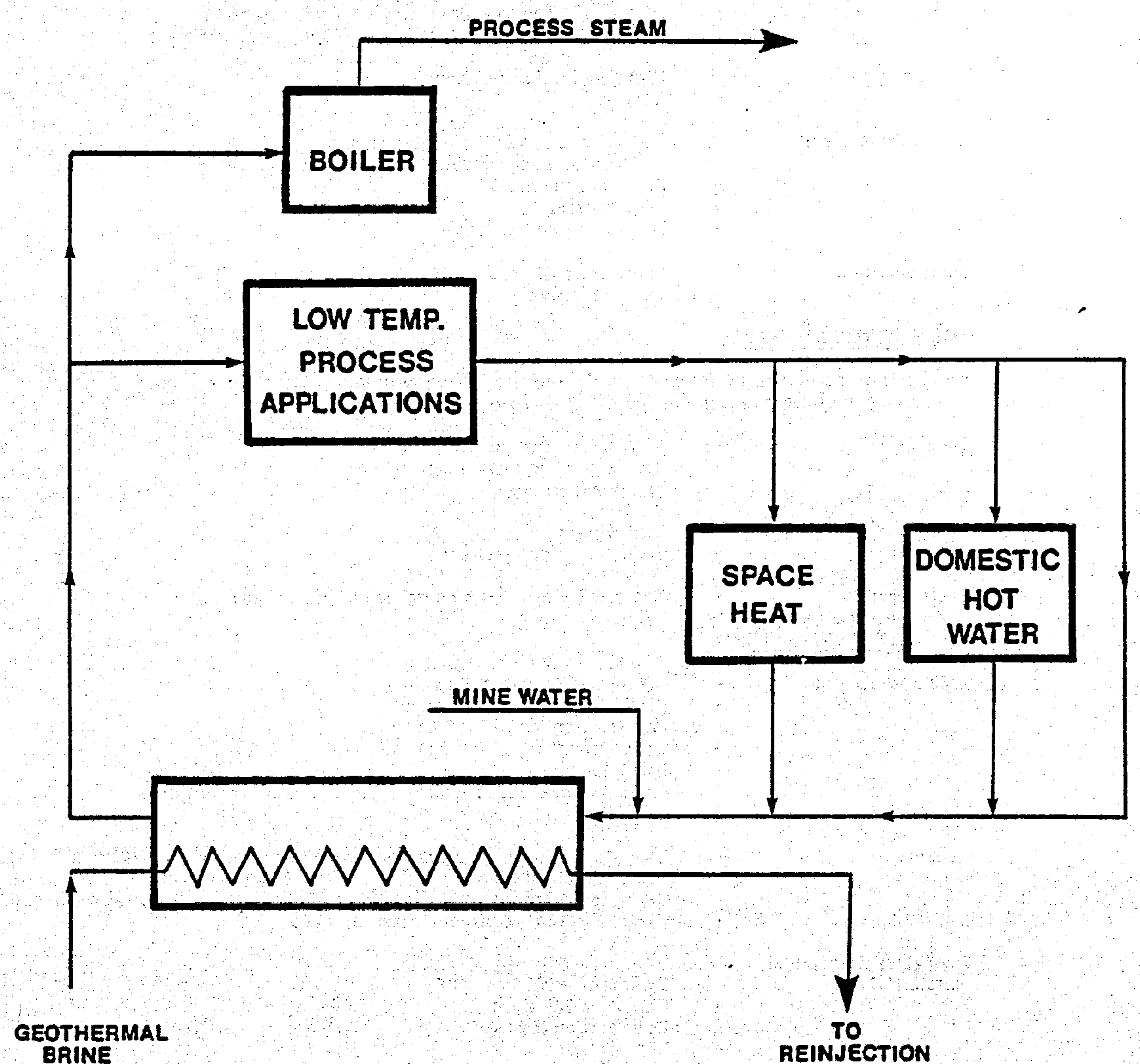
2.4.4.1 Pipe Materials

A preliminary investigation into the different types of pipe materials would indicate quite a wide variety from which to choose. The basic criteria in choosing the best pipe-insulation conduit combination would be: (1) the pipe must meet the requirements of the heat transfer medium, i.e., the pipe must not be adversely affected by the medium's temperature, pressure, or chemistry; (2) the insulation must properly limit thermal losses or gains; (3) if placed underground, some form of encasement must protect the pipe and insulation from external loads and the underground environment; and (4) the cost-benefit ratio for the pipe-insulation conduit combination must be examined in relation to the medium being transferred.

There are, of course, many other factors to be considered such as heat transfer characteristics, thermal expansion, creep strength, and corrosion protection. Some of the different types of pipe materials are listed in Table 2-1, which gives a brief description of the characteristics of each.

Mild steel is the most commonly used material in prefabricated pipe and conduit casing because of its relatively low cost, availability, and ease of fabrication. Carbon steel pipe for brine transmission has been successfully used in the past. Proper precautions must be taken, however, to prevent pitting and crevice corrosion especially by geothermal brine. High salinity geothermal fluids will cause high uniform corrosion as well as localized corrosion.

Preinsulated pipe using non-metallic materials of the asbestos-cement or fiberglass reinforced plastic (FRP) type appears to be popular for geothermal district heating systems. Preinsulated pipe, very simply, is a prefabricated pipe usually from



ENERGY CASCADE FOR GEOTHERMAL SYSTEM

FIGURE 2-3

Table 2-1

PIPING MATERIALS

Material		Characteristics
FERROUS METALS		
Cast Iron	-	Widely used in water and sewer lines
	-	High resistance to atmospheric and soil corrosion
	-	Are comparatively brittle but have acceptable strength
Wrought Iron	-	Highly corrosion resistant
	-	Expensive
Low Carbon Steel	-	Widely used in various applications
	-	Good for low and medium pressure steam & water
	-	Rather economical
	-	Easy to weld
	-	Low corrosion resistance
Stainless Steel	-	Highly corrosion resistant
	-	Very expensive
NON-FERROUS METALS		
Note: The use of these materials is confined to within buildings. They are not used extensively in underground mains for thermal conveyance systems.		
Copper	-	Widely used for indoor plumbing
	-	Good corrosion resistance
	-	Highly expensive
Aluminum	-	Lightweight
	-	Good corrosion resistance
Brass, Bronze	-	Suitable for low and medium temperature service
NON-METALLIC MATERIALS		
Asbestos-cement	-	Often used in water lines
	-	High resistance to corrosion
	-	Low friction losses
	-	Good strength
	-	Highly brittle
	-	Sizes up to 36 in., pressures up to 200 psi, temperatures up to 200F
Concrete	-	Used for large water mains and sewer lines
	-	High flow coefficient
	-	Corrosion resistant
	-	Can withstand significant external loads
Fiberglass Reinforced Plastic (FRP)	-	Temperatures up to 300F
	-	Corrosion resistant
	-	Low friction losses
	-	Lightweight
	-	Easy to install
	-	Good strength
Thermoplastics	-	Temperatures up to 200F
	-	Pressures up to 100 psia
	-	Relatively low strength
Thermosetting Resins	-	Can be used as liner for other pipe materials
	-	Good corrosion resistance
	-	Good for low temperature water service

10 feet to 13 feet in length, which contains an inner core (copper, asbestos-cement, steel, or PVC) insulating material around this core (polyurethane foam or calcium silicate), and an outer casing (asbestos-cement or PVC). Because all of the components are packaged into a pipe spool at the factory, the cost per unit length is relatively inexpensive. Besides this main advantage, the prefabricated system is fast and easy to install.

While preinsulated pipe has certain advantages which make it suitable for district distribution systems, it may not be suitable for the Pine Creek mill situation. First of all, preinsulated pipe is good for long straight runs where its ease of installation saves greatly in cost. In the Pine Creek project this is not required if it is assumed that the well is at the mill site. In addition, pipe materials of the asbestos-cement variety are limited to maximum working temperatures of around 200F. FRP pipe can take temperatures up to 300F but requires more time for installation because each spool must be glued together.

It appears that for the Pine Creek mill, carbon steel pipe would suffice for both the brine loop and the freshwater loop with proper insulation. Carbon steel pipe is relatively inexpensive, readily available, and holds up surprisingly well in geothermal applications. Carbon steel pipe has been extensively used in all types of brine, and carbon steel can handle a wide range of temperature and pressure conditions.

2.4.4.2 Insulation

An ideal material for insulation service should be: (1) capable of withstanding repeated wetting and drying without serious deterioration; (2) non-corrosive to pipe materials when wet; (3) a nonconductor of electricity; (4) vermin proof; and (5) chemically and physically stable at operating temperatures.

Insulation materials basically fall into four temperature ranges—cryogenic (below to -150F), low temperature (-150F to 250F), moderate temperature (250F to 1200F), and high temperature (above 1500F). Insulation types include calcium silicate, fibrous and cellular glasses, urethane foam, rock and mineral wools, expanded perlite, ceramic brick, and various fibers (mineral, ceramic, oxide, carbon). Physical forms of insulation can be loose-fill, flexible, rigid, reflective, and formed in place; forms can be foam, blocks, blankets, granular, mats, boards, and tape.

Of the abundant variety of materials from which to choose, fiberglass, calcium silicate, and polyurethane foam appear to be the most widely used in geothermal applications (see Table 2-2).

Polyurethane foam is an organic plastic which is confined to the low-temperature application range. This material comes in blocks, boards, flexible sheets, or can be foamed in place. It has also been widely used in preinsulated pipe for low temperature geothermal brine service. Polyurethane has a very low conductivity factor, making it one of the best materials in this category. Unfortunately, permeability to water vapor has been a problem with polyurethane foam in cryogenic service. Water vapor penetrates the foam and deposits ice when it freezes, destroying the insulation properties.

TABLE 2-2

PROPERTIES OF GEOTHERMAL INSULATING MATERIALS

	Calcium Silicate	Fiberglass	Urethane Foam
Temp. range	100F to 1500F	-120F to 650F	-250F to 225F
Conductivity, K Btu-in/hr-ft^2-°F	0.33 to 0.72	0.15 to 0.54	0.11 to 0.14
Density, lb/ft^3	10.0 to 14.0	0.60 to 3.0	1.6 to 3.0
Compressive strength lb/in^2 @ % deformation	100 to 250 @ 5%	0.02 to 3.4 @10%	16 to 100 @5%
Relative cost	high	low	low

Fiberglass is formed from fine, resilient glass fibers. It has been used in service up to 650F in temperature. Fiberglass most popularly comes in blankets, semi-rigid boards, and molded sections. In blanket form, fiberglass is easy to install around pipes and tanks. Although fiberglass does not have the compressive strength of either polyurethane foam or calcium silicate, it does have excellent thermal resistivity and is relatively cheaper than calcium silicate for moderate temperature use.

Calcium silicate is a mixture of lime and silica reinforced with organic and inorganic fibers. It is used up to 1500F temperatures. It comes in boards and blocks, and quarter-round and half-round segments for pipes. Because of its rigidity, this material has a higher resistance to mechanical abuse than most insulating materials. A typical aluminum jacketing around the insulation provides protection against weather and other damage.

2.4.4.3 Conduit

Conduit envelopes protect pipe and insulation against wetness, corrosive soils, and mechanical loads. The two basic types of conduit are: (1) poured field constructed type; and (2) prefabricated type. Both types can be either pressure tight or non-pressure tight. Many of the poured envelopes incorporate a combination cement-insulation or insulating cement which is poured around the pipes. Others use a hydrocarbon envelope of a natural granular asphaltic material of high resin content, or asphalt contained in a metal jacket surrounding the pipe.

Because field constructed conduits are more costly than factory prefabricated conduit sections, which can be easily assembled at the site, examination of the prefabricated conduit types is in order.

Prefabricated pressure tight steel conduit can be made of either smooth or corrugated steel. The pipe is surrounded with preformed insulation and then the conduit is placed around it with a drain space in between. A coupling is welded to join two sections of conduit; a protective coating, enamel or mastic is used to seal the joints. Sealed asbestos-cement conduits are similar in configuration to the prefabricated steel type except asbestos-cement is used for both the pipe and outer casing. Joints are made with compression type couplings and O-rings for sealing. Epoxy lining and polyurethane foam insulation is also used.

Also similar to this configuration is fiber-reinforced plastic conduit using FRP pipe with polyurethane insulation. Sections are joined by use of a bonding cement or mastic.

2.4.4.4 Heat Exchanger Materials

In the binary heat extraction process, well site heat exchanger(s) would be called upon to transfer heat between the geothermal reservoir fluid (estimated at approximately 240F, 116C) and the freshwater taken from the Pine Creek mine (at approximately 40F, 4C).

A wide variety of materials can be used for heat exchangers. Tube materials range from mild steel and copper alloys, to expensive titanium. Mechanically, these materials have high strength combined with excellent ductility so that they can be handled with reasonable care without bending, kinking, becoming dented or otherwise damaged.

Copper alloys are prone to chemical attack by copper embrittlement due to the H_2S (hydrogen sulfide) in the geothermal brine. Cracking of some copper-based alloys exposed to ammonia or its derivatives also may occur.

Titanium and titanium-based alloys tested on geothermal fluids have shown excellent results in resistance to corrosion, impingement, and cavitation damage. Titanium is relatively expensive and experiences with cheaper carbon steel material have been quite positive.

Tests have been conducted on heat exchanger tube materials under experimental conditions at a Heber Reservoir site. Results taken from tests at Heber's Nowlin No. 1 Well have shown that carbon steel or titanium tubes can be considered for service at Heber if proper precautions are taken to prevent excessive exposure to air (oxygen) during start-up, shutdown, and maintenance operations. Tests performed at an East Mesa geothermal well site have also shown positive results utilizing carbon steel tubes. After formation of a tenacious layer of magnetic iron oxide, corrosion appeared to have ceased. No signs of pitting or flaking of the oxide were apparent. Copper nickel (90:10) proved to function satisfactorily in lower temperatures but in hotter temperatures corrosive attack was excessive. Titanium tubes showed no signs of corrosion or other damage.

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SECTION 3

DESIGN OF GEOTHERMAL ENERGY SYSTEM

3.1 INTRODUCTION

Energy use at Pine Creek has been thoroughly examined, and end uses that are considered feasible with a low temperature resource have been pinpointed. The following section addresses the specifics of a geothermal energy system at Pine Creek, the associated equipment and the expected retrofit required.

3.2 MECHANICAL EQUIPMENT

3.2.1 General

The Pine Creek geothermal system is comprised of a brine and fresh water binary heat delivery system. The brine production, surface and injection facilties are shown in Figure 3-1. A submersible downhole pump will provide brine for the geothermal fluid side of the system at a peak load flow of 450 gpm. Two heat exchangers will be used to transfer heat from the geothermal brine to clarified mine water. After exiting the second heat exchanger, the spent brine will be injected with a centrifugal pump into a compatible aquifer through an injection well. The major system components and requirements for the proposed system are described in further detail below.

3.2.2 Submersible Pump

A downhole pump will be required to provide a sufficient fluid flow for the Pine Creek geothermal system. There are basically two types of pumps used for geothermal fluid production: the shaft-driven downhole pump and the submersible pump and motor. The lineshaft pumps are rather limited in the depth at which the pump can be placed. The maximum practical depth for pumping brine with lineshaft pumps is around 1000 feet although shallower depths are more common. The reliability of the shaft bearings becomes questionable as the depth and temperature are increased. The setting of the pump at Pine Creek is assumed to be 1000 feet. At this depth, a lineshaft pump would be operating in a marginal range, therefore, a submersible pump was decided on for this application.

After well conditions are known, the submersible pump should be sized to avoid marginal design efficiency. A pump that is incorrectly sized and operates substantially off peak pump capacity will result in excessive thrust bearing and impeller wear. Pumps operating in an off-peak condition can also accelerate cable wear. Without liquid to dissipate the heat, the temperature in the cable can become excessive, resulting in cable failure.

For preliminary design calculations, the desired discharge conditions were teamed with assumed reservoir data which resulted in determination of specific well parameters that would fit the design criteria. A setting depth of 1000 feet was chosen with an anticipated wellhead pressure of 100 psig which will provide the brine system pressure and the pressure required to overcome friction losses.

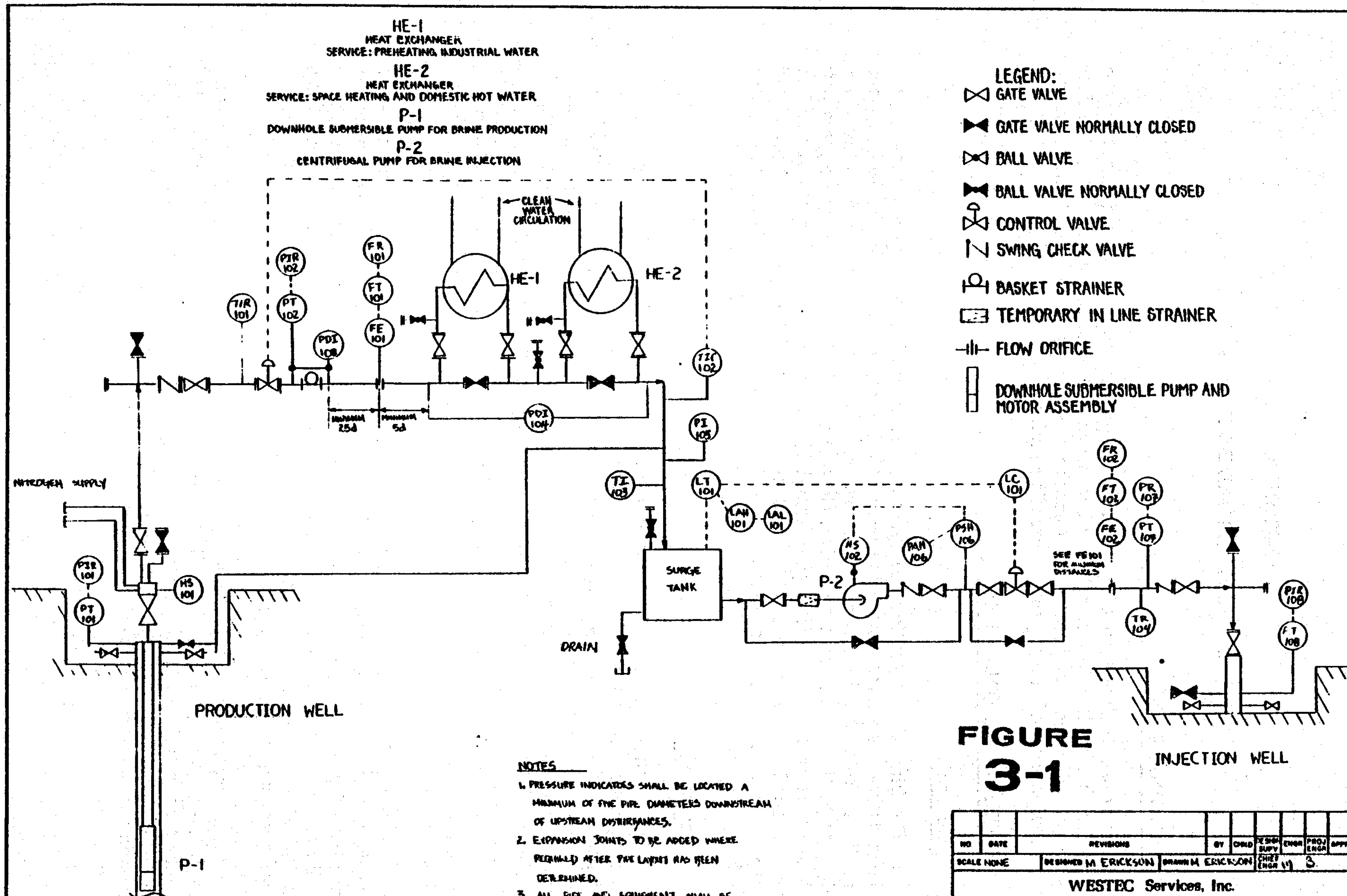

FIGURE 3-1

NOTES

1. PRESSURE INDICATORS SHALL BE LOCATED A MINIMUM OF FIVE PIPE DIAMETERS DOWNSTREAM OF UPSTREAM DISTURBANCES.
2. EXPANSION JOINTS TO BE ADDED WHERE REQUIRED AFTER PIPE LAYOUT HAS BEEN DETERMINED.
3. ALL PIPE AND EQUIPMENT SHALL BE PROPERLY INSULATED

NO	DATE	REVISIONS	BY	CHKD	DESIGN SUPV	ENGR	PROJ ENGR	APPR

SCALE NONE | DESIGNED M. ERICKSON | DRAWN M. ERICKSON | CHIEF ENGR 3.

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PRODUCTION, SURFACE, INJECTION FACILITIES

PINE CREEK FEASIBILITY STUDY

JOB NO.	DRAWING NO.	REV.
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3.2.3 Heat Exchangers

Fluid extracted from a reservoir at the Pine Creek location is expected to be fairly clean with a small component of dissolved solids in the brine. Carbon steel will be used for all piping and in the heat exchangers as a significant corrosion problem is not anticipated. The 365 day fouling factor for the brine side of the heat exchanger should not exceed .0012 based on tests conducted on carbon steel heat exchangers at the geothermal Heat Exchange Test Unit (HETU) in Heber, California (Ghormley, 1978). This fouling factor was based on a brine temperature range of 180 - 145F.

The heat exchangers will be arranged in series and will be of the standard shell and tube design. The first heat exchanger will be used for preheating the industrial water, with an annual load of 1.8×10^{10} Btu/yr. As the geothermal brine passes through the industrial water heat exchanger, the temperature of the brine drops from 115C to 109C (240F-228F), assuming a flow of 450 gpm on the brine side.

For space heating, the peak load demand is approximately 8.3×10^{6} Btu/hr. After passing through the industrial water heat exchanger, the brine heats charged water for use in space heating and domestic hot water heating. The brine enters the heat exchanger at 115C and after giving up energy for space heating, exits the second heat exchanger at 87C.

The predicted temperature of the brine at the wellhead is 121C (250F). With the use of a downhole pump, the predicted flow rate from the production well is 450 GPM. A pump placed in the production well will not only provide the necessary fluid flow, but will pressurize the brine transmission system to prevent brine flashing from taking place in the production pipeline or heat exchangers.

3.2.4 Existing System

The layout of the Pine Creek tungsten mining complex is shown in Figure 3-2. This shows the relative location of the office building and the office building annex to the mine and mill change rooms that will be heated with a geothermal energy system. The tungsten mill itself generally does not require direct space heating. Heat radiated from steam pipes and process equipment provides adequate space heating within the mill buildings. An energy profile of the Union Carbide mining complex is shown below in Table 3-1.

Although electrical generation is not feasible with a low temperature resource, and gasoline and diesel fuel are used exclusively for mobile equipment, approximately 4.1×10^{10} Btu/yr supplied currently by fuel oil could be replaced if geothermal brine was used as an energy input.

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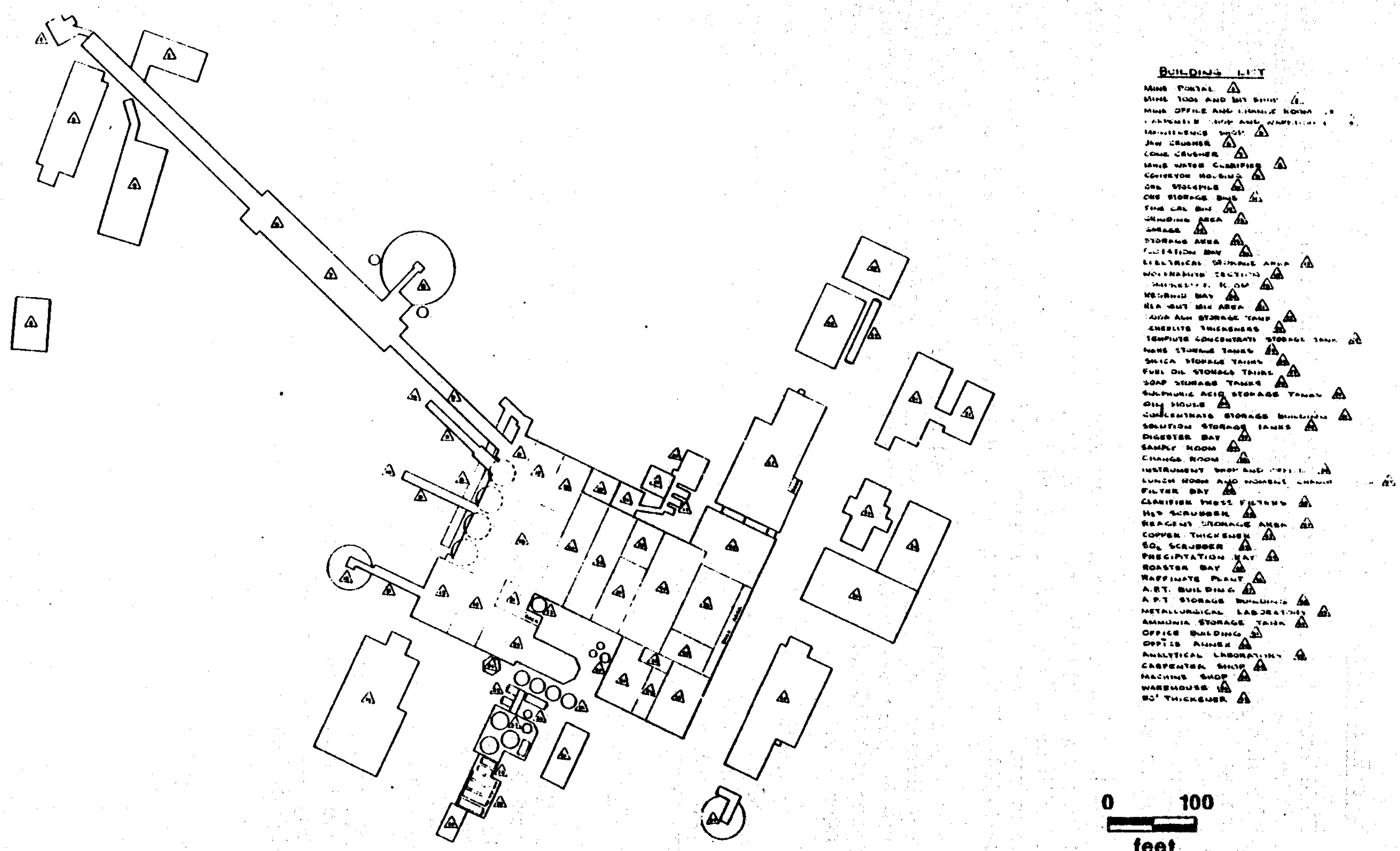


PINE CREEK TUNGSTEN MINING COMPLEX

FIGURE
3-2

Table 3-1

ENERGY CONSUMPTION AT UNION CARBIDE'S TUNGSTEN MINING COMPLEX

	%	Btu/yr	KWH/yr
Electricity	19	1.22×10^{11}	3.6×10^{7}
Gasoline	1	6.3×10^{9}	1.8×10^{6}
Diesel	5	3.3×10^{10}	9.7×10^{6}
Fuel Oil	75	4.7×10^{11}	1.4×10^{8}
TOTAL:	100	6.3×10^{11}	1.9×10^{8}

3.2.4.1 Mine and Mill Change Rooms

The change rooms at the Pine Creek tungsten complex are currently heated via a steam distribution system that supplies steam to radiators within the mine and mill change rooms. A typical piping schematic for the steam supply and condensate return is shown in Figure 3-3. Currently two steam radiators heat the mill change room and ten radiators heat the mine change room.

3.2.4.2 Office Building

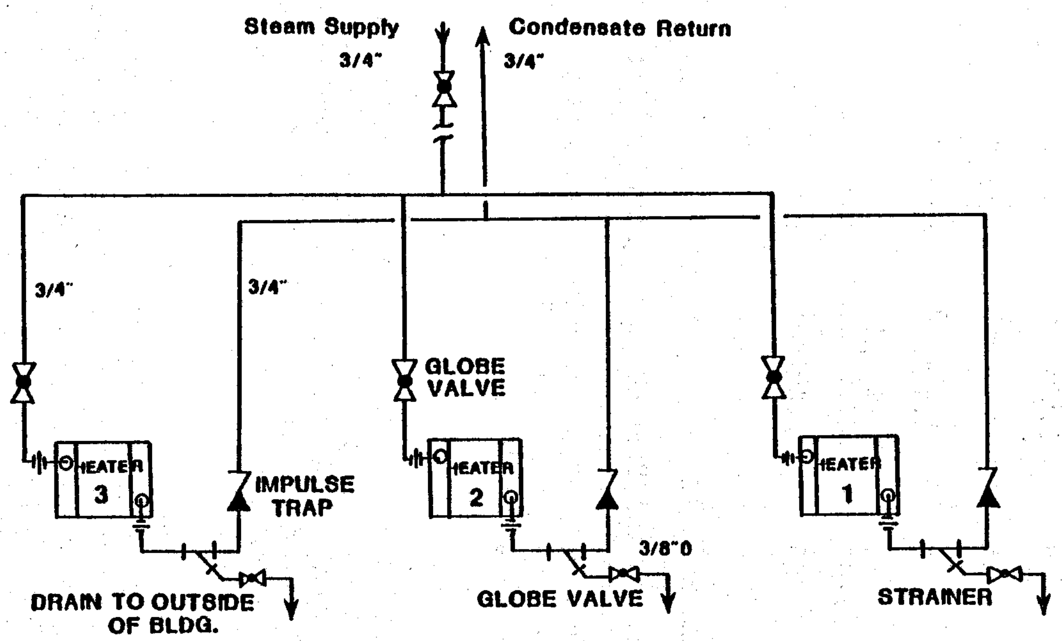
The office building that houses the professional and adminstrative personnel is heated by a furnace which burns fuel oil. The furnace burns 2186 gallons of fuel oil per year during the winter months. The building is normally occupied nine hours a day during the week and five hours each day on the weekends. Forced air supplies heat to the entire building. This two story office builidng has walls constructed of stucco and wood with R-11 fiberglass insulation.

Heat flux from the buildings was calculated using selected representative values of heat transfer coefficients for the various types of construction. These heat flux calculations were made with the assumption that exemplary conditions of components and installation are present in the building construction, and there are no free air cavities within the construction. An example of the heat flux calculations and thermal analysis of the wall construction is contained in Appendix A.

3.3 GEOTHERMAL ENERGY APPLICATIONS

3.3.1 Space Heating

A binary system was chosen for space heating the office buildings and the change rooms. The proposed space heating/water heating system is basically a closed water loop that obtains its energy input from geothermal brine in a liquid-liquid heat



HEATER PIPING SCHEMATIC

FIGURE 3-3

exchanger (see Figure 3-4). Clean water acting as the secondary fluid passes through the heat exchanger obtaining on outlet water temperature of 85C (185F).

A small circulation pump is required for the clean water loop that will keep the water pressurized and flowing through the system. After obtaining a heat input from the brine, the clean heated water passes through heating coils where forced air circulation through the coil unit provides space heating to the rooms. After leaving the heating coils, the relatively cool water (63C, 146F) is cascaded to heat domestic hot water for office use.

3.3.1.1 Domestic Hot Water

A temperature controller on the hot water tank maintains domestic hot water temperature between the band of 50 - 60C (122 - 140F). If the temperature in the water tank is below 50C, the three-way control valve directs the discharge from the heating coils through the hot water tank until a maximum temperature of 60C is reached. When the temperature of the tank attains a temperature of 60C, the three way valve closes the path through the water heater and bypasses it. This should conserve the greatest possible amount of heat in the clean water loop which will reduce the heat input demand from the geothermal brine.

A temperature controller will be installed on the brine circulation loop immediately after the brine exits the second heat exchanger. This temperature controller will control the exit temperature from the heat exchangers between 65 - 75C (150 - 167F) by modulating a control valve on the brine supply from the geothermal production well. This should reduce the amount of fluid pumped by the downhole production pump, thus reducing operation costs of the system.

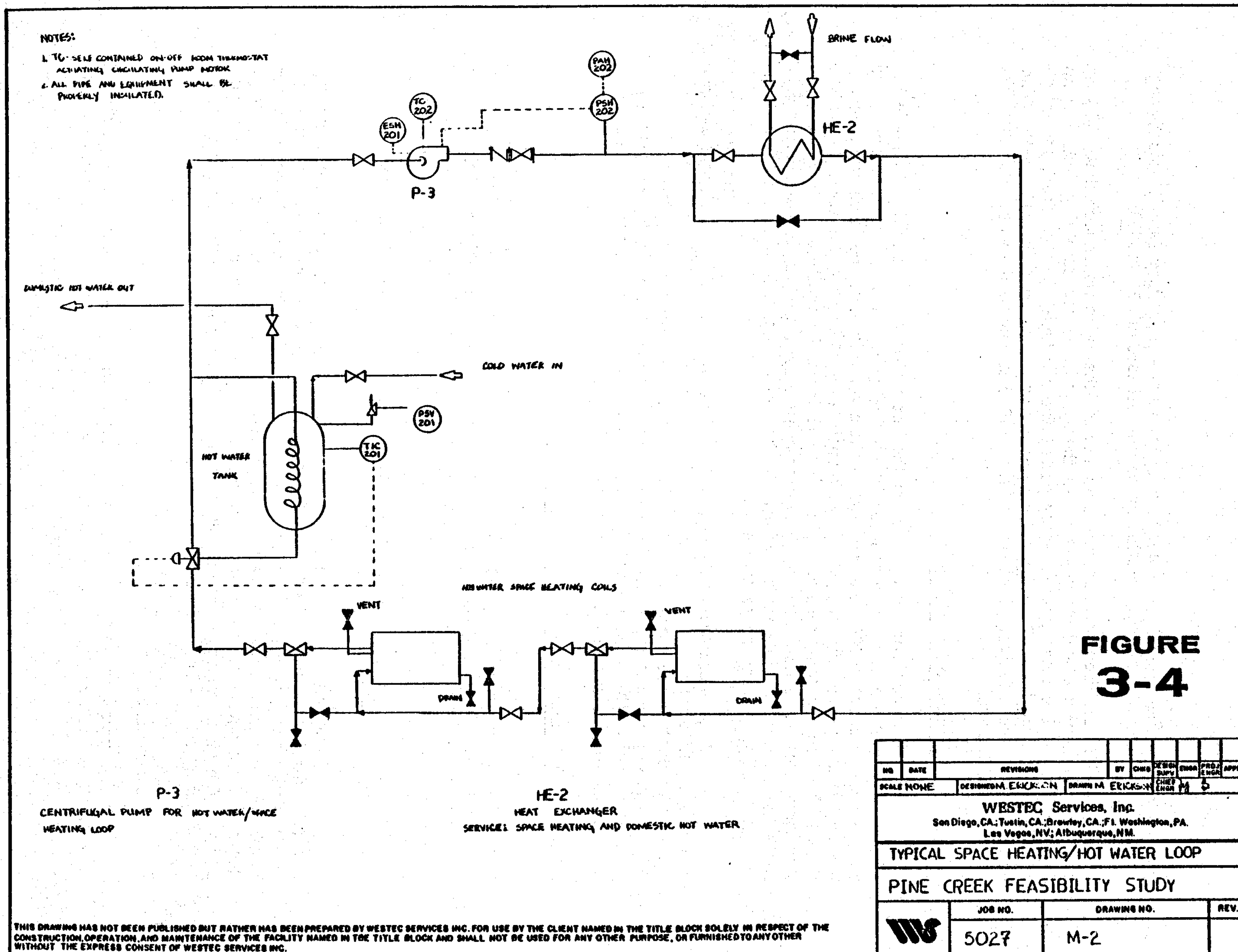
3.3.2 Industrial Boiler Water Preheat

The system will consist of a brine/water heat exchanger which will heat clarified mine water from an inlet temperature of 4C (40F) to an outlet temperature of 85C (185F). Because 78 percent of the steam generated by the boilers is injected into the tungsten processing stream, the clean water in this system passes through the heat exchangers only once. This heat exchanger unit will require no major modifications of the present plant configuration. Immediately before entering the tungsten mill, the clarified water will enter the designated heat exchangers and then follow the same path that it currently follows.

No unusual problems are anticipated with this new system design. Although the fluid entering the boiler feed water pumps will have a lower vapor pressure because of its higher temperature, the water will be under a slightly greater pressure which should prevent any potential cavitation problems in the boiler feedwater pumps. Because the proposed modifications maintain the design of a closed system, the supply pump in the clean water system should be adequate for providing the positive suction head required for the boiler feed water pumps.

3.4 UTILIZATION FACTORS

The proposed geothermal energy system will have a high year-round load factor. The tungsten mill processes raw tungsten ore to ammonium paratungstate



NOTES:
1. TC- SELF CONTAINED ON-OFF ROOM THERMOSTAT ACTIVATING CIRCULATING PUMP MOTOR
2. ALL PIPE AND EQUIPMENT SHALL BE PROPERLY INSULATED.
BRINE FLOW
PAH 202
PSH 202
TC 202
ESH 201
HE-2
P-3
DOMESTIC HOT WATER OUT
COLD WATER IN
PSV 201
TIC 201
HOT WATER TANK
HOT WATER SPACE HEATING COILS
VENT
VENT
DRAIN
DRAIN
P-3
CENTRIFUGAL PUMP FOR HOT WATER/SPACE HEATING LOOP
HE-2
HEAT EXCHANGER
SERVICE: SPACE HEATING AND DOMESTIC HOT WATER
NO
DATE
REVISIONS
BY
CHKD
DESIGN SUPV
ENGR
PROJ ENGR
APPR
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FIGURE 3-4

24 hours a day. Although some system loads such as space and domestic water heating will fluctuate with building occupancy, the industrial water demands will maintain a high utilization factor for the overall geothermal system resulting in a lower unit cost of energy supplied to the Pine Creek tungsten complex.

If the geothermal system is sized for peak loads (which would normally occur during winter months) the annual utilization factor should approach 40 percent. If an increase in the utilization factor is desired, the system could be sized so that it provides all of the energy input possible for the industrial water demand, and a portion of the energy input for space heating. This design would necessitate incorporation of a hybrid system sized to supply all of the space heating required on an average winter day, and for colder temperatures oil heaters could be used to boost the temperature sufficiently.

Another possibility would be the use of heat pumps for amplification of the heat supplied by the geothermal system. A more thorough analysis of the temperature fluctuations and the percentage of time the temperature is within specified narrow temperature ranges is required to use these types of geothermal "boost" systems. Temperature monitoring would be required at the Pine Creek site to establish a baseline for average winter conditions and space heating loads. This information would allow determination of the fraction of the annual total heating needs that must be supplied by a supplementary furnace or boiler and the fraction of the heating season that the supplementary boiler would need to operate at complete or partial load.

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SECTION 4

ECONOMICS

4.1 INTRODUCTION

A preliminary economic evaluation was undertaken for geothermal system development on the project site at Pine Creek. Space heating, domestic water heating and a portion of industrial water heating using geothermal brine as an energy source, was compared to current conventional energy sources to determine the economic feasibility of geothermal energy substitution at the tungsten mining complex. The analysis was conducted by comparing capital recovery charges for the proposed geothermal energy system with the projected savings of conventional fuel charges over the study period. Capital cost estimates were taken in part from Richard Engineering Services, Inc. Estimating Standards copyright 1979.

4.2 ECONOMIC INCENTIVES

4.2.1 Introduction

The economic analysis for a geothermal energy system must include an evaluation of cash flows that will show that the annual savings of the proposed project will justify the front-end capital investment. Capital investment must be encouraged so that technical progress is achieved that will promote improvement of the standard of living. The United States government has taken action to reduce the deterrent to capital formation in general, and has implemented laws to advance alternative energy development.

The tax and economic incentives described in further detail below promote geothermal development as they reduce the financial liability of the geothermal developer. Additional favorable legislation has been proposed to the United States Congress that would further increase the attractiveness of investments for geothermal utilization.

4.2.2 Tax Incentives

4.2.2.1 Investment Tax Credit

In 1962 tax laws were revised to alleviate some of the undesirable effects of income taxation on capital investment. One of these actions involved shortening the estimated lives of depreciable property acceptable for tax purposes. This permits a larger fraction of the total depreciation to be written off in the early years of the project. The other major legislative action that reduced the tax deterrent to capital investment was the establishment of an "investment tax credit" (Grant et al., 1976). The investment tax credit allowed businesses to deduct from their income taxes a stipulated percentage of the qualified investment. With certain exclusions, the eligible property included tangible personal property subject to depreciation. This credit is a reduction of the tax assessed by the government rather than a reduction in the taxable income.

The Energy Tax Act of 1978 provides a business investment tax credit for investment in "energy property." This credit is in addition to other tax credits for which the taxpayer may be eligible. This definition specifically encompasses "equipment used to produce, distribute or use energy derived from a geothermal deposit." For investments in energy property made between January 1, 1980 and December 31, 1989, the credit will be 15 percent.

4.2.2.2 Intangible Drilling and Development Costs

The Internal Revenue Code Section 263(c) allows the taxpayer at his option to deduct intangible drilling and development costs of geothermal wells. The Energy Tax Act of 1978 extends this tax advantage to geothermal developers which was previously available only to oil and gas well developers.

Under this provision, the taxpayer may elect to deduct these intangible costs from taxable income in the year that the costs were incurred as opposed to capitalizing them. This option is applicable to all expenditures incurred by the developer for wages, fuel, repairs, hauling, supplies, etc. incident to and necessary for the drilling and preparation of wells for geothermal production. In general, intangible drilling and development costs are those items which in themselves have no salvage value.

4.2.3 Other Financial Incentives

4.2.3.1 Percentage Depletion

The Energy Tax Act of 1978 granted geothermal developers the right to use the percentage depletion allowance previously allowed for oil and gas for geothermal deposits in the United States or its posessions. The taxpayer may deduct 22 percent of gross income for depletion in 1980, 20 percent in 1981, 18 percent in 1982, 16 percent in 1983 and 15 percent in 1984 and thereafter. These percentages are subject to an overall limitation: the allowances for depletion may not exceed 50 percent of the taxpayer's taxable income from the property.

The tax advantage of the percentage depletion allowance for geothermal reservoirs is that the taxpayer may deduct the statutory percentage from gross income each year that the property produces income. In contrast, cost depletion allowance, allows no further deduction after the capital investment has been recovered. If the property on which geothermal development has begun is sold, the new owner of a geothermal proven property can continue to take percentage depletion.

4.2.3.2 Geothermal Loan Guaranty Program

The Department of Energy administers a program to guaranty lenders against loss of principal and accrued interest on loans for specified aspects of geothermal development, including acquisition of rights to geothermal resources, determining and evaluating the resource, research and development respecting extraction and utilization, and construction and operation of a new commercial or industrial facility or modification of an existing facility when hot water is to be used within such facility for industrial purposes. All of these aspects would be relevant regarding Pine Creek.

The federal regulations promulgated by the Department of Energy, effective December 18, 1979 state that the amount guaranteed on each project cannot exceed $100,000,000. A single borrower cannot obtain guarantees in excess of $200,000,000. The Department of Energy determines what the rate of interest will be before a loan guaranty will be granted the applicant must present satisfactory evidence regarding environmental impact. Issuance of the guaranty is subject to the provisions of NEPA.

The loan guarantees are only available if the agreement is entered into by September 3, 1984.

4.2.3.3 User Coupled Confirmation Drilling Program

This is a new program of the DOE, Division of Geothermal Energy. Through this program, the federal government will cost share 20-90 percent of the expenses incurred during exploration to site drill holes, drilling, flow testing, reservoir engineering and injection well drilling. The percentage of costs that the government will support decreases as the success of the project increases.

4.3 CONVENTIONAL ENERGY COSTS

In any analysis comparing alternative and conventional energy sources, a model, must be constructed that will be capable of giving price projections for conventional fuel sources over the life of the study period. These predictions are accurate only to the extent that uncertainties regarding foreign energy imports can be minimized. Recent months have shown conventional fuel prices the victim of dramatic price increases due to fluctuation in prices and supplies from foreign oil producers. The changing energy situation that confronts the United States is forcing an appraisal of energy use patterns based on overall energy conservation and economic principles.

If actual escalation of conventional fuel prices is less than predicted, the project could prove to be uneconomical, therefore, to minimize risks associated with price forecasting, inflation rates associated with conventional fuel prices are conservative for use in economic comparisons.

A summary of conventional fuel costs are shown below in Table 4-1:

Table 4-1

ENERGY COSTS AT PINE CREEK (1979 DOLLARS)

Source	Consumption	Cost	Unit Cost
Electricity	36,573,000 KWH/YR	$1,352,000	$ .037/KWH
Fuel Oil	3,894,000 GAL/YR	$1,442,000	$ .370/GAL
Gasoline	54,230 GAL/YR	$ 40,130	$ .740/GAL
Diesel	233,000 GAL/YR	$ 137,500	$ .590/GAL

The fuel oils used at Pine Creek are #4 and #6, middle distillates used for fuel for the boilers and the office furnace. For direct heat applications at this location geothermal energy will replace energy currently supplied by fuel oil. Fuel oil available at contract prices to industrial users were evaluated for constant dollar price escalations over the 30 year study period based on a price forecast by San Diego Gas and Electric Company and raw energy cost data from the Federal Register. The following assumptions were made in determining the constant dollar fuel costs:

1) 1 January 1980 price - $27.00/barrel $.64/GAL

2) 1 January 1981 price - $39.15/barrel $.93/GAL

3) Price escalation for the following years

   1981 - 20%
   1982 - 14%
   1983 - 7%
   1984 - 7%
   1985 and thereafter 9%

4.3.1 Initial Economic Evaluation

The following assumptions were made for economic evaluation of the Pine Creek geothermal system:

Reservoir Characteristics and Well Properties

- 30 year production life of supply well
- Maximum flowrate of geothermal fluid 500 gpm or 249,900 lb/hr
- Temperature of the geothermal fluid at the reservoir well head = 121C (250F)
- Production well drilling cost (1980 dollars)
  $1,180,250
- Injection well drilling costs (1980 dollars)
  $890,000

Financing and Tax Data

- Drilling intangibles for production well
  $843,750
- Drilling intangibles for injection well
  $632,000
- Income tax rate (federal and state) - .50

- Startup year for operation - 1983
- Cost of borrowed money - 11 percent
- Debt/equity ratio - 80/20
- Required rate of return for risky business venture - 25 percent

The cash flow was based on eliminating 4.1 x 10^{10} Btu/yr currently supplied by fuel oil that the geothermal energy system would replace. Also included were operation and maintenance costs assumed to be 5 percent of the capital cost of the system per year. These calculations can be seen in Table 4-2.

Table 4-3 calculates the net cash flow after taxes computing depreciation on capital investment and cash flow for debt payment. Intangible drilling costs were not deducted from taxable income, but were capitalized because intangible drilling costs can only be charged against income from the energy property, and if Union Carbide owns the geothermal wells and utilizes all of the produced fluid, no actual income will be realized from this project.

Using the assumptions listed above, this project's present worth was found to be less than zero, and therefore not economically feasible (see Table 4-4). Further investigation of fuel and energy price forecasts and a more detailed economic analysis will be included in the final report.

Table 4-2

CASH FLOW BEFORE DEBT SERVICE

Year	$/Gal. Fuel Oil	$/$10^6$ Btu	Net Savings Per Year	Operations and Maintenance	Net Cash Flow
1983	$ 1.36	$ 9.38	$ 384,580	-157,500	227,080
1984	$ 1.45	$ 10.00	$ 410,000	-157,500	252,500
1985	$ 1.58	$ 10.90	$ 446,900	-157,500	289,400
1986	$ 1.72	$ 11.87	$ 486,670	-157,500	329,170
1987	$ 1.88	$ 12.97	$ 531,770	-157,500	374,270
1988	$ 2.05	$ 14.15	$ 580,150	-157,500	422,650
1989	$ 2.23	$ 15.39	$ 630,990	-157,500	473,490
1990	$ 2.43	$ 16.77	$ 687,570	-157,500	530,070
1991	$ 2.65	$ 18.28	$ 749,480	-157,500	591,980
1992	$ 2.89	$ 19.94	$ 817,540	-157,500	660,040
1993	$ 3.15	$ 21.74	$ 891,340	-157,500	733,840
1994	$ 3.43	$ 23.67	$ 970,470	-157,500	812,970
1995	$ 3.75	$ 25.87	$1,060,670	-157,500	903,170
1996	$ 4.08	$ 28.15	$1,154,150	-157,500	996,650
1997	$ 4.45	$ 30.70	$1,258,700	-157,500	1,101,200
1998	$ 4.85	$ 33.46	$1,371,860	-157,500	1,214,360
1999	$ 5.29	$ 36.50	$1,496,500	-157,500	1,339,000
2000	$ 5.76	$ 39.74	$1,629,340	-157,500	1,471,840
2001	$ 6.28	$ 43.33	$1,776,530	-157,500	1,619,030
2002	$ 6.85	$ 47.26	$1,937,660	-157,500	1,780,160
2003	$ 7.46	$ 51.47	$2,110,270	-157,500	1,952,770
2004	$ 8.14	$ 56.17	$2,302,970	-157,500	2,145,470
2005	$ 8.69	$ 59.96	$2,458,360	-157,500	2,300,860
2006	$ 9.66	$ 66.65	$2,732,650	-157,500	2,575,150
2007	$10.54	$ 72.73	$2,981,930	-157,500	2,824,430
2008	$11.48	$ 79.21	$3,247,610	-157,500	3,089,810
2009	$12.52	$ 86.39	$3,541,990	-157,500	3,384,490
2010	$13.65	$ 94.19	$3,861,790	-157,500	3,704,290
2011	$14.88	$102.67	$4,209,470	-157,500	4,051,970
2012	$16.21	$111.85	$4,585,850	-157,500	4,428,350

Table 4-3

AFTER TAX ANALYSIS OF GEOTHERMAL SYSTEM

Year	A Net Cash Flow Before Debt Service and Taxes	B Cash Flow For Debt Repayment	C Cash Flow For Interest On Debt	D (A+B+C) Cash Flow After Debt Service	E Depreciation (Straight Line)	F (A+C+E) Taxable Income	G -(.5F) Cash Flow For Taxes	H (D+G) After Tax Net Cash Flow
	-3,150,000							
0	+2,520,000							-630,000
1	227,080	-84,000	-277,200	-134,120	-105,000	-155,120	+77,560	-56,560
2	252,500	-84,000	-267,960	-99,460	-105,000	-120,460	+60,230	-39,230
3	289,400	-84,000	258,720	-53,320	-105,000	-74,320	+37,160	-16,160
4	329,170	-84,000	-249,480	-13,550	-105,000	-25,310	+12,655	895
5	374,270	-84,000	-240,240	+50,030	-105,000	29,030	-14,515	35,515
6	422,650	-84,000	-231,000	+107,650	-105,000	86,650	-43,325	64,325
7	473,490	-84,000	-221,760	+167,730	-105,000	146,730	-73,365	94,365
8	530,070	-84,000	-212,520	+233,550	-105,000	212,550	-106,275	127,275
9	591,980	-84,000	-203,280	+304,700	-105,000	283,700	-141,850	162,850
10	660,040	-84,000	-194,040	+382,000	-105,000	361,000	-180,500	201,500
11	733,840	-84,000	-184,800	+465,040	-105,000	444,040	-222,020	243,020
12	812,970	-84,000	-175,560	+553,410	-105,000	532,410	-266,205	287,205
13	903,170	-84,000	-166,320	+652,850	-105,000	631,850	-315,925	336,925
14	996,650	-84,000	-157,080	+755,570	-105,000	734,570	-367,285	388,285
15	1,101,200	-84,000	-147,840	+869,360	-105,000	848,360	-424,180	445,180
16	1,214,360	-84,000	-138,600	+991,760	-105,000	979,760	-485,380	506,380
17	1,339,000	-84,000	-129,360	+1,209,640	-105,000	1,188,640	-594,320	615,320

Table 4-3 (Continued)

Year	A Net Cash Flow Before Debt Service and Taxes	B Cash Flow For Debt Repayment	C Cash Flow For Interest On Debt	D (A+B+C) Cash Flow After Debt Service	E Depreciation (Straight Line)	F (A+C+E) Taxable Income	G -(.5F) Cash Flow For Taxes	H (D+G) After Tax Net Cash Flow
18	1,471,840	-84,000	-120,120	+1,267,720	-105,000	1,246,720	-623,360	644,360
19	1,619,030	-84,000	-110,880	+1,424,150	-105,000	1,403,150	-701,575	722,575
20	1,780,160	-84,000	101,640	+1,594,520	-105,000	1,573,520	-786,760	807,760
21	1,952,770	-84,000	-92,400	+1,776,370	-105,000	1,755,370	-877,685	898,685
22	2,145,470	-84,000	-83,160	+1,978,310	-105,000	1,957,310	-978,655	999,655
23	2,300,860	-84,000	-73,920	+2,142,940	-105,000	2,121,940	-1,060,970	1,081,970
24	2,575,150	-84,000	-64,680	+2,426,470	-105,000	2,405,470	-1,202,735	1,223,735
25	2,824,430	-84,000	-55,440	+2,684,990	-105,000	2,663,900	-1,331,995	1,352,995
26	3,089,810	-84,000	-46,200	+2,999,610	-105,000	2,978,610	-1,489,305	1,459,315
27	3,384,490	-84,000	-36,960	3,261,530	-105,000	3,242,530	-1,621,265	1,642,265
28	3,704,290	-84,000	-27,720	3,592,570	-105,000	3,571,570	-1,785,785	1,806,785
29	4,051,070	-84,000	-18,480	3,949,490	-105,000	3,928,490	-1,964,245	1,985,245
30	4,428,350	-84,000	-19,240	4,335,110	-105,000	4,274,110	-2,137,055	2,198,055

Table 4-4

PRESENT WORTH ANALYSIS

Year	Cash Flow After Taxes	PWF @ 25%	PW
0			-630,000
1	-56,560	0.8000	-45,249
2	-39,230	0.6400	-25,107
3	-16,160	0.5120	-8,274
4	+895	0.4096	+366
5	35,515	0.3277	11,638
6	64,325	0.2621	16,859
7	94,365	0.2097	19,788
8	127,275	0.1678	21,358
9	162,850	0.1342	21,854
10	201,500	0.1074	21,641
11	243,020	0.0859	20,875
12	287,205	0.0687	19,731
13	336,925	0.0550	18,531
14	388,285	0.0440	17,085
15	445,180	0.0352	15,670
16	506,380	0.0281	14,293
17	615,320	0.0225	13,845
18	644,360	0.0180	11,598
19	722,575	0.0144	10,405
20	807,760	0.0115	9,289
21	898,685	0.0092	8,268
22	999,655	0.0074	7,397
23	1,081,970	0.0059	6,384
24	1,223,735	0.0047	5,752
25	1,352,995	0.0038	5,141
26	1,459,315	0.0030	4,378
27	1,642,265	0.0024	3,941
28	1,806,785	0.0019	3,433
29	1,985,245	0.0015	2,978
30	2,198,055	0.0012	2,638
			-$376,408

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SECTION 5

THE GEOTHERMAL RESOURCE

5.1 INTRODUCTION

5.1.1 Purpose and Scope

The purpose of this study was to investigate the potential availability of geothermal energy resources for economic utilization at Union Carbide-Metals Division's Pine Creek Tungsten Mine and Mill. This report is a preliminary answer to the question of whether a low temperature geothermal resource exists at the Pine Creek Mine based on surface observations alone to decide whether drilling should be recommended.

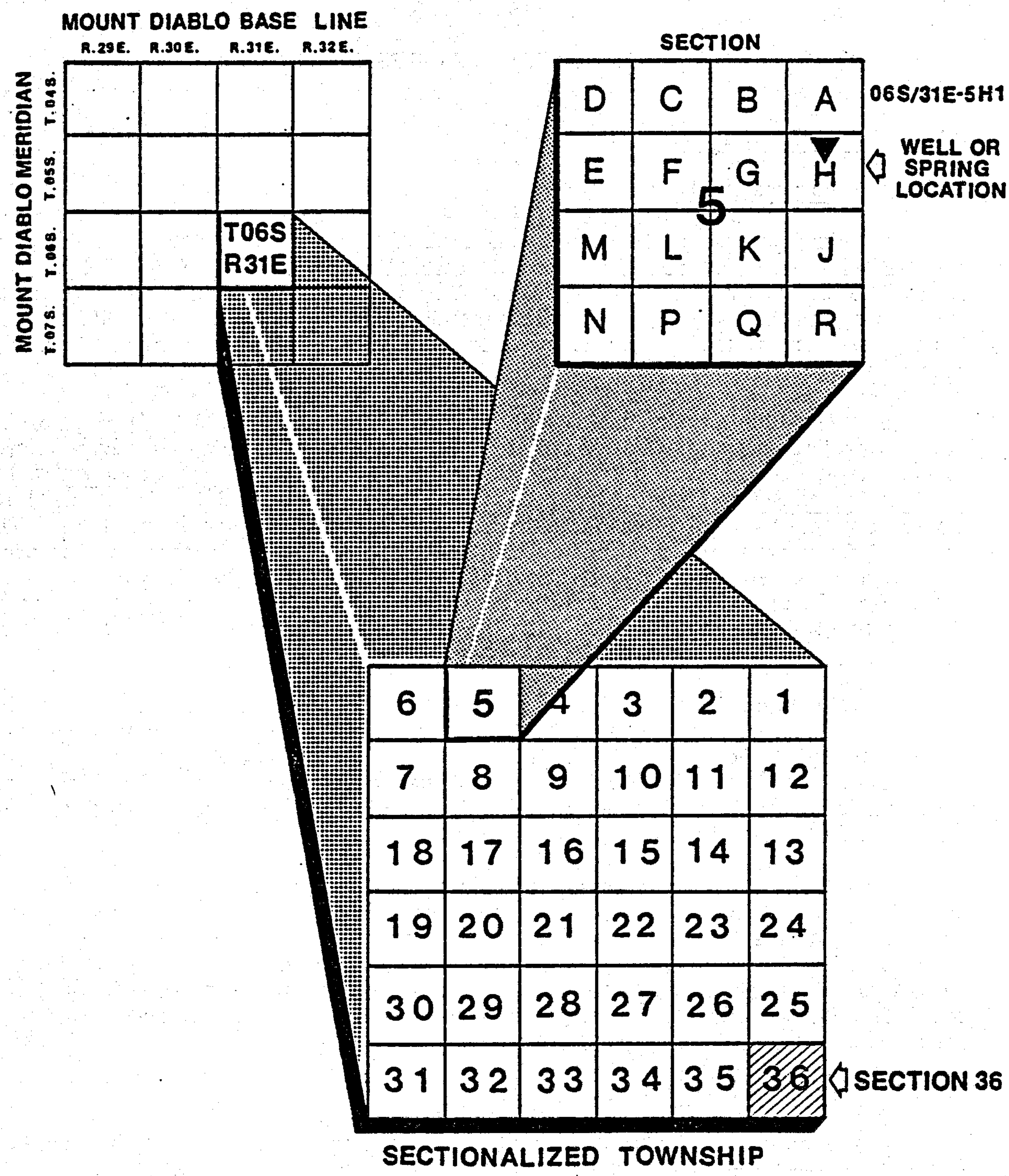
The Pine Creek Mine is located about 20 kilometers (12.4 mi) south of the Mono-Long Valley Known Geothermal Resource Area in an area designated as a prospective geothermal resource area on the Map of Geothermal Energy Resources of the Western United States prepared by the National Geophysical and Solar Terrestrial Data Center for the National Oceanographic and Atmospheric Administration (1977). The potential for geothermal resources occuring at the mine was encouraged by the presence of a relatively warm water spring inside the mine. The area in which the mine occurs was not classified as a potential geothermal resource area in a later edition of the aforementioned map published with U.S. Geological Survey Circular 790 (Muffler, 1979).

Chemical analyses of groundwater from the vicinity of the Pine Creek Mine were obtained from the available literature and from the files of public agencies. These data and the locations of springs shown on the U.S. Geological Survey Mount Tom and Casa Diablo Mountain 15 minute quadrangles were used to select springs where water samples could be obtained for chemical analysis. Wells were selected on the basis of location and accessibility for sampling.

Water samples were sent to various laboratories for analysis which included dissolved chemical species and oxygen and hydrogen isotopes. Interpretations are made on the basis of the chemical character and quality of the groundwaters as they affect the suitability of individual samples for use in various published geochemical geothermometers. Deuterium and oxygen-18 content were determined on select samples to check for possible heating effects, and tritium levels were determined to estimate relative ages of the various groundwater types.

5.1.2 Spring and Well Numbering System

Each spring and well encountered during the investigation was assigned a letter in order of sample collection. The locations of the wells and springs were identified by numbers according to the California State Well Numbering System. In this system wells and springs are assigned numbers which are referenced by the U.S. Public Land Survey System; a rectangular system for the subdivision of land. For example, as shown in Figure 5-1, in the number 06S/31E-5H01, the part of the number preceding the



Spring and Well Numbering System

FIGURE 5-1

virgule indicates the township (Township 06 South); the part between the virgule and the dash indicates the range (Range 31 East); the number between the dash and the letter indicates the section (Section 05); and the letter indicates the 16.2 hectare (40-acre) tract within the section.

Within the 16.2 hectare (40-acre) tract wells are numbered serially, as indicated by the final digit. Thus, well 06S/31E-5H01 is the first well to be listed in the SE¼:NE¼:Sec. 5, T6S, R31E, Mount Diablo baseline and meridian. Springs are numbered similarly except that an S is placed between the 16.2 hectare (40-acre) tract letter and the final digit, as shown in the following spring number: 07S/30E-9QS01.

5.2 GEOLOGIC SETTING

5.2.1 Location and General Features

Pine Creek is in east-central California, in northern Inyo County, about 27 kilometers (16.8 mi) west of Bishop (Figure 5-2). Elevation at the main adit of the mine is approximately 2469 meters (8100 ft) above mean sea level. The mine is high on the eastern slope of the Sierra Nevada mountains near the head of the alluvium filled glaciated canyon of Pine Creek which opens outward about 11 kilometers (6.8 mi) northeast of the mine into Round Valley, a northwestern extension of the Owens Valley. The last three kilometers (1.9 mi) of the canyon are formed by lateral moraines which extend outward from the shear granitic walls of the canyon.

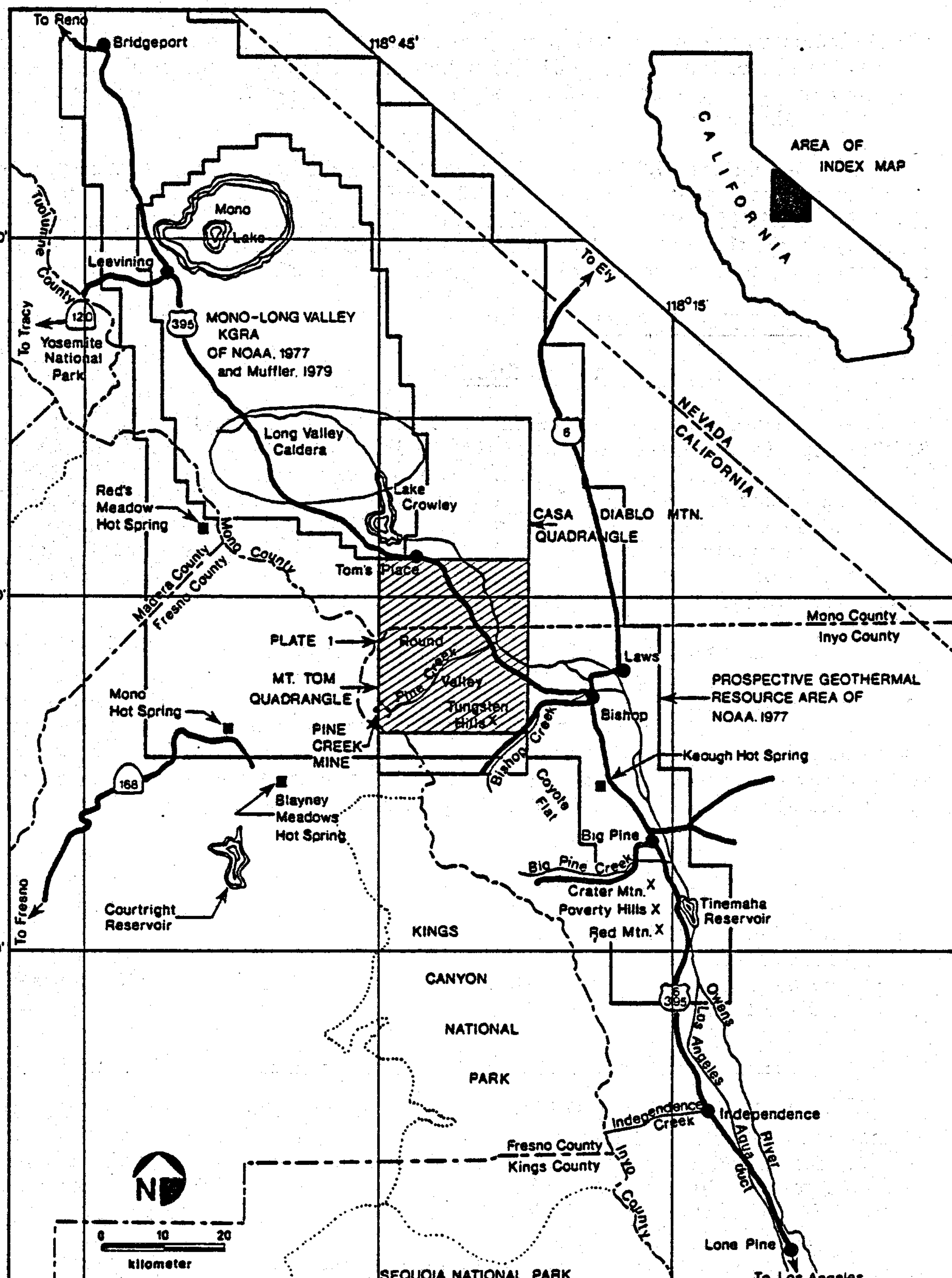
From the myriad of lithologic units recognized in the area by Bateman (1965) four groupings of units are considered to be relevant to this investigation. The pertinent units are all a grouping of granitic, metamorphic and other basement rocks into pre-Quaternary basement rocks which form the Wheeler Crest, Mount Tom, the Tungsten Hills, and other topographic high areas in the Sierra Nevada portion of the study area. Individual lithologic units in the basement rocks are retained for certain springs and when discussing a model of the geothermal resource.

Glacial and alluvial units are grouped into Quaternary sediments and make up the bulk of the central portion of the study area in Round Valley as well as scattered other portions of the study area. Two volcanic units are significant to this study: the Pleistocene Bishop Tuff in the northeastern quarter of the study area and late Tertiary or early Pleistocene basalt in the Tunsgsten Hills. The distribution of these units in the vicinity of the Pine Creek Mine is shown in Plate 1. The sources of the geologic data shown on Plate 1 are identified on Figure 5-3.

5.2.2 Geophysical Measurements in the Vicinity of the Pine Creek Mine

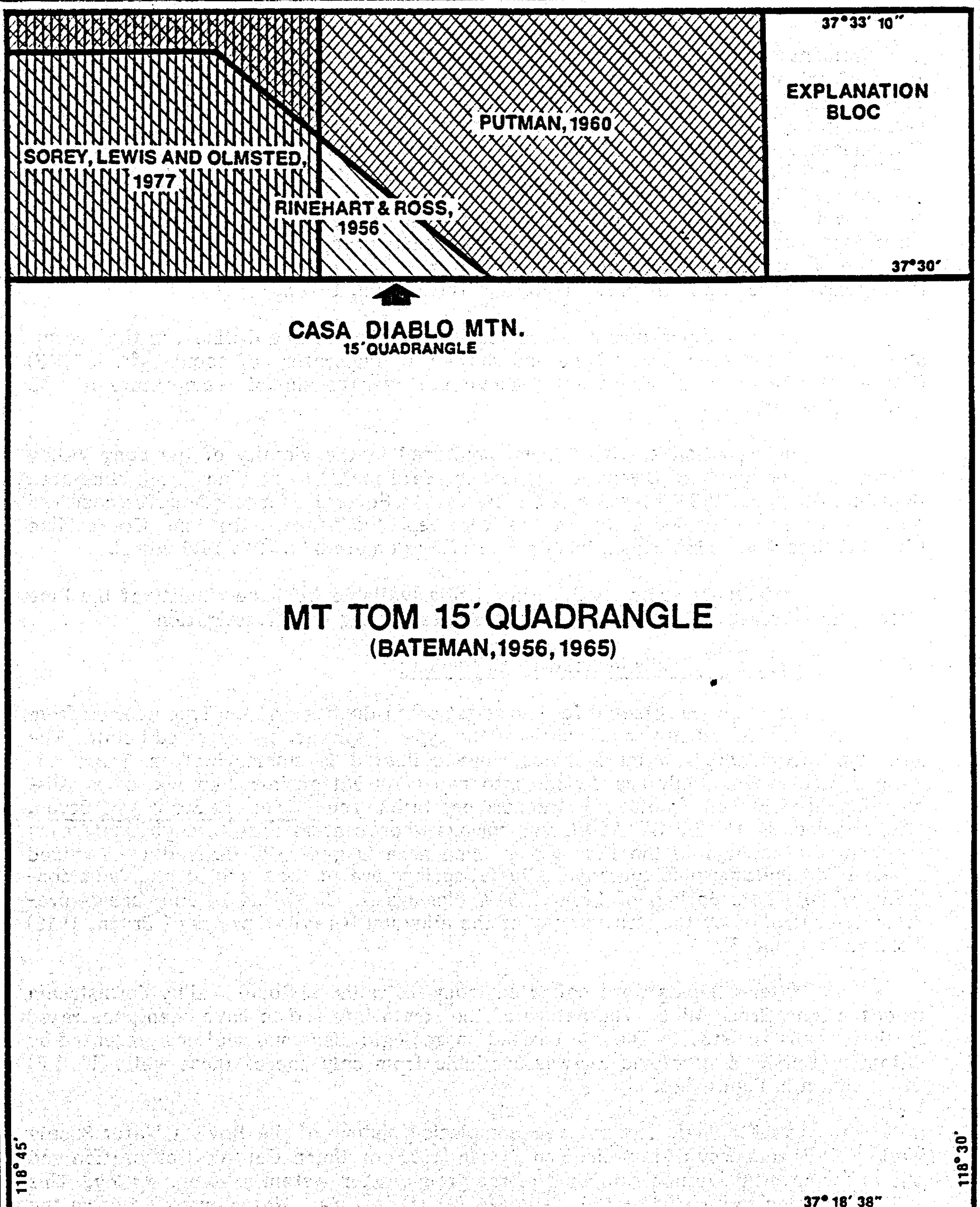
Pakiser, et al. (1964) and Pakiser and Kane (1965) presented a gravity map of the northern Owens Valley area which included Round Valley. A gravity low was reported for the volcanic tableland east of Round Valley which was shown to diminish westward toward Round Valley. The authors interpreted the data to mean that the Bishop Tuff extended into the alluvium of Round Valley at shallow depth.

Several heat flow measurements have been attempted inside the Pine Creek Mine by the U.S. Geological Survey but were unsuccessful (Posner, 1979). A heat flow



Map showing the location of the Pine Creek Mine Area.

FIGURE 5-2



Source of Geologic Data Shown on Plate 1

FIGURE 5-3

measurement about 35 kilometers (21.7 mi) southwest of the mine (drillhole HC, near Helms Creek at Courtright Reservoir) was reported by Lachenbruch (1968) as 1.30 Heat Flow Units (HFU) (1.30 μcal $cm^{-2}s^{-1}$; 0.054 Wm^{-2}; 0.017 Btu ft^{-2} hr^{-1}) and a geothermal gradient of 17.2°C per kilometer (49.8° F/mi) of depth was reported. Two heat flow measurements of .93 HFU (.93μ cal cm^{-2} sec^{-1}; 0.039 Wm^{-2}; 0.012 Btu ft^{-2} Hr^{-1}) and 1.27 HFU (1.27μ cal cm^{-2} sec^{-1}; .053 Wm^{-2}; .017 Btu ft^{-2} hr^{-1}) were reported by Lachenbruch, et al., (1976) for the east and west sides of the Tungsten Hills, respectively, which are about 10 kilometers (6.2 mi) east of the mine. These heat flow measurements were reported to indicate a geothermal gradient of 15.1°C per kilometer (43.7° F/mi) of depth. Each of these geothermal gradients is lower than the typical global valve of 25°C per kilometer (72.4° F/mi) (Gouguel, 1976).

A rock temperature measurement has been made in a drillhole in the Brownstone adit of the Pine Creek Mine and showed a temperature of about 14°C (57.2°F) (Posner, 1979) which is significantly above the average annual temperature of 4°C (39.2°F) (Brewer, 1979).

Microearthquakes have been monitored in the vicinity of the Long Valley Caldera and the northern Owens Valley and the data includes the Pine Creek Mine area (Pitt and Steeples, 1968; Steeples and Pitt, 1976). Several microearthquakes occurred beneath Round Valley and a few events were reported beneath the Pine Creek Mine (Pitt and Steeples, 1968), at depths of 6.5 to 17.5 kilometers (4.04 to 10.9 miles).

No further geophysical information is available from the vicinity of the Pine Creek Mine (Posner, 1979) and none was attempted during this investigation.

5.2.3 Springs and Wells in Relation to Geology

Springs were selected for investigation on the basis of the type of rock from which they discharged and on the basis of the type of springs, as described below. The rock type from which water samples were collected is summarized in Table 5-1. Springs used in this study are divided into two main categories: bedrock springs discharging directly from fractures in the hard crystalline rock (Fracture Springs of Bryan, 1919) (Springs B, C, and D) and alluvial springs whose waters arise through Quaternary sediments. Alluvium in the Pine Creek Mine area is generally derived from mixed granitic and metamorphic sources. Alluvial springs are further divided into fault controlled (Fault Dam Springs of Bryan, 1919) (Springs A, G, K, and L) and springs presumably controlled by the stratigraphy of the alluvium (Gravity Springs of Bryan, 1919) (Springs E, J, and P).

Water samples were collected from six wells in Round Valley downstream from the Pine Creek Mine. The nature of the strata inferred to have been penetrated by these wells is listed in Table 5-1 based on geologic maps and sections presented by Bateman (1965). A lithologic log was available from only one of these wells (Well F) and is shown in Figure 5-4.

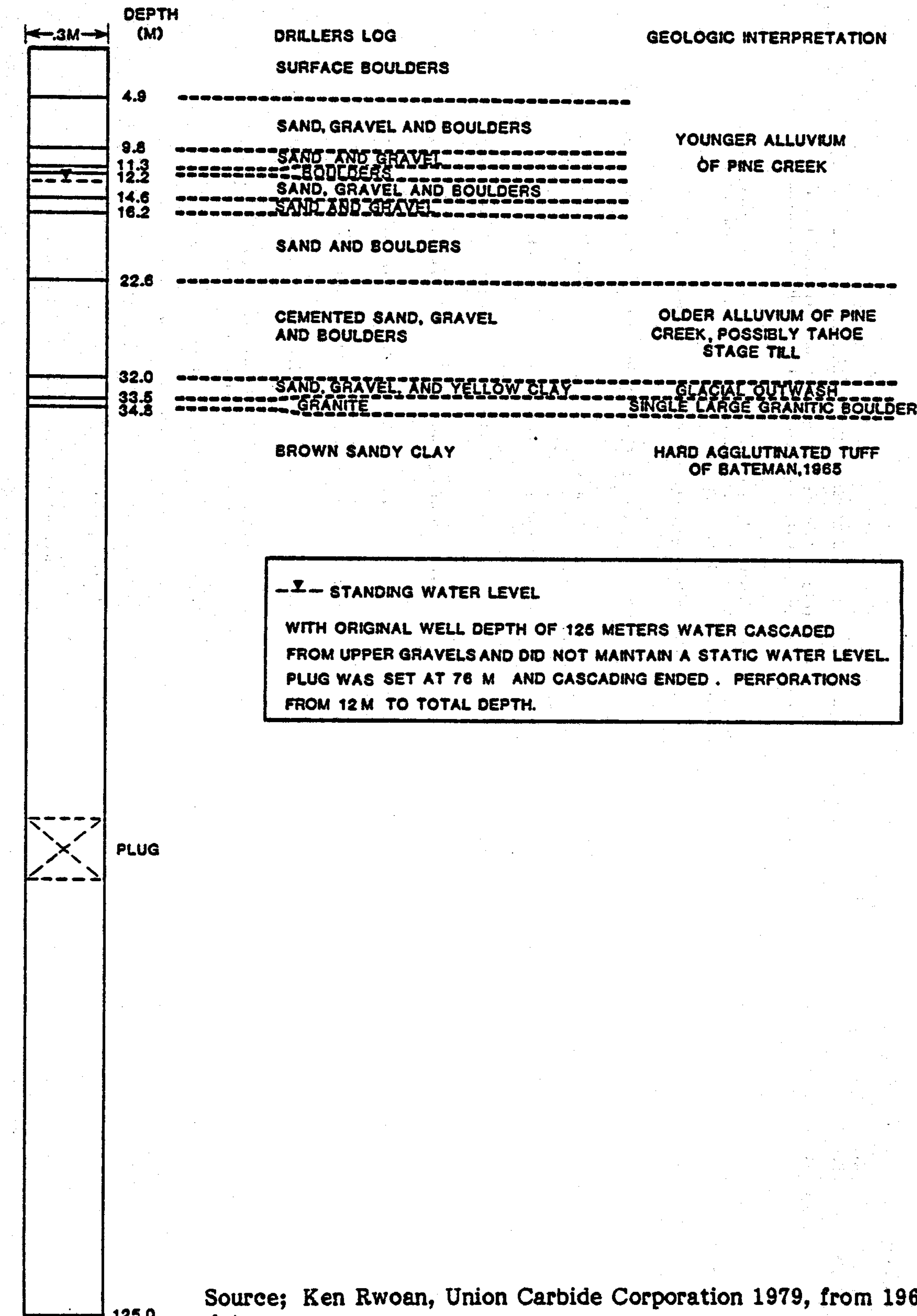
The lithologic log and well completion history of the Rovana Water Supply Well (Well F) was provided by Mr. Ken Rwoan (1979) of Union Carbide Corporation and allows for an intuitive understanding of the groundwater system in Round Valley. This well was drilled to a depth of 125 meters (410.1 ft) in 1964. Water cascaded down the

Table 5-1

LOCATION, NAME, AND GEOLOGICAL RELATIONS OF SPRINGS AND WELLS UTILIZED FOR THIS INVESTIGATION

Spring or Well Letter	Location of Well or Spring	Name of Well or Spring	Geology of Spring or Well
A	06S/31E - 31RS1	"Basco" Spring	Sierran frontal spring. Discharges along short fault in alluvial fan about 0.8 km from base of mountain. Alluvium derived from granitic and metamorphic rock.
B	07S/30E - 8CS1	Easy Going Warm Spring	Discharges from fracture through drill holes from marble in underground workings. This is one of several drillholes which discharge warm water in this portion of the mine. Location 524 m from portal.
C	06S/30E - 31RS1	Easy Going Cold Spring	Discharges from fractures in marble in underground workings. Location 2.4 km from portal.
D	07S/30E - 9QS1	Gable Creek Spring	Discharges from fractures in granitic rock beneath shallow colluvium on steep west-facing slope of Gable Creek Canyon.
E	07S/30E - 8AS1	Mill Spring	Discharges from granitic rock derived alluvium on floor of Pine Creek Canyon below the Pine Creek Mine mill.
F	06S/31E - 19G1	Rovana Water Supply Well	125 Meter deep well penetrating alluvium, alluvial fan deposits, and Bishop Tuff (Figure 5-4).
G	06S/30E - 26CS1	Rovana Water Supply Spring	Discharges from Tioga stage moraine of Pine Creek at contact with valley floor alluvium.
H	06S/31E - 21E1	Round Valley School Well	Well, depth uncertain, penetrating alluvium, alluvial fan deposits and possibly Bishop Tuff.[1]
I	06S/31E - 27Q1	CCC Well	61 meter deep well penetrating alluvial fan deposits and possibly other deposits.[1]
J	05S/30E - 31NS1	Mile Post 333.5 Spring	Discharges from beneath ridge crest in Tioga moraine of Rock Creek Canyon.
K	05S/30E - 26HS1	Ainsley Spring	Sierran frontal spring. Discharges from beneath granitic talus at contact with alluvial fan.
L	06S/30E - 1LS1	Wells Meadow, main spring	Sierran frontal spring. Discharges along short fault in granitic alluvium parallel with sierran frontal fault and approximately 200 meters from base of mountain.
M	06S/31E - 17B1	C-Bar-O Ranch Well (40 acres)	25 meter deep well penetrating alluvial fan deposits of granitic composition.[1]
N	06S/31E - 5H1	North Schober Well	38 meter deep well penetrating shallow (<3m) alluvium and Bishop Tuff.
O	06S/31E - 22B1	South Schober Well	40± meter deep well penetrating alluvium and possibly Bishop Tuff.
P	07S/31E - 20GS1	Buttermilk Spring	Discharges from between boulders in alluvial fan deposits derived from granitic terrane.
Q	08S/33E - 17FS1	Keough Hot Springs	Discharge from fractures in granitic rocks through cement lined basins.
R	07S/30E - 8 (creek)	Pine Creek Surface Flow	

[1] Well log was not available for examination.



Source; Ken Rwoan, Union Carbide Corporation 1979, from 1964 file data.

Drillers Log and Interpretation of Rovana Water Supply Well (Well F)

FIGURE 5-4

wellbore and failed to maintain a water level sufficiently high to allow pumping from a pump set at about 45 meters (147.6 ft). An airlift system was capable of sustaining 132 liters per minute (34.87 gal min^{-1}) from near total depth. The wellbore was later plugged at about 76 meters (249.4 ft) depth which allowed standing water level to rise to 12.8 meters (42.0 ft) below the surface and allow sustained pumping of about 208 liters per minute (54.95 gal min^{-1}). The cascading water in this well suggests a two tier groundwater system separated by an unsaturated interval in the Bishop Tuff for at least the western portion of Round Valley. Sulfate and tritium concentrations discussed later suggest a fairly rapid rate of groundwater movement through the upper aquifer.

5.3 HYDROGEOCHEMISTRY

5.3.1 Field and Laboratory Analysis

The groundwater of the vicinity of the Pine Creek Mine contains a variety of chemical species in solution at low concentrations. Knowledge of the chemical types and concentrations is useful in interpreting patterns of groundwater movement, source of the water, and for screening samples for further interpretations.

As part of this study, samples for chemical and isotope analysis were collected in December 1979 from 17 springs and wells. Table 5-3 gives the results of the chemical analysis made for this study. The concentration of certain dissolved constitutents may change between the time of field collection and the time of laboratory analysis owing to loss of gases, temperature changes, and precipitation of solids. Certain analyses were made in the field and parts of the samples were treated before analysis.

Due to the unimproved condition of most of the springs encountered during this investigation and occasionally the precipitious conditions under which the springs occur few attempts were made to measure the flow. However, estimates of the flow rate were made based on the field personnel's experience and on approximate measurements (Table 5-2).

Temperature of the spring waters were measured to the nearest 0.1°C (0.18°F) as close to spring orifice as possible and the temperature of the well water was measured as close to the wellhead as possible. These data are listed in Table 5-2.

Silica was measured in the field with a HACH Chemical Company field test kit, as were several other constituents. The only field analysis reported herein is silica and these values were adjusted as explained in Section 5.4.5, below. All other field determinations were abandoned because of inaccuracies introduced through severe environmental conditions encountered during the field investigation.

A separate bottle of each sample was acidified at the time of collection and taken to the laboratory for analysis for aluminum (Al), iron (Fe), manganese (Mn), zinc (Zn), calcium (Ca), magnesium (Mg), and strontium (Sr). Analysis for these seven cations, as well as for sodium (Na), potassium (K), and lithium (Li) were made by atomic absorption spectroscopy. Analyses were conducted by Environmental Engineering Laboratory in San Diego, California. (In this section and those that follow, superscripts showing the ionic charge of dissolved species are not shown.)

Table 5-2

ESTIMATED FLOW RATES OF SPRINGS AND GROUNDWATER TEMPERATURE IN THE VICINITY OF THE PINE CREEK MINE

Well Flow or Spring Letter	Estimate Flow Rate (liters/min.)	Temperature °C
A	200	12.3
B	75 (spring system)	19.9
C	200	7.6
D	40	13.4
E	100	8.3
F	—	12.7
G	56.8 (measured)	13.4
H	—	12.9
I	—	15.0
J	20	5.6
K	80	13.9
L	150	11.3
M	—	11.6
N	—	10.7
O	—	9.0
P	150	11.8
Q	>2,000[1]	51.4

[1] Mariner, et al., 1977.

Table 5-3

CHEMICAL ANALYSIS OF WATER FROM THE VICINITY OF THE PINE CREEK MINE AS DETERMINED DURING THIS INVESTIGATION[1]

(results in milligrams per liter, except as indicated)

WELL OR SPRING LETTER (Plate I)	LOCATION OF WELL OR SPRING (Plate I)	NAME OF WELL OR SPRING	DATE OF COLLECTION	WATER TEMPERATURES (°C)	SILICA (SiO_2) (adjusted as per Table 5-8)	ALUMINUM (Al)	TOTAL IRON (Fe)	TOTAL MANGANESE (Mn)	ZINC (Zn)	CALCIUM (Ca)	MAGNESIUM (Mg)	STRONTIUM (Sr)	BARIUM (Ba)	LITHIUM (Li)	SODIUM (Na)	POTASSIUM (K)	AMMONIUM as NH_4	BICARBONATE (HCO_3) (laboratory)	BORON (B)	SULFATE (SO_4)	CHLORIDE (Cl)	FLUORIDE (F)	NITRATE (NO_3)	ORTHOPHOSPHATE (PO_4)	DISSOLVED SOLIDS: RESIDUE ON EVAPORATION AT 180C	DISSOLVED SOLIDS: SUM OF CONSTITUENTS	pH (units) (laboratory)
A	06S/31E - 31RS1	"Basco" Spring	12-9-79	12.3	17.3	<0.3	<0.01	<0.01	<0.01	9.9	0.3	<0.1	<0.1	0.005	8.0	1.6	0.09	37		7.0	3.0	0.74	1.5	0.28	28	87	7.13
B	07S/30E - 8CS1	Easy Going Warm Spring	12-10-79	19.9	15.2	<0.3	<0.01	<0.01	<0.01	4.0	0	<0.1	<0.1	0.012	9.0	0.4	0.12	27		3.6	2.5	0.79	2.1	0	10	65	8.70
C	06S/30E - 31RS1	Easy Going Cold Spring	12-10-79	7.6	10.1	<0.3	<0.01	<0.01	<0.01	7.1	0.8	<0.1	<0.1	0.008	6.0	0.6	0.12	23		4.5	3.0	0.23	0.93	0.06	10	56	8.52
D	07S/30E - 9QS1	Gable Creek Spring	12-11-79	13.4	13.9	<0.3	0.23	<0.01	<0.01	12	0.8	<0.1	<0.1	0.015	9	0.8	0.21	31		13	2.8	1.2	0.35	0.02	52	85	7.45
E	07S/30E - 8AS1	Mill Spring	12-12-79	8.3	11.8	<0.3	0.07	<0.10	<0.01	6.9	1.6	<0.1	<0.1	0.006	26	0.7	0.21	34		40	3.0	0.97	0.18	0.04	72	125	6.74
F	06S/31E - 19G1	Rovena Water Supply Well	12-12-79	12.7	15.0	<0.3	<0.01	0.01	<0.01	17	0.91	<0.1	<0.1	0.004	46	2.5	0.12	48	.062	93	5.0[2]	0.80	0.93	0.02	152	229	6.59
G	06S/30E - 26CS1	Rovena Water Supply Spring	12-12-79	13.4	12.8	<0.3	<0.01	<0.01	<0.01	8.4	0.49	<0.1	<0.1	0.003	9	1.6	0.13	35		7.8	2.0	0.18	1.1	0.01	32	79	7.22
H	06S/31E - 21E1	Round Valley School Well	12-13-79	12.9	16.2	<0.3	0.08	<0.01	0.03	23	1.3	<0.1	<0.1	0.006	42	3.1	0.14	62		73	5.0[2]	0.54	0.71	0.08	192	227	6.55
I	06S/31E - 27Q1	CCC Well	12-13-79	15.0	21.1	<0.3	3.0	0.09	<0.01	10	1.8	<0.1	<0.1	0.003	8	1.7	0.13	50		4.1	2.0	0.48	0.84	0.01	97	103	6.71
J	05S/30E - 31NS1	Mile Post 333.5 Spring	12-14-79	5.6	16.2	<0.3	<0.01	<0.01	<0.01	5.4	0.61	<0.1	<0.1	0.002	3.0	1.4	0.08	21		2.9	1.5	0.46	0.04	0.01	16	53	6.64
K	05S/30E - 26HS1	Ainsley Spring	12-15-79	13.9	14.7	<0.3	<0.01	<0.01	<0.01	9.6	0.62	<0.1	<0.1	0.005	8	1.4	0.10	41	.037	3.3	2.0	0.86	1.0	0.02	36	83	7.39
L	06S/30E - 1LS1	Wells Meadow Main Spring	12-15-79	11.3	14.1	<0.3	<0.01	<0.01	<0.01	9.8	0.61	<0.1	<0.1	0.003	6.5	1.6	0.21	36	.067	3.3	2.0	0.19	0.93	0.02	20	75	7.23
M	06S/31E - 17B1	C-Bar-O Ranch Well (40 acres)	12-15-79	11.6	15.0	<0.3	1.7	<0.01	0.13	18	1.1	<0.1	<0.1	0.005	52	2.6	0.07	45	.064	115	5.7	0.50	1.9	0.05	248	259	6.41
N	06S/31E - 5H1	North Schober Well	12-16-79	10.7	42.1	<0.3	<0.01	<0.01	0.41	9.6	0.86	<0.1	<0.1	0.013	15	2.2	0.05	54	.014	9.1	3.0	0.59	1.5	0.06	80	139	7.25
O	06S/31E - 22B1	South Schober Well	12-16-79	9.0	17.7	<0.3	0.04	<0.01	0.07	46	3.7	<0.1	<0.1	0.005	24	2.2	0.05	89	.062	91	12[3]	0.32	0.80	0	212	287	7.05
P	07S/31E - 20GS1	Buttermilk Spring	12-17-79	11.8	20.4	<0.3	0.04	<0.01	<0.01	18	2.3	<0.1	<0.1	0.004	11	2.5	0.07	66	.037	15	4.0	0.24	1.8	0	—[3]	141	6.81
Q	08S/33E - 17FS1	Keough Hot Springs	12-18-79	51.4	27.4	<0.3	<0.01	<0.01	0.07	8.8	0.02	<0.1	<0.1	0.480	159	3.0	0.04	36	.44	69	187	6.2	0.84	0	514	498	8.71
R	07S/30E - 8 creek	Pine Creek Surface Flow	12-18-79	—	10.5	<0.3	0.03	<0.01	<0.01	7.1	0.20	<0.1	<0.1	0.008	9.0	0.7	0.05	38	.048	12	2.5	1.2	2.2	0	80	84	7.28

[1]Analysis conducted by Environmental Engineering Laboratory, 3538 Hancock Street, San Diego, California, 92138

[2]Probably chlorinated.

[3]Insufficient sample.

[4]Not measured - about 0°C.

[5]Collected from a polyvinylchloride pipe.

The precision of all analysis is estimated to be plus or minus one-half of the last reported digit. That is, a reported 6.9 mg/l implies a concentration of between 6.85 and 6.95 mg/L. A reported analysis of 0 mg/l indicates that analysis was made for that constituent but the constituent was not found in concentrations greater than the detection limit. For certain ions the detection limit is listed.

5.3.2 Quality of the Groundwater

The chemical analyses made during this investigation are given in Table 5-3 and are arranged in order of sample collection. In addition to the analysis conducted as a part of this investigation, water quality analyses from several springs and wells in the vicinity of the Pine Creek Mine are available in the published literature and from the files of the California Department of Water Resources, southern district. Table 5-4 lists the available analysis. The sampled locations listed in both Tables 5-3 and 5-4 are shown in Plate 1.

The general chemical character of the sampled groundwater from the vicinity of the Pine Creek Mine is fresh sodium-chloride water and is shown diagrammatically in Figure 5-5. This diagram is the combined field of a trilinear diagram similar to that of Piper (1944). Also shown on Figure 5-5 are water quality data from cold and hot springs and wells in the Long Valley Caldera to the north of the Pine Creek Mine, Red's Meadow Hot Springs adjacent to the Devil's Postpile National Monument, Keough Hot Springs 13 km (8.1 mi) south of Bishop, and Mono Hot Springs and Blayney Meadows Hot Springs, 29 km (18 mi) west and 24 km (14.9 mi) southwest of the mine, respectively, near the terminus of California State Highway 168 (Figure 5-2). These data were taken from sources shown on the figure. The locations from which these later data were derived are listed in Table 5-5. Mole ratios of several major and minor constituents from groundwater investigated during this study are listed in Table 5-6 for the groundwaters listed in Table 5-3.

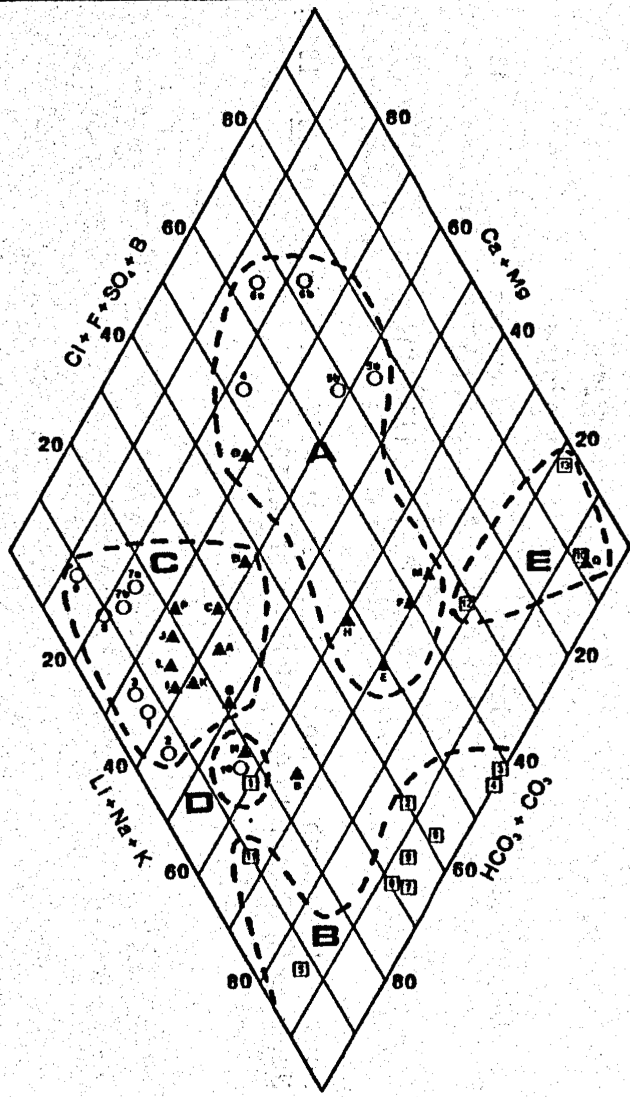
Lithologic control of the general chemical character of the groundwater in the study area was previously alluded to and is shown in Figure 5-5. Sample clustering on this figure indicates a definite separation in the chemical character of groundwater from volcanic rock aquifers (Long Valley Caldera and Red's Meadows Hot Springs) and basement rock (and basement rock derived alluvium) aquifers. Groundwater from alluvial aquifers derived from mixed basement rock and volcanic rock sources cluster between the chemical character fields for the two primary sources. A large number of additional samples would probably obscure these relationships. Groundwater Sample B from the warm spring group in a drift of the Easy Going adit at the Pine Creek Mine also plots between the groundwaters derived from granitic and volcanic rocks. Sample B was collected from an area of marble and quartz monzonite as was Sample C, a cold spring farther into the Easy Going adit. The higher percentage of Li+Na+K relative to Ca+Mg for the warm spring is thought to be a consequence of increased water-rock reaction due to the slight heating of the warm water or possibly through mixing of considerably hotter water with the local cold water. Keough Hot Springs (Q and 10 on Figure 5-5), Mono Hot Springs (12), and Blayney Meadows Hot Springs (13) plot in a position considerably removed from the granitic rock source field, possibly due to increased rock-water reaction at the higher temperature.

Table 5-4

GROUNDWATER QUALITY ANALYSIS IN THE VICINITY OF THE PINE CREEK MINE OBTAINED FROM A LITERATURE AND AGENCY SEARCH

(Exclusive of geothermal areas)

	LOCATION (date collected)	TEMP-ERA-TURE °C	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	Cl mg/l	F mg/l	HCO_3 mg/l	SO_4 mg/l	NO_3 mg/l	B mg/l	SiO_2 mg/l	TDS	pH	REF-ER-ENCE	TEMPERATURE °C Na-K-Ca Geotherm-mometer	REMARKS
1	04S/29E-36RS1 (11-8-59)	10	9.2	0.7	6.9	0.6	0.3	0.2	45	3.3	0.9	—	19	63	7.6	Feth, <u>et</u> <u>al</u>., 1964	10.7	Perennial spring along Sierra Front
2	05S/30E-14ES (11-8-59)	8.3	6.1	0.9	6.8	0.1	0.2	0.1	34	3.2	0.2	—	20	55	6.5	Feth, <u>et</u> <u>al</u>., 1964	18.2	Perennial spring along Sierra Front
3	05S/30E-26HS1 (11-8-59)	"Cold"	10.0	1.2	6.2	0.8	0.2	0.1	48	3.4	1.0	—	16	63	6.7	Feth, <u>et</u> <u>al</u>., 1964	14.9	Perennial spring along Sierra Front (same as Ainsley Spring (K))
4	06S/31E-19G1 (03-02-70)	—	62.0	6.0	23.0	3.0	7.0	0.3	48	178.0	1.8	0.00	—	343	7.4	Cal. DWR 1970	27.3	Well in Rovana
5a	06S/31E-20H1 (06-25-60)	—	29.0	2.0	27.0	2.0	16.0	0.4	26	77	3.1	0.06	11.0	284	7.4	Cal. DWR WDIS File	31.0 Ave. 29.4	Residential Well
5b	(02-09-61)	—	35.0	2.0	26.0	2.0	18.0	—	39	50	3.9	0.03	13.0	181	6.6	Cal. DWR WDIS File	27.7	
6a	06S/31E-21D1 (07-14-55)	—	39.0	3.0	9.0	3.0	14.0	0.4	33	57	1.0	0.02	—	210	7.2	Cal. DWR WDIS File	27.3 Ave. 28.8	Round Valley School Well (H)
6b	(02-09-61)	—	40.0	3.0	14.0	3.0	14.0	0.1	27	74	4.1	0.02	18.0	282	6.9	Cal. DWR WDIS File	30.4	
7a	06S/31E-22B1 (07-14-55)	—	19.0	3.0	7.0	2.0	3.0	0.4	35	11	1.5	0.00	—	140	7.4	Cal. DWR WDIS File	27.0 Ave. 19.6	Residential Well (Possibly same as South Schober Well; O)
7b	(02-08-61)	—	18.0	2.0	7.0	2.0	2.0	0.1	33	9.0	4.1	0.01	21.0	64	7.5	Cal. DWR WDIS File	12.3	
8	06S/31E-23N1 (02-09-61)	—	35.0	1.0	10.0	2.0	2.0	0.2	56	15	5.3	0.01	42.0	133	7.1	Cal. DWR WDIS File	20.0	Residential Well
9	06S/31E-26E1 (02-09-61)	—	19.0	1.0	6.0	1.0	0.0	0.0	33	5.0	0.9	0.01	30.0	74	7.1	Cal. DWR WDIS File	10.3	Residential Well
10	06S/31E-31J1 (07-14-55)	22.2	14.0	0.0	21.0	1.0	3.0	0.5	45	4.0	0.0	0.00	—	145	7.3	Cal. DWR WDIS File	24.1	Residential Well



PERCENTAGE REACTING VALUES

DATA IDENTIFICATION AND SOURCE

▲ - Groundwater Samples A through Q. This study, Table 5-3.

O - Groundwater Samples 1 through 10, Table 5-4.

□ - Groundwater Samples 1 through 9, Long Valley Caldera Cold and Hot Waters, Willey et al., 1974. Groundwater Samples 10 through 13, Sierra Nevada Hot Springs, Mariner et al., 1977, listed in Table 5-5.

SAMPLE CLUSTERING

A - Groundwater influenced by Constituents from Mill Waste from the Pine Creek Mine and Individual Chloride Sources.

B - Groundwater from Volcanic Rock.

C - Groundwater from Granitic Rock and Alluvium Derived from Granitic Rock. Some Metamorphic Rocks Present.

D - Groundwater from Mixed Granitic Rock Alluvium and Volcanic Rocks.

E - Hot Spring in Granitic Rock.

Diagram Showing General Chemical Character of Groundwater From the Vicinity of the Pine Creek Mine

FIGURE 5-5

Table 5-5

NAMES, LOCATIONS AND TEMPERATURES OF NUMBERED SPRINGS AND WELLS SHOWN ON FIGURES 5-5 and 5-6

No.	Name	Location	Temperature (°C)
1	Big Spring Campground	02S/27E-25AS1	11
2	Hot Spring, Little Hot Creek	03S/28E-13ES1	79
3	Geothermal Well Magma-Ritchie	03S/28E-32ES9	94
4	Hot Bubbling Pool	03S/28E-35ES1	60
5	Artesian Well near N.E. Rim	03S/29E-13C1	10
6	Hot Spring	03S/29E-21NS1	56
7	Hot Spring SE of Big Alkali Lake	03S/29E-28HS1	49
8	Hot Spring N of Whitmore Hot Springs	03S/29E-31AS1	58
9	Hot Spring W of Lake Crowley	03S/29E-34KS1	41
10	Keough Hot Springs	08S/33E-17FS1	51
11	Red's Meadow Hot Springs	Unsurveyed 37°37'N, 119°04'W	45.5
12	Mono Hot Springs	Unsurveyed 37°27'N, 119°01'W	43
13	Blayney Meadows Hot Springs	Unsurveyed 37°14'N, 118°52'W	43

NOTE: Numbers 1 through 9 from Willey, et al., 1974 and Sorey, et al., 1978; Numbers 10 through 13 from Mariner, et al., 1977.

5.3.3 Groundwater of Round Valley and Pine Creek Canyon

Several of the analyses given in Tables 5-3 and 5-4 are not of particular use in describing the natural chemical character of the groundwaters. The Round Valley School Well (H) and the Rovana Water Supply Well (F) were found to have chlorinators upstream from the sampling point. The South Schober Well (0) water sample was collected from a polyvinylchloride pipe and the C-BAR-0 Ranch Well (M) had been recently washed, presumably with dilute hydrochloric acid, which would also account for the water from this well having the lowest observed pH (6.41). The unnamed residential well (5) in Table 5-4 also has an anomalously high chloride content and may not be representative. The observed chloride anomaly in these waters account for a portion of the segregation of these samples into a separate chemical character grouping from the remainder of the groundwater from geologically similar sources as shown in Figure 5-5. Chloride concentrations in the aforementioned water are not sufficiently high to show up in more than one of the chloride containing molar ratios listed in Table 5-6. This ratio (SO_4/Cl) is probably influenced by the anomalous sulfate content.

Several of the groundwater samples collected from downstream of the Pine Creek Mine contain anomalous sodium and sulfate concentrations (Table 5-3: E, F, H, M, and O; Table 5-4: 4, 5, and 6). Sodium sulfate brine is a waste product produced during tungsten ore processing at the Pine Creek Mine complex. Until removal of this waste product to subsurface disposal areas at Owens Lake began in 1973, the sodium sulfate containing process water was added to the tailings stream.

Figure 5-6 shows possible contours of sulfate concentration during the early to mid-1960s (from Table 5-4) and for 1979. A migration of sulfate concentration contours toward the mouth of Pine Creek Canyon is suggested to have occurred from the early 1960s to 1979. This is believed to show a rapid rate of groundwater movement through the alluvium of Round Valley as well as a cleansing effect of trucking the sodium sulfate waste from the mine.

The Li/Na ratio (Table 5-6) of the groundwater of most samples from Round Valley show the marked influence of the abnormal sodium content introduced through milling activity. The anomalous sulfate content is masked in the SO_4/Cl ratio by the abnormal chloride mentioned above. Because of the suspect nature of the sodium content in these waters (Table 5-3: E, F, H, M, and O), cation geothermometers cannot be meaningfully applied (Section 5.4.2, below).

5.4 GEOCHEMICAL PREDICTION OF AQUIFER TEMPERATURE

5.4.1 Introduction

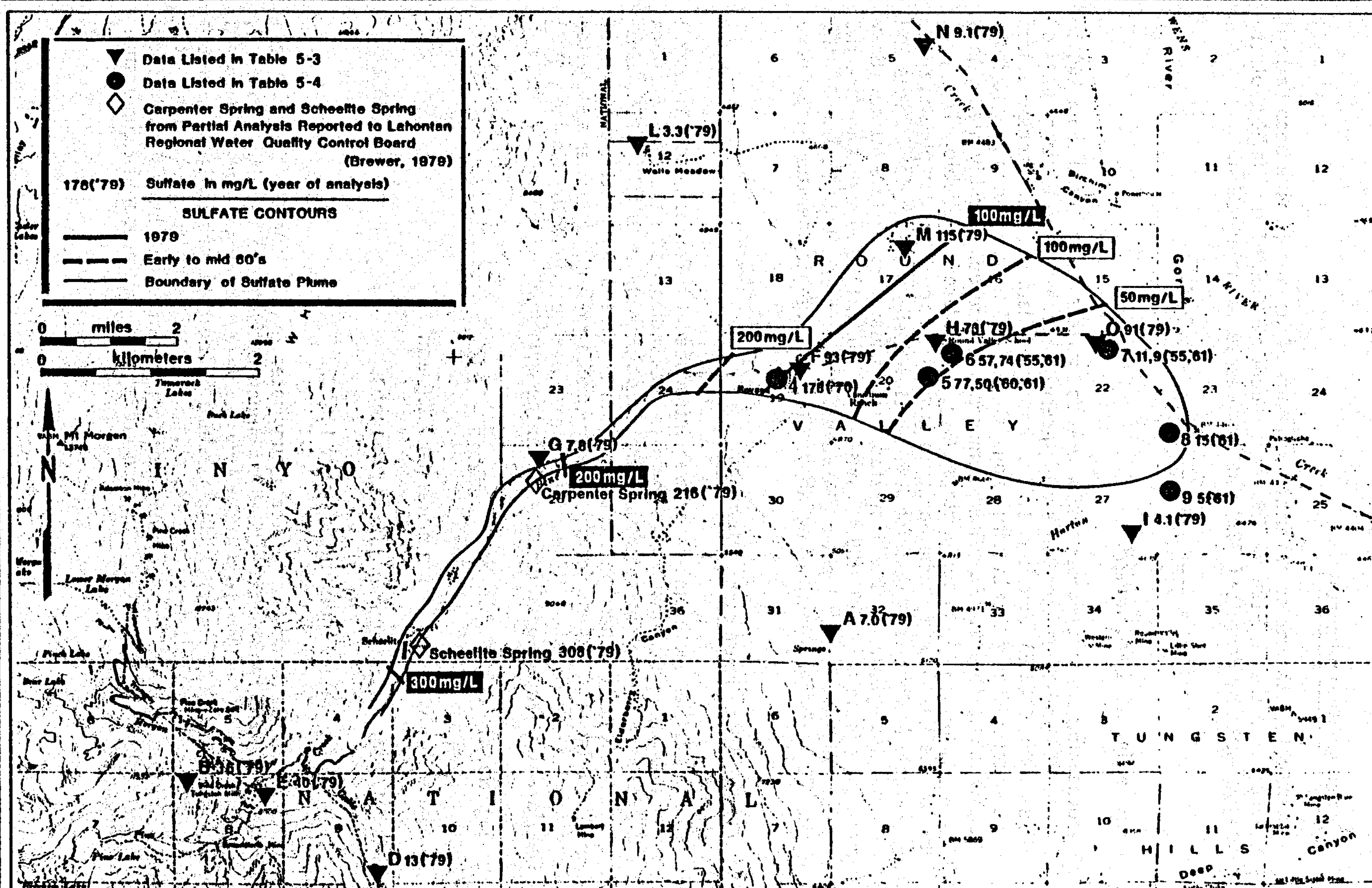
Geochemical methods of estimating the subsurface temperatures at which water-rock reactions have equilibrated have been developed by several investigators. Basic assumptions inherent in the utilization of these methodologies have been provided by Fournier, et al. (1974) and the techniques of estimating the subsurface temperature has been reviewed by Fournier and Truesdell (1974) and Fournier (1977). The subsurface temperature estimating procedures are the Na/K, the Na/K/Ca, and the silica geothermometers.

Table 5-6

MOLE RATIOS OF THE MAJOR AND MINOR CONSTITUENTS IN THE GROUNDWATERS FROM THE VICINITY OF THE PINE CREEK MINE

	$\frac{Ca}{Na}$	$\frac{Mg}{Ca}$ x10^2	$\frac{Na}{K}$	$\frac{Na}{Li}$	$\frac{Na}{Cl}$	$\frac{HCO_3}{Cl}$	$\frac{SO_4}{Cl}$	$\frac{F}{Cl}$ x10^2	$\frac{B}{Cl}$ x10^2
A	45.17	5	8.50	482.93	4.11	7.17	0.86	46	0
B	25.52	0	38.27	226.37	5.55	6.28	0.53	59	0
C	51.00	19	17.01	226.37	3.08	4.46	0.55	14	0
D	44.20	11	19.13	181.10	4.96	6.43	1.71	80	0
E	11.60	38	63.17	1307.93	13.37	6.59	4.92	60	0
F	10.30	88	31.30	3471.04	14.19	5.58	6.86	30	4.1
G	36.98	96	9.57	905.49	6.94	10.17	1.44	17	0
H	13.11	9	23.04	2112.81	12.95	7.20	5.39	20	0
I	45.39	30	8.00	804.88	6.17	14.53	0.76	45	0
J	88.95	19	3.64	452.74	3.08	8.13	0.71	57	0
K	44.48	11	9.72	482.93	6.17	11.91	0.61	80	6.1
L	55.31	10	6.91	653.96	5.01	10.46	0.61	18	11.0
M	9.37	10	34.02	3139.03	14.07	4.59	7.45	16	3.7
N	23.72	15	11.60	348.26	7.71	10.46	1.12	37	1.5
O	32.45	13	18.55	1448.78	3.08	4.31	2.80	5	1.7
P	44.29	21	7.48	830.03	4.24	9.59	1.38	11	3.0
Q	2.14	0.4	90.14	99.98	1.31	0.11	0.14	6	0.8

WESTEC Services, Inc.



Sodium Sulfite Plume in Groundwater Downstream From the Pine Creek Mine

FIGURE 5-6

5.4.2 Cation Geothermometers

Chemical geothermometers utilizing ratios of Na and K have been refined since their inception in the mid-1960s. The most recent revision of the Na/K geothermometer was presented by Fournier (1979) and is expressed by the equation:

$$T°C = \frac{1217}{\log(Na/K) = 1.483} - 273.15$$

where Na and K are in mg/l.

The Na/K geothermometer reportedly works well for waters equilibrated from 150 to 200°C (302 to 392°F) and gives anomalously high results for waters in environments of less than about 100°C (212°F) (Fournier, 1979). Table 5-7 lists the Na/K temperatures for waters encountered during this investigation. Calculated temperatures ranged from 123.8 to 322.1°C (254.8 to 611.8°F). These temperatures are considerably higher than the measured temperatures of the cold springs and are considered unreliable. The Na/K temperature for the Easy Going Warm Spring is lower than the Na/K temperature calculated for the cold springs as is that for Keough Hot Springs, Mono Hot Springs and Blayney Meadows Hot Springs. The indicated equilibrium temperature of the Easy Going Warm Spring is below 150°C (302°F) but above 100°C (212°F) and therefore the geothermometer may not be applicable. However, this suggests that heating of the waters of the Easy Going Warm Spring above its discharge temperature may have occurred.

5.4.3 Cation Geothermometers: Na/K/Ca

The Na/K/Ca geothermometer was introduced by Fournier and Truesdell (1973) to account for the anomalously high temperatures indicated by the early versions of the Na/K geothermometer for waters equilibrating below about 100°C (212°F). Corrections to the Na/K/Ca geothermometer have been suggested for partial pressure of carbon dioxide by Paces (1978) and for magnesium concentration by Fournier and Potter (1978). The applicability of the CO_2 correction has been questioned by Mariner, et al (1977). The Na/K/Ca geothermometer is based on the equation:

$$\log(Na/K) + \beta \log(\quad Ca/Na) = \frac{1647}{273.15 + T°C} - 2.24$$

where Na, K, and Ca are in moles per kilogram.

$\beta = 1/3$ for waters equilibrated above 100°C.

$\beta = 4/3$ for waters equilibrated below 100°C.

The Na/K/Ca temperatures for groundwater in the Pine Creek Mine area that have not been shown to be influenced by human activity are listed in Table 5-7. Temperatures for both $\beta = 1/3$ and $\beta = 4/3$ are given. Na/K/Ca temperatures for $\beta = 4/3$ more closely approximate the observed temperature of the cold springs than do the $\beta = 1/3$ temperatures or the Na/K temperature. The $\beta = 4/3$ temperatures ranged from 13.4 to 37.1°C (56.1 to 98.8°F) for groundwater from granitic and metamorphic rock. Figure 5-7A is a plot of the Na/K/Ca temperature against the measured temperature.

Table 5-7

MEASURED SPRING AND WELL TEMPERATURES AND ESTIMATED AQUIFER TEMPERATURES BASED ON CHEMICAL GEOTHERMOMETERS

(All temperatures in °C)

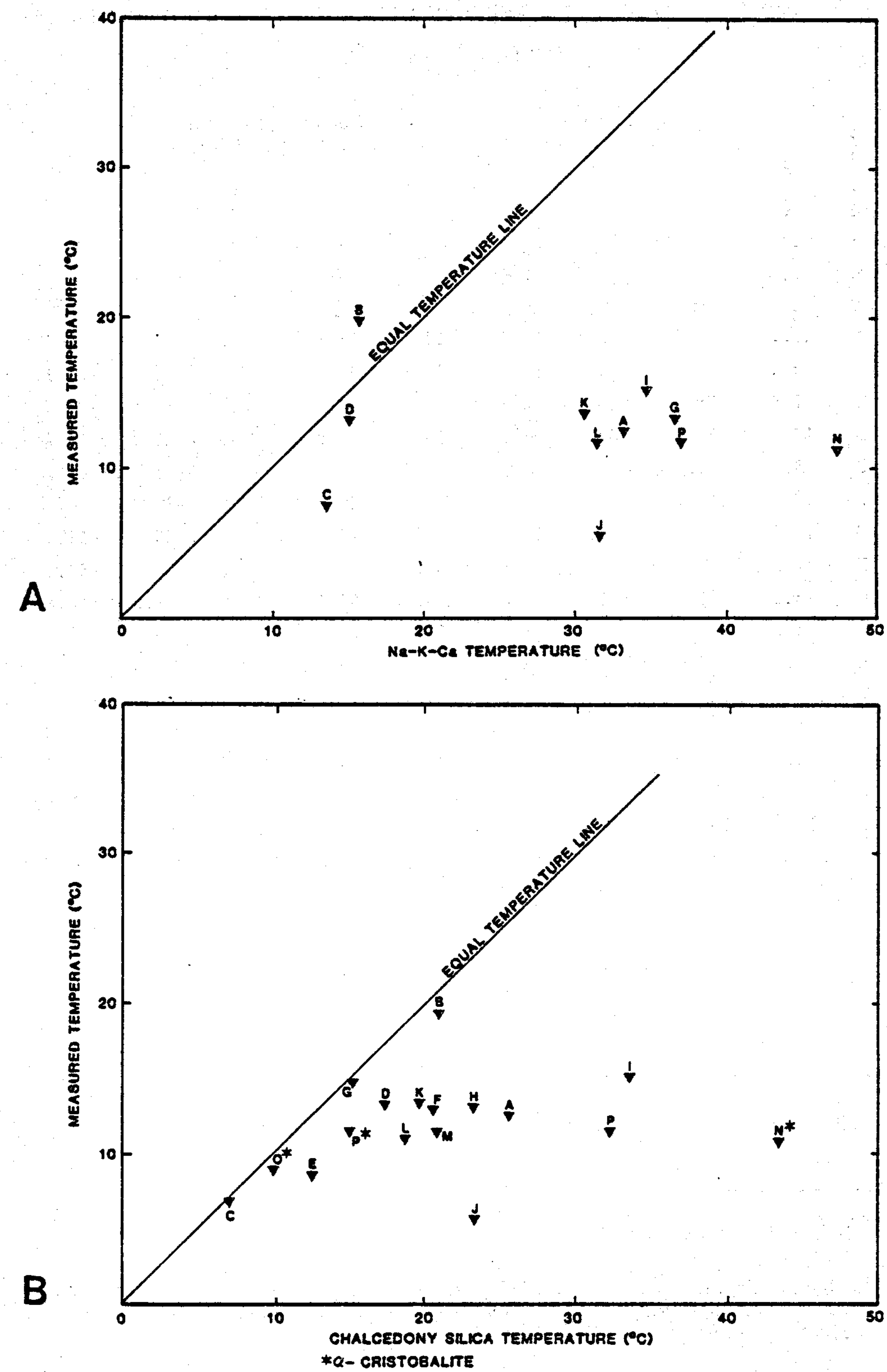
		Ion Exchange Geothermometers			Silica Geothermometers[3] (Adjusted Silica)				
Spring or Well Letter	Spring Temperature	Na-K[1]	Na-K-Ca[2] β = 1/3	Na-K-Ca[2] β = 4/3	Quartz	Chalcedony	α-Cristobalite	β-Cristobalite	Amorphous Silica
A	12.3	231.3	169.5	33.2	58.1	25.8	9.2	-34.5	-50.4
B	19.4	123.8	110.6	15.9	53.4	21.0	4.8	-38.5	-54.2
C	7.6	175.3	134.5	13.4	39.6	6.9	-8.3	-50.4	-65.2
D	13.4	167.0	131.5	15.0	50.3	17.8	1.8	-41.2	-56.7
E	8.3	N/A	N/A	N/A	44.7	12.1	-3.5	-46.0	-61.2
F	12.7	N/A	N/A	N/A	53.0	20.5	4.3	-38.9	-54.5
G	13.4	220.8	166.8	36.9	47.5	14.9	-0.9	-43.6	-59.0
H	12.9	N/A	N/A	N/A	55.7	23.4	6.9	-36.1	-52.3
I	15.0	236.8	172.5	34.6	65.5	33.5	16.2	-28.0	-44.4
J	5.6	322.1	204.1	31.8	55.7	23.4	6.9	-36.5	-52.3
K	13.9	219.4	162.9	30.4	52.3	19.8	3.7	-39.5	-55.1
L	11.3	250.9	176.8	31.7	50.8	18.3	2.3	-40.8	-56.3
M	11.6	N/A[4]	N/A	N/A	53.0	20.5	4.3	-38.9	-54.5
N	10.7	204.6	164.6	47.4	94.0	63.5	43.7	-2.5	-20.7
O	9.0	N/A	N/A	N/A	58.9	26.7	10.0	-33.7	-49.7
P	11.8	243.2	176.5	37.1	64.2	32.1	15.0	-29.1	-45.5
Q	51.4	80.9	109.4	82.1	75.7	44.2	26.0	-18.9	-36.0
No. 10[4]	51	96.9	102	75	96	52	33	—	3
No. 12[4]	45.5	155.9	130	65	161	127	105	—	66
No. 12[4]	43	130.4	122	80	110	81	62	—	26
No. 13[4]	43	121.3	110	57	102	70	52	—	17

[1] Method of Fournier, 1979.

[2] Method of Fournier and Truesdell, 1973; Magnesium correction of Fournier and Potter, 1978 not applicable and carbon dioxide deviation noted by Paces, 1975 ignored on account of Mariner et al, 1977 and low CO_2 content.

[3] Based on equations in Table 5-9 from Fournier, 1977.

[4] From Mariner, et al., 1977; 10, Keough H.S.; 11, Red's Meadow H.S.; 12, Mono H.S.; 13, Blayney Meadows H.S.



Measured Temperature Versus Na-K-Ca Temperature (A) and Chalcedony Temperature (B)

FIGURE 5-7

The only groundwater for which the calculated temperature is below the observed temperature is the Easy Going Warm Spring.

5.4.4 Explanation of Cation Geothermometer Results

The above observation suggests that either the waters issuing from the warm spring are not equilibrated with the rock at the temperature of the warm spring, or that mixing of two waters of totally different geochemical history has occurred. Cation geothermometers for Keough Hot Springs determined for this investigation agree favorably. The geothermometers applied to the data of Mariner et al. (1977) are reasonably close for Keough Hot Springs, but are considerably different for Red's Meadow Hot Springs, Mono Hot Springs, and Blayney Meadows Hot Springs (Table 5-7). This suggests that the waters of the Easy Going Warm Spring may have been heated to a temperature below that to which the waters of Keough Hot Springs were heated, but possibly to a temperature as high as that to which the other hot spring waters were heated.

The discrepancy noted between the observed temperature and the Na/K/Ca temperature of the cold groundwater could be due to a general mixing of heated water with the regional groundwater discharging as Sierra Frontal Springs or a general heating of all of the groundwater discharging from these springs. (The magnitude of the discrepancy between the cation geothermometer and measured temperature is unlikely to be accounted for by either of these hypothesis since spring J, which presumably consists of locally infiltrated groundwater discharging from a lateral moraine and has not passed through the bedrock (Bateman, 1965), is also affected.) A more likely explanation is a confirmation of the observations of Mariner, et al. (1977) that "in the Sierra Nevada, changes in the (Ca/Na) ratio (on which the geothermometer is based) may be a function of the total dissolved solids (as controlled by other phenomena) rather than the temperature of the aquifer."

5.4.5 Silica as a Basis for Estimating Aquifer Temperature

The solubility of silica minerals in water increase with an increase in temperature. Under natural conditions, silica minerals dissolve until a saturated solution is formed many times faster than they precipitate from an oversaturated solution. Thus, a groundwater will dissolve silica minerals as its temperature rises, but as the water cools it will not rapidly lose silica from solution. Because of these relations, the silica concentration of a water can be used as a measure of the maximum temperature reached by the water (Fournier and Rowe, 1966; Fournier, 1973).

The actual silica concentration of a groundwater depends on the particular silica mineral to which the groundwater is exposed, as well as the temperature and the time available in which dissolution can occur. In the fractured crystalline rock groundwater system of the Pine Creek Mine the only silica mineral which groundwater comes in contact with is quartz in the granitic and metamorphic rocks (Bateman, 1965; Posner 1979). In addition to quartz, groundwater in Round Valley downgradient from the mine comes in contact with several silica species where it is influenced by the Bishop Tuff; notably chalcedony and cristobalite (Sheridan, 1975). Low concentrations of silica in groundwater are also controlled by weathering reactions of the silicate minerals during rock decomposition (Feth, et al., 1964).

The silica concentrations of groundwater investigated during this study were determined in the field within an hour of the sample collection using a HACH Chemical Company High Range Silica Test Kit. Field analyses were performed twice and the average value was recorded in the field notes and is listed in Table 5-8. Variations in the field analysis never varied by more than 2 mg/l (except for sample N, which varied by 10 mg/l). Laboratory analysis was performed on water samples which had been stored under refrigeration for up to two months. The silica concentrations determined during laboratory analysis were consistently lower than the field determined concentration (Table 5-8). The ratio: field value/laboratory value ranged between 1.70 and 2.86 if the higher values of samples N and Q are excluded. The average ratio is 2.10. Because of the narrow range over which the field/laboratory ratio varied, the person-to-person variability of the field test method, and the reproducibility of the laboratory method, the silica concentration used for this study was adjusted by multiplying the laboratory value by the average field/laboratory ratio (Tables 5-3 and 5-8) to obtain an adjusted silica concentration. As mentioned later and in the notes to Table 5-8, this discrepancy in laboratory and field analysis may be due either to polymerization of silica or precipitation of a silica species such as chalcedony.

Figure 5-8 is a plot of the adjusted silica concentration versus the temperature of the source from which the water sample was collected. Also shown are the solubility lines for four silica minerals (quartz, chalcedony, α- and β-cristobalite) extrapolated from data presented by Fournier (1977). All of the samples are oversaturated with respect to quartz. The Easy Going Cold Spring and Keough Hot Springs were undersaturated with respect to chalcedony. The silica determination for Keough Hot Springs presented by Mariner, et al. (1977) shows this water to be oversaturated with respect to chalcedony. Except for samples C and Q, each of the other samples were also oversaturated with respect to chalcedony. Sample N (the North Schober Well) is clearly oversaturated with respect to α-cristobalite, a possible reflection of the Bishop Tuff aquifer from which it was collected. Sample P (Buttermilk Spring), from granitic rock alluvium, is slightly oversaturated with respect to α-cristobalite and may represent analytical error since only a field determination is available for this sample. Oversaturation of the samples with respect to chalcedony suggests that this species may have precipitated in the geological environment from which the samples came and could mean that this species may have precipitated during sample storage, which would account for the discrepancy between field and laboratory analysis.

5.4.6 Silica Temperatures

Measured spring or well temperature and maximum temperature calculated from the various silica species equilibrium relations are shown in Table 5-7 for the adjusted silica concentrations. Equations used to calculate silica equilibrium temperatures are given in Table 5-9. Quartz temperatures of groundwater from granitic and metamorphic rock terrain range from 39.6 to 65.5°C (103.3 to 149.9°F) and chalcedony temperatures ranged from 12.1 to 33.5°C (53.8 to 92.3°F) (both exclusive of Keough Hot Springs). Chalcedony temperatures are closer to the observed temperatures of the cold springs and are also more compatible with the Na/K/Ca temperatures. Figure 5-7B shows the relationship between measured temperature and silica temperature.

Figure 5-9 shows the relationship between the silica species temperature which is most compatible with the Na/K/Ca temperature (generally the chalcedony

Table 5-8

ADJUSTMENT OF SILICA VALUES FOR OBSERVED INCONSISTENCIES

Well or Spring Letter	Field[1] Determined Silica (mg/l)	Laboratory[2] Determined Silica (mg/l)	Ratio: Field Laboratory	Adjusted[3] SiO_2
A	15.0	8.2	1.83	17.3
B	16.5	7.2	2.29	15.2
C	10.5	4.8	2.18	10.1
D	13.5	6.6	2.04	13.9
E	10.5	5.6	1.89	11.8
F	13.5	7.1	1.90	15.0
G	13.5	6.1	2.21	12.8
H	16.0[4]	7.71	2.08	16.2
I	17.0	10	1.70	21.1
J	17.0	7.7	2.21	16.2
K	16.5[5]	7.0	2.36	14.7
L	14.0	6.7	2.09	14.1
M	13.0	7.1	1.83	15.0
N	80.0	20	4	42.1
O	24.0	8.4	2.86	17.7
P	20.4	—[6]	—	20.4
Q	(44)[7]	13	3.38	27.4
Average:			2.105[8]	

Notes:

[1]Reactive silica by the Ammonium molybdate method using occular comparator colorimeter (Hach Chemical Company, Silica Test Kit, Low Range).

[2]Reactive silica by Ammonium molybdate method using laboratory colorimeter with comparison standards.

[3]Laboratory value multiplied by the average ratio between field and laboratory value (2.10). Adjustment made because of apparent loss of silica through sample ageing. The laboratory determined quantity is considered more accurate and field determined value is considered more precise. Values of silica content contained in the literature and file data, Table 5-3, agree favorably with the field determined values.

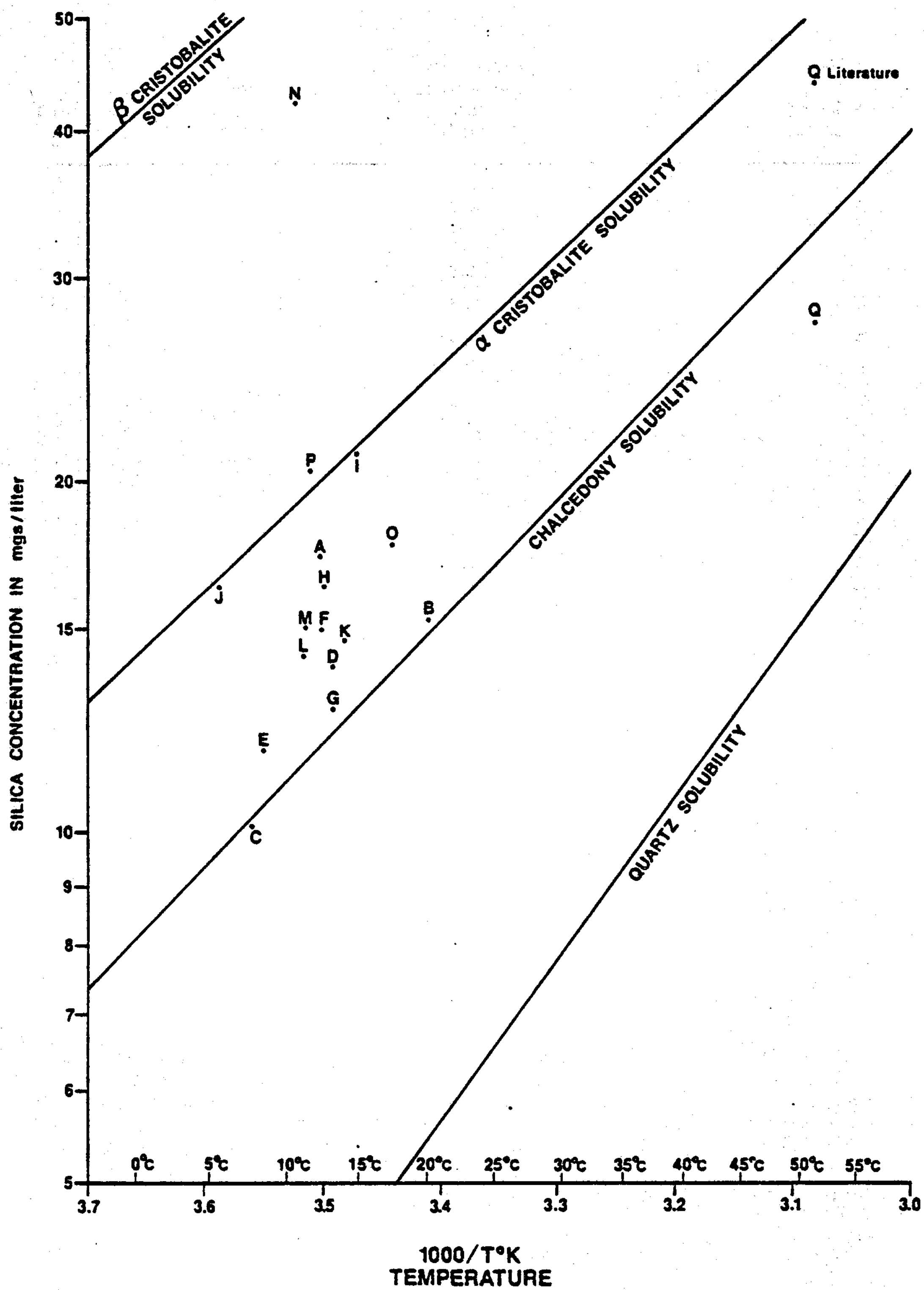
[4]18 mg/l from Cal DWR-WDIS file.

[5]16 mg/l from Cal DWR-WDIS file.

[6]Not determined.

[7]Determined by USGS (Mariner et al., 1979).

[8]Does not include N, P, or Q.



Variation of Dissolved-Silica Concentration With Temperature

FIGURE 5-8

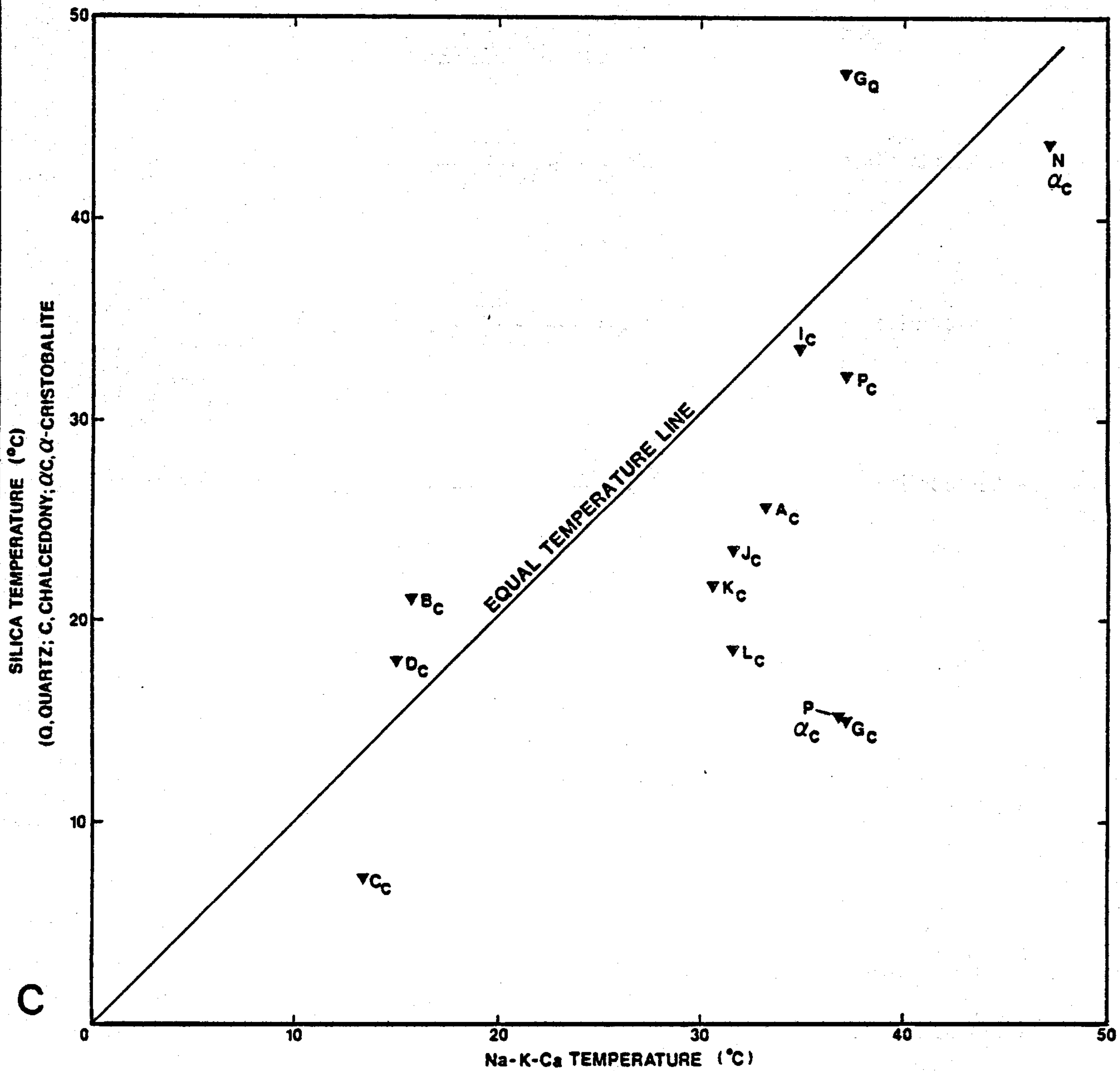
Table 5-9

EQUATIONS RELATING THE SOLUBILITY OF SILICA AS A FUNCTION OF TEMPERATURE

Amorphous silica	$T_{°C} = \frac{731}{4.52 - \log C} - 273.15$
β-Cristobalite	$T_{°C} = \frac{781}{4.51 - \log C} - 273.15$
α-Cristobalite	$T_{°C} = \frac{1000}{4.78 - \log C} - 273.15$
Chalcedony	$T_{°C} = \frac{1032}{4.69 - \log C} - 273.15$
Quartz	$T_{°C} = \frac{1309}{5.19 - \log C} - 273.15$

Where C is silica solubility in mg SiO_2 per kg water.

Source: Fournier, 1977



Silica Temperatures Versus Na-K-Ca Temperature

FIGURE 5-9

temperature) and the Na/K/Ca temperature. A general clustering of samples A, I, J, K, L, and P occurs on this figure and on Figure 5-7A. Samples B, C, and D are isolated from this clustering by differences in the Na/K/Ca temperatures. The higher Na/K/Ca temperature clustered samples were derived from granitic rock alluvium (wells and springs in alluvium) and the cooler Na/K/Ca temperature samples were collected from bedrock springs. This relationship suggests that the higher mineral particle-water contact available in the porous alluvium as compared to that of flow through fractured bedrock controls exchange reactions and may in part account for the deficiency of the Na/K/Ca geothermometer noted by Mariner, et al. (1977) and quoted earlier. Because of these phenomena, only the bedrock springs B, C, and D are used to apply mixing models below.

5.4.7 Silica Mixing Models

Conceptual models allowing calculation of temperature and fraction of the hot water component in a mixture of two waters of differing geochemical history are presented by Fournier and Truesdell (1974), Truesdell and Fournier (1977) and Fournier (1977). The mixing model thought to be applicable at the Pine Creek Mine (Model 1 of Fournier and Truesdell, 1974) is one where cold groundwater geochemically similar to either cold spring C or D mixes with a hot groundwater to emerge as the Easy Going Warm Spring. Thus, in this model it is assumed that the enthalpy of the hot water component that mixes with the cold water is the same as the initial enthalpy of the deep hot water. This is expressed in the following equation (Fournier and Truesdell, 1974):

$$(H_{cold})(x) + (H_{hot})(1 - x) = H_{spring}$$

where H_{cold} = enthalpy of the cold water,

H_{hot} = enthalpy of the presumed hot water source,

H_{spring} = enthalpy of the observed warm water,

x = fraction of cold water in the mixture, and

$1 - x$ = fraction of hot water in the mixture.

The silica content of a water in contact with silica minerals is related to its enthalpy (Fournier, 1973) and therefore can be used in a similar fashion (Fournier and Truesdell, 1974):

$$(Si_{cold})(x) + (Si_{hot})(1 - x) = Si_{spring}$$

where Si_{cold} = silica content of the cold water,

Si_{hot} = silica content of the presumed hot water source,

Si_{spring} = silica content of the observed warm water, x = fraction of cold water in the mixture, and

1 - x = fraction of hot water in the mixture.

Figure 5-10 is a graphical solution to the above two equations based on the method of Fournier and Truesdell (1974) for two pairs of groundwaters: Springs B and C and Springs B and D. This graphical solution to the mixing model shows that the temperature of the hot water component may be in the range of 75.9 to 99.4°C (168.6 to 210.9°F). The model also shows that the hot water component may comprise only 10 to 13 percent of the total flow of the Easy Going Warm Spring.

5.4.8 Hydrogen and Oxygen Isotopes: Stable Isotopes

Analysis of the stable isotopes of hydrogen (deuterium; H^2 or D) and of oxygen (oxygen-18; O^{18}) are reported relative to an arbitrary standard which has been defined as Standard Mean Ocean Water (SMOW) (Craig, 1961a). The reported concentrations are in parts per thousand (per mil; o/oo) deviation (δ) from this standard.

During evaporation and condensation in the hydrologic cycle, water molecules containing heavier isotopes are concentrated in the liquid phase. As water evaporates from the ocean, the vapor is depleted in D and O^{18} and therefore their values are generally negative in waters originating as meteoric precipitation. The concentration of D and O^{18} in meteoric water varies regularly over the land surface of the Earth. A great number of measurements has shown that for meteoric waters not subject to much reevaporation, δD and δO^{18} are related by the Craig (1961b) meteoric water expression:

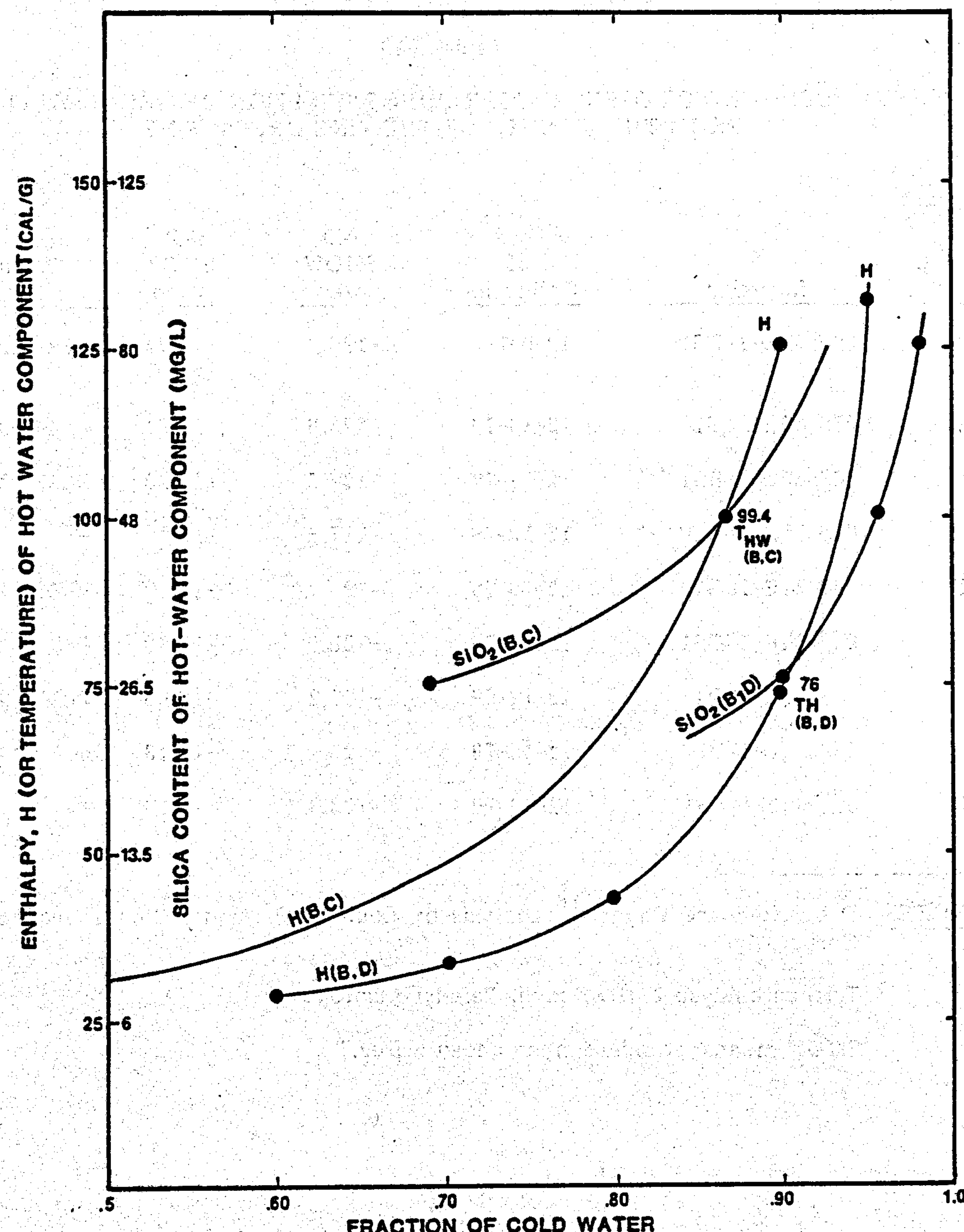
$$\sigma D = 8\delta O^{18} + 10$$

Other factors which control the D and O^{18} concentrations are altitude, latitude, and distance from the ocean.

When meteoric water enters a groundwater aquifer, isotopic as well as chemical changes can occur to the water. An enrichment in the O^{18} content of groundwater has been reported for many geothermal areas (Craig, 1967) and is believed to be due to a temperature control of exchange of O^{16} of the water for O^{18} of the silicate minerals in the rock. Because of the low hydrogen concentrations of most of the rock, the δD of the waters is relatively unchanged.

Deuterium and O^{18} analysis of select groundwaters from the vicinity of the Pine Creek Mine are given in Table 5-10. δD ranged from -117.6 to -133.4 which is consistent with deuterium concentrations reported for Sierra Nevada snow reported by Friedman and Smith (1970, 1972). The range in δD reported by these authors for snow samples collected from various altitudes along the eastern escarpment of the Sierra Nevada have too great a range to allow estimations of groundwater recharge areas to be made for this study.

δO^{18} values ranged from -16.15 to -18.18 for the groundwaters investigated. Figure 5-11 is a plot of δD versus δO^{18} for groundwaters from the vicinity of



Graphical Interpretation of Silica Mixing Model Temperatures

FIGURE 5-10

Table 5-10

HYDROGEN- AND OXYGEN-ISOTOPE CONCENTRATION OF GROUNDWATERS FROM THE VICINITY OF THE PINE CREEK MINE

Spring or Well Letter	Location	Date of Collection	δD SMOW o/oo	δO^{18} SMOW o/oo	Tritium TU $\pm 1\sigma$
A	06S/31E-31RS1	12-9-79	-128.7	-17.74; 17.79	8.94 $\pm$1.09
B	07S/30E-8CS1	12-10-79	-124.6	-17.01	33.44 $\pm$3.75
C	06S/30E-31RS1	12-10-79	-127.5	-17.28	25.28 $\pm$3.09
E	07S/30E-8AS1	12-12-79	-117.6	-16.15	—
F	06S/31E-19G1	12-12-79	-126.7	-17.12	37.81 $\pm$4.38
G	06S/30E-26CS1	12-12-79	-130.0	-17.79	—
I	06S/31E-27Q1	12-13-79	-125.2	-16.95	55.31 $\pm$6.25
M	06S/31E-17B1	12-15-79	-125.1	-17.13	—
Q	08S/33E-17FS1	12-18-79	-133.4	-18.18	—

NOTES: Deuterium and Oxygen^{18} analysis by Louis J. Pandolfi, Global Geochemistry Corporation.

Tritium analysis by K. Roach, Teledyne Isotopes.

SMOW means "standard mean ocean water."

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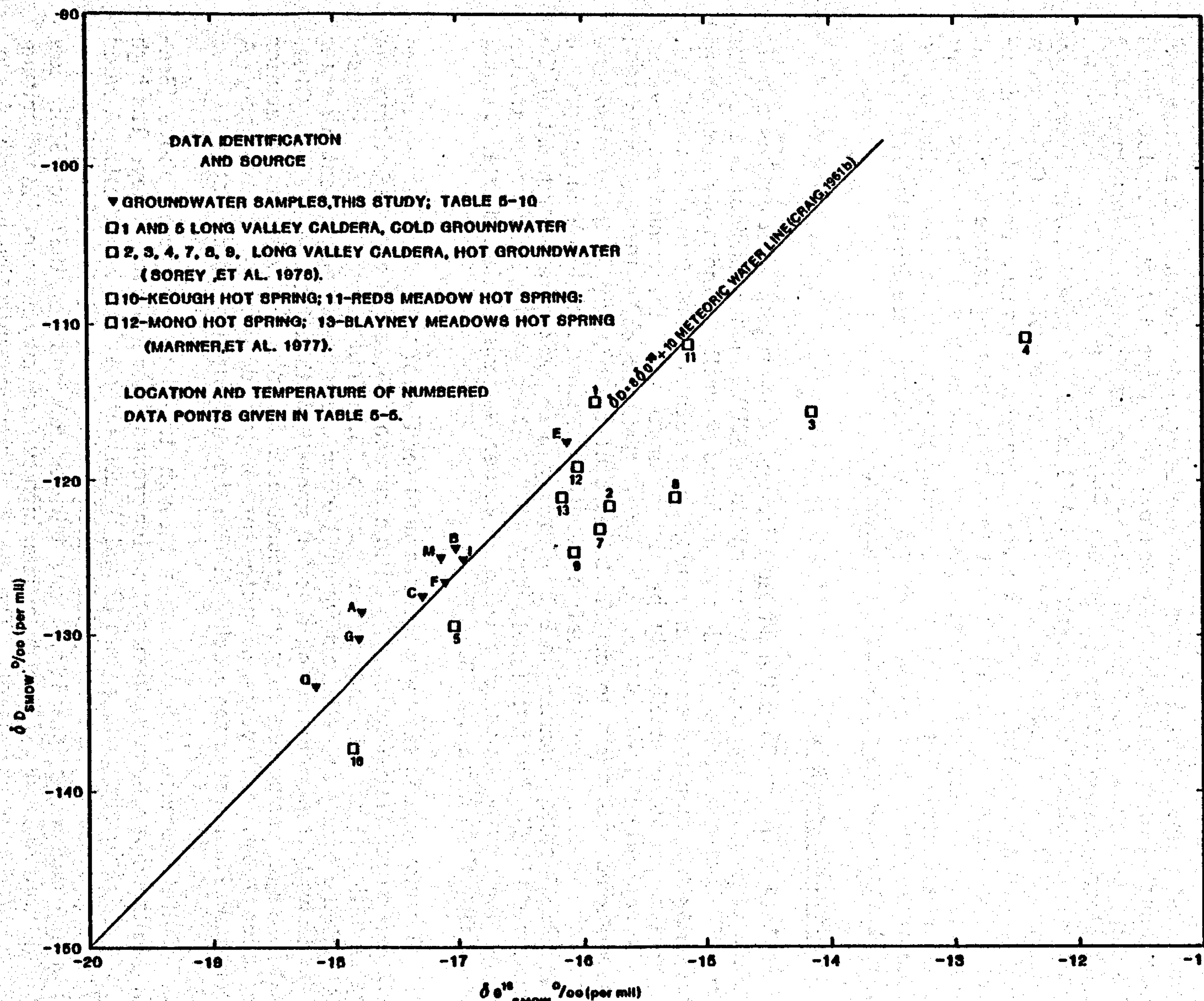


Plot of δ D versus δ O^{18} in groundwater from the vicinity of the Pine Creek Mine.

FIGURE 5-11

the Pine Creek Mine and for select thermal and non-thermal waters of the Long Valley Caldera, and Red's Meadow Hot Springs, Mono Hot Springs, Blayney Meadows Hot Springs, as well as Keough Hot Springs which was also reported in this study (Spring Q).

The waters of the Easy Going Warm Spring do not show a shift in δO^{18} from that of the local meteoric water (Spring C) or the Craig meteoric water line. However, neither do Keough Hot Springs (Q), Red's Meadow Hot Springs (11), or Mono Hot Springs (12). A slight δO^{18} shift of 0.58 per mil was reported for Keough Hot Springs and 0.20 per mil for Blayney Meadows Hot Springs by Mariner, et al. (1977). δO^{18} shifts of hot waters of the Long Valley Caldera ranged from 0.78 to 2.68 (Figure 5-10) as reported by Sorey, et al. (1978). The lack of a δO^{18} shift in the waters of the Easy Going Warm Spring and the hot springs could be due to any of several phenomena. Possible explanations are: 1) heating of the waters was not to a sufficient temperature to bring about any significant isotope exchange; 2) water residence time in the aquifer was insufficient to bring about exchange; 3) the rock was of similar oxygen isotopic composition to the water; and 4) the fractures through which the water flowed were isotopically flushed. Items 1 and 2 above are the preferred explanations.

5.4.9 Unstable Isotopes

Tritium (H^3 or T) is the unstable isotope of hydrogen. Tritium has a half-life of 12.28 years and is reported in Tritium Units (TU) which consist of one tritium atom per 10^{18} hydrogen atoms. Tritium is produced naturally in the upper atmosphere such that natural tritium is present in rainfall in concentrations of from 1 to 10 TU. Tritium is also produced artificially by the detonation of thermonuclear devices. Atmospheric concentration of tritium was highest from the early 1950s through 1962 when they peaked and began to decline because of the banning of the atmospheric testing of such devices. The concentration of tritium reached high levels in this period: on July 2, 1963 the concentration in Lake Crowley, a few kilometers northeast of the study area, was 420 TU (Leventhal and Libby, 1970). The highest tritium concentration reported by these authors was for rainfall at Jasper National Park, Alberta, Canada, which was 8200 TU on July 11, 1963.

Tritium concentrations were measured for five of the groundwaters sampled for this investigation (Table 5-10). The tritium concentrations are reported within one standard deviation (1 σ) and ranged from 8.94 to 55.31 TU. Each of these analyses suggests that the spring or well from which it came has a major component of water which was derived from precipitation that fell since 1950, though probably later. Other than that a major component of each groundwater sample has been in the aquifer probably much less than 30 years, no statements of groundwater age can be made. A tritium concentration profile for precipitation in the study area is not available.

Sulfate concentration changes through time were reported above (Section 5.3.3) to indicate a short residence time for groundwater in Round Valley. The high tritium concentration in these waters (F and I) substantiates this hypothesis. A rapid aquifer or wellbore mixing of newly infiltrated water (post, 1973, high tritium, low sulfate) with older water (pre 1937: low tritium, low sulfate; 1937 to 1955: low tritium, high sulfate; 1955-1973: high tritium, high sulfate) may account for the tritium effects but not the sulfate effects. The lower tritium concentration in Spring A supports a larger old water component in the Sierra Frontal Springs.

The tritium concentration of the Easy Going Warm Spring (B) is higher than the nearby Easy Going Cold Spring (C) and suggests that either a much hotter old water mixes with a large quantity of old cold water or that a younger water, essentially the same age as the cold water, is rapidly heated to the observed temperature. The lack of O^{18} shift mentioned earlier adds no information on this subject.

5.5 MODEL OF THE PINE CREEK MINE LOW-TEMPERATURE GEOTHERMAL RESOURCE

5.5.1 Summary of Data on the Easy Going Warm Spring

Data gathered during this investigation has been presented in the previous sections on its own merit, without detailed consideration of the integral workings of the natural environment and with few interpretations offered. Chemical geothermometers have been shown to yield seemingly conflicting results. The Na/K geothermometer and the silica mixing model have shown temperatures of the Easy Going Warm Spring source waters to be 124 and 94°C (255.2 to 201.2°F), respectively. The Na/K/Ca geothermometer gives a temperature of 16°C (60.8°F), and the most probable silica temperature is the chalcedony temperature at 21°C (69.8°F). The quartz temperature is 54°C (129.2°F) and is within range of the other geothermometers. If the Gable Creek Spring is assumed to be a cold spring, the silica mixing model suggests a source temperature of 76°C (168.8°F). Thus, the chemical geothermometers show a possible range of source water temperature of 16 to 124°C (60.8 to 255.2°F), with a higher probability for the lower end of the temperature range.

Oxygen-18 and deuterium analyses suggest that Easy Going Warm Spring has not been significantly heated. Similar observations from hot springs in the region would not allow narrowing of the possible temperature range. High tritium concentrations imply short aquifer residence times, which may not allow adequate time for the water to be heated or chemical and isotopic equilibrium to occur.

The only clear evidence found to differentiate between the hypothesis that either: 1) water of the Easy Going Warm Spring was heated to a temperature only slightly above the spring temperature (19.9°C) (67.8°F); or 2) an unknown quantity of significantly hotter water mixes with local cold water to produce the Easy Going Warm Spring, is the similarity in the total dissolved solids content between the cold and warm waters. To retain the observed similar and low total dissolved solids, any hot water component mixing with the local cold waters would have to be exceedingly low in total dissolved solids. This is likely only if the hot water component were condensed steam. This is improbable, and is not supported by oxygen-18 data: the steam should be enriched in O^{16} and thus the admixed water would show a shift away from Standard Mean Ocean Water (SMOW) and the meteoric water line (i.e., to the left of Figure 5-11). Thus, the hypothesis of local heating to a low temperature is preferred. This could be brought about if the heat generation rate of the local rock were adequate or by circulation of the groundwater to necessary depths as required by the local geothermal gradient.

5.5.2 Heat Generation and Loss

Wollenberg and Smith (1970) reported heat generation rates equivalent to 31 cal m^{-3} yr^{-1} (0.0094 Btu yd^{-3} yr^{-1}) and 11.7 cal m^{-3} yr^{-1} (0.035 Btu yd^{-3} yr^{-1}) marble and clastic metasedimentary rocks of the Paleozoic pendants of the eastern Sierra, assuming densities of 2.6 g/cm^3 (162.3 lbs/ft^{-3}) twenty percent marble and eighty percent clastics, is 9.9 cal m^{-3} yr^{-1} (0.030 Btu yd^{-3} yr^{-1}). A heat generation rate of 21.8 cal m^{-3} yr^{-1} (0.066 Btu yd^{-3} yr^{-1}) was reported for granitics surrounding the pendant (predominently the Tungsten Hills quartz monzonite) (Wollenberg and Smith, 1968).

The Easy Going Warm Spring system discharges about 200 liters per minute (52.8 gal min^{-1}) at 19.9°C (67.8°F). If the average annual temperature is 4°C (39.2°F), the warm spring system loses 6.27 x 10^{11} cal yr^{-1} (2.49 x 10^9 Btu yr^{-1}) to the water draining the mine. This amount of heat would be produced by about 63 cubic kilometers (15 mi^3) of the pendant rock or 29 km^3 (7 mi^3) of quartz monzonite. The pendant has a volume of only about 8 km^3 (1.9 mi^3) and can therefore not be locally providing all of the observed heat in the Easy Going Warm Spring. The low thermal conductivity of the rock and unaccounted groundwater effects would require an even larger volume of rock explained by deeper circulation. A model of the geothermal regime at the Pine Creek Mine is presented below.

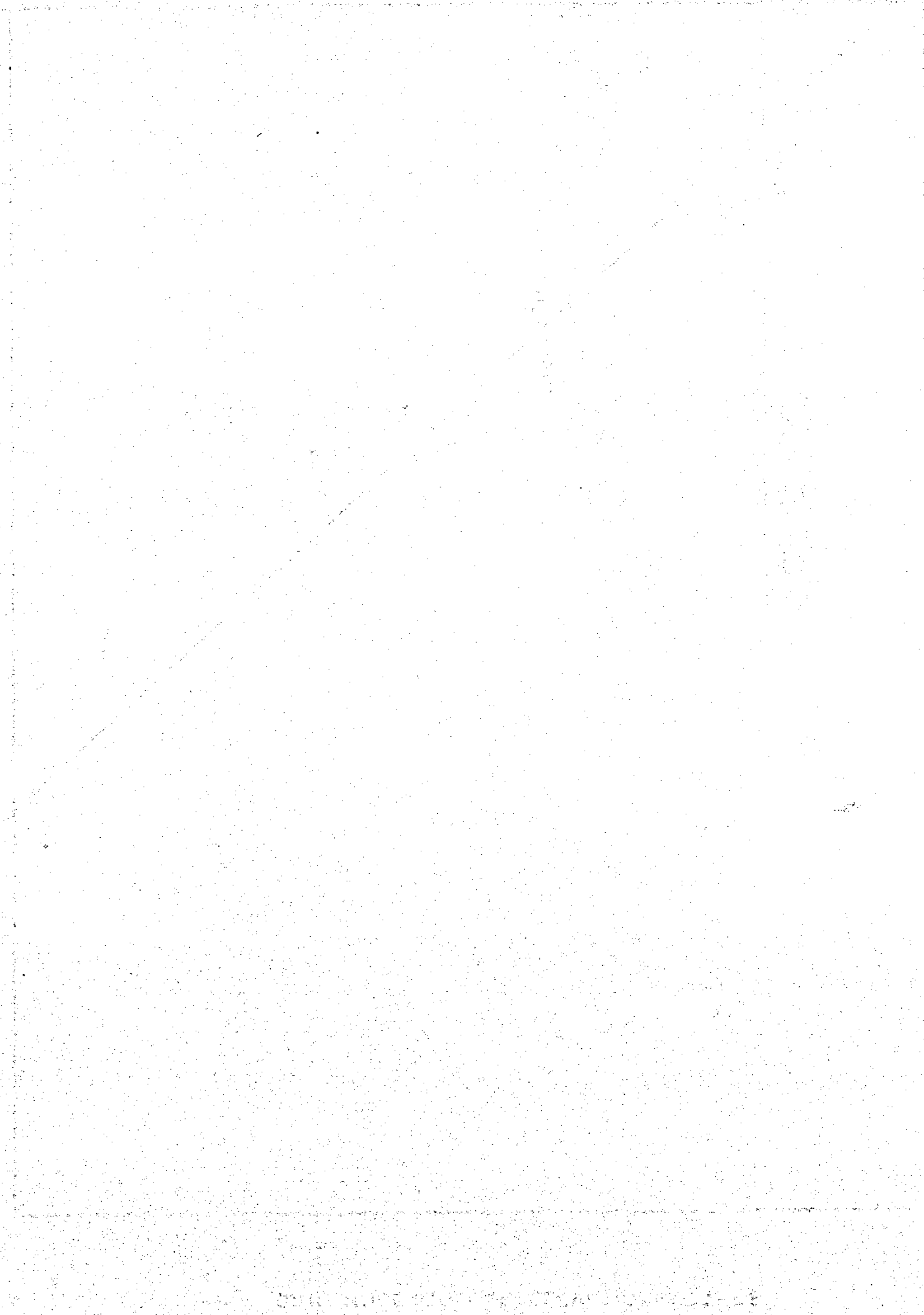
5.5.3 Geothermal Regime of the Pine Creek Mine

Lachenbruch (1968) and Lachenbruch, et al. (1976) presented heat flow and heat production data for seven drillholes in granitic rocks in the Sierra Nevada not in association with the Long Valley caldera. Four of these drillholes (ST, SJ, JB, and HC) formed a transect aligned perpendicular to the axis of the range at about 30 km (18.6 mi) intervals. These are herein plotted to show the fair correlation of geothermal gradient with drill collar elevation (Figure 5-12). One of the drillholes (JA) was about 50 km (31.1 mi) north of the transect and agreed favorably with data from the transect. The remaining two drillholes (THE and THW) are in the Tungsten Hills to the east of the Sierras and within the present study area. Data from these two drillholes also agrees with the collar elevation/geothermal gradient relationship. The regular increase in geothermal gradient in granitic rocks of the Sierra Nevada with collar elevation is attributed to a regular pattern of relict heat flow and heat production in the plutonic rocks from the prebatholothic source and the erosional history of the range. Lachenbruch (1968) presented a set of graphs showing steady-state limits for crustal temperatures beneath the Sierra Nevada based on the aforementioned data (Figure 5-13). These data can be used in conjunction with the altitude relation to approximate the geothermal gradient at any station in the plutonic rock in the Sierra Nevada.

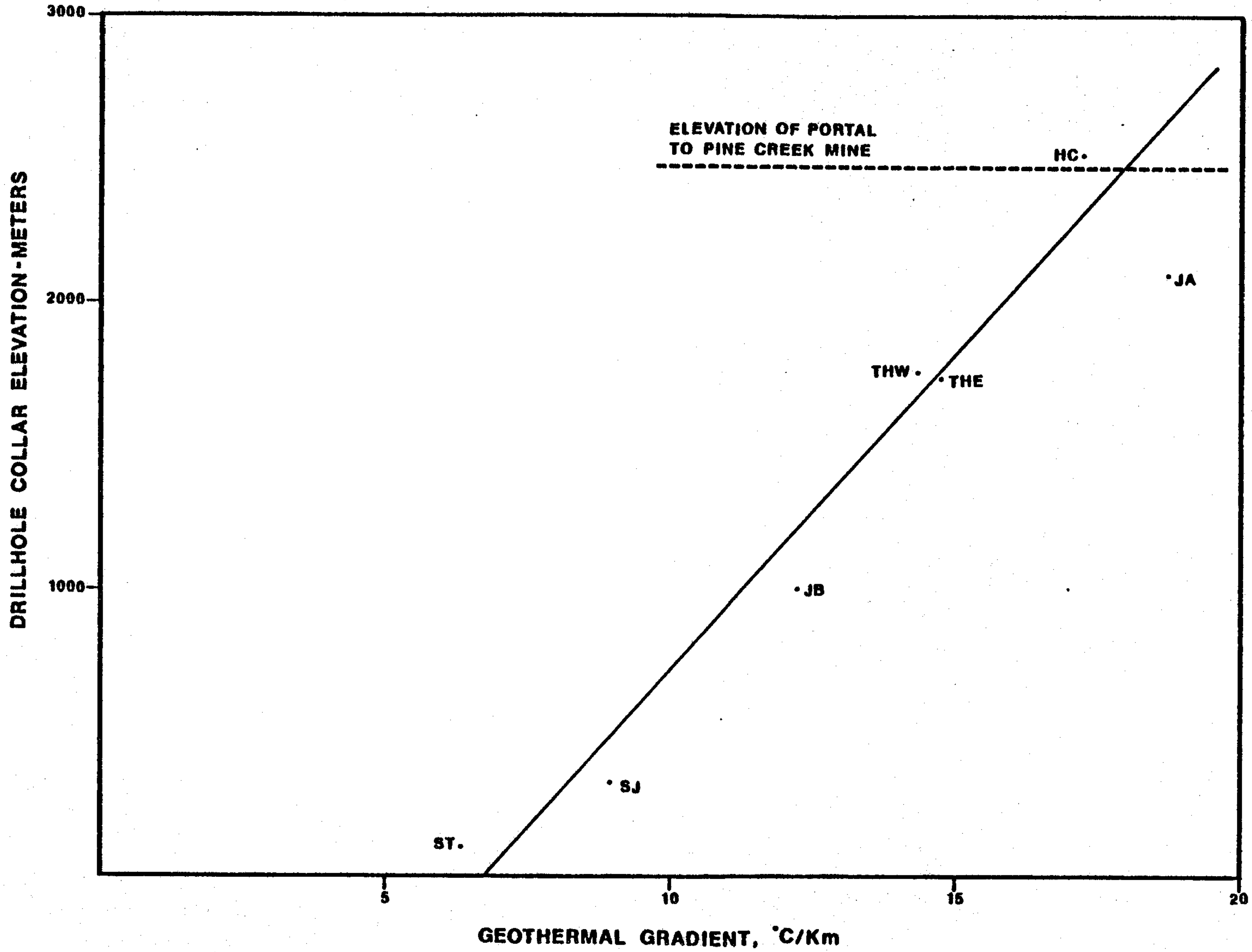
Based on the above regional model, the geothermal gradient at the Pine Creek Mine should be between 15 and 18°C (43.5 and 52.1°F per mile) per kilometer of depth. Assuming the lower limit of 15°C/km (43.5°F/mi), which is also the gradient below the Tungsten Hills, a model of the geothermal environment at the Pine Creek Mine was developed which accounts for the field observations and laboratory analyses. This model is shown on Plate 2.

Plate 2 is a cross-section through the Pine Creek Mine area from the summit of Mount Morgan to the drillhole on the eastern side of the Tungsten Hills (THE), passing through spring C, B, D, and A and the western Tungsten Hills drillhole (THW). Geologic features shown on Plate 2 were interpreted from maps and sections prepared by Bateman (1965). The line of the cross-section (Plate 2) is shown on Plate 1. Attitudes of relic bedding in the metamorphic complex and faults is approximate.

Plot of Drillhole Collar Elevation versus Geothermal Gradient for Data Presented by Lachenbruch (1908), and Lachenbruch, et al. (1976).

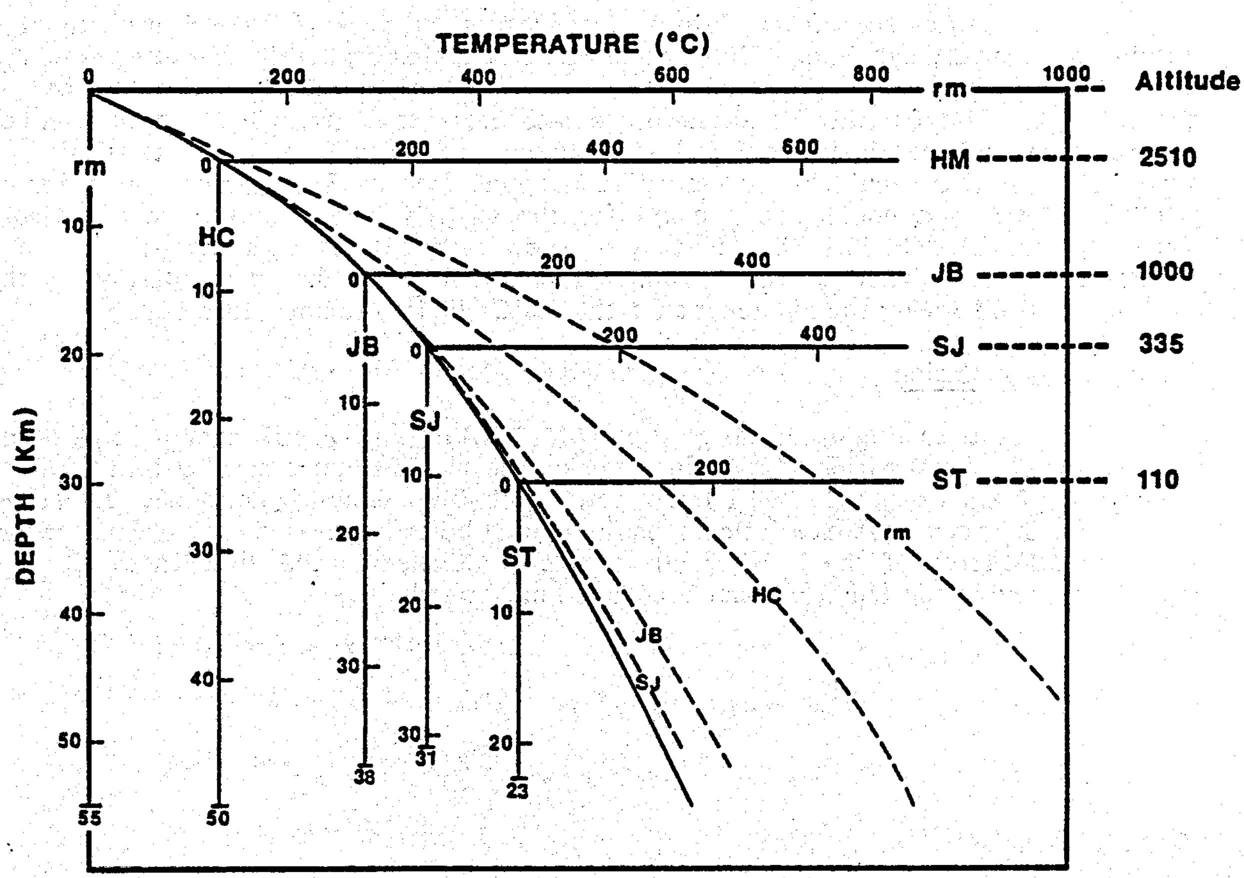


WESTEC Services, Inc.



Plot of Drillhole Collar Elevation versus Geothermal Gradient for Data Presented by Lachenbruch (1908), and Lachenbruch, et al. (1976).

FIGURE 5-12



NOTE:
Solid curve gives lower limit to crustal temperatures at the four drillholes(ST, SJ, JB, HC) and for the reference model, when referred to the appropriate reference frames. Dashed curves show effect of uniform vertical redistribution of heatgenerating sources through crust (Both curves coincide for ST.) Horizontal bars on ordinate line denote base of seismic crust. For explanation of curve derrivation see Lachenbruch (1968)

Steady-state Limits for Crustal Temperatures, Sierra Nevada, California (from Lachenbruch, 1968).

FIGURE 5-13

Plate 2 shows 10°C (18°) isotherms based on a thermal gradient of 15°C/km (43.5°F/mi) and an average ambient temperature of 14°C (57.2°F) in Round Valley and the Tungsten Hills. The measured rock temperature of 14°C (57.2°F) in the Brownstone adit of the Pine Creek Mine was used instead of the 4°C (39.2°F) average ambient temperature at the mine complex. The isotherms are extended across the Pine Creek pendant syncline because of the indicated 14°C rock temperature.

As can be seen from Plate 2, temperatures of over 30°C (86°F) are expected within the pendant syncline. The metamorphic complex is highly fractured and has probably developed a closed groundwater circulation system which may be confined by the relatively less fractured and therefore less permeable granitics. Circulation of groundwater to a depth of from 500 to 1000 meters (1640.5 to 32.81 ft) within the syncline is all that would be necessary to account for the Easy Going Warm Spring (19.9°C; 67.8°F) and could also account for the slightly heated waters of the Gable Creek spring (13.4°C; 56.1°F). Heating of snowmelt water, originally at about 5°C (41°F), infiltrated higher on the surrounding massif through direct circulation to the Easy Going Cold Spring would account for the 7.6°C (45.7°F) temperature observed.

5.5.4 Conclusion

Based on a geothermal gradient of 15°C/km (43.5°F/mi), economic resource temperatures for utilization at the Pine Creek Mine would require drilling to a depth in excess of 5.7 kilometers (18,700 ft) and would probably encounter dry rock. Investigation of hot dry rock heat extraction techniques will be incorporated in the final report to cover all facets of the geothermal resource potential on the Pine Creek site. A specific reservoir confirmation plan is outlined in Appendix B.

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SECTION 6

INSTITUTIONAL BARRIERS ASSESSMENT

6.1 INTRODUCTION

Governmental controls over geothermal exploration at the Union Carbide-Metals Division facility site near Bishop, California are described in this section. The following assumptions were made for this description:

1. All geothermal exploratory drilling will take place on the site of the existing mill.

2. The purpose of the proposed project will be to extract hydrothermal fluid for direct heat application at the mill site.

3. The temperature of the hydrothermal fluid at the wellhead is expected to be approximately 250F.

4. No surface use of land beyond the site where the mill is located is anticipated, with one possible exception involving the use of existing pipeline and tailings ponds.

To determine which governmental controls Union Carbide must comply with if it decides to initiate geothermal exploration at the mill site, it was first necessary to determine the ownership of the surface and mineral estates at the site. It was concluded that the patents which Union Carbide presently holds would in all probability allow it to explore for geothermal resources at the site without acquiring a federal geothermal lease or any additional private ownership rights.

Governmental controls with which Union Carbide must comply are those of the California Division of Oil and Gas, the California Environmental Quality Act, the Regional Water Quality Control Board, the Air Pollution Control District, and the Geothermal Ordinance of Inyo County.

6.2 OWNERSHIP OF THE RESOURCE

The Union Carbide tungsten mill at Pine Creek is located within the Inyo National Forest. To determine which governmental controls would apply to a geothermal operator at the mill site, Union Carbide's mineral and surface rights at the mill site and in the immediate surrounding area were researched.

6.2.1 Surface and Mineral Rights

Union Carbide's right to occupy the surface estate at the mill site and the areas surrounding it and to conduct mining operations beneath the surface of these same areas is defined by patented mining and mill site claims, unpatented mining claims, and special use permits. A patent is a deed from the federal government which conveys the legal title of public lands to the party to whom the patent is issued. By granting patents to Union Carbide, the United States conveyed away its entire interest in the land. Union Carbide received legal title in fee simple. This title encompasses both the surface and mineral estates.

Union Carbide holds Patent No. 1170240 and Patent No. 1170242, which were granted to it in 1957 by the United States. These patents include the land on which the mill is presently located. They contain no reservation of minerals to the United States.

The Bureau of Land Management office at Bishop, California maintains the Union Carbide patent records. These records contain no indication that the federal government reserved any ownership interest in the surface or mineral estates in the land patented to Union Carbide.

The mill site at Pine Creek is surrounded by federally-owned land which is part of the Inyo National Forest. If the mill site were located on National Forest land Union Carbide could explore for and develop geothermal resources at the mill site only after it obtained a federal geothermal lease. The Bureau of Land Management has statutory authority to issue geothermal leases on all federal lands (Geothermal Steam Act of 1970).

Because Union Carbide has fee simple ownership of the surface and mineral estates at the mill site, it need not obtain a federal geothermal lease. Applicable governmental controls will be those imposed by the State of California on geothermal operators drilling on privately-owned land within the state. These controls are discussed in Section 6.3 below.

6.2.2 Water Rights

The patents held by Union Carbide contain the following conditions:

> "That the premises hereby granted shall be held subject to any vested and accrued water rights for mining, agricultural, manufacturing, or other purposes, and rights to ditches and reservoirs used in connection with such water rights, as may be recognized and acknowledged by the local laws, customs, and decisions of the courts."

Los Angeles County holds a power site withdrawal which encompasses the area occupied by the Union Carbide mill complex (Norton, 1980). Other vested water rights in the area may also exist. Numerous issues regarding the relationship between a geothermal resource and surface and subsurface water systems have not been resolved (Olpin & Tarlock, 1978).

In Geothermal Kinetics, Inc. v. Union Oil Co., 75 Cal. App. 3d 56 (1977), a California appellate court determined that ownership of the mineral estate included ownership of geothermal resources. The resource involved was geothermal steam. The evidence in the case convinced the court that the geothermal steam reservoir was completely separate and distinct from the ground water system. The parties were not litigating water rights; the issue was whether the owner of the surface estate or the mineral estate owned the geothermal steam resource.

In United States v. Union Oil Co. of California, 549 F. 2d 1271 (9th Cir. 1977), the Court of Appeals concluded that the federal government's reservation of "all the coal and other minerals" in land patented under the Stock-Raising Homestead Act of 1916 encompassed geothermal steam resources. The court did not accept the defendant's contention that Congress must not have intended to reserve geothermal resources to the government because homesteaders on the patented lands could drill wells and develop springs. The court distinguished between geothermal resources and surface fresh water supplies. As in the Geothermal Kinetics fact situation, however, the principal issue was whether reserved minerals included geothermal steam resources. Discussion of water rights issues was tangential.

In the Pine Creek fact situation, Union Carbide already owns both the surface and mineral estates at the mill site. The geothermal resource, however, is liquid-dominated. Union Carbide's rights to use of a liquid-dominated resource might be challenged by parties contending that they hold superior water rights.

California law contains a mechanism to resolve this issue. Public Resources Code section 3742.2 provides for issuance of a "certificate of primary purpose" by the Geothermal Resources Board. The board will issue the certificate when it determines that a well which is producing or is capable of producing geothermal resources is primarily for that purpose as opposed to being primarily for the purpose of producing water usable for domestic and irrigation purposes. The effect of the certificate is to establish a rebuttable presumption that the holder has absolute title to those geothermal resources reduced to his possession from the well.

6.2.3 Surface Rights in the Area Surrounding the Mill

Union Carbide's surface rights on the Forest Service land surrounding the mill site are defined by Special Use Permits issued by the Forest Service. It is anticipated that all geothermal drilling will take place at the mill site. Possible involvement of the surrounding area is contemplated, however, with respect to disposal of cuttings during the drilling operation. One method of disposing of the cuttings would be to use existing pipes which run from the mill to the tailings ponds. These pipes could also be used during production tests of the supply well after well completion. The pipes and ponds are on land occupied by Union Carbide under the Special Use Permits (see Figure 7-9).

The permits indicate that among the uses allowed are those connected with mining, milling, and processing. Surface use contemplated for geothermal purposes is closely related to these specified uses. Since the purpose of all geothermal activity at the mill site would be to obtain geothermal fluid for direct heat application at the mill, disposal of soil displaced by geothermal drilling would likely be "connected with mining, milling, and processing." The United States Forest Service White Mountain District office has informally concluded that no additional Special Use Permit would be required, although rewriting the existing permits to specifically authorize geothermal surface use might be appropriate (Norton, 1980).

6.3 PERMITS REQUIRED FOR GEOTHERMAL EXPLORATION AT THE EXISTING MILL SITE

If it is assumed that Union Carbide, by virtue of the patents it holds at the existing mill site, is the owner of private land within the State of California, the corporation must comply with requirements imposed by state and county governments on geothermal operators. Union Carbide must obtain approval of a Notice of Intention to Drill (NOI) from the State Division of Oil and Gas (DOG) and also comply with the requirements of the Regional Water Quality Control Board, the local Air Pollution Control District, and Inyo County.

6.3.1 California Division of Oil and Gas

6.3.1.1 Drilling Requirements

Prior to drilling a geothermal well at the mill site, Union Carbide must file a Notice of Intention to Drill (NOI) with the State Oil and Gas Supervisor or the District Director (CAL. PUB. RES. CODE § 3724). A fee of $1,000 is required for drilling an exploratory well of 1000 feet or greater. An additional fee up to a maximum of $1,000 may be assessed for drilling in areas of unstable terrain (Stockton, 1979). The mill site area might be considered an area of unstable terrain by the DOG due to a series of earthquakes occurring in the spring of 1980.

The State Oil and Gas Supervisor or District Director must respond within ten working days in writing to an application for approval of an NOI. Failure to respond within the ten day limit is treated as approval of the program.

A $25,000 individual indemnity bond is required for the drilling, redrilling, deepening, maintaining, or abandoning of any well. This bond is filed along with the NOI. The operator has the option to file a single bond of $100,000 to cover all of the filer's operations in the state.

Although less costly bond requirements (CAL. PUB. RES. CODE § 3725.5) are imposed on operators of low temperature wells, as defined in Public Resources Code Section 3703.1, the well proposed for the mill site at Pine Creek would not be classified as low temperature. The estimated boiling point of water at the altitude of the Pine Creek site, about 7800 feet, is 195F. The estimated temperature of the geothermal resource at Pine Creek is 250F. For purposes of the statutory definition of a "low-temperature geothermal well," the temperature of the fluid from the resource must be no greater than the boiling point of water at the altitude of occurrence.

6.3.1.2 Environmental Requirements

Receipt by the DOG of an application for approval of an NOI triggers the need for the DOG to comply with the provisions of the California Environmental Quality Act (CEQA). This act applies to situations in which a public agency proposes to approve a discretionary project (CAL. PUB. RES. CODE § 21080(a)). Assembly Bill No. 2644, enacted in 1978, designated the DOG "lead agency" for purposes of CEQA for any "geothermal exploratory project" (CAL. PUB. RES. CODE § 3715.5). The term "geothermal exploratory project," defined in Section 21056.6 of the Public Resources Code, means a project of no more than six wells which is chiefly undertaken to evaluate the presence and characteristics of geothermal resources before beginning development. The project must be located at least one-half mile from geothermal development wells which are capable of producing geothermal resources in commercial quantities. The proposed exploratory drilling at the mill site, if confined to six wells or less, would fit within this definition. No geothermal development wells are located within one-half mile of the mill site.

DOG may delegate its lead agency responsibility to a county which has adopted a geothermal element for its general plan. Imperial County, however, is the only county which has thus far adopted a geothermal element. As discussed in Section 7.3 of this report, a joint geothermal element is being prepared for Mono and Inyo Counties. DOG could elect to delegate its lead agency responsibilities regarding geothermal exploration at the Pine Creek site to Inyo County upon completion of the joint geothermal element by the two counties.

Assembly Bill No. 2644 also imposes a time limit on the "lead agency," whether it is the DOG or a county to which the DOG has delegated these responsibilities. The lead agency must complete its responsibilities under CEQA as lead agency within 135 days of receipt of a completed application for a geothermal exploratory project (CAL. PUB. RES. CODE § 3715.5). This statutory time limit was designed to expedite geothermal exploration. Prior to passage of Assembly Bill No. 2644, processing of environmental impact reports had taken up to one year (Nevis, 1979).

6.3.2 The Regional Water Quality Control Board

The mill site at Pine Creek is under the jurisdiction of the Lahontan Region of the California Regional Water Quality Control Board. This agency administers the federal Water Pollution Control Act and the state Water Quality Control Act. Before beginning geothermal drilling, an operator must obtain a document entitled Waste Discharge Requirements which will specify detailed conditions pertinent to the project.

Copies of waste discharge requirements imposed on geothermal testing operators in Lahontan Region were obtained. Waste Discharge Requirements formulated in the 1960s, which have subsequently been rescinded, specified types and amounts of various chemicals which the operator could discharge into designated areas. Currently valid Waste Discharge Requirements are less detailed in nature, tending to indicate instead where existing water quality must be preserved. An operator must also comply with monitoring and reporting requirements.

6.3.3 The Air Pollution Control District

The Great Basin Unified Air Pollution Control District has jurisdiction over the Pine Creek mill site. This local agency administers the requirements of the State Air Resources Board. A geothermal operator must obtain an Authority to Construct and a Permit to Operate. Although several parties have begun the application process regarding geothermal drilling in the Great Basin District, no Authority to Construct or Permit to Operate has been issued thus far for a geothermal drilling project (Fryxell, 1980).

6.3.4 The Geothermal Ordinance of Inyo County

Before any geothermal exploratory project may be carried out in the unincorporated areas of Inyo County, a conditional use permit must be obtained from the county planning commission. This requirement is imposed by the Geothermal Ordinance of the County of Inyo (Ord. 239 Section 1.20, 1973) which is analyzed in detail in Section 8 of the First Quarterly Report on this project.

In view of the fact that the state extensively regulates geothermal drilling activity through the Department of Oil and Gas, an argument can be made that a local government's efforts to control this activity through legislation are invalid. An opinion of the state attorney general examines whether the state has fully occupied the field of drilling, operating, maintaining and abandoning oil, gas and geothermal wells (Opinion of the California Attorney General, 1976). If the state has fully occupied, or preempted, the field, the Inyo County Geothermal Ordinance is void. The Attorney General concluded, however, that the state has not fully occupied the field, except regarding regulation of the <u>underground</u> phases of oil, gas and geothermal activities. The conclusion reached in the opinion is that local governments may validly regulate the <u>surface</u> activities of geothermal operators.

The Inyo County Geothermal Ordinance is basically a regulatory mechanism directed at surface conditions. The ordinance would probably survive a challenge based on the state preemption issue.

6.4 SUMMARY AND CONCLUSION

The focus of this section of the Quarterly Report was on potential institutional barriers which Union Carbide would encounter if it engaged in geothermal exploration at the tungsten mill site at Pine Creek in Inyo County. Ownership of the surface and mineral estates was researched. Following a determination that Union Carbide is the fee simple owner of the surface and mineral estates on which the mill is presently located, requirements imposed by state and local governments upon geothermal exploration on private land in California were discussed. It was concluded that to drill a geothermal exploratory well in Inyo County, an operator must obtain a Notice of Intention to Drill from the DOG, a Waste Discharge Requirement from the local Water Quality Control Board, an Authority to Construct and Permit to Operate from the local Air Pollution Control District, and a Conditional Use Permit from Inyo County.

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SECTION 7

ENVIRONMENTAL FACTORS

7.1 PRELIMINARY ASSESSMENT OF ENVIRONMENTAL DATA BASE

The first step towards a full assessment of the potential environmental impact of using geothermal resources to run the Pine Creek Mine and mill facilities was a review of the available environmental data base. The methodology involved in the collection and assimilation of information for this report included three phases: (1) literature search, (2) limited field investigation and (3) interviews.

7.1.1 Literature Search

The literature search consisted of a review of printed and unprinted documents and maps relating to Pine Creek Canyon and the environmental resources in the region. The literature review included research in numerous areas throughout the State of California: San Diego, Los Angeles, Independence, Sacramento, and in the general Pine Creek/Bishop region.

The results of the literature search were limited in extent and most of the available data addresses the region rather than Pine Creek specifically. A fairly large amount of information is available for the areas farther north within the Forest Service's Mammoth-Mono Planning Unit. That area is both more recreation-oriented and more highly developed than Pine Creek Canyon; consequently, it has a larger data base. Pine Creek Canyon has historically been used almost entirely for mining activities. In recent years, it has served as a trailhead for growing numbers of backpackers traveling into the wilderness above the canyon, however recreation has not been encouraged in the canyon itself. Since very little expansion of mining activities in Pine Creek Canyon has been proposed since the passage of the National Environmental Protection Act (NEPA) and the California Environmental Quality Act (CEQA) in the early 1970s, environmental surveys and monitoring in the canyon have been minimal.

The most useful document for this study was an environmental survey report prepared by the U.S. Forest Service in 1971 (USDA, 1971). It covered the proposed expansion of the tailings pond for the Pine Creek Mine and mill facilities and provided an introduction to the resources in the area. It also identified some of the sensitive issues involved in further industrial expansion in Pine Creek Canyon and made recommendations for future management.

A number of documents are available on water quality in the region (California, 1965; California, 1964; U.S. Department of Interior, 1979a). The State of California has funded a number of studies because the water coming from Pine Creek and surrounding areas goes into the Los Angeles aqueduct. In addition, the Bureau of Land Management monitored water quality in Pine Creek Canyon after two spills from the tailings pipelines (U.S. Department of Interior, 1979) and the Union Carbide Corporation keeps its own records (Union Carbide Corporation, 1979a,b).

Written information on air quality, biological resources, archaeological resources, land use, air quality and geologic hazards in the vicinity of Pine Creek is scarce and largely of a regional nature. There are no known data on the ambient noise levels in Pine Creek Canyon at this time.

7.1.2 Field Investigation

The amount of field investigation was kept to a minimum during this phase of the project. Since the only areas flat and large enough to contain potential geothermal wells are in the immediate vicinity of the existing tungsten mill and related facilities, it was not deemed necessary that on-foot site-specific field surveys be conducted. Instead, it is recommended that these be performed on the two selected geothermal sites in a later phase. For the current study, recent color photographs were used extensively as an introduction to Pine Creek Canyon along with numerous maps. The project manager and the geologist/hydrologist visited the project site.

7.1.3 Interviews

Personal interviews were a particularly important source of data and were quite necessary due to the relative absence of an environmental data base for the area. The following agencies were contacted: U.S. Forest Service, U.S. Bureau of Land Management, University of California at Riverside, California Department of Fish and Game, Great Basin Unified Air Pollution Control District, Great Basin Foundation, California Department of Water Resources, Union Carbide Corporation, and the U.S. Weather Service.

7.2 ENVIRONMENTAL ASSESSMENT

The next step towards a full environmental impact assessment of geothermal development in the Pine Creek area was the preparation of an environmental constraints study. This step involved a synthesis of the available literature and interviews. The object of the study was to ascertain any potential significant environmental effects which might result from the use of geothermal resources to operate the tungsten mill and if any significant constraints were found, to develop possible alternative measures to avoid potential environmental effects.

7.2.1 Water Quality

7.2.1.1 Environmental Setting

Pine Creek and its tributaries drain a small watershed on the eastern side of the Wheeler Crest within the Sierra Nevada Mountains. The creek has its headwaters in a chain of lakes above 11,000 feet (3353 m) and flows 15 miles (24.14 km) to join the Owens River. The Pine Creek Tungsten Mine and mill are located in the eastern end of Pine Creek Canyon; there are three streams in the canyon which are in the vicinity of the Union Carbide facilities. Morgan Creek enters the main canyon from the north above the mine portal and flows past the crushing plant and conveyors to join Pine Creek just below the tungsten mill operations. Pine Creek runs the length of the main canyon in a southeast-northwest orientation and is sometimes dry during a few months of the year when its headwaters are frozen. Gable Creek enters Pine Creek from the south side of the main canyon and is east of the Union Carbide mining and mill operations.

The Pine Creek Tungsten Mine is located in the Lahontan Region of the California Regional Water Quality Control Board (RWQCB). The mine has had two spills in recent years, one in 1977 and one in 1978. The first spill, consisted of 300 tons (272,400 kg) of finely ground rock tailings wastes, resulting in large quantities of sludge in the Avena River. The second spill, consisting of concentrated sulphuric acid, resulted in a large fish and invertebrate kill. An inventory of the Pine Creek area in 1978 also noted that some sediment is being added from the river banks where the road nears the stream (U.S. BLM, 1979). The effects of the tailings ponds have not been thoroughly studied and the proposed project would not affect the ponds. However, at some point, a quantitative analysis of the ponds' impact on water quality should be prepared.

The waters of Pine Creek are currently of excellent quality (Table 7-1) and make up a portion of the water going to the Los Angeles/Owens River Aqueduct. Insignificant levels of contaminants are contributed by mining and milling activities at the Pine Creek Tungsten Mine. The contaminants include: turbidity, total nitrogen, sulfate, sodium, and heavy metals. These are monitored by the RWQCB; contaminant levels are usually below the maximum limit.

Table 7-2 summarizes quarterly total nitrogen and total filterable residue (turbidity) for 1975 through 1977 at three surface water monitoring stations near the Pine Creek Tungsten Mine. The locations of these stations are shown in Figure 7-1. A detailed analysis of the existing water quality in the Pine Creek area is included in Section V of this report.

Union Carbide Corporation currently monitors the three streams in the area (Pine Creek, Gable Creek, and Morgan Creek) every three hours for turbidity and pH value. In addition, a Union Carbide employee walks the length of the pipeline between the mill and the tailings ponds every two hours looking for possible pipeline breaks or spills. Potential contamination of the watershed is further protected by the placement of concrete trenches beneath the pipelines to contain any spillage. In areas where the collapse of snow drifts might cause a pipeline break, the pipeline is enclosed within special tunnels.

Union Carbide Corporation monitors the three streams monthly for total dissolved solids, sulfate, sodium, ammonia, pH value, chloride, total nitrates, total filterable residues, tungsten, and molybdenum. Monthly and annual reports are available at the Pine Creek Union Carbide offices. Twice a year the water from Morgan Creek is run into a large tub into which numerous fish are introduced. This test verifies that the clarifier is sufficiently removing the mud.

The quality of geothermal fluids associated with the potential Pine Creek geothermal resource is unknown. It is anticipated that the quality of the resource fluids would be high because of the high quality of the warm spring waters in the mine.

Table 7-1

PINE CREEK
QUARTERLY RECEIVING WATERS

Total-N & TFR in mg/l

	R-1		R-3		R-5	
	-N	TFR	-N	TFR	-N	TFR
1975						
1	0.80	64	0.51	88	1.03	396
2	0.32	20	1.29	52	1.05	200
3	0.38	18	0.51	52	0.61	272
4	1.01	67	1.45	86	0.79	286
1976						
1	NS	NS	0.72	48	0.35	296
2	0.92	16	1.89	68	0.53	276
3	0.48	4	0.57	96	0.34	248
4	1.35	39	0.50	68	0.42	236
1977						
1	NS	NS	0.34	82	0.36	316
2	0.18	16	0.26	48	0.60	185
3	0.42	8	0.67	52	0.70	252
4	NS	NS	0.34	76	0.40	312
1978						
1	NS	NS	0.68	96	0.75	304
2	1.15	36	1.55	80	1.69	248
3	1.46	4	0.63	24	0.91	96
4	0.96	24	1.38	92	1.14	268
1979						
1	0.11	16	0.50	72	0.64	216
2	0.42	36	0.62	84	0.51	263
3	0.45	96	1.19	76	1.07	144
4	0.36	24	0.97	72	0.50	228

-N = Nitrogen
TFR = Total Filterable Residue

R-1 = Brownstone Bridge
R-3 = Tungstar Bridge
R-5 = S-turn

Source: Union Carbide, "Evaluation of Total Filterable Residue and Total -Nitrogen in Bishop Mill Waste Effluent, Receiving Waters and Springs, 1978-79."

Table 7-2

WATER QUALITY IN PINE CREEK AND A LOCAL WARM SPRING

	Pine Creek Below Brownstone Bridge	1962 Drinking Water Standards[4]	Easy Going Warm Spring (mg/l)
Total Dissolved Solids (Evaporation)	80	500[1]	10
pH	7.28	—	8.70
Li	0.008	—	0.012
Na	9.0	—	9.0
K	0-7	—	0.4
Mg	0-20	50[1]	0
Ca	7.1	—	4.0
Sr	< 0.1	—	< 0.1
Ba	< 0.1	1.0[2]	< 0.1
Al	< 0.3	—	< 0.3
Zn	< 0.1	5[1]	< 0.01
Mn	< 0.01	0.05[1]	< 0.01
Fe	0.03	0.3[1]	< 0.01
B	0.048	—	0
SiO_2	5.0	—	7.2
NH_4	0.05	—	0.12
NO_3	38	45[1]	27
HCO_3	38	—	27
SO_4	12	250[1]	3.6
F	1.2	3.4[2,3]	0.79
Cl	2.5	250[1]	2.5

NOTES:

1. Recommended limits.
2. Mandatory limits.
3. Varies with temperature.

Source: U.S. Dept. of Public Health, 1962, Public Health Publication 956, 1962.

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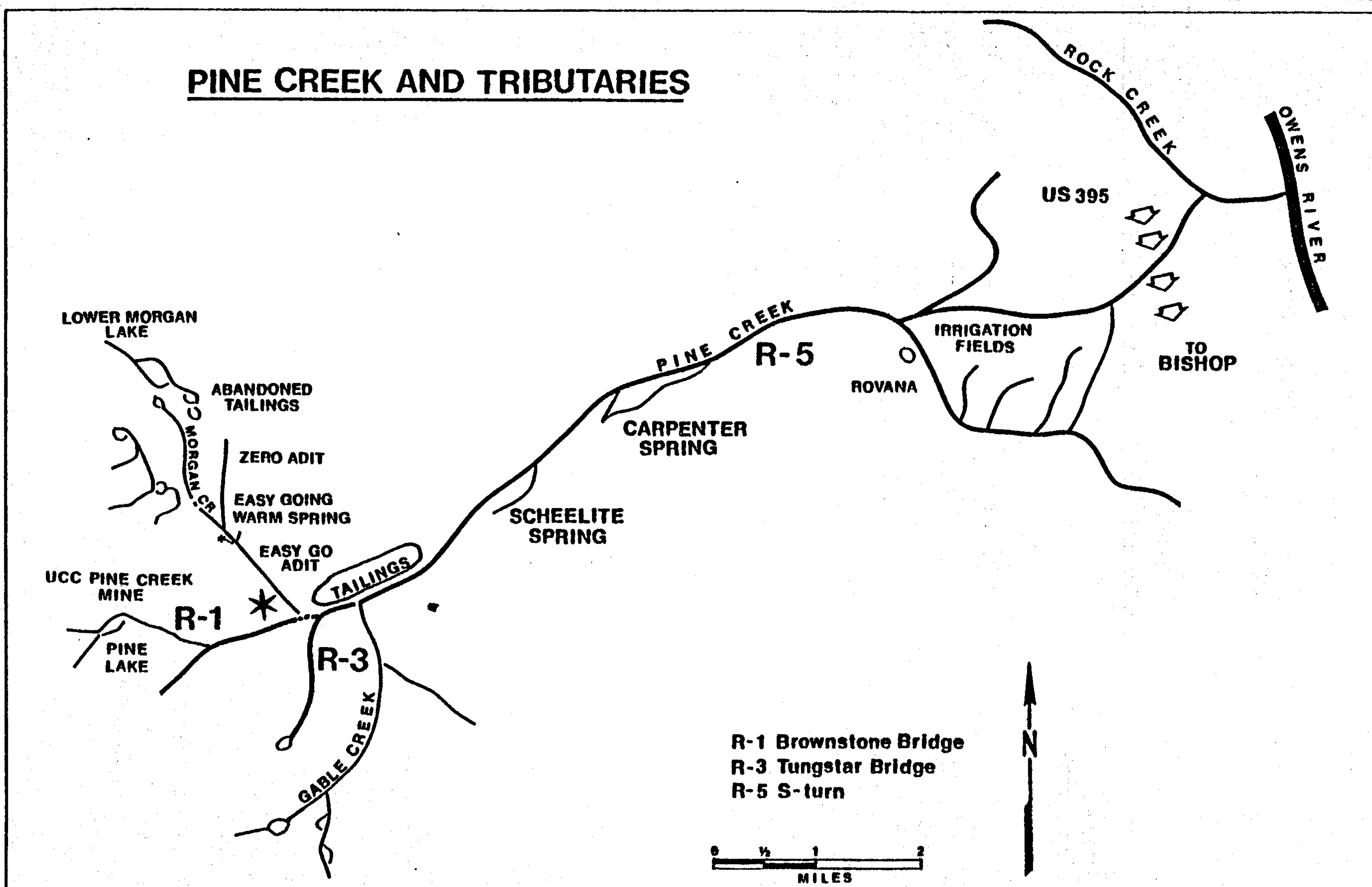


Location of Water Quality Monitoring Stations Near the Pine Creek Tungsten Mine

FIGURE 7-1

7.2.1.2 Potential Impacts/Constraints

There are no potential water quality impacts which cannot be mitigated or which would act as a constraint to the use of the potential geothermal resource in the area. The identification of potential water quality impacts which could result from use of the potential geothermal resource is dependent upon the chemical characteristics of the geothermal fluid. Since the geothermal fluid characteristics are unknown at the present time, specific potential water quality impacts cannot yet be determined. It is believed that the potential impacts would be similar to those associated with many of the water-dominated geothermal reservoirs: thermal pollution, hydrogen sulfide, heavy metals, etc. All water contaminants are monitored and regulated by the RWQCB.

7.2.1.3 Mitigation/Alternatives

Mitigation of water quality impacts would be brought about by following waste discharge requirements of the RWQCB. The bulk of any dissolved contaminants would be reinjected with the fluid. Minor spills would be the only potential source of input and would be mitigated by cleanup operations, as necessary.

7.2.2 Biological Resources

No field work was conducted for the biological constraint analysis. Instead, biologists familiar with the area working for the U.S. Forest Service, California Department of Fish and Game, and the U.S. Bureau of Land Management were interviewed. General familiarity with the study area was accomplished through a large collection of recent photos.

7.2.2.1 Environmental Setting

The Pine Creek Tungsten Mine is situated at an elevation of about 8000 feet along the eastern slope of the High Sierra Crest. The mine is located in a steep-walled valley at the juncture of Pine and Morgan Creeks. The vegetation in the vicinity of the mine within Pine Creek Canyon is expected to be representative of the upper montane-subalpine forest formation (Kuchler, 1977). Predominant species would include Jeffrey pine (*Pinus jeffreyi*) and fir (*Abies* sp.). The project area is below alpine forests dominated by lodgepole pine (*Pinus contorta* var. *murrayana*) and whitebark pine (*Pinus albicaulis*) (Rundel *et al.*, 1977). A number of trees on the hillside behind the tungsten mill have died recently, however, the exact cause has not yet been determined. One possibility might be the hydrogen sulfide emitted at the mill (Leys, 1980).

Photographs of the area around the mine show deciduous trees along the creek. These trees are expected to be a combination of willows (*Salix* spp.), poplar (*Populus* spp.), and possibly birch (*Betula occidentalis*). Floral inventories taken farther downstream also indicated the presence of sage (*Salvia*), alder (*Alnus*), and Wildrose (*Rosa californica*) (U.S. BLM, 1979). Much of the area about the mine is very steep and rocky and devoid of trees of shrubs. This includes the tailings ponds down the valley, the areas around them, and the pipeline which carries the tailings. The probable geothermal well sites at the mine are generally flat, previously graded or disturbed areas which are completely devoid of vegetation.

Numerous sensitive plant species have been recorded in the vicinity of the project area and generally along the east slope of the southern Sierra Crest. Most of these species would not be expected in the area of the Pine Creek Tungsten Mine due to the high amount of disturbed areas, rock type, or habitat type. None of these species are expected in the flat, disturbed areas proposed for well sites. Two plant species which prefer rocky areas and which may be found in the general vicinity of the tungsten mine are Inyo penstemon (Penstemon var. papillatus) and Inyo lomatium (Lomatium rigidum).

The California bighorn sheep (Ovis canadensis californiana) is listed by the California Department of Fish and Game as a rare species. The Wheeler Ridge area was rated as one of the best sites for transplantation of the species, and a portion of one of the two existing herds in the Sierra Nevada was recently introduced into the Mount Morgan-Wheeler Ridge area just northwest of the Pine Creek Tungsten Mine (Stefferude, 1980).

Two mine spills in recent years, one each in 1977 and 1978, have significantly impacted the fauna of the Pine Creek area. The first spill consisted of 300 tons of finely ground rock tailings wastes. The second spill consisted of concentrated sulfuric acid and occurred three weeks after the BLM survey. The latter spill caused a large fish kill which extended down into Round Valley and killed large numbers of invertebrates upstream. The invertebrates were expected to recover quickly, however there haven't been any official field surveys in the area to determine recovery from the spills (U.S. BLM, 1979). Further studies should be conducted to determine the current faunal level before approving any further mine projects upstream.

There are currently two deer herds wintering in the vicinity of Pine Creek Canyon. The Buttermilk-Elderberry and Sherwin herds have a wintering range near Rovana, just northwest of the canyon.

7.2.2.2 Potential Impacts/Constraints

The placement of the geothermal wells and associated processing equipment will not necessitate the loss of any natural habitat areas, as the entire operation will probably utilize existing graded or disturbed zones. No offsite improvements are planned which would necessitate habitat alteration. No rare or endangered species listed by the U.S. Fish and Wildlife Service (USF&WS, 1979), California Department of Fish and Game (CDF&G, 1978; 1979), or the California Native Plant Society (CNPS, 1974) are expected to occur at the potential well sites.

The geothermal operation at the site may be expected to produce minor levels of air pollutants; however, these levels are expected to be masked by those from the mine operation and would only occur during the initial well testing phase of the geothermal program. Once the program becomes operational, no emissions are anticipated.

If the geothermal wells are drilled with air instead of drilling mud, as anticipated, there will be no wastes generated during the well testing period. When the wells are put into operation, the geothermal fluids will be reinjected. Water quality will be monitored and regulated by the Regional Water Quality Control Board. Thus, no significant water quality-related biological effects are expected from the use of potential geothermal resources in the Pine Creek area.

Noise from geothermal operations will be noticeable during the pad construction and well drilling phases. This potential impact is expected to be both temporary and all or partially masked by the overall mill operation. Once on-line, the geothermal well will not necessitate the occasional expulsion or venting of steam. Such venting has been necessary in some geothermal operations and can adversely affect wildlife.

The proposed geothermal component of the mine is not expected to adversely affect the California bighorn sheep (Ovis canadensis californiana) program currently underway northwest of the mine in the Mount Morgan-Wheeler Ridge area. Nor will the project have an adverse effect on wintering deer herds in the general region.

In summary, it is not expected that there would be any biological constraints on the development and use of two geothermal wells if they are located in the area around the mill and mine operations.

7.2.2.3 Mitigation/Alternatives

Biological concerns with the project as proposed center around air pollutants and water quality. Both of these effects are expected to be very minor, with water quality effects being controlled by the Regional Water Quality Control Board. No specific mitigation measures with regard to biological resources are recommended at this time.

7.2.3 Noise

7.2.3.1 Environmental Setting

Noise levels in the general project vicinity reflect the natural forest setting. Ambient noise levels would be expected to be very low. Noise levels around the tungsten mine and mill would be expected to be higher due to general industrial noise, cars, and the initial processing of the rock from the mine (i.e., ore cars and crusher), but would still be relatively low on an average. The potential geothermal well sites are adjacent to the mine and mill operations, and noise levels at the sites would be comparable to those about the mine and mill.

7.2.3.2 Potential Impacts/Constraints

The noise effects from geothermal operations are expected to be temporary and noticeable only during the well drilling phase. Union Carbide employees and travelers entering the adjacent wilderness will be impacted. Once the well is drilled and tested, the geothermal operation will be relatively quiet and will be masked by the noise of the mine and mill. Thus, no long-term adverse noise effects from the geothermal program are anticipated. The proposed process will not necessitate loud releases of steam as is the case in other geothermal resource areas. Thus, no noise constraints on the geothermal operations are expected.

7.2.3.3 Mitigation/Alternatives

Aside from standard muffling of drilling equipment, no specific noise abatement recommendations are deemed necessary.

7.2.4 Geological Resources

7.2.4.1 Environmental Setting

The Pine Creek Mine is situated in Pine Creek Canyon, which is carved into the eastern escarpment of the Sierra Nevada Mountains. Operations at the mine produce and process tungsten ore and other minerals from Paleozoic metasedimentary rocks that make up the Wheeler Crest. Wheeler Crest forms a north-south ridge between the main Sierra crest and Round Valley, the northern extension of the Owens Valley, northwest of Bishop, California.

The tungsten mill is located on a flat area created through filling a portion of the canyon floor with mine tailings. Natural slopes on bedrock and talus surfaces in the vicinity of the mine are steep, generally considerably in excess of 50 percent. The floor of Pine Creek Canyon is relatively flat and is underlain by Quaternary alluvium. Rockfalls are common from the steep-sided canyons surrounding the mine, resulting in numerous talus cones along the canyon walls. Rockfalls have always been common in Pine Creek Canyon, however, this has not significantly interfered with mine and mill operations (Brewer, 1980).

The nearest active fault to the Pine Creek Tungsten Mine is the Owens Valley fault. This fault is considered capable of generating a maximum credible earthquake of Richter Magnitude 8.25, which at the minimum fault distance of 22 miles (35.4 km), would result in groundshaking due to bedrock accelerations of about 0.32 gravity (Greensfelder, 1974). Such bedrock accelerations are approximately equivalent to a Modified Mercalli Intensity of VII (Table 7-3). Other active and potentially active faults located within a few miles of the mine include the Sierra Nevada fault zone, the Hilton Creek fault, and several other unnamed faults (Jennings, 1975). These faults were not evaluated by Greensfelder (1974), although a few historic earthquakes are recorded from this area.

7.2.4.2 Potential Impacts/Constraints

Geothermal development at the Pine Creek Tungsten Mine could be impacted by known geologic hazards. The assembly and operation of a rotary drilling rig in the vicinity of the mine is feasible only on the existing mill pad and on the flats of the bottom of Pine Creek Canyon due to the steep canyon walls. Settlement of the fill which makes up the mill pad is not likely to occur. However, movement of this material, if it were to occur, could shear the well casing.

Potential impacts from a geothermal operation on the canyon floor would be minimal. However, the expected low temperature of the geothermal resource and its distance from the mill may eliminate this location as a viable option. If the canyon floor was used as a site for wells, there would be a potential for flooding along the creek channel. In addition, rockfalls along the canyon walls could pose a problem.

Table 7-3

THE MERCALLI INTENSITY SCALE

(As modified by Charles F. Richter in 1956 and rearranged)

If most of these effects are observed	*then the intensity is:*
Earthquake shaking not felt. But people may observe marginal effects of large distance earthquakes without identifying these effects as earthquake-caused. Among them: trees, structures, liquids, bodies of water sway slowly, or doors swing slowly.	*I*
Effect on people: Shaking felt by those at rest, especially if they are indoors, and by those on upper floors.	*II*
Effect on people: Felt by most people indoors. Some can estimate duration of shaking. But many may not recognize shaking of building as caused by an earthquake: the shaking is like that caused by the passing of light trucks.	*III*
Other effects: Hanging objects swing. *Structural effects:* Windows or doors rattle. Wooden walls and frames creak.	*IV*
Effect on people: Felt by everyone indoors. Many estimate duration of shaking. But they still may not recognize it as caused by an earthquake. The shaking is like that caused by the passing of heavy trucks, though sometimes, instead, people may feel the sensation of a jolt, as if a heavy ball had struck the walls. *Other effects:* Hanging objects swing. Standing autos rock. Crockery clashes, dishes rattle or glasses clink. *Structural effects:* Doors close, open or swing. Windows rattle.	*V*
Effect on people: Felt by everyone indoors and by most people outdoors. Many now estimate not only the duration of shaking but also its direction and have no doubt as to its cause. Sleepers wakened. *Other effects:* Hanging objects swing. Shutters or pictures move. Pendulum clocks stop, start or change rate. Standing autos rock. Crockery clashes, dishes rattle or glasses clink. Liquids disturbed, some spilled. Small unstable objects displaced or upset. *Structural effects:* Weak plaster and Masonry D* crack. Windows break. Doors close, open or swing.	*VI*
Effect on people: Felt by everyone. Many are frightened and run outdoors. People walk unsteadily. *Other effects:* Small church or school bells ring. Pictures thrown off walls, knicknacks and books off shelves. Dishes or glasses broken. Furniture moved or overturned. Trees, bushes shaken visibly, or heard to rustle. *Structural effects:* Masonry D* damaged; some cracks in Masonry C*. Weak chimneys break at roof line. Plaster, loose bricks, stones, tiles, cornices, unbraced parapets and architectural ornaments fall. Concrete irrigation ditches damaged.	*VII*
Effect on people: Difficult to stand. Shaking noticed by auto drivers. *Other effects:* Waves on ponds; water turbid with mud. Small slides and caving in along sand or gravel banks. Large bells ring. Furniture broken. Hanging objects quiver. *Structural effects:* Masonry D* heavily damaged; Masonry C* damaged, partially collapses in some cases; some damage to Masonry B*; none to Masonry A*. Stucco and some masonry walls fall. Chimneys, factory stacks, monuments, towers, elevated tanks twist or fall. Frame houses moved on foundations if not bolted down; loose panel walls thrown out. Decayed piling broken off.	*VIII*
Effect on people: General fright. People thrown to ground. *Other effects:* Changes in flow or temperature of springs and wells. Cracks in wet ground and, on steep slopes. Steering of autos affected. Branches broken from trees. *Structural effects:* Masonry D* destroyed; Masonry C* heavily damaged, sometimes with complete collapse; Masonry B* is seriously damaged. General damage to foundations. Frame structures, if not bolted, shifted off foundations. Frames racked. Reservoirs seriously damaged. Underground pipes broken.	*IX*
Effect on people: General Panic. *Other effects:* Conspicuous cracks in ground. In areas of soft ground, sand is ejected through holes and piles up into a small crater, and, in muddy areas, water fountains are formed. *Structural effects:* Most masonry and frame structures destroyed along with their foundations. Some well-built wooden structures and bridges destroyed. Serious damage to dams, dikes and embankments. Railroads bent slightly.	*X*
Effect on people: General panic. *Other effects:* Large landslides. Water thrown on banks of canals, rivers, lakes, etc. Sand and mud shifted horizontally on beaches and flat land. *Structural effects:* General destruction of buildings. Underground pipelines completely out of service. Railroads bent greatly.	*XI*
Effect on people: General panic. *Other effects:* Same as for Intensity X. *Structural effects:* Damage nearly total, the ultimate catastrophe. *Other effects:* Large rock masses displaced. Lines of sight and level distorted. Objects thrown into air.	*XII*

* Masonry A: Good workmanship and mortar, reinforced, designed to resist lateral forces.

* Masonry B: Good workmanship and mortar, reinforced.

* Masonry C: Good workmanship and mortar, unreinforced.

* Masonry D: Poor workmanship and mortar and weak materials, like adobe.

Potential seismic constraints include (1) the potential for ground shaking if a large earthquake were to occur during drilling and (2) possible induced seismicity from fluid reinjection during production level operations. Possible impacts such as subsidence and fault displacement are not considered probable at the Pine Creek Tungsten Mine.

7.2.4.3 Mitigation/Alternatives

Mitigation of potential impacts which have been identified as possible constraints to geothermal development at the Pine Creek Mine can be accomplished through project plan and operation mode. Impacts due to flooding, rockfall, and well casing shear can be minimized by drilling the well in a location that would avoid these problems. One such location is on the floor of Pine Creek Canyon adjacent to the tailings which make up the mill pad.

Earthquake-induced ground shaking is not known to have caused serious problems with drilling rigs in the past, even in the seismically active Imperial Valley. A properly designed and installed rig should be able to withstand the highest probable earthquake event. Seismicity induced by fluid reinjection is a poorly understood phenomena. However, evidence exists that alterations of the injection mode could be made to reduce the impact if induced seismicity should become a problem.

7.2.5 Climatology and Air Quality

7.2.5.1 Environmental Setting

The Pine Creek Tungsten Mine is located at the western end of Pine Creek Canyon, on the eastern slope of the Sierra Nevada. It is situated approximately 8000 feet (2438 m) above mean sea level (MSL), approximately 16 miles (25.7 km) east of Bishop. The Sierra Nevada Mountains have a major effect on area climate: the mountainous portions receive the greatest amount of rain and snow and snow accumulations vary with exposure, topography and ground cover. The lower slopes and valleys are arid (USDA, 1979a).

Local climatological data is available at the Bishop U.S. Weather Service Office at the Municipal Airport, approximately 2.5 (4 km) miles east of Bishop. This data is specific to the Bishop area, which is approximately 16 miles (25.7 km) and 2000 feet (610 m) lower in elevation than the project site. During summer and autumn the Mohave Desert, about 150 miles (241 km) south, causes an early morning and late evening northerly wind; conversely, in the heat of the afternoon it causes a southerly wind that is occasionally strong. Summer skies are usually clear with thunderstorms occurring sporadically from May through August. The days are hot and dry and the nights are cool. The average July temperature in Bishop is 76.6F (24.7C), the average precipitation is 0.17 inch (0.43 cm), and the relative humidity is 19 percent at 10 a.m. and 14 percent at 4 p.m.

Winter and spring, although seasons of adverse weather in Bishop, are generally mild. Daytime temperatures average in the 50s (Farenheit), with nighttime temperatures in the 20s (Farenheit). The greatest amounts of precipitation occur from November through April. Strong northerly winds are common through February, March, and April. It has been reported that east and west winds alternately flow through Pine Creek in summer and fall. In addition, during winter and spring, strong westerly winds flow at higher altitudes over the Sierra Nevada, creating the "Sierra Wave." The average January temperature is 37.1F (2.8C); average rainfall is 1.20 inches (3.0 cm), and average snowfall of 23.2 inches (58.9 cm). The relative humidity averages 49 at 10 a.m. and 35 at 4 p.m. (U.S. Department of Commerce, no date).

The National Weather Service has not compiled meteorological data for the Pine Creek Tungsten Mine area. However, because of daily barometer readings at the site conducted by Union Carbide, pressure data is available. The lowest reading for the area is 22.10 inches of mercury (561 mm), the highest 22.90 (582 mm), with an average of 22.60 (574 mm) (Brewer, 1980).

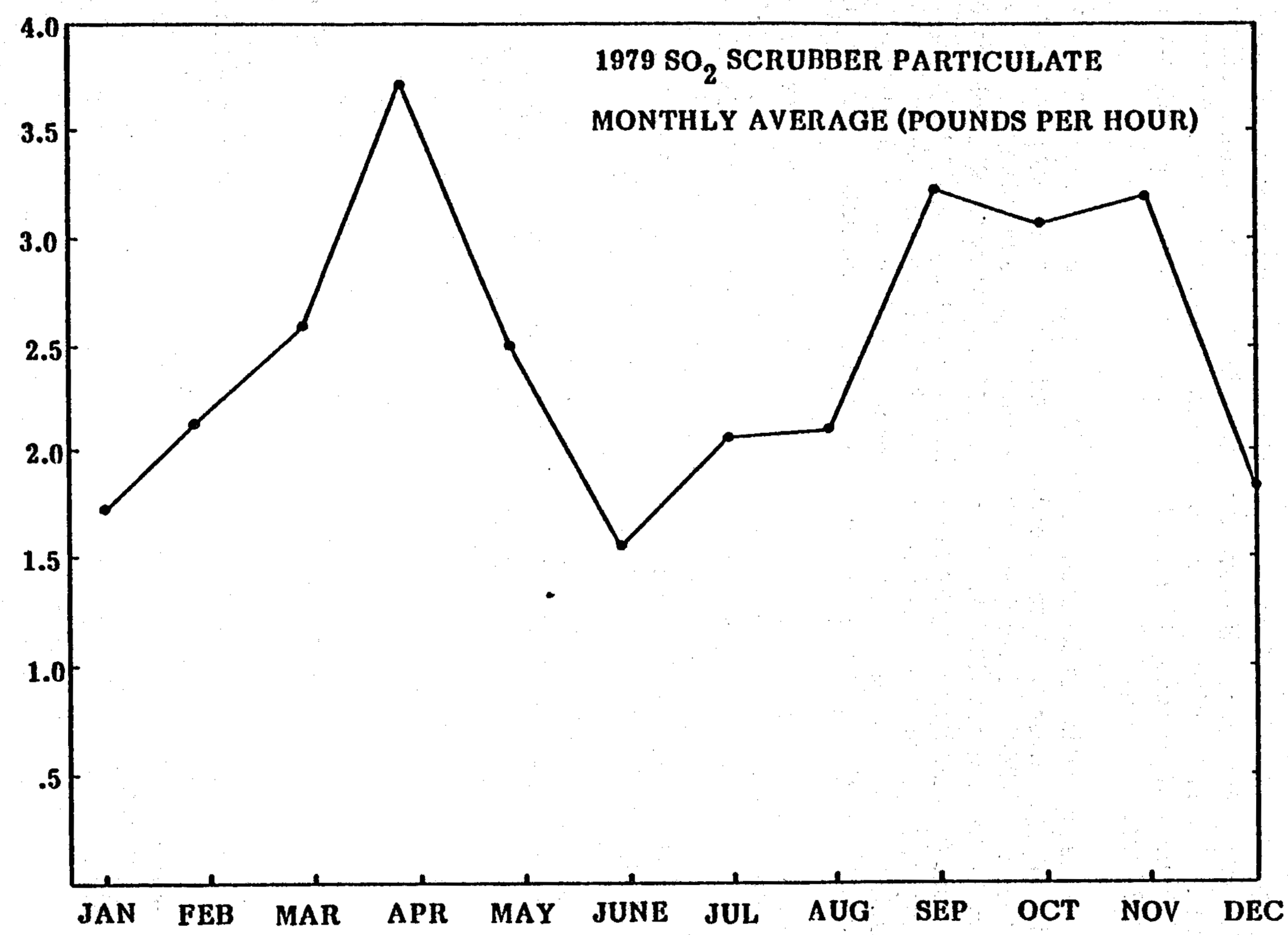
The mine operation is located at the head of a box canyon. Therefore, winds generally do not flow over the site in either direction, but instead tend to swirl within the area (Brewer, 1980). Hydrogen sulfide emissions have been observed for distances up and down the canyon (USDA, 1971; Leys, 1980). If the proposed geothermal program is approved, additional hydrogen sulfide monitoring should be conducted prior to and during the geothermal operations. Monitoring should be conducted at varying distances from the mill and mine operations as well as at several locations within the portions of the John Muir Wilderness Area closest to the tungsten mill.

There are two smokestacks in the project area. One emits hydrogen sulfide (H_2S) and carbon dioxide (CO_2); the other emits primarily sulfur dioxide (SO_2). Data has been compiled by Union Carbide for 1979 emissions of H_2S and SO_2 (Figures 7-2 through 7-6). No ambient air measurements have been conducted for other pollutants, however, it is expected that the amount of all types of emissions from the mill are well below that allowed by State or Federal standards (Fryxell, 1980).

Air quality monitoring in the area is provided by the Great Basin Air Pollution Control District located in Bishop. Monitoring of total suspended particulates (TSP) has been conducted from mine locations around the Bishop area; the nearest location to the tungsten mine is in Bishop. This information, including State and Federal standards, and days TSP exceed the standards, is found on Tables 7-4 and 7-5.

In addition to TSP, the Great Basin Air Pollution Control District has an ozone monitor in Bishop and a carbon monoxide monitor at Mammoth Lakes. Limited preliminary data from these sites suggest no violations of standards for either station (Fryxell, 1980).

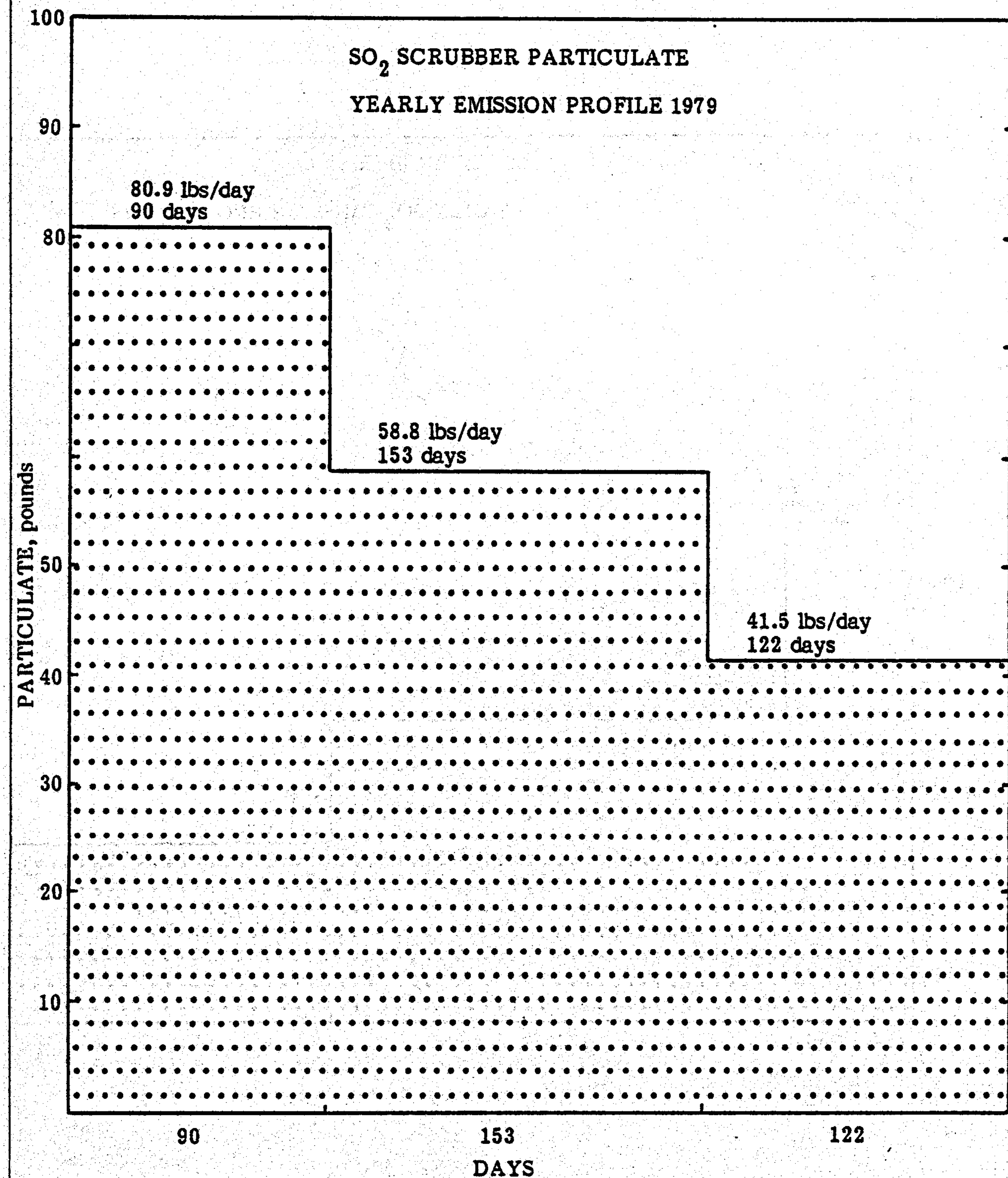
The Pine Creek Tungsten Mine operation is currently entirely dependent on fuel oil for the production of process steam and on electrical energy for prime movers. The processing mill operates 24 hours a day, seven days a week. Operational steam demand is 55,000 (24,970 kg) pounds per hour which is presently generated with package boilers utilizing approximately 3.4 million gallons (12.9 million liters) of fuel oil per year. The electrical demand of the facility is approximately 36 million kilowatt hours per year. Measures are available to determine amounts of pollutants emitted into the atmosphere from these sources. If the proposed geothermal program proceeds, current emissions from these sources should be quantified so that an assessment of air impacts can be made at a later date.



1979 SO_2 Scrubber Particulate Monthly Average

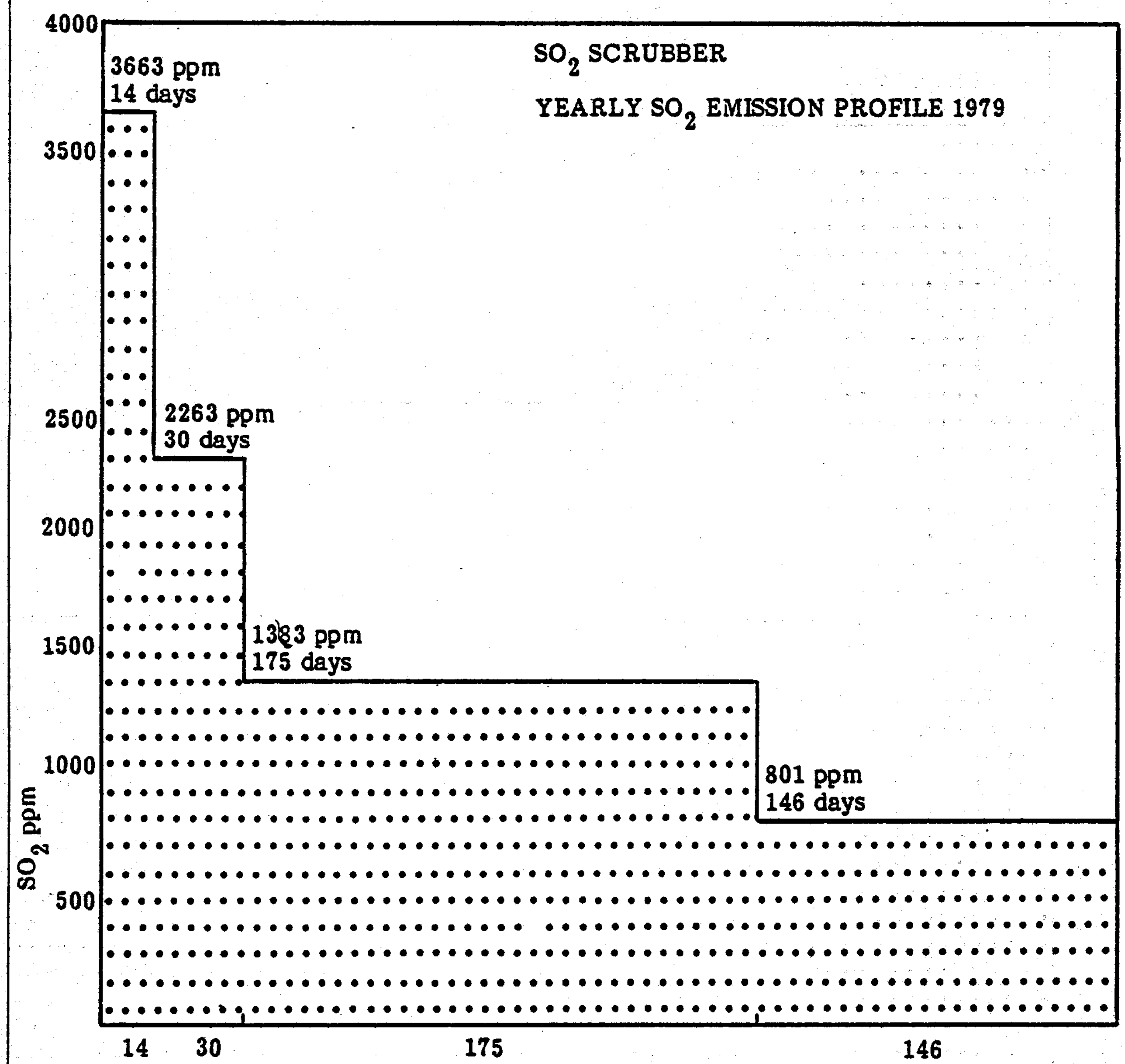
FIGURE 7-2

WESTEC Services, Inc.



SO_2 Scrubber Particulate Yearly Emission Profile, 1979

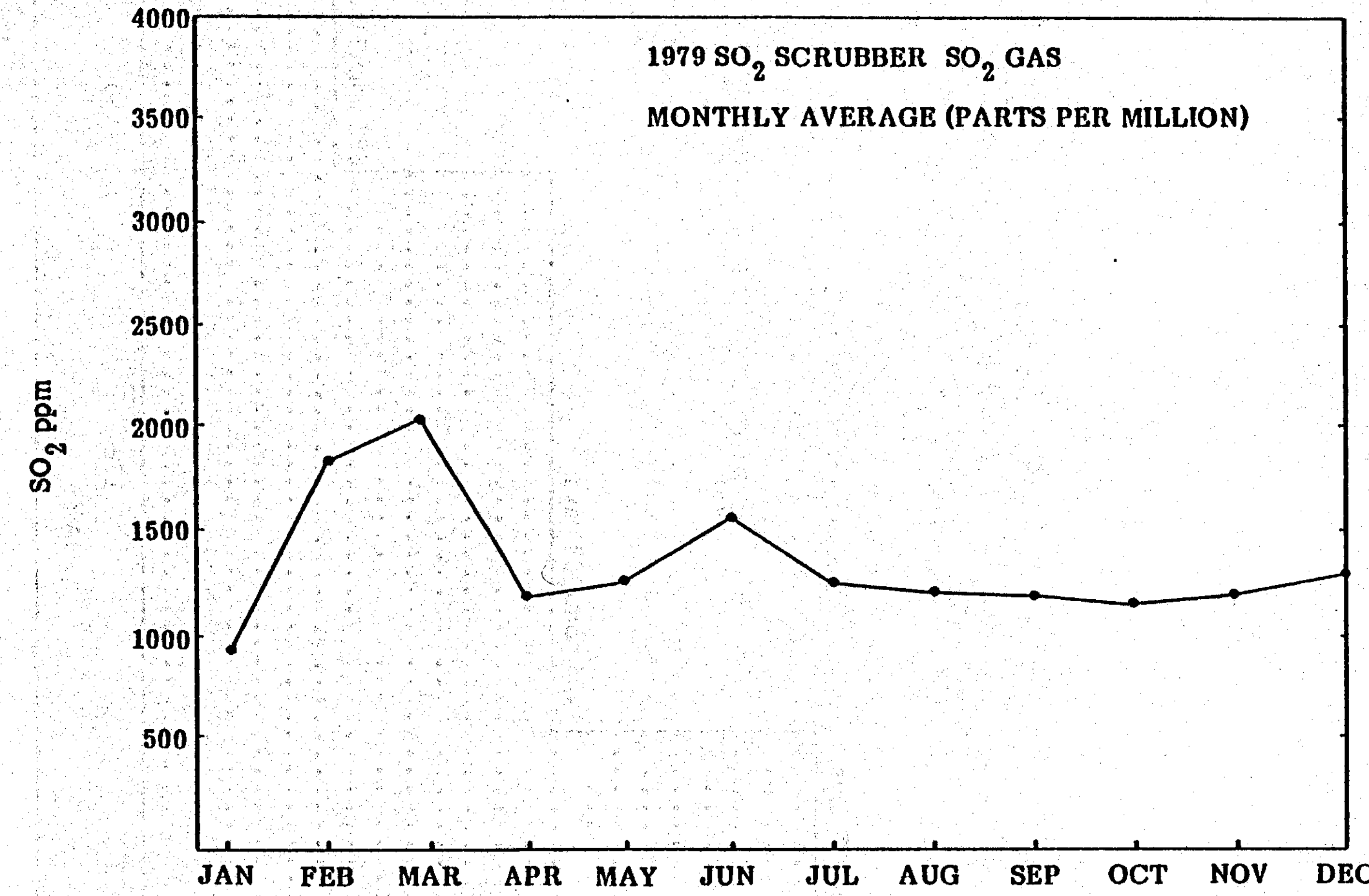
FIGURE 7-3



SO_2 Scrubber Yearly SO_2 Emission Profile, 1979

FIGURE 7-4

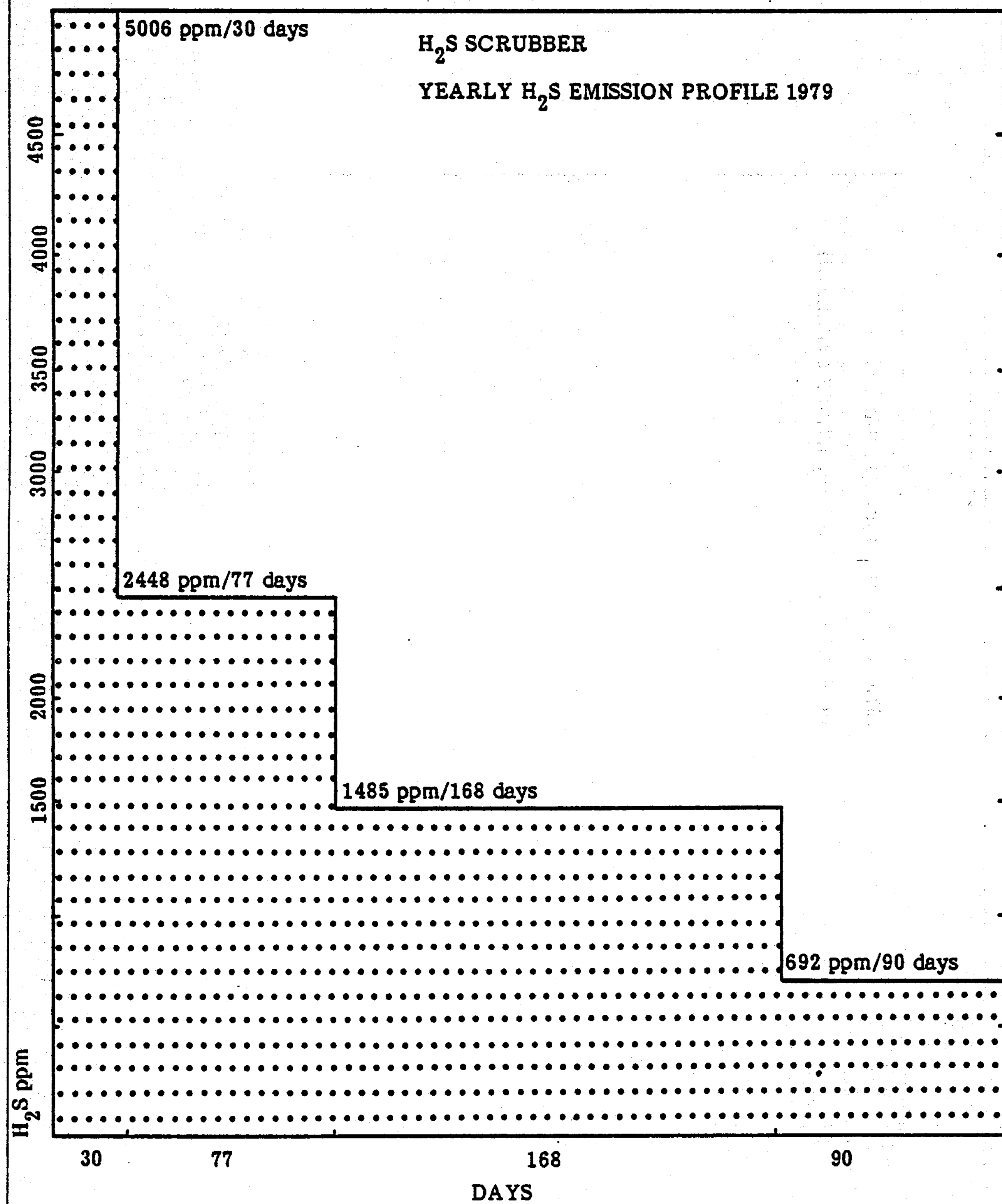
WESTEC Services, Inc.



1979 SO_2 Scrubber SO_2 Gas Monthly Average

FIGURE 7-5

WESTEC Services, Inc.



H_2S Scrubber, Yearly H_2S Emission Profile, 1979

FIGURE 7-6

Table 7-4

TOTAL SUSPENDED PARTICULATE CONCENTRATIONS

STATION	NUMBER OF MONTHS	NUMBER OF SAMPLES	HIGH U/M³	LOW U/M³	GEOMETRIC MEAN U/M³
Coso Junction Rest Area	8	36	140	10	31
Lone Pine Airport	7.5	39	269	10	30
Lone Pine Visitor Center	5.5	23	51	16	28
Bishop	12	50	227	4	32
Keeler	6	86	1,865	7	39*
Mono Lake Hansen	9	52 1	100	3	22
Mono Lake Binderup	7	17	481	31	92
Mammoth Airport	3	22	400	8	54
Mammoth Fire Station	3.5	18	226	19	99

*The Geometric Mean for the Keeler station was computed on values for scheduled sampling dates only.

u/m^3 = micrograms per cubic meter
National Primary Standard = 260 u/m^3
National Secondary Standard = 150 u/m^3
State Standard = 100 u/m^3

Table 7-5

TOTAL SUSPENDED PARTICULATES

STATE AND FEDERAL AMBIENT AIR QUALITY STANDARD VIOLATION ANALYSIS

	260 U/M^3 EXCEEDED	150 U/M^3 EXCEEDED	100 U/M^3 EXCEEDED	ANNUAL GEOMETRIC MEAN		
				NPS	NSS	SS
Coso Junction Rest Area	—	—	2	—	—	—
Lone Pine Airport	1	1	2	—	—	—
Lone Pine Visitor Center	—	—	—	—	—	—
Bishop	—	4	6	—	—	—
Keeler	6	8	9	—	—	—
Mono Lake Hansen	—	—	1	—	—	—
Mono Lake Binderup	2	4	7	X	X	X
Mammoth Airport	3	4	8		X	X
Mammoth Fire Station	—	5	8	X	X	X

National Primary Standard	(NPS)	260 U/M^3
National Secondary Standard	(NSS)	150 U/M^3
State Standard	(SS)	100 U/M^3
Annual Geometric Mean Standards		
National Primary Standard	(NPS)	60
National Secondary Standard	(NSS)	50
State Standard	(SS)	50

___ Did not exceed

$\overline{u/m}^3$ micrograms per cubic meter

X Did exceed

According to an environmental survey report submitted by the U.S. Forest Service in 1971 relating to the Pine Creek Tungsten Mine operation, the "discharge into the atmosphere (of pollutants) is relatively light from the mill and does not impart visually objectionable impurities. There is a definite sulfide odor which can be noted for miles both up and down the canyon. During windy periods, fine sediments are lifted from the tailings dump and pollute the air on a local basis before settling" (USDA, 1971).

Few fishermen use Pine Creek due to the lack of camping, picnicking and resort facilities. It is estimated that the area usage is generally 100 to 300 visitor days per year. Recreation opportunities in the canyon center around travel into the John Muir Wilderness Area just west of the mine and mill operations. The Pine Creek Pack Station, just south of the mill operations, provides pack service for about 250 wilderness travelers each season. Approximately 2250 backpackers leave yearly from the trailhead near the confluence of Gable Creek and Pine Creek (USDA, 1971). These people are currently impacted by the smell of hydrogen sulfide under certain weather conditions, however, Great Basin Air Pollution Control District has received no complaints and has not felt it necessary to monitor Pine Creek Canyon (Fryxell, 1980).

7.2.5.2 Impacts/Constraints

7.2.5.2.1 Emission Sources

Air pollutant emissions generally are greatest during the pre-operational phase of geothermal resource development, rather than during continued operations. The sources of pollutant emissions from each phase of the project development and operations are discussed individually below.

7.2.5.2.1.1 Drill Site Preparation

Production and injection wells and related structures at the Pine Creek site will be located on previously graded surfaces, eliminating the major grading usually necessary for drill site preparation. Therefore, adverse effects created by this process, such as accumulation of fugitive dust and susceptibility of the earth to erosion, are not anticipated.

7.2.5.2.1.2 Well Drilling

During drilling, emissions from diesel drives on the drilling equipment will release combustion emissions (principally oxides of nitrogen and carbon monoxide) that may create local pollutant concentrations. Additional minor vehicular emissions from drilling crew traffic could also be added to the local airstream if new workers do not use the bus. To quantify the amounts generated from these sources, additional information would be necessary regarding drilling equipment utilized, the number of persons included in the drilling crew, and their method of transportation to and from the site (bus or individual vehicles). If a high level of H_2S is encountered during drilling, small amounts may occasionally escape. However, normal drilling procedures generally do not create problems related to this emission.

7.2.5.2.1.3 Flow Testing

The most probable adverse effect of the Pine Creek project on air quality will occur during well cleanout; any noncondensable gases such as H_2S may be noted at nearby locations. Considering that only one injection well and one production well are anticipated at the site, the magnitude of this impact is expected to be low.

7.2.5.2.1.4 Operational Emissions

During operation of the geothermal system, amounts of H_2S could be emitted to the atmosphere. These amounts should be fairly low, due to the size of the project. As previously mentioned, this emission is currently released at the site because of the mine operation. Therefore, any addition would incrementally increase the present levels.

A definitive source receptor analysis of hydrogen sulfide emissions is possible because of the definite source and low threshhold of odor nuisance. By applying a Gaussian diffusion equation to a wide scenario of meteorological conditions and input characteristics, the probable "envelope" of potential H_2S impact during well flow testing could be defined. This would probably be necessary since Union Carbide's current monitoring is generally done manually.

Any other increases anticipated to occur because of electrical generation or combustion of fuels would need to be identified and quantified. Based on the air pollution control district's air monitoring measurements of pollutants in the Bishop region, and on air monitoring occuring at the site, a standard emission analysis should follow. This analysis should include 1) total suspended particulates, 2) sulfur dioxide, 3) carbon monoxide, 4) oxides of nitrogen, and 5) total hydrocarbons. Any site-specific pollutants, such as hydrogen sulfide, sulfur dioxide, or ammonia, should also be quantified, and compared with any State or Federal standards.

7.2.5.2.2 Local Impacts

Visitors to the surrounding wilderness area would be affected by any increased air pollution emissions. Hydrogen sulfide would be the obvious offender, and could degrade the quality of a wilderness experience. However, it should be noted that some natural wilderness areas which exhibit or are near thermal features also have this odor. As stated earlier, present discharge into the atmosphere is relatively light and does not impart visually objectionable impurities. The sulfide odor is already present and can be detected for miles up and down the canyon. The nearest urban center, Bishop, is located approximately 16 miles due east of the mine site; sulfide emissions are generally dispersed by this point.

The cumulative impacts of all emission sources is anticipated to be small, with the most serious impacts to aesthetics in the surrounding wilderness areas. The impacts to air quality are neither unique nor excessive and would not act as a constraint to the proposed geothermal project.

7.2.5.3 Mitigation/Alternatives

Although the project impact is small, especially during the operational phase of the program when emissions are essentially negligible, certain specific actions will help minimize the air quality impact. Regular watering during any dust raising construction, drilling and testing activities could reduce local dust levels. If the number of vehicles traveling to and from the site during the site preparation phase is anticipated to increase, then restricting direct access to the site, or preparing an oiled access and parking area could reduce air quality impacts from vehicles. New employees should be strongly encouraged to use the bus provided by Union Carbide Corporation.

The fact that geothermal energy will replace energy generated by the combustion of fossil fuels will result in a net air quality improvement. Average system energy savings can be computed when more information is available regarding the resource. In addition, the total resulting emissions can be computed and compared with current emissions if the project proceeds. Future mitigation measures may be necessary and can be presented when the project is more fully defined.

7.2.6 Visual Quality/Aesthetics

7.2.6.1 Environmental Setting

The project site is located at the western end of Pine Creek Canyon on the eastern side of the Wheeler Crest, a north/south trending ridge between the main Sierra crest to the west and Round Valley (the northern extension of Owens Valley) to the east. The existing tungsten mine is tunneled beneath the lower slopes of Mount Morgan but is not visible on the surface except for the portals (mine entrances). The tungsten mill and related facilities are situated near the confluence of Pine, Morgan, and Gable Creeks. The Pine Creek Pack Station is just south of the Union Carbide facilities and trails into the John Muir Wilderness Area leave from three locations in the vicinity of the Union Carbide operations. The trailhead near the pack station is the most frequently used trail (Leys, 1980).

The Union Carbide Tungsten Mine, mill, and related facilities are located at the end of a road traversing the length of Pine Creek Canyon. This road begins at U.S. Highway 395 approximately 9.3 miles (14.9 km) north of Bishop. The portions of Highway 395 both north and south of the road to Pine Creek Canyon have been nominated as part of a scenic highway system for Inyo County. However, Pine Creek Canyon is not visible from Highway 395 because of its distance (approximately six miles from the highway to the easternmost portion of the canyon) and the intervening topography.

The road to Pine Creek Canyon passes through Rovana, a very small residential area where Union Carbide employees live. The tungsten mine and mill facilities are located at the western terminus of the road and are not visible from the residential area or from any populated area or major road. The Union Carbide mine and mill facilities are not generally visible from the road to the east until the last tailings pond is passed or from the pack station to the south due to the nature of the topography, forest vegetation, and the location of the road. The tailings ponds which settle out the mine and mill waste products and the pipelines which carry the wastes from the mill and mine to the tailings ponds are highly visible from the road. The silver tunnels used to encase the pipelines in some areas to prevent breakage from collapsing snow drifts are highly visible in the eastern end of the canyon, as are the steep slopes cut out of the northern hillsides for the road and tailings ponds. These features are visible from the surrounding wilderness forested areas as well as from the road.

The Union Carbide Tungsten Mine, mill, and related facilities are located just north of Pine Creek and immediately west of Morgan Creek. A narrow dirt road switchbacks up a steep slope just east of Morgan Creek to another mine portal. The appearance of the mill and office building area on the lower level is a startling contrast to the natural scenery but is dominated and dwarfed by the surrounding mountain scenery. The rock crusher building and conveyor tunnel located on the upper pad at a higher elevation are far more dominant than the buildings at the lower elevation. Numerous locations around the buildings are used for storage of parts and equipment which are not aesthetically pleasing.

The mine, mill and related facilities are expected to be visible from the old mining road which is now a hiking and riding trail leading from the Pine Creek Pack Station into the John Muir Wilderness Area. Another narrow dirt road leading to the previously used mine portals at higher elevations on the east side of Morgan Creek and any mining machinery left in that vicinity are probably visible to hikers and packers visiting Lower Morgan Lake and Mount Morgan.

A brief visual survey of Pine Creek Canyon during the winter season, when snow covered many areas, prevented an in-depth reconnaissance to determine if equipment stockpiles and mining debris are visible. If the proposed geothermal project proceeds, the environmental document should include field surveys of Pine and Morgan Creek Canyons and the lowest portion of the Gable Creek drainage, as well as the area surrounding the mill. This would serve to update the environmental data base for the area and would facilitate future monitoring of rehabitation.

7.2.6.2 Potential Impacts/Constraints

The introduction of geothermal testing and production equipment into the immediate area of the existing Pine Creek Tungsten Mine and mill would have an almost unnoticeable visual impact which would be largely temporary. The geothermal well would necessarily be placed somewhere on the existing pads of either the mill area or the upper area pad around the mine portal and electric substation, where much machinery already exists. Thus, the aesthetic impact would be insignificant. In addition, the drilling rigs would be temporary. From a close-up view, the transformation could even be a positive effect if the wells were placed in areas now used for parts storage or unpaved parking areas. There are no visual/aesthetic considerations which would act as a constraint on the proposed project unless the wells were to be located away from the existing facilities.

7.2.6.3 Mitigation/Alternatives

The presence of a drilling rig would probably be less obtrusive if located on the lower pad area rather than on the upper area near the mine portal. No other mitigation is considered necessary.

7.2.7 Land Use Compatibility

7.2.7.1 Environmental Setting

7.2.7.1.1 Land Ownership

The vast majority of land within a 14-mile (22.5 km) radius of the Pine Creek tungsten mine and facilities is publicly owned (Figure 7-7). Most of Round Valley, the Tungsten Hills, and the volcanic tableland to the east are within the Owens Valley Planning Unit of the Bureau of Land Management's Bishop Resource Area (Figure 7-8). At least 82 percent of the public lands in this planning unit have been withdrawn for special purposes, primarily the protection of the watershed for the benefit of the City of Los Angeles.

The vast majority of land in Pine Creek Canyon and in the nearby vicinity is under the jurisdiction of the U.S. Forest Service as part of Inyo National Forest, though there are a few isolated portions of land under private ownership. Approximately 20.7 acres 8.4 ha) just below the former location of Scheelite are owned by Inyo County.

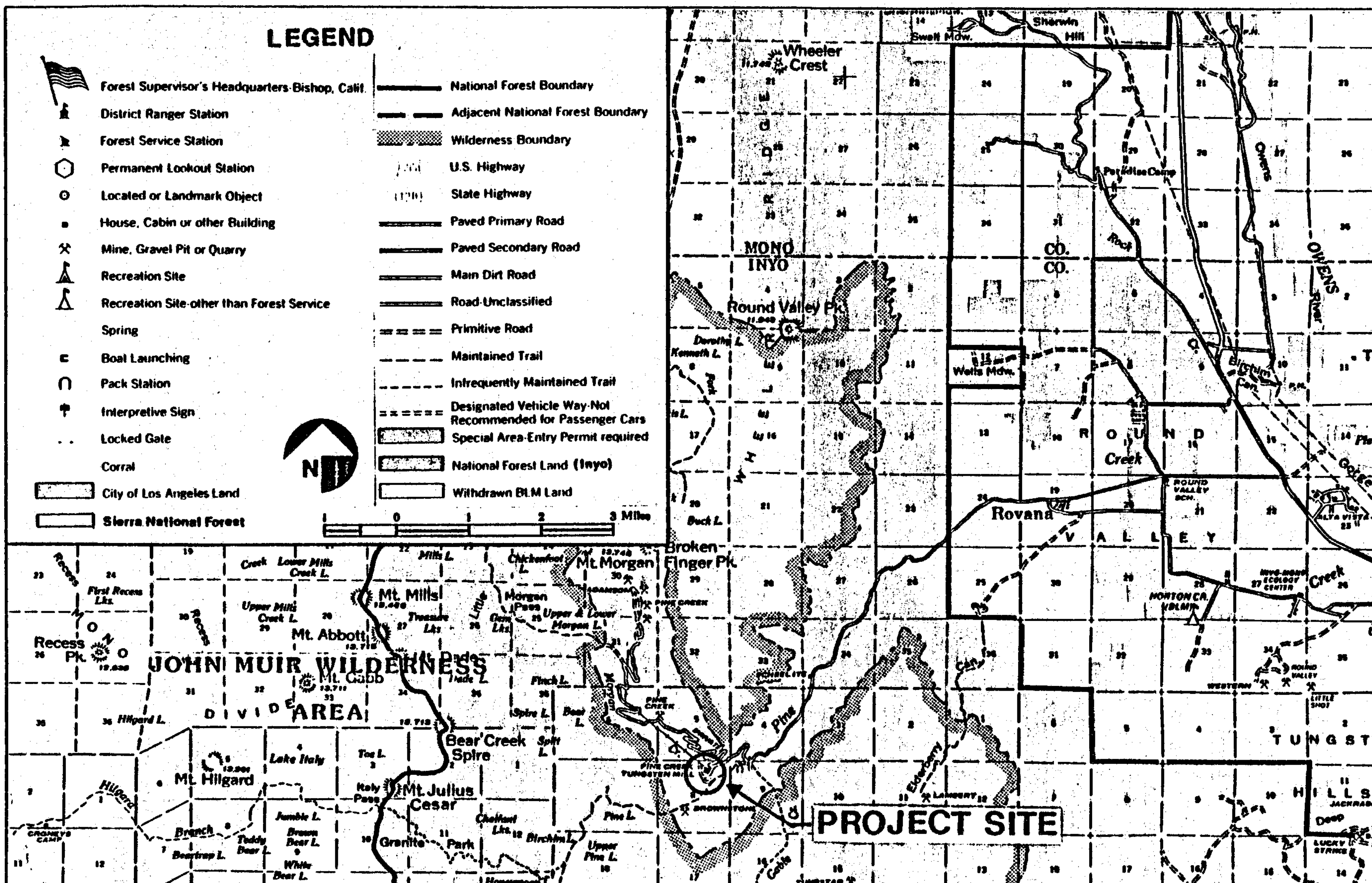
The Forest Service's Mammoth-Mono Planning Unit (MMPU) encompasses 695 square miles (444,744 acres or 180, 121 hectares) of land and water north of Pine Creek. The MMPU includes the John Muir Wilderness Area, which surrounds Pine Creek and Morgan Creek Canyons on three sides at higher elevations and includes Gable Creek Canyon (Figure 7-7). This wilderness area is administered by the Inyo National Forest office and requires a permit for entry.

The Pine Creek Tungsten Mill and related facilities are on privately-owned land within the publicly-owned Inyo National Forest. Much of the associate surface activities involve National Forest land under special use permits, mining, and millsite claims (Figure 7-9).

7.2.7.1.2 Existing Land Uses

Mining operations have dominated land use in Pine Creek Canyon since 1918. Early operations were situated in the hanging valley of Morgan Creek between 11,000 and 12,000 feet (3353 m and 3658 m), with access via the Rock Creek drainage and Morgan Pass. Union Carbide Corporation acquired an interest in the property in 1936 and has since enlarged and improved the mining and milling capacity. There may be previous mining and processing remnants at the 11,000 foot (3353 m) level above Morgan Creek Canyon. The steep narrow road leading to the former mine portal is still evident.

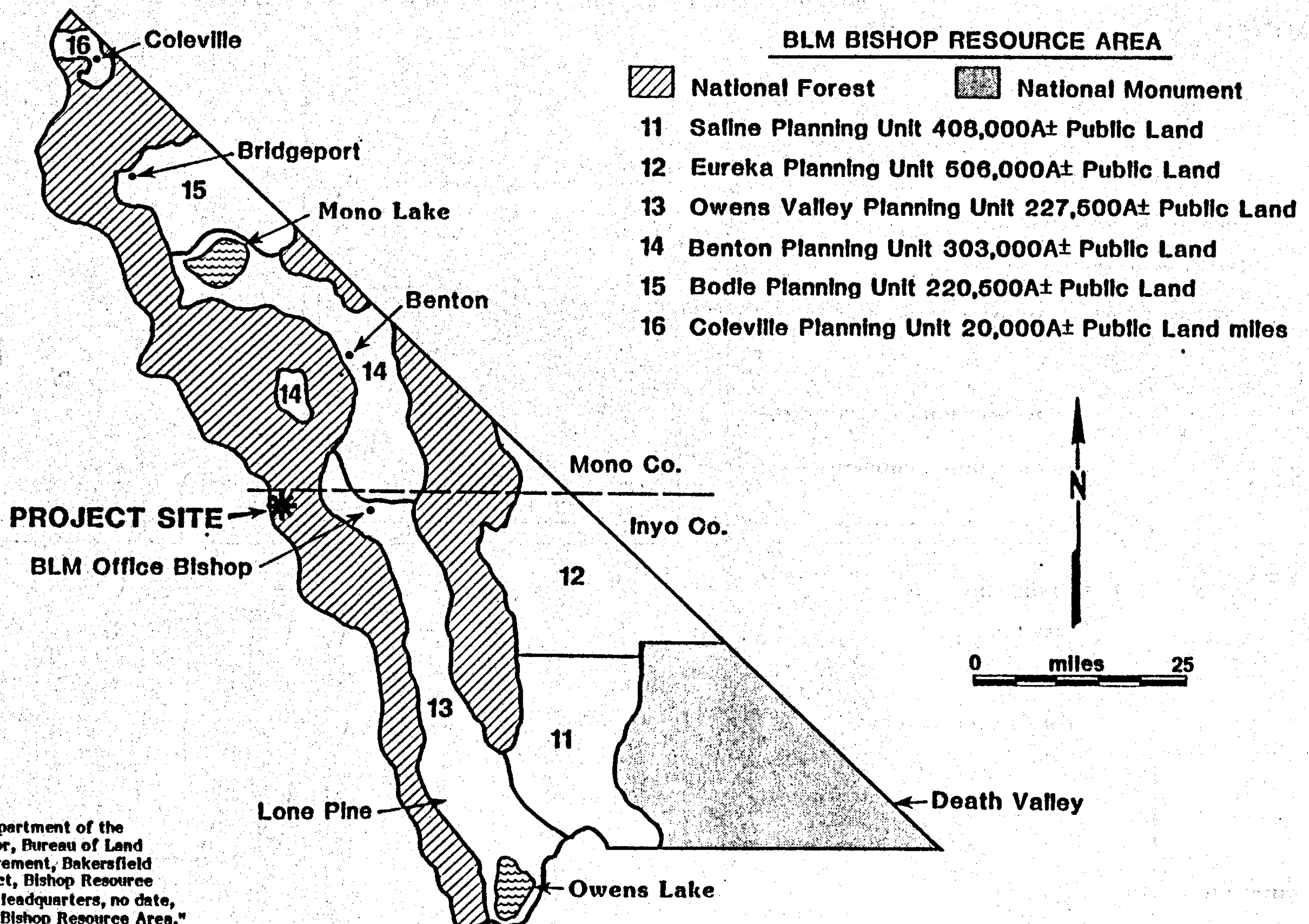
A small area known as Scheelite, located almost midway in Pine Creek Canyon, previously contained a tungsten processing plant and housing for Union Carbide employees. Although these have been removed, it is expected that this area probably is still used for storage. Approximately 20.7 acres (8.4 ha) just below Scheelite were previously used for a federal housing project constructed during World War II; the land is now owned by Inyo County. Although the buildings were removed, it is probable that some foundations still remain.



Land Ownership in the Project Vicinity

FIGURE 7-7

WESTEC Services, Inc.

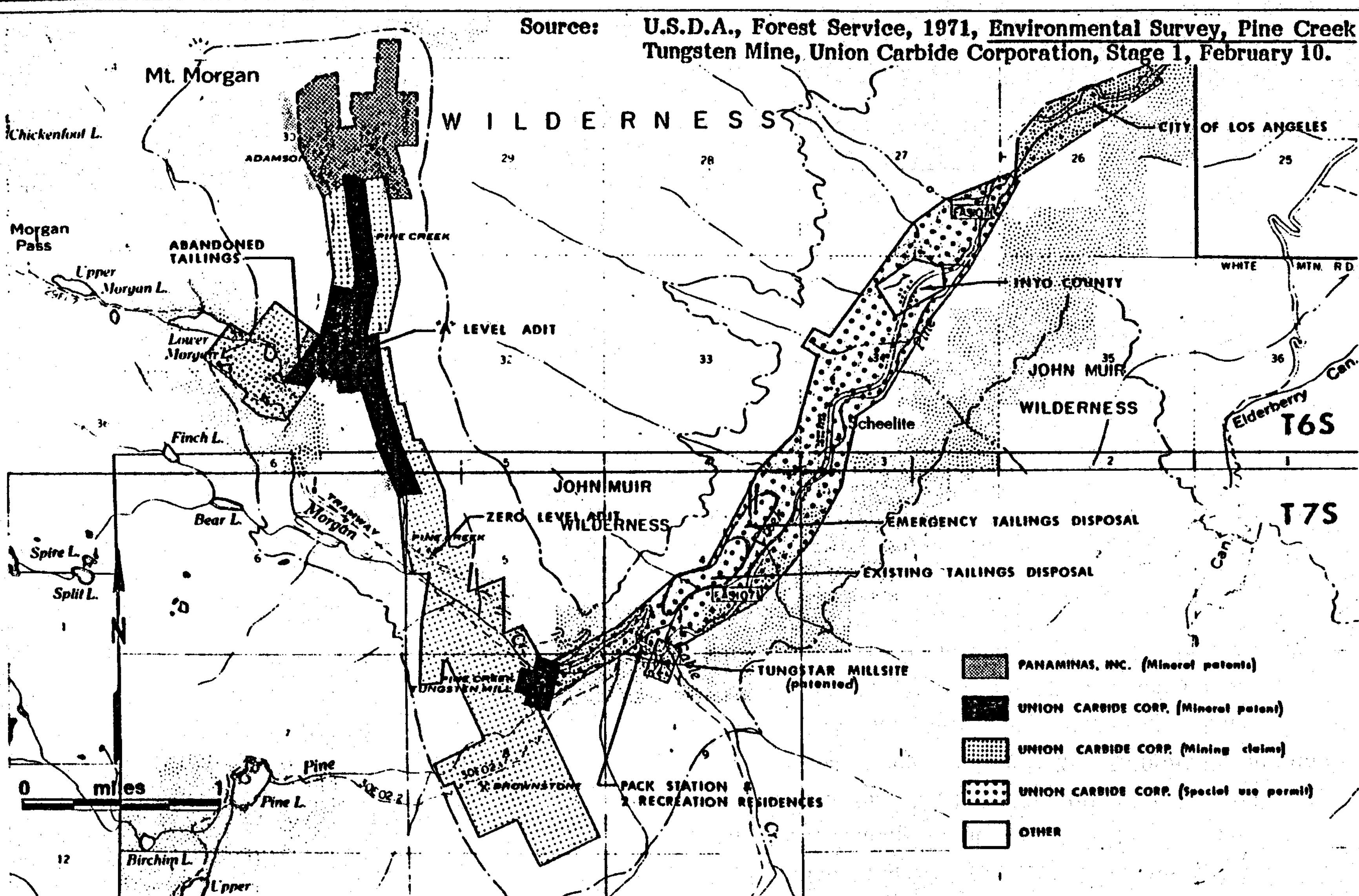


Source: U.S. Department of the Interior, Bureau of Land Management, Bakersfield District, Bishop Resource Area Headquarters, no date, "BLM Bishop Resource Area."

Bureau of Land Management Bishop Resource Area

FIGURE 7-8

Source: U.S.D.A., Forest Service, 1971, Environmental Survey, Pine Creek Tungsten Mine, Union Carbide Corporation, Stage 1, February 10.



Land Ownership and Use Permits, Pine Creek Tungsten Mine

FIGURE 7-9

Several tailings ponds are located adjacent to the road south of the mill site. Other remnants of past mining activity exist in the area near the confluence of Gable Creek and Pine Creek Canyons.

The Union Carbide Tungsten Mine, mill and related facilities are located at the westernmost (upper) end of Pine Creek Canyon and dominate the land use in that area. The tailings ponds and pipelines adjacent to the road are the first evidence of mine activities as one approaches from the east. The Union Carbide offices, the tungsten mill and its related facilities, and the parking areas are located just north of Pine Creek and immediately west of Morgan Creek at approximately 8000 feet. An unpaved road leads up to the mine portals, the "easy go tunnel," and the electrical substation at about 9500 feet (2896 m) on the west side of Morgan Creek. In addition, an unpaved road switchbacks up the hillside east of Morgan Creek to previously used mine portals and facilities at 11,000 feet (3353 m).

Pine Creek flows nearly year-round, however, few fishermen use the creek because of the lack of camping, picnicking, and resort facilities. Camping has been restricted in the canyon since about 1948 because Pine Creek was then the domestic water supply for the residents in Rovana, just east of the canyon. Rovana no longer relies on Pine Creek, however, the restrictions have never been lifted. It is estimated that the area usage is generally 100 to 300 visitor days per year. Recreational opportunities in the canyon center around travel into the surrounding John Muir Wilderness Area. The wilderness area is a popular one for hiking and back country activities. The Pine Creek Pack Station just south of the tungsten mill and related facilities generally provide pack service for about 250 wilderness travelers each year (USDA, 1971).

The John Muir Wilderness Area nearly surrounds the Pine Creek Tungsten Mine and mill on three sides. It includes all of the land at higher elevations above the rims of Pine Creek and Morgan Creek Canyons and most of Gable Creek Canyon. Heavily used by backpackers, it is a popular backcountry area. The Forest Service has recently had to limit the number of permits for this wilderness area to 50 people per day (Leys, 1980). At least 2250 of these annually leave from one of the trailheads in Pine Creek Canyon (USDA, 1971), primarily from the trailhead that follows Pine Creek up to Pine Lake (Leys, 1980).

7.2.7.1.3 Land Use Management

The U.S. Forest Service defines the land use management goals and policies for the project site and all of the land immediately surrounding the site. The Mammoth-Mono Planning Unit's Land Management Plan includes a portion of the John Muir Wilderness Area to the northwest of Pine Creek Canyon (USDA, 1979). The entire Pine Creek Canyon area is within the Forest Service's White Mountain Ranger District within Inyo National Forest. The Pine Creek area, as well as the surrounding wilderness land within Inyo National Forest, is currently covered by the Forest Service's 1972 Multiple Use Plan for Inyo National Forest. Although this plan is still in effect, it is currently being updated. The revised plan is expected to be completed by 1983 and will replace the Mono-Mammoth Planning Unit Land Management Plan (Suter, 1980).

The 1972 Multiple Use Plan for Inyo National Forest noted that mining was the dominant land use in Pine Creek Canyon at that time. It also noted that mining has effects on other resources and recommended restoration measures for mined areas. The plan made a number of recommendations relating to land use management in Inyo National Forest. It was recommended that the Forest Service should: 1) acquire as much private land as possible; 2) construct and develop trails and trail facilities; 3) construct day-use facilities at trailheads, such as the trailhead for the Gable Lakes trail; 4) prepare a recreational composite management plan for the Pine Creek water influence and crest zone; 5) eliminate unnecessary storage areas around the mines inside the national forest; and 6) develop new tailings ponds which will be more easily restored to natural conditions upon closing of the mine (Leys, 1980).

7.2.7.2 Potential Impacts/Constraints

The addition of a geothermal resource program to the immediate vicinity of the Pine Creek Tungsten Mine and mill would probably have no significant land use impacts since this would merely be an extension of the existing industrial uses onsite. The existing land use plan for Inyo National Forest recognizes the presence of the mine and has sought only to improve rehabilitation of the area; it has not proposed the elimination of the current uses.

If the proposed geothermal well drilling and testing period generates a substantially larger number of people in the area than there are at present, the use of the canyon for quiet activities such as fishing, hiking and birdwatching could be further impacted. However, this would be a temporary effect and would diminish after the testing period. It is likely that the geothermal operations onsite will hardly be noticeable and will be far less significant then the existing mining operations.

The other potential secondary land use effects of geothermal production relate to the presence of sulfurous odors during certain weather conditions and noise intrusions into a wilderness area, and thus, the reduction of the quality of the wilderness experience. However, it should be noted that many natural geologic features emit sulfurous odors and it is possible that this odor might be present in the area even without any manmade intrusions.

In summary, there are no potential land use impacts which would act as a constraint on the proposed geothermal program as long as the wells are on the existing pads.

7.2.7.3 Mitigation/Alternatives

The proposed geothermal program would have the least land use impacts if the wells were located in the immediate vicinity of the existing mill and related facilities on the lower level (8000 feet).

7.2.8 Archaeological Resources

7.2.8.1 Environmental Setting

The Pine Creek Tungsten Mine is situated at an elevation of approximately 8000 feet above mean sea level along the eastern slope of the Wheeler Crest. Located near the juncture of Pine and Morgan Creeks, the project site is within the upper montane-subalpine forest formation. Dominant species include Jeffrey pine (Pinus jeffrey) and fir (Abies sp.).

The mill itself is situated on a man-made flat created by filling a portion of the canyon floor with mine tailings. An adjacent hillside has been terraced to accommodate mine facilities. Natural slopes surrounding the project are steep bedrock and talus slopes, frequently exceeding fifty percent.

The presence of a steady water flow, timber for shelter and construction material, and readily available food sources would have made the Pine Creek area a suitable place for human habitation and exploitation. The availability of large bedrock outcrops in the vicinity of the tungsten mill that could have been used for milling or processing food stuffs further increases the potential for aboriginal use.

A survey of available literature and record searches at the University of California at Riverside and the U.S. Forest Service White Mountain Ranger District indicates that no known archaeological or historical sites are situated on or within three miles at the project area. However, it should be stressed that no field survey has been conducted within the project vicinity or on the Union Carbide property. It is possible that although badly impaired by landform alteration, unexamined and thus undiscovered sites may exist. It is also possible that the Pine Creek area possesses historical significance as a technological-historical feature of the land.

The lack of research and field surveys in the area makes it difficult to estimate the potential for archaeological resources. However, it can be generally stated that the native Americans who occupied the general project area in prehistoric times were probably Northern Paiutes, a Shoshone-speaking tribe. Their two tribal groups, the Mono Lake Paiute and Owens Valley Paiute, were nomadic and somewhat dependent on seasonal food supplies. These two tribes have left tools and structures in areas slightly to the north indicating at least 6000 years of occupation. In some of those areas, the predicted archaeological site densities ranged as high as 51 sites per square mile (U.S. Forest Service, 1979b; Heizer and Whipple, 1973; Powers, 1976).

7.2.8.2 Potential Impacts/Constraints

Until a field survey is conducted in and around the project site, potential impacts to, or adverse effects upon, cultural resources cannot be determined. Past impacts to the landform may have already destroyed or badly impaired cultural resources if they existed on the project site. Although it is possible that such resources still exist, the probability is relatively low given the degree of landform alteration. Nevertheless, further destruction or impairment of cultural resources would constitute adverse impacts. Evidence dating from early historic mining and ranching activities are probably the most likely materials to be encountered, although prehistoric material could also be present (Goggin, 1980; McCarthy, 1980).

7.2.8.3 Mitigation/Alternatives

To ensure that potential adverse impacts will not occur to cultural resources that may exist on the project site, a series of data recovery programs are recommended. Phase I should consist of a 100 percent in-field systematic survey of the entire project area and adjacent areas that may be indirectly affected. If the survey is negative and no cultural resources are encountered, mitigation will be achieved through report preparation and official review. This should include an analysis of the historical significance of the area. The absence of resources will preclude the necessity for further analysis or research.

Should cultural resources be discovered on or near the project area, mitigation can be achieved through: (1) full preservation of significant resources, (2) partial preservation in combination with a data recovery excavation program or (3) full site salvage and data recovery through an extensive data recovery excavation program. Regardless of which Phase I mitigation program is pursued, the historical significance of the area should be fully discussed. Any proposed mitigation program beyond the Phase I field survey should be carefully coordinated with the State Office of Historic Preservation, the Native American Heritage Commission, and other involved agencies.

7.3 KNOWN DATA SOURCES NOT YET REVIEWED

The Natelson Company, a private consulting firm in Los Angeles, is preparing a joint Geothermal Element of the General Plan for Mono and Inyo Counties with a specific element for each County which should be available by fall 1980. Environmental statements which support the geothermal leasing program have been prepared by the Department of the Interior beginning in 1973. The Bureau of Land Management State office in Sacramento is presently reviewing those statements that pertain to Inyo County, and will forward them to WESTEC. Additional data for the region as a whole may be available from private companies in the area, such as Southern California Edison. A complete data search for the region would require much additional research in the Bishop, Independence and Sacramento areas.

7.4 CONCLUSION

The environmental assessment failed to turn up any potentially significant environmental effects which might result from geothermal development at the Pine Creek Tungsten Mine and mill sites. As long as the geothermal facilities are located on the existing pads, no significant adverse environmental effects are anticipated. If the facilities were to be located anywhere else, additional environmental research would be necessary.

In order to meet the requirements of the National Environmental Policy Act (NEPA) and of the California Environmental Quality Act (CEQA), certain additional environmental research would be required before any geothermal program could be initiated. A biological field survey would have to be conducted during a snow-free period, followed by a written report. The report would have to include an inventory of vegetative types, a discussion of high interest plant and animal species known or thought to be in the immediate vicinity of the mine and mill facilities, and a notation of areas with potential problems. The biological report could be tied in with a visual survey of Pine Creek, Morgan Creek, and Gable Creek Canyons and the portion of the John Muir Wilderness Area directly above and adjacent to these canyons. The visual survey should note existing disturbed areas and the general health of the forest. Color photographs should be taken of areas where numerous plants or trees appear to be unhealthy or where there is a noticeable absence of wildlife. Yearly visual surveys, and possibly some biological reconnaissance, should be used to monitor any changes in the health of the forest for the duration of the geothermal program. There is already a good deal of water quality monitoring in Pine Creek Canyon. This should be continued and tied in with the biological and visual surveys to document possible impact areas.

A full archaeological survey of all open areas around the mine and mill facilities should be conducted. If no cultural resources are encountered, the written report will end the research. If cultural resources are discovered on or near the project area, there are generally a number of possible data recovery programs available. These alternatives can almost always be used to mitigate potential environmental effects to a level of insignificance.

Air quality monitoring in Pine Creek Canyon and in the John Muir Wilderness Area directly above the canyon should be conducted prior to and during the life of the geothermal operations. At the minimum, this monitoring should measure the amounts of hydrogen sulfide and particulates. A quantitative analysis should then be made of the increased amount of various emissions as compared with the decreased emissions resulting from the elimination of a portion of the fuel oil currently burned to produce power.

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SECTION 8

ALTERNATE SITES AND ENERGY SOURCES

8.1 INTRODUCTION

Installation of a geothermal energy system described for use at the Pine Creek complex was designed for a resource that would deliver fluid with a temperature of 121C (250F) at the wellhead. Due to the initial geophysical interpretation of the surrounding area and geochemical analysis of local groundwater, reaching geothermal fluid at this temperature may not be possible at Pine Creek because of the projected depth to which drilling may be required to reach an economically viable resource. An examination of other local resources was undertaken to determine possible options for replacing some portion of conventional energy requirements at the Pine Creek tungsten complex with alternate energy sources.

8.2 MONO-LONG VALLEY KGRA

A survey of alternative energy potential for use at the Pine Creek tungsten complex first evaluated the feasibility of transporting geothermal fluid from a known resource. An abbreviated map of Mono and Inyo Counties shows the proximity of the Mono-Long Valley Known Geothermal Resource Area (KGRA) to the Pine Creek tungsten complex in Figure 8-1. This possible location for drilling geothermal wells to supply energy to the Pine Creek tungsten complex is described in further detail below.

8.2.1 Transportation from Mono Long Valley

The closest resource to the mining and processing complex is the Mono-Long Valley KGRA which is approximately 30 miles from the project site. Considering the high temperatures of brine in this KGRA at relatively shallow depths, the high temperature geothermal fluid has the potential of being delivered economically. The surrounding topography of the eastern Sierras is the main complication in the discussion of fluid transportation. Heat losses over long distance transport are compounded by the expense of pumping fluid over the mountainous terrain to reach the mill site.

Transport costs of geothermal brine decrease with increasing temperature because at higher temperatures the fluid contains a higher energy content per pound of delivered fluid. The production pipeline will be insulated to prevent excessive heat losses and the pipeline may be burned in concrete tunnels pending further heat transfer and environmental analysis.

The major cost of this project will be the pipeline from the KGRA to the Pine Creek tungsten complex, a distance of 34 miles if the pipeline route parallels existing roads. If required, a parallel reinjection pipeline will be laid concurrently with the production pipeline which will reduce pipeline installation costs per foot of pipe. If possible, reinjection will be conducted on the Pine Creek tungsten complex to reduce the large capital expense associated with the additional pipeline.

Various parameters influence the economic viability for geothermal fluid transport. Ideally, the point of end use should be located near the supply of geothermal

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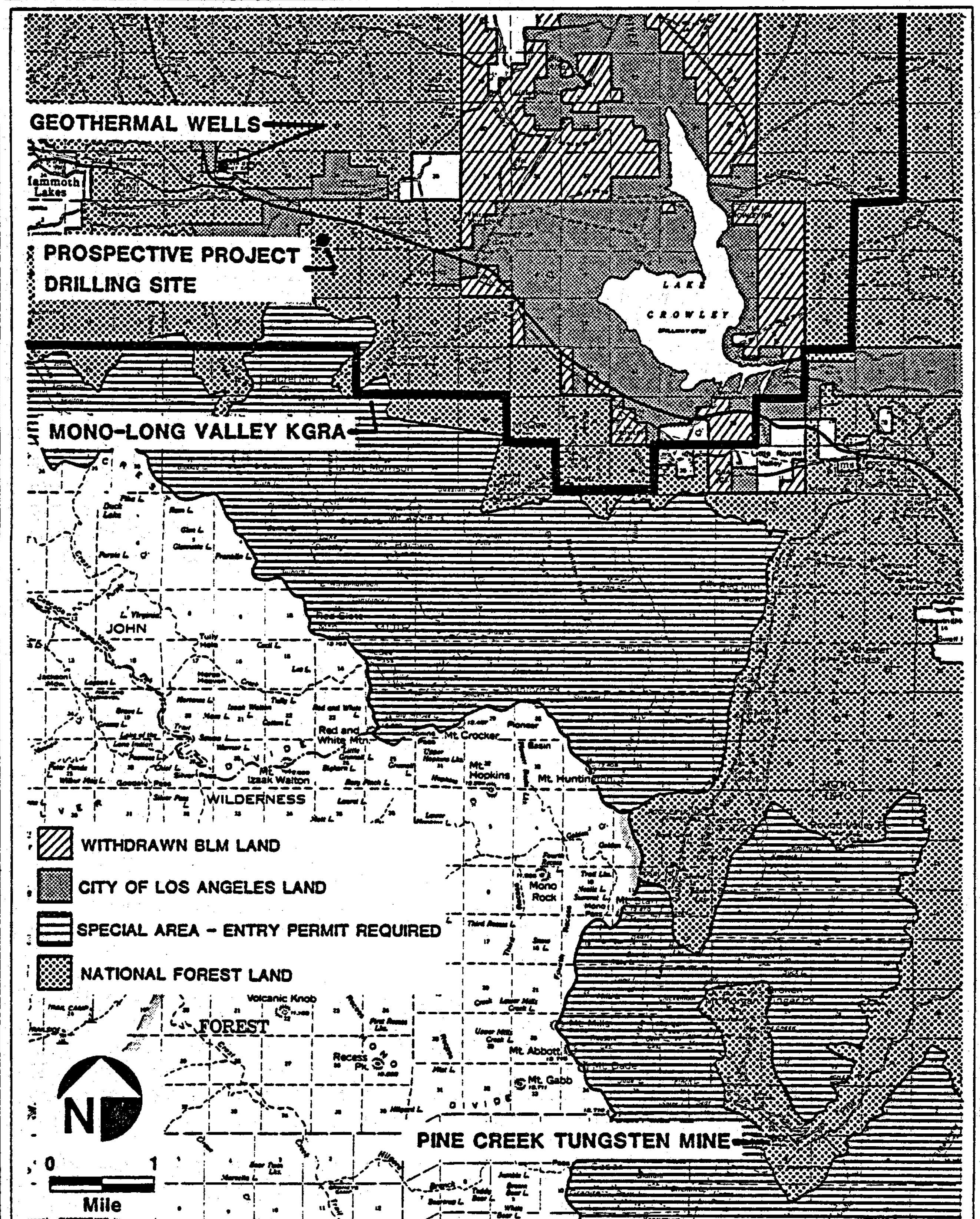

ALTERNATE SITE LOCATION MONO-LONG VALLEY KGRA

FIGURE 8-1

fluid, high temperature fluid should be transported to a large concentrated market, and the load factor for the geothermal system should be high. The unit cost of delivering heat in large pipes to meet large demands is much lower than delivering heat in small pipes. Large pipes are also attractive because they have a low surface area-to-volume ratio which reduces the percentage of heat loss from each pound of fluid.

It is anticipated that a high year-round load factor can be achieved at the tungsten mining complex because of the industrial water requirements. The tungsten mill normally operates 24 hours a day, 7 days a week, 365 days a year and the steam requirements are fairly constant for the tungsten processing. If the geothermal system is sized to handle the peak space heating load, the annual utilization factor should approach 40 percent. Fluid transport costs are primarily fixed costs with the exception of pumping expenses because the high initial capital expense of pumps and pipelines are independent of the utilization of pipeline capacity. Although variable costs increase slightly as the load factor increases, due mainly to additional pumping costs, the unit cost of delivered energy decreases as the load factor of system capacity increases (see Figure 8-2) because the large fixed costs are spread over more units of production.

8.2.2 Reservoir Assessment

The Mono-Long Valley KGRA is a major exploration target of geothermal development because of its recent rhyolitic volcanism and the hot springs and steam vents in the area. Examination of exploratory wells that were drilled in the Mono-Long Valley KGRA shows that five wells were drilled to a depth of 174 m-247 m (571- 810 ft) in T3S, R28E, Sec. 32. These wells had temperatures ranging from 157-181C (315-358F) as shown in Table 8-1. At these depths, the pressure ranged from 7.5 to 39 psig, steam produced ranged from 19,000 to 69,000 lbs/hr, and the hot water produced ranged from 233,500 to 473,000 lbs/hr. The silica dissolved in the geothermal fluids suggests a reservoir temperature of at least 185-190C (365-374F) (U.S. Department of Interior, 1973).

8.2.3 Site Selection

An initial location for a drilling site was chosen within the Mono-Long Valley KGRA in T4S, R28E, Sec. 3. This site was chosen in part for the minimal environmental impact of geothermal development based on the Environmental Assessment published by the USDA Forest Service as shown in Figure 8-3 (Rice, 1980). This project site specifically allows drilling of deep geothermal wells, plant siting and other activities related to geothermal development. The prospective drilling site is approximately three miles southeast of the area where the five exploratory wells have been drilled. This particular site was chosen for its proximity to successful geothermal wells and its location adjacent to Highway 395, which will facilitate grants for right-of-way and pipeline placement.

8.2.4 Institutional Barriers

The institutional barriers assessment for the final report as related to the Mono-Long Valley KGRA will address the following:

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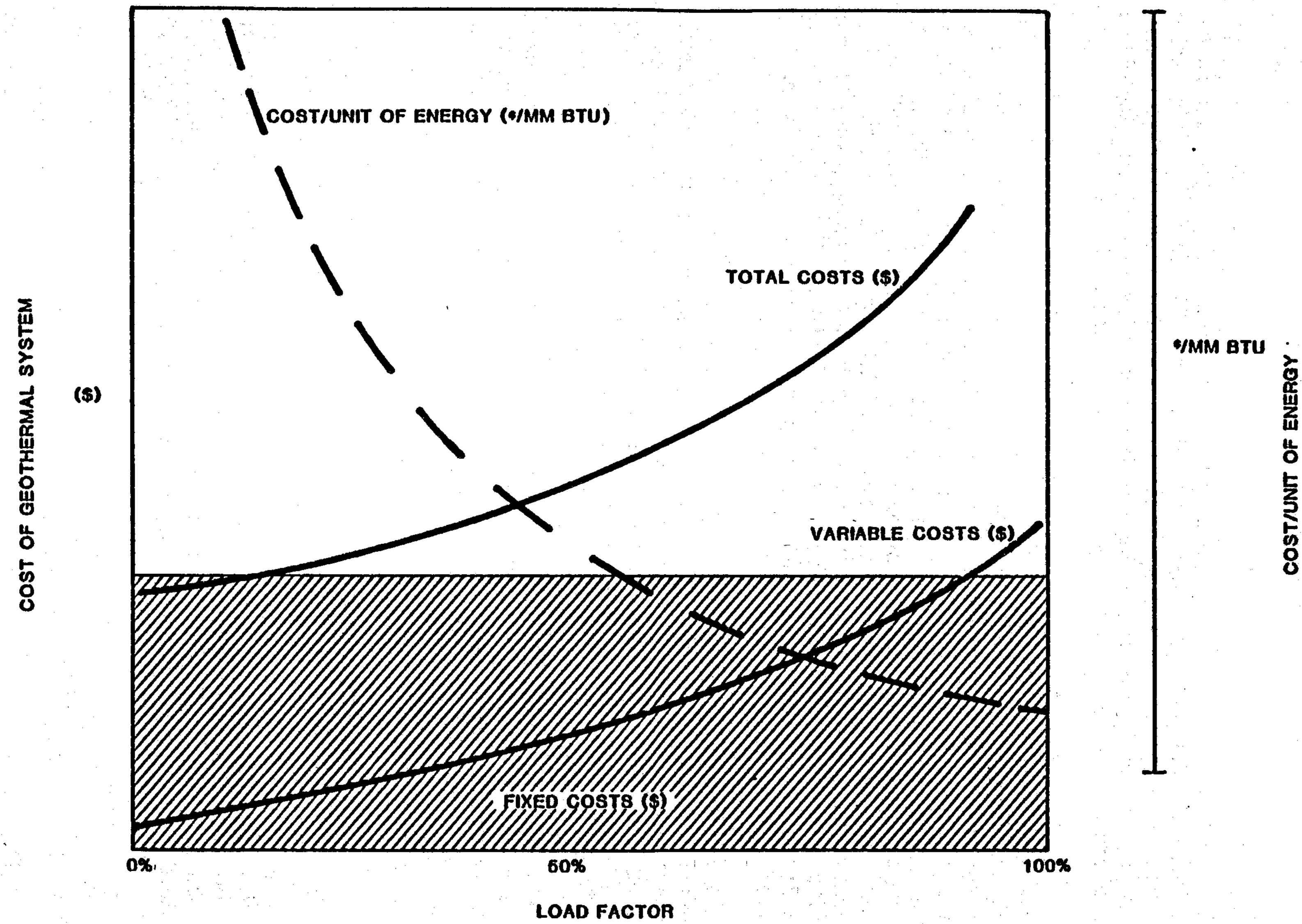


UNIT COST OF ENERGY VERSUS LOAD FACTOR

FIGURE 8-2

Table 8-1

WELLS IN MONO-LONG VALLEY KGRA

ENDOGENOUS 1

Location: T3S, R28E, Sec. 32, 184 ft N, 655 ft E, from W Q cor.

Well data:

- Depth - 192 m
- Temperature - 178C @ 122 meters
- Flow information - 69,300 lb/hr steam, 473,000 lb/hr water at 39 psig and 148C
- Ph - 7.50

Brine Data

Constituent	Concentration
SiO_2	278
Ca	2
Mg	Trace
Na	236
K	62
Li	4
Fe	5
Al	2
B	60
Cl	266
SO_4	108

Sources: McNitt 63, Witham 76

ENDOGENOUS 2

Location: T3S, R28E, Sec. 32, 516 ft N, 431 ft E, from W Q cor.

Well data:

- Depth - 247 m
- Temperature - 174C @ 122 meters
- Flow information - 45,000 lb/hr steam, 233,500 lb/hr water at 38.5 psig, 181C
- Ph - 8.61

Brine Data

Constituent	Concentration
SiO_2	250
Na	375
K	45
Cl	276
SO_4	62

Sources: McNitt 63, Witham 76

ENDOGENOUS 3

Location: T3S, R28E, Sec. 32, 866 ft N, 159 ft E, from W Q Cor.

Well Data:

- Depth - 174 m
- Temperature - 172C @ maximum
- Flow information - 19,000 lb/hr steam, 330,000 lb/hr water @ 30 psig and 157C

Brine Data

None Available

Sources: McNitt 63, Witham 76

Table 8-1 (Continued)

ENDOGENOUS 4

Location: T3S, R28E, Sec. 32, 797 ft N, 884 ft E, from W Q cor.

Well data:
- Depth - 156 m
- Ph - 6.50
- Temperature - Not Given
- Noncondensable Gas in Steam - 0.87 percent by weight 98.64 percent of gas by wt. is CO_2, 1.36 percent H_2S

Brine Data

Constituent	Concentration
SiO_2	200
Ca	4
Na	308
K	32
Li	.3
B	11
Cl	227
SO_4	96
H_2S	14
F	20
NH_3	.1
CO_2	180
As	.2

MAMMOTH 1

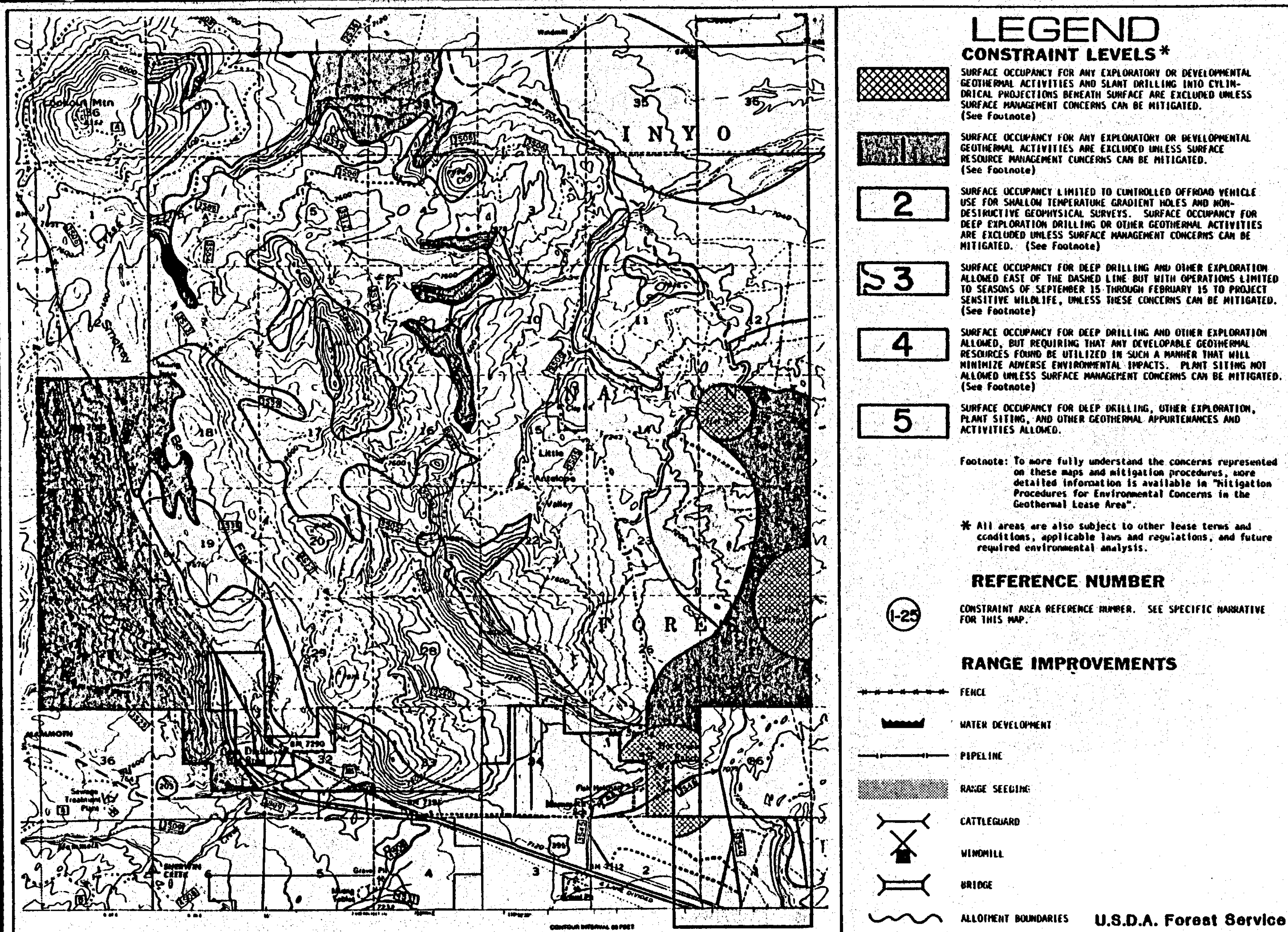
Location: T3S, R28E, Sec. 32, 1240 ft N, 3043 ft E, from NQ cor.

Well data:
- Depth - 324 m
- Temperature - 148C @ maximum
- Flow information - 25,000 lb/hr steam, 471,000 lb/hr water at 7.5 psig, 132C
- Ph - 8.00

Brine Data

Constituent	Concentration
SiO_2	292
Ca	30
Mg	Trace
Na	247
K	71
Li	3
Fe	4
Al	1
B	49
Cl	301
SO_4	124

Sources: McNitt 63, Witham 76



COMPOSITE ENVIRONMENTAL MAP

FIGURE 8.3

1. Since the alternate site is located on federal lands, leasing requirements and procedures for geothermal exploration on federal lands should be discussed.

2. Ownership of surface rights along the transmission corridor between the proposed well site in the KGRA and the tungsten mill site in Pine Creek should be researched.

3. Finally, governmental controls over surface use along the transmission corridor should be described.

8.2.5 General

Environmental constraints of developing an alternate site for delivery of geothermal fluid will be discussed in more detail in the final report. An engineering evaluation coupled with an initial economic assessment of all proposed project will also be addressed in the final study report. Capital investment for drilling geothermal wells in the Mono-Long Valley KGRA could be reduced or eliminated if the waste heat from a geothermal power plant is used for energy input at the Pine Creek complex.

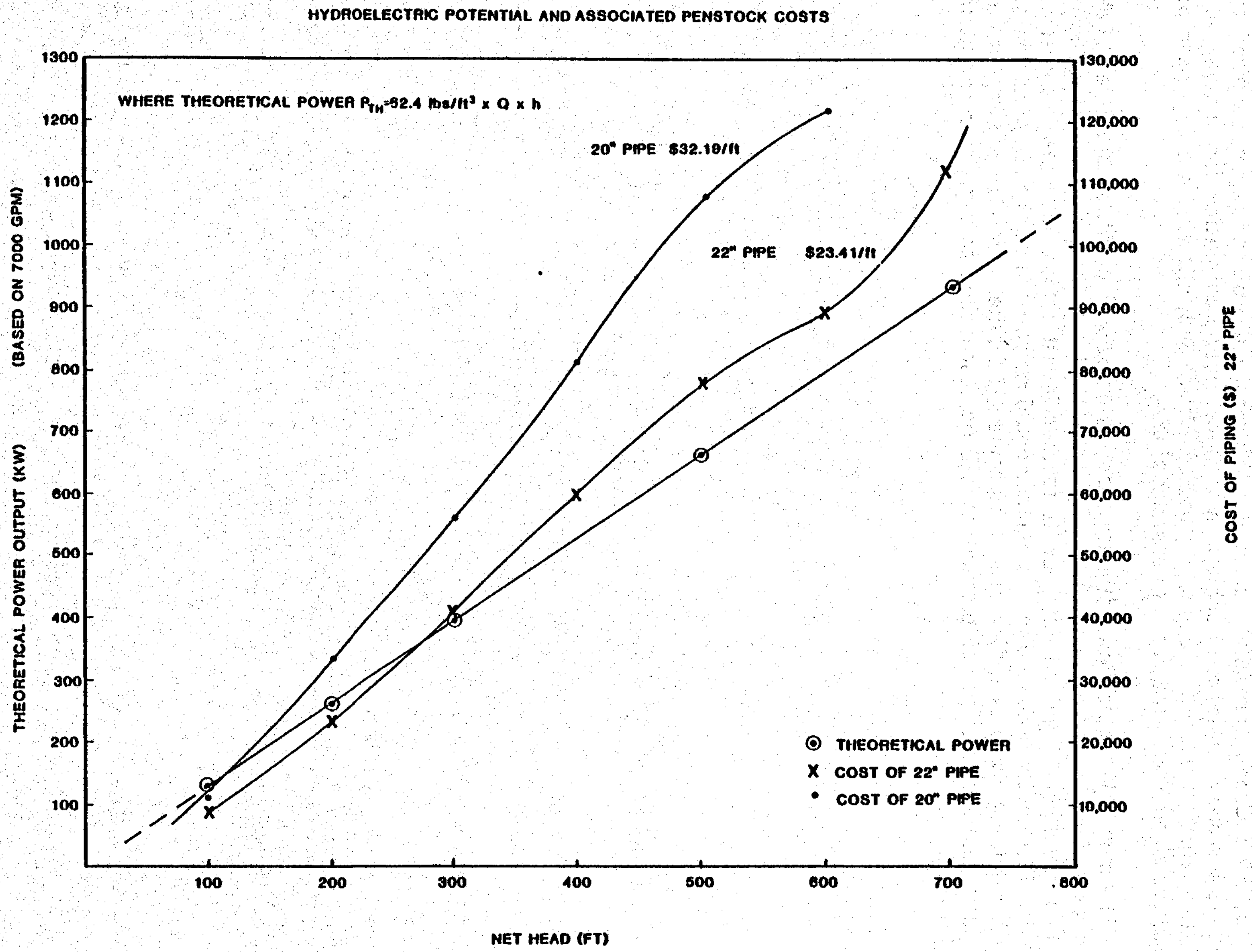
Relocation of the tungsten processing plant to the Mono-Long Valley KGRA could make the tungsten mill independent of conventional energy sources. A small portable turbine-generator could generate electricity for the mill and the steam discharge of the turbine could be used for the lower pressure requirements of the ammonium paratungstate process. An additional well could supply the high temperature, high pressure steam for the remaining steam requirements of the tungsten mill.

8.3 HYDROELECTRIC POWER AT PINE CREEK

The potential of hydroelectric generated power at the Pine Creek tungsten complex was investigated to determine theoretical and expected power output for a micro-hydro system. In order to avoid serious institutional and environmental problems, the initial evaluation was based on runoff from the water clarifier which discharges 6000-8000 gpm. Piping this water to some point at a lower elevation would necessitate little or no stream modifications and minimal construction costs.

The power output is dependent on what portion of the available elevation gradient is used. The theoretical power that could be produced by a hydroelectric turbine was evaluated for a number of elevation drops from the Pine Creek mill site using the formula $P_{TH} = 62.4\ lbs/ft^3 \times Qkh$ (Alward, 1979). A rough estimate for the theoretical power production and a cost etimate of the penstock for the associated power output is shown in Figure 8-4.

Conversion of the power in the water resource to mechanical shaft work will be less than predicted by theory as the equipment is less than 100 percent efficient. Water turbines are fairly efficient (75 - 85 percent) in converting the energy in the flowing water into mechanical or electrical energy. Water wheels have typical efficiencies of less than 50 percent. Other losses are incurred when transmitting power from the water wheel or turbine to a generator, alternator, or some mechanical system. Typical efficiencies for hydroelectric generation sytems range from 50 - 75 percent with the higher overall efficiencies occurring with the high speed, high heat turbines.



THEORETICAL HYDROELECTRIC POWER FOR PINE CREEK

FIGURE 8-4

The expected power output for an electrical generation facility with 65 percent overall efficiency is shown in Figure 8-5. Using data from the topographical map supplied by Pine Creek personnel, an estimation was made of the piping required to obtain elevation drops at specific points. A first order approximation for piping costs at the site-specific elevation drops is plotted on Figure 8-5, allowing a comparison of the power produced versus the cost of penstock piping.

The available water flow without construction of a reservoir at the Pine Creek complex is unusually low for commercial power production. However, a custom built turbine and generator might be obtained if further investigation warrants the cost of such a unit. Electricity produced in this manner could reduce the power consumption of the tungsten mining complex during peak load hours. If further investigation appears to be advisable, hydroelectric power production will be researched to a greater extent in the final report.

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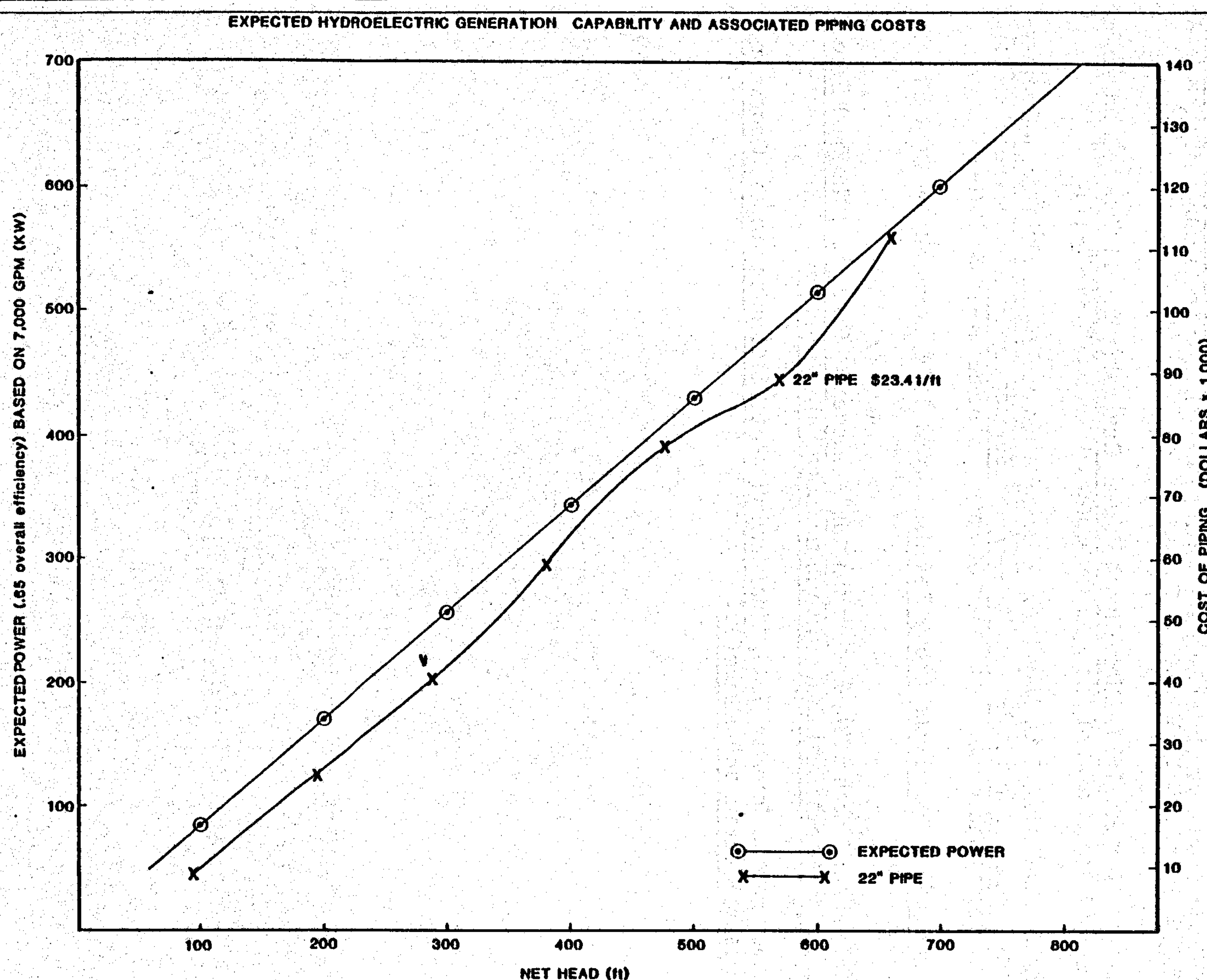

EXPECTED HYDROELECTRIC POWER FOR 65% EFFICIENCY

FIGURE 8-5

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APPENDIX A

APPENDIX A

The method for calculating heat flux from the office buildings and change rooms is shown below. A detailed calculation for heat losses is shown for the mill change room. Cross sections of a typical wall section is shown in Figure A-1. These heat flux calculations were used in calculating the heating load on the buildings that would replace current space heating with a geothermal energy source. Thermal properties and resistance values of typical building and insulating materials were taken from ASHRAE Handbook and Product Directory (ASHRAE, 1977).

HEAT FLUX CALCULATIONS

WALLS

U_{av} = $S/100\ (U_s) + (1 - S/100)\ U_i$

U_{av} = average U value for building section

U_i = U value for area between framing members

U_s = U value for area backed by framing members

S = percentage of area backed.

Using values from Figure A-2

20% framing typical for 2" x 4" studs

R_i = 13.53, U_i = .074; R_s = 6.91, U_i = 1.45

U_{av} = $20/100\ (.145) + (1 - 20/100)\ .074$

U_{av} = .0882 Btu/(h•ft^2•F)

WINDOWS

Flat glass, exterior, winter conditions

U = 1.10 Btu/(hr•ft^2•F)

DOORS

Exterior door, winter conditions

1.25 in. thick

U = .28 Btu/(hr•ft^2•F)

CEILING

Coefficient for pitched roofs (see Figure A-3)

R_i = 2.33, U_i = .43 R_s = 6.71, U_s = .149

10% framing typical of 2 in. rafters

U_{av} = 10/100 (.149) + 90/100 (.43)

U_{av} = .402 Btu/(hr•ft^2•F)

FLOORS

See Figure A-3

R_i = 13.68; U_i = .073, R_s = 11.74, U_s = .085

Typical 10% framing of 2 in. boards

U_{av} = .1 (.085) + .9(.073)

U_{av} = .0742 Btu/(hr•ft^2•F)

TOTAL HEAT TRANSFER COEFFICIENT

U_t = (U_{walls} x wall area) + (U_{door} x door area) + (U_{window} x window area) + ($U_{ceiling}$ x ceiling area) + (U_{floor} x floor area) + (infiltration)

MILL CHANGE ROOM

Volume = 42 x 32 x 10.4 ft = 13843 ft^3

Exterior walls gross

(42 ft x 10.3 ft)2 =	434
(32 ft x 10.3 ft)2 =	331
	765 sq ft

DOORS

2 (3 ft x 7 ft) = 42 sq ft

WINDOWS

5 (3 ft x 1.5 ft) = 22 sq ft

<u>EXTERIOR WALLS NET</u>

765 -42 -22 = 701 sq ft

<u>CEILING</u>

$(29\ ft \times 32\ ft) = 1856\ ft^2$

<u>FLOOR</u>

$42\ ft \times 32\ ft = 1344\ ft^2$

$$U_{total} = (701\ ft^2 \times 0.0882\ Btu/hr{\cdot}ft^2{\cdot}F) + (42\ ft^2 \times 0.28\ Btu/hr{\cdot}ft^2{\cdot}F)$$
$$+ (22\ sq\ ft \times 1.10\ Btu/hr{\cdot}ft^2{\cdot}F) + (1856\ sq\ ft \times 0.42\ Btu/hr{\cdot}ft^2{\cdot}F)$$
$$+ (1344\ sq\ ft \cdot 0.0742\ But/hr{\cdot}ft^2{\cdot}F)$$

$$U_{total} = 977\ Btu/hr{\cdot}F$$

Total heat flux = Total heat transfer from building + infiltration losses

$$= (977\ Btu/hr{\cdot}F)\ 60^{o}F + 2.16\ (13843\ ft^3)$$

Total heat flux $= 8.85 \times 10^4$ Btu/hr

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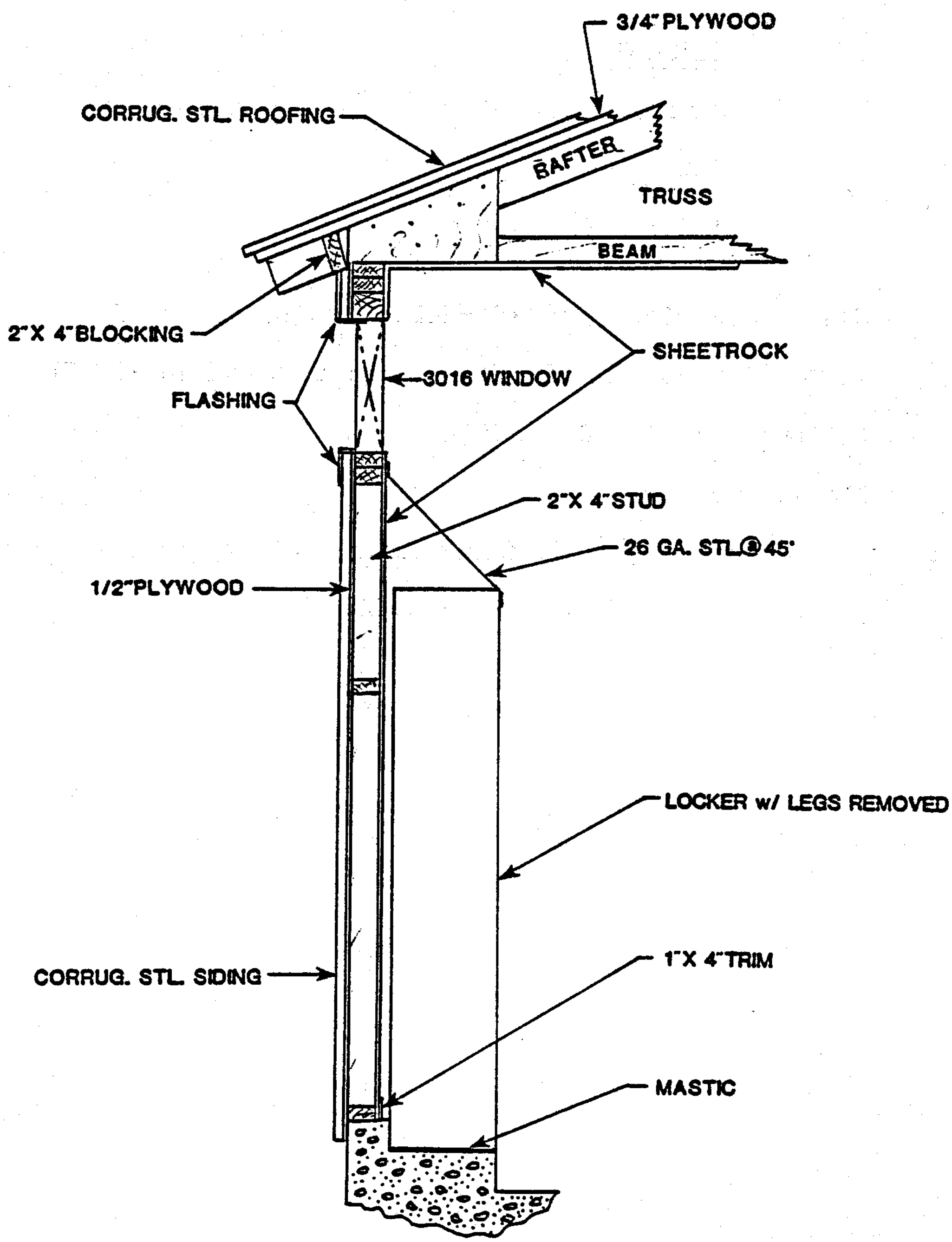
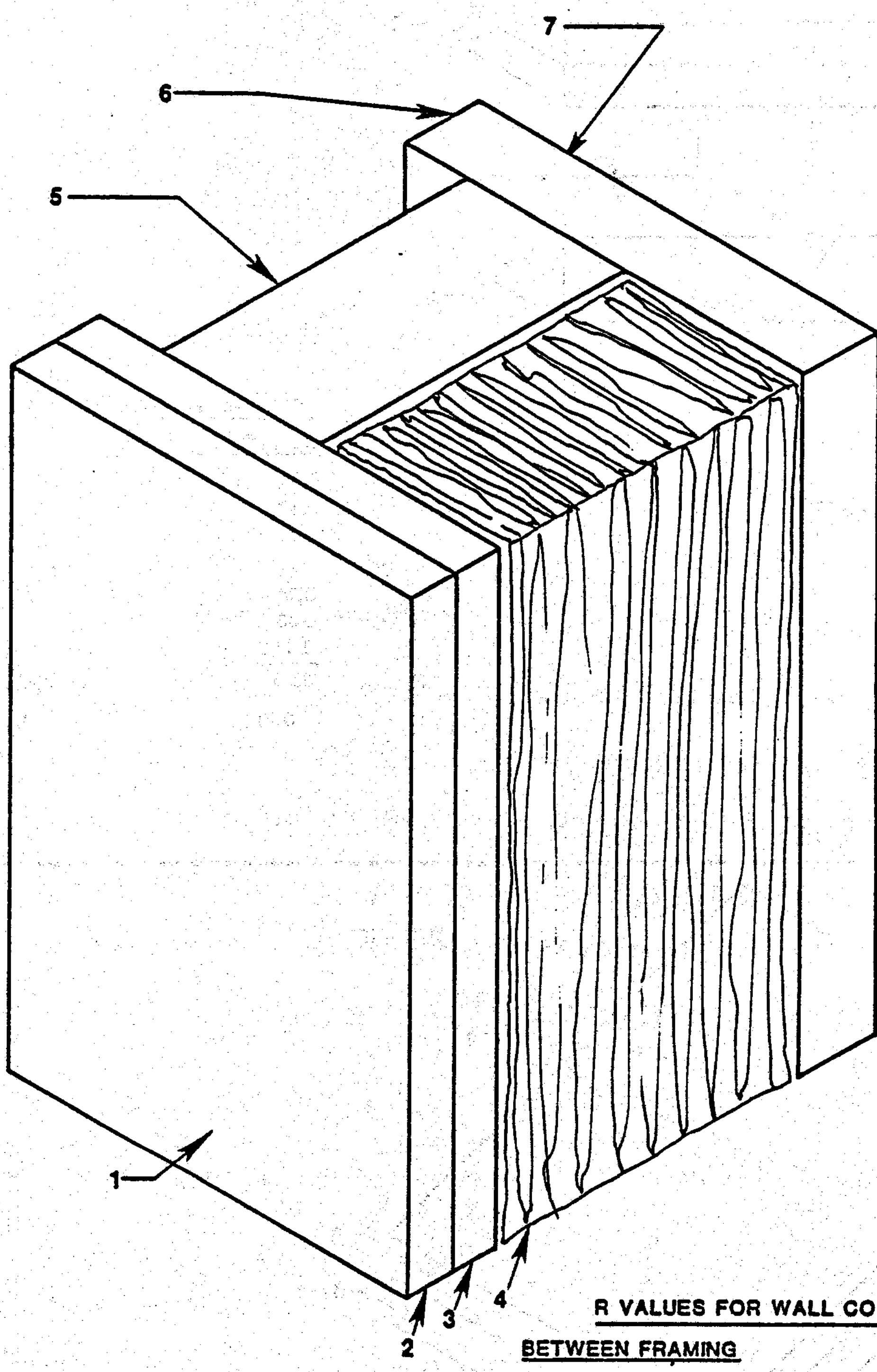


TYPICAL CROSS SECTION OF OUTER WALL 1/2"=1'-0"

FIGURE A1

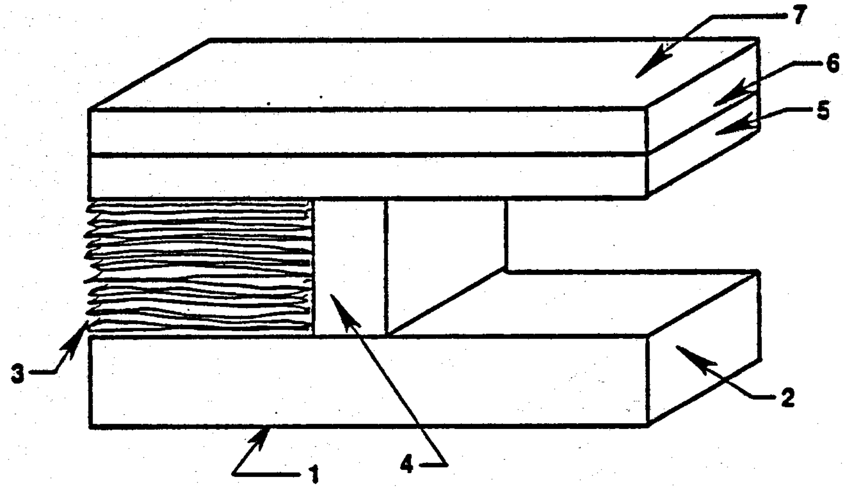


R VALUES FOR WALL CONSTRUCTION

	BETWEEN FRAMING	AT FRAMING
1 OUTSIDE SURFACE 15 MPH WIND	0.17	0.17
2 CORRUGATED STEEL SIDING	.61	.61
3 1/2" PLYWOOD	.62	.62
4 3.5" R11 INSULATION	11.00	
5 2" x 4" WOOD STUD		4.38
6 SHEETROCK	.45	.45
7 INSIDE SURFACE, STILL AIR	0.68	0.68
TOTAL THERMAL RESISTANCE (R)	R_i = 13.53	R_s = 6.91

$U_{TOTAL} = 1/R_{TOTAL}$ U_i = .074 BTU/ft^2 x h x°F U_s = .145 BTU/ft^2 x h x°F

WALL CONSTRUCTION **FIGURE A-2**

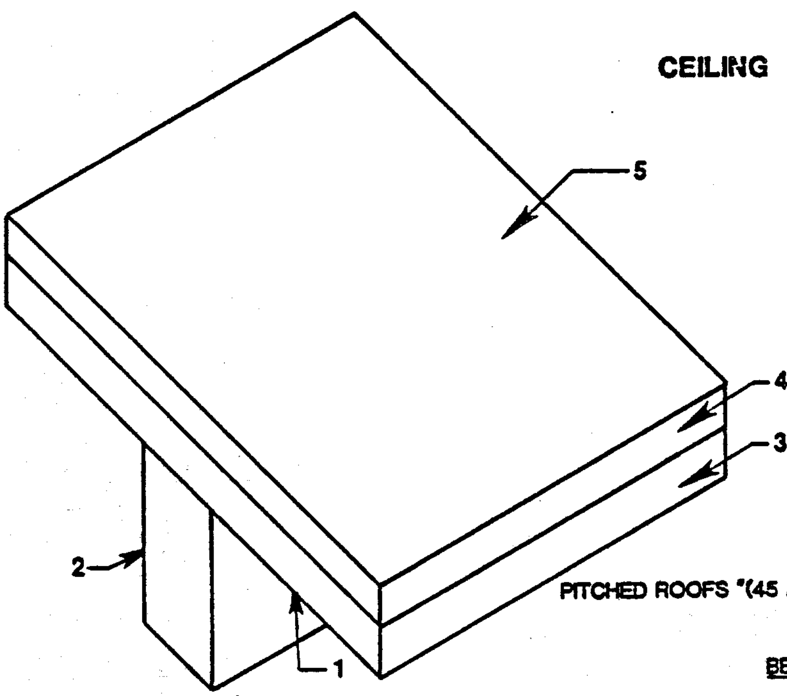


FLOOR

RESISTANCE VALUES (ft² x h x°F/BTU)

		BETWEEN FLOOR JOISTS	AT FLOOR JOISTS
1	BOTTOM SURFACE STILL AIR	0.61	0.61
2	LIGHTWEIGHT AGGREGATE PLASTER	0.47	0.47
3	R-11 INSULATION	11.00	
4	2"x 8" FLOOR JOIST		9.06
5	WOOD SUBFLOOR .75"	0.94	0.94
6	TILE	0.05	0.05
7	TOP SURFACE STILL AIR	0.61	0.61
	TOTAL THERMAL RESISTANCE	R_1 13.68	R_2 11.74
		U_1 = .073	U_2 = .085

CEILING



PITCHED ROOFS °(45 ANGLE) HEAT FLOW UPWARD

RESISTANCE VALUES (ft² x h x°F/BTU)

		BETWEEN RAFTERS	AT RAFTERS
1	INSIDE SURFACE (STILL AIR)	0.62	0.62
2	NOMINAL 2"x 4" CEILING RAFTER		4.38
3	3/4" PLYWOOD	0.93	0.93
4	CORRUGATED STEEL ROOFING	0.61	0.61
5	OUTSIDE SURFACE (15 MPH WIND)	0.17	0.17
	TOTAL THERMAL RESISTANCE (R)	R_1 = 2.33	R_2 = 6.71
		U_1 = 0.43 BTU/ft² x h x°F	U_2 = 0.149 BTU/ft² x h x °F

FLOOR AND CEILING CONSTRUCTION **FIGURE A-3**

APPENDIX B

RESERVOIR CONFIRMATION PLAN

A potential low temperature geothermal resource was identified at the Pine Creek Mine based on observations by Union Carbide personnel of relatively warm water springs inside the mine, by the mine's proximity to the extant Long Valley Known Geothermal Resource Area (KGRA), and by the mine's placement by NOAA (1977) in a potential KGRA. Hydrogeochemical investigations undertaken as part of this study indicate three thermally and chemically distinct groundwaters, which have been used to identify a potential geothermal reservoir with a temperature of up to 100°C (212°F) as the thermal component to the observed warm spring.

Confirmation of a geothermal reservoir at up to 100°C (212°F), capable of providing thermal fluid to produce the observed warm spring, must be approached through data acquisition closer to the anticipated resource. The reservoir confirmation plan includes phased data collection programs that will allow feasibility analysis of proceeding to each sequential phase.

Phase I. Additional Geochemical and Geophysical Investigations

Task: Geochemical studies of the individual diamond drillholes and fracture springs which contribute to the Easy Going Warm Spring system and identification of other groundwaters in the mine which may have a thermal component. Geophysical measurements in the mine should include heat flow measurements at various locations inside the Pine Creek Mine complex and thermal gradient measurements at various locations in existing drillholes. Seismic monitoring should be designed and conducted to reveal the locations of faults and other anomalies.

Discussion: Further geological studies will allow a refinement of the entropy of the source reservoir. Heat flow and thermal gradient studies will allow an estimate of depth to the resource. Seismic monitoring may identify paths by which geothermal fluids rise to near the surface. The results of the Phase I study will lower the financial risk of starting the investigation with the Phase II study.

Cost Estimate:

Geochemistry	$20,000
Heat Flow and Temperature Gradient	$25,000
Seismic Monitoring	$15,000
TOTAL	$60,000

Phase II. Exploration Drilling

Task: Drilling a small diameter intermediate depth range hole (600-1000 meters) (1968.6 to 3281 ft), performing borehole geophysical measurements and monitoring geochemistry of fluids encountered. Borehole geophysics should include induced current and gamma ray logs to indicate lithology, density and neutron logs to indicate porosity, and radioactivity logs. Temperature surveys, fracture frequency and orientation logs should also be conducted.

Discussion: Slim hole investigations will allow prediction of the depth at which usable temperatures can be achieved. Fluid productivity of rocks in the intermediate depth range will be determined and will allow projection of these parameters to reservoir depths. Initial understanding of the ability of the rocks to receive reinjected fluid can be evaluated. Geochemistry of recovered fluid samples mayallow a refinement of reservoir temperature. This phase will reduce the risk of drilling a production diameter and depth drillhole.

Cost Estimate:

Move-on Costs	\$ 12,000
Drilling (1000 m)	\$175,000
Expendable Materials (casing, etc.)	\$ 25,000
Data Analysis	\$ 12,000
TOTAL	\$224,000

Phase III. Drilling and Test Production Well

Task and Discussion: The production diameter drillhole should be drilled to the depth indicated in Phase II. Well completion should be per appropriate regulations, leaving the production zone chosen during drilling uncased. Perform borehole geophysics as in Phase II and run short duration production tests to determine feasibility of continuing project. Determine bottom hole temperature and make estimations of fluid productivity. If appropriate, proceed to next phase.

Cost Estimate:

Contractor Drilling and Supervisor	$ 504,000
Rig-up and Tear-out	$ 200,000
Drilling Fluids	$ 25,000
Non-salvable	$ 12,000
Transportation	$ 22,000
Contract Services (directional tools, surveys, etc., drill pipe, bits, etc. other subsurface services)	$ 82,500
Conductor Casing 100' - 10"	$ 7,500
Surface Casing 1000' - 13 3/8"	$ 37,500
Production Casing 7000' - 8 5/8	$ 172,500
Tubing 1000' - 2 7/8	$ 30,000
Well Head	$ 15,000
Master Valve	$ 7,000
Well Pump and Motor	$ 45,000
Cementing	$ 20,000
Wing Valves	$ 7,000
TOTAL	$1,180,250

Phase IV. Drill Reinjection Well and Test Production Well

Task and Discussion: Drill reinjection well to the depth and design selected from an evaluation of the Phase III drilling and preliminary testing results. Design and implement a long-term well test of the production well, including both geophysical (temperature and pressure) monitoring and geochemical testing. If indicated from well testing, proceed with the project.

Cost Estimate:

Drilling and etc.	$590,000
Phase III x .5	$300,000
TOTAL	$890,000