Geothermal Resources Council

TRANSACTIONS, VOL 9 - PART I, August 1985

A E I O U: ACCELERATED EXPLORATION for INTEGRATED and OPTIMAL UTILIZATION
A Strategy for Geothermal Resource Development at Department of Defense Installations

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ABSTRACT

A program is currently being conducted by the Division of Earth Sciences, UNLV, and the Geothermal Utilization Division, China Lake Naval Weapons Center (and funded jointly by the U. S. Navy and U. S. Department of Energy), at the Marine Corps Air-Ground Combat Center, Twentynine Palms, California, as an example of accelerated development of geothermal resources at Department of Defense installations. The focus of this program is to assess the potential for development of low-temperature geothermal resources for space heating applications. Decisions are based on data derived from geologic and geophysical surveys, temperature gradient holes, environmental issues, and engineering and economic studies.

There are several important differences between this and previous studies. The most important is that the geothermal reservoir data are known and not assumed. In addition, selected base heat loads are considered as separate items and specific environmental issues are identified in areas of greatest anticipated activity. Recommendations are also made for reservoir confirmation, retrofitting existing structures, and co-locating new structures within the areal extent of the geothermal resource.

INTRODUCTION

Since 1978, members of the Division of Earth Sciences (DES) at the University of Nevada, Las Vegas, have performed assessment studies of geothermal resources throughout the west. The approach has been based on an efficient application of capital resources to obtain a multi-perspective data base that integrates natural resource characteristics, economic qualifications, technical possibilities, and environmental liabilities.

This paper describes an integrated program for development of low- to moderate-temperature geothermal resources that was jointly conceived by the U.S. Navy, the U.S. Department of Energy, and the University of Nevada, Las Vegas. The program consists of the four major aspects of development: 1) exploration; 2) resource definition; 3) environmental considerations; and 4) optimal resource utilization (fig. 1).

Although military installations throughout the United States require vast amounts of energy, traditional marketing strategies of alternate energy resources are not entirely applicable to most mission-oriented bases. There are two important reasons for this. First, the primary function of the active military base is to supply or support the National Defense. Any extracurricular activity that either damages, compromises, or adversely affects this fundamental mission is wholly unacceptable. Second, most energy conservation plans rely largely on economics; market competition and variations in energy prices and availability are the fundamental requirements in the business world. The military first recognizes the mission, then the cost. It is mainly for these two reasons that, although many bases are capable of geothermal resource development, no active base in the United States uses a geothermal resource to offset as much as a single BTU. Indeed, considerable effort has been directed toward geothermal resource development on active bases for more than a decade. Although some resources have been found, there has been no subsequent development. It is clear that if geothermal resources are to become an important factor of the military's energy formula, future effort must focus on active and accelerated integration of exploration, development, and utilization.

Working closely with both military and civilian personnel is mandatory and may result in identification of potential applications not normally considered for commercial development. Providing key military personnel with timely, detailed plans for activities in both restricted and non-restricted areas is a requirement for a safe, efficient assessment program. This requires that the first three elements outlined above be tailored to the base characteristics.

Experience has shown that identification of geothermal resources at military installations does not necessarily result in resource utilization. A moderate temperature (95°C) geothermal resource was identified at the Hawthorne Army Ammunition Plant in western Nevada in 1981 (Trexler and others, 1981). Development of that resource has been slow due to the uncoordinated activity by civilian contractors and government agencies who are not familiar with optimal development of geothermal resources.

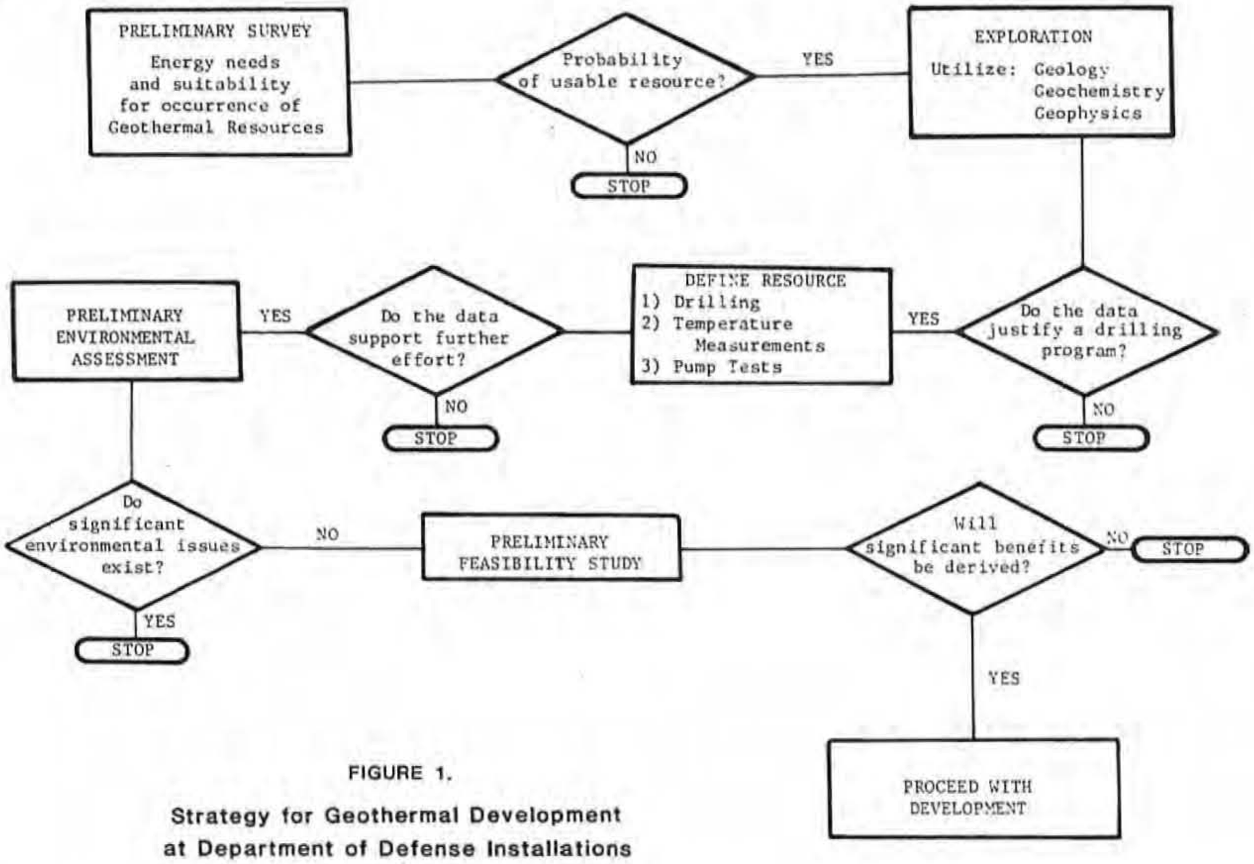

FIGURE 1.

Strategy for Geothermal Development at Department of Defense Installations

The integrated program approach that is currently underway at the Marine Corps Air-Ground Combat Center (MCAGCC), Twentynine Palms, California, demonstrates the benefits of resource development by the directed efforts of agencies familiar with military operations and geothermal energy.

PRELIMINARY SURVEY

Interest in development of geothermal resources beneath the MCAGCC was stimulated by the report of a well, 122 m deep, with a water temperature of 73°C, located 3.6 km southeast of the Center's boundary.

Warm ground water in the Twentynine Palms area has been known for at least 30 years. Wells drilled for domestic water north of the city of Twentynine Palms have reported temperatures of 40-73°C. Higgins (1980) reported 3 wells ranging in temperature from 48°C to 63°C. The approximate boundary of the geothermal area in the vicinity of Twentynine Palms was described in Leivas and others (1981) as extending approximately 15 km in an east-west direction and 6 km north-south.

The Center encompasses approximately 2,600 square kilometers of the southern Mojave Desert. The administrative and housing area is located 8 km north of the city of Twentynine Palms, California (fig. 2). Large buildings such as offices, barracks and classrooms are heated by a central boiler plant employing a low pressure steam and distribution system. Individual and multiple family housing employ individual gas-fired forced air heating systems.

An expeditionary air field (EAF) is located at Camp Wilson, approximately 10 km northwest of the Center's administrative area. The only permanent structures at Camp Wilson are 14 shower and lavatory buildings. Water is heated by fuel oil.

The annual expenditures for heating oil and natural gas for the entire Center were $2,050,000 for fiscal 1983 (Facilities Engineer personnel per. comm., 1983).

EXPLORATION

Geophysical exploration was performed by the Geothermal Utilization Division, Naval Weapons Center, China Lake. Gravity and magnetic surveys indicated a geologic structure, the Bullion Mountain fault, trending northwest-southeast beneath the MCAGCC administrative area and trending southeasterly towards the geothermal well mentioned above. Other geophysical anomalies tended to confirm the

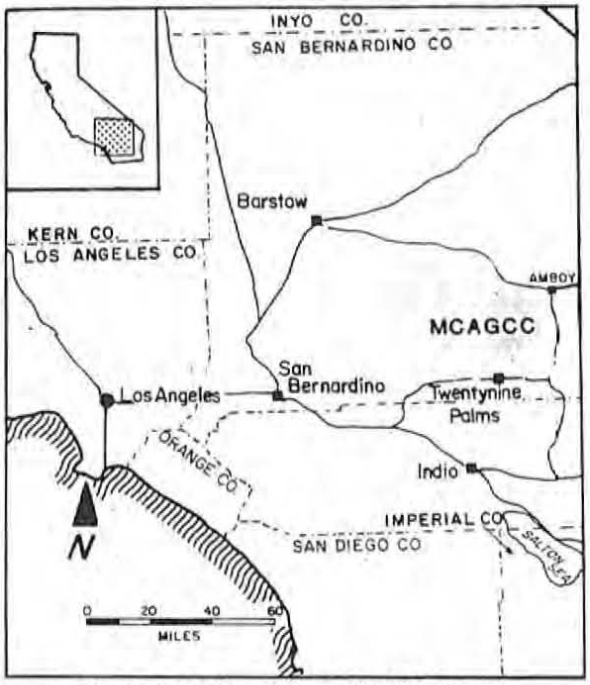

Figure 2. Index map of MCAGCC, Twentynine Palms, California

existence of northwest trending structures subparallel to the Bullion Mountain fault. These are from east to west: 1) Mesquite Lake fault; 2) Surprise Spring fault; and 3) Emerson Copper Mountain fault system (fig. 3).

RESOURCE DEFINITION

Seven sites for temperature gradient drilling were selected based on geophysical surveys and proximity to the Center's administrative area. The drilling program was supported by the Navy and the U.S. Department of Energy, as a cooperative program agreement, and supervised by the Division of Earth Sciences, University of Nevada, Las Vegas (Trexler and others, 1984). A pre-drilling conference was held at MCAGCC to appraise base personnel of our intent to proceed with temperature gradient drilling and to ascertain what restrictions would be placed on drilling operations.

The drilling plan specified drilling to a depth of 304 m or bedrock, which ever came first. Since no wells had been drilled at the Center to a depth of 304 m or greater, blowout prevention equipment was required on the first hole. Hole No. 1 (fig. 3) was located adjacent to a housing area and as near to the suspected trace of the Bullion Mountain fault as possible. Quartz monzonite bedrock was encountered at 201 m; drilling continued to 268 m. Maximum mud return temperature recorded during drilling was 27°C.

Hole No. 2 was located 1.37 km southwest of hole No. 1, perpendicular to the strike of the Bullion Mountain fault. This location is near the Mesquite Lake fault which was considered to be a favorable controlling structure for geothermal fluid migration.

Hole No. 2 was completed to a depth of 304 m without encountering bedrock. Maximum mud return temperature of only 27°C suggested that if a geothermal resource was present it was very deep.

The third drill site was located approximately half-way between temperature gradient hole No. 1 and temperature gradient hole No. 2 (fig. 3) along the trend of the gravity anomaly and 2.1 km to the north of temperature gradient hole No. 2. This location would confirm if the Bullion Mountain fault (gravity anomaly) was the controlling structure for the geothermal fluids.

This hole was completed to 335 m and maximum mud return temperatures were 30°C. These data confirmed that the Bullion Mountain fault, in the vicinity of the Center's administrative area, was not the controlling structure for the migration of geothermal fluids.

After analyzing the results of drilling, it was decided by DES and Navy personnel to drill different structural blocks on the Center to determine which faults controlled the migration of geothermal fluids.

Temperature gradient hole No. 4 was located immediately east of the Bullion Mountains (east of the Bullion Mountain fault, fig. 3), to ascertain if the geothermal fluids reported south of the Center were controlled by faults on the east side of the Bullion Mountains. Bedrock was encountered at 271 m and drilling was terminated at 280 m. Maximum mud return temperature was 29°C at 280 m which indicated that the geothermal fluids are not in this structural block.

At this point, DES and Navy personnel agreed to drop two remaining primary sites near the administrative area and focus on other secondary sites west of the Bullion Mountain fault. This was done in an effort to locate the controlling structures for the geothermal fluids. These two additional sites were chosen on opposite sides of the Surprise Spring fault. A major logistical problem surfaced because these sites are located on training ranges with restricted access. Temperature gradient hole No. 5 was drilled while permission to enter the training area was obtained.

Site 5, is located 3 miles west-northwest of the Center's administrative area. It is situated between the Mesquite Lake fault on the east an Surprise Spring fault on the west. Maximum mud return temperatures were 34°C, indicating the presence of geothermal fluids. The hole was to be drilled to 335 m, however, a bit change was required at 287 m and, upon tripping back into the hole, circulation could not be recovered. Subsequent attempts to recover circulation failed and temperature gradient hole No. 5 was completed to 287 m.

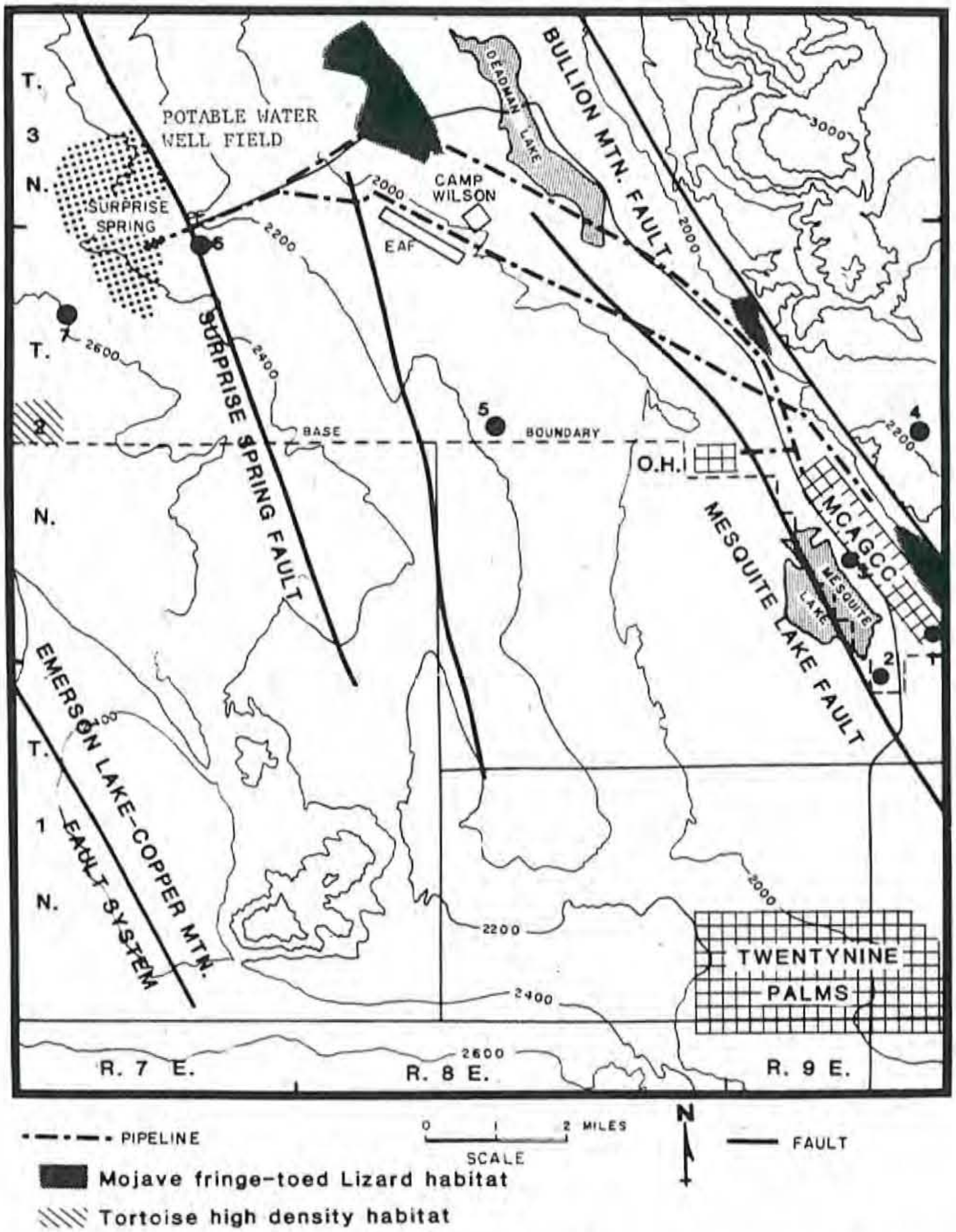

Figure 3. Composite map showing important geologic, geothermal, and environmental features at MCAGCC

Once permission to enter the training area was received, hole No. 6 was drilled to a depth of 335 m. Maximum mud return temperatures were 39.4°C, however, after termination of drilling and prior to trip-out, the mud return temperature increased 1.4°C in 20 minutes during circulation.

Hole No. 7 is located west of the Surprise Spring fault (fig. 3). The hole was completed to 323 m and the maximum mud return temperature was only 23°C. The low mud return temperatures tentatively indicated that geothermal fluids were migrating up the Surprise Spring fault and flowing east.

All drill holes were cased with 6.35 cm T. & C. iron pipe capped on the bottom and filled with water. The holes were back-filled with cuttings and a cement seal was placed from ground surface to 3.3 m.

TEMPERATURE GRADIENTS

Temperature gradient measurements were made on February 13th and 14th, and February 27th and 28th, 1984, two and four weeks after the termination of the drilling program. Temperature measurements were made at 6 m intervals.

A maximum temperature of 32.6°C was measured at 268 m in hole No. 1. The temperature gradient calculated over the interval from 61 m to 244 m was 1.3°C/100 m. Hole No. 2 had a BHT of 29.7°C and a gradient of 2.7°C/100 m. A similar temperature gradient of 2.7°C/100 m was measured in hole No. 3. The temperature gradient in hole No. 4 was 2.6°C/100 m which is quite similar to holes 2 and 3.

The temperature gradients in holes 1 through 4 probably reflect the regional background temperature gradient for this portion of the Mojave block, which is 2.5 to 3.0°C/100 m.

A maximum temperature of 51.6°C was measured at 287 m in hole No. 5 (fig. 4). The temperature gradient calculated in the interval between 110 m and 287 m was 8°C/100 m. As shown in figure 4, the gradient remains positive at the bottom of the hole. Hole No. 6 had the highest measured temperature of all holes drilled during this phase of geothermal development at MCAGCC. A maximum temperature of 67.1°C was measured at 335 m. The temperature gradient below 275 m (fig. 4) is 3.3°C/100 m and probably reflects the convective gradient in the geothermal reservoir.

Hole No. 7, located west of the Surprise Spring fault, has a maximum temperature of 33.9°C at 323 m and a gradient of 3.8°C/100 m.

ENVIRONMENTAL FACTORS

The ultimate development of geothermal resources at the MCAGCC will require an acceptable method of fluid disposal and will have an impact upon the desert ecosystem. Although the absolute magnitude of the environmental impact is not presently known, selected fluid disposal options can be discussed in terms of the impact they will have on the major environmental issues on the base. A technical report completed in April, 1984, described the fluid disposal options available at the Center (Flynn and others, 1984).

Four fluid disposal options, identified as technically feasible at MCAGCC, included surface disposal on existing playas, fluid injection, irrigation, and sewage disposal. Figure 5 shows a suggested utilization rationale that includes all four and that may be easily accommodated by the existing base structure.

Nine major environmental issues were also identified and the ramifications of each, with respect to geothermal fluid utilization, were discussed. The nine issues and pertinent comments are presented in Table 1.

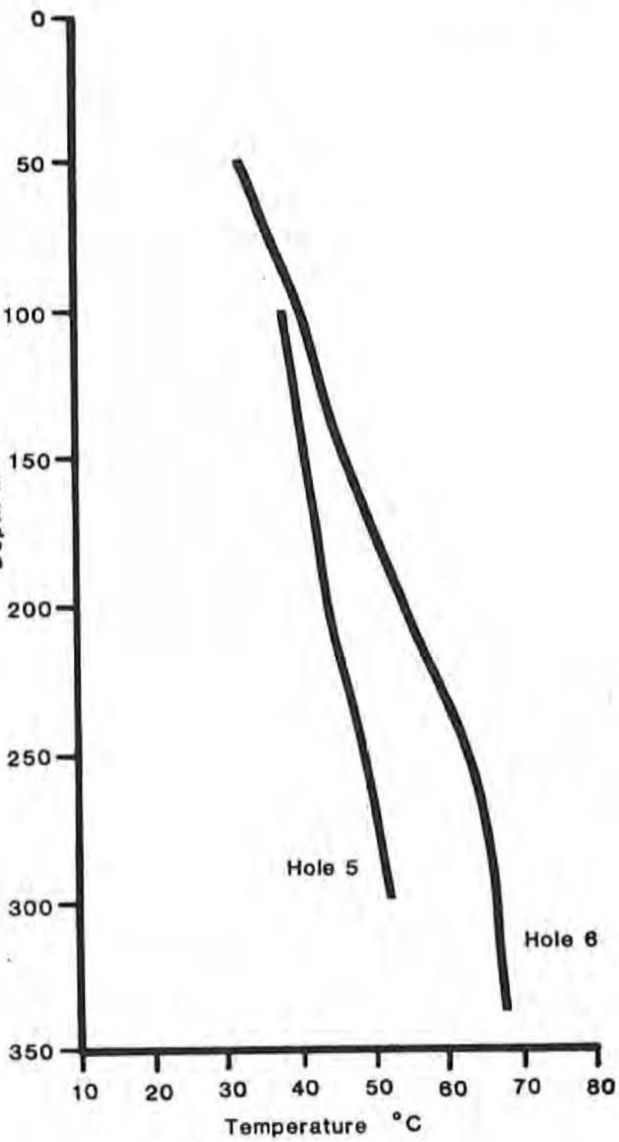

Figure 4. Temperature gradient profiles of holes 5 and 6

No environmental issues were identified that would preclude development of geothermal resources at MCAGCC. The total impact is estimated to be equivalent to the impact of the existing potable water well field and associated pipelines.

In addition to the obvious fuel savings, several ancillary benefits will accrue from the development:

1) reduce stress on potable water aquifer
2) enhance vegetation and tree growth with irrigation
3) increase bacterial digestion efficiency (sewage)
4) mitigation of dust from Deadman Lake Playa

Table 1.

Environmental Issue	Site Characteristics
1. Land use	Well field and fluid distribution system will be in training area - present potable water distribution system is located along roads in training area. Proposed surface disposal on playa (Deadman Lake) represents area of minor concern.
2. Fish, wildlife, vegetation, endangered species of plants and animals	There are no species of fish within the study area. Although some sensitive species have been identified surrounding the base, the prospects of geothermal utilization and surface disposal (on playas) represents no more hazard than present activities associated with training. The habitats of two sensitive species, indigenous to the area, have been identified and will not be seriously affected by proposed development.
3. Water quality	There are no permanent surface waters within the study area that can be used as a source of potable water. Geothermal waters are likely to contain slightly high concentrations of fluoride and boron.
4. Air quality	Although geothermal fluids for direct-use rarely contain appreciable amounts of noncondensable gases, a chemical analysis is warranted.
5. Hot springs	There are no thermal springs presently flowing within the study area.
6. Physical geology a) subsidence	The geothermal reservoir rock at MCAGCC, Twentynine Palms, is nearly identical to the unconsolidated formations that produce non-thermal drinking waters. Although 35 feet of drawdown has occurred, there have been no reports of subsidence within the well field.
b) induced seismicity	This is generally associated with deep, high-pressure injection and is not likely to be a problem.
7. Noise	The area is presently used as an air-ground combat training center. Also, no residential, recreational or breeding areas are adjacent to proposed production area.
8. Socioeconomics	Will likely reduce the cost of heating at Mainside. Secondary application may also reduce amount of fluids pumped from non-thermal aquifers. An economic feasibility study is presently being conducted.
9. Archaeological/ cultural resources	Archaeological surveys have been successfully used to locate and isolate sensitive cultural areas (i.e., Surprise Spring) within the study areas. Proposed development will not affect sites.

ENGINEERING FEASIBILITY

Estimated temperatures of the geothermal fluids at a depth of 610 m near hole No. 5 range from 80°-85°C based on the observed temperature gradient. The primary uses for fluids at these temperatures are space heating and domestic hot water. These uses employ existing technology and commercially available equipment.

Cost effectiveness is a primary concern at the Center. The costs for a new geothermal heating system include a production well, piping system, disposal system, and end-user heating retrofits. Each of these costs increase as the service area expands. Critical to the geothermal system is the location of the production well in close proximity to the heat load.

Relative to the known geothermal reservoir, Ocotillo Heights, which is composed of 250 family housing units, is the closest existing large heat load. A preliminary cost estimate for converting Ocotillo Heights (O.H. on fig. 3) to geothermal heating from a source at hole No. 5 is presented in Table 2.

The estimated offset natural gas consumption is 150,000 therms per year or $90,000/year in natural gas costs. This gives a simple payback period

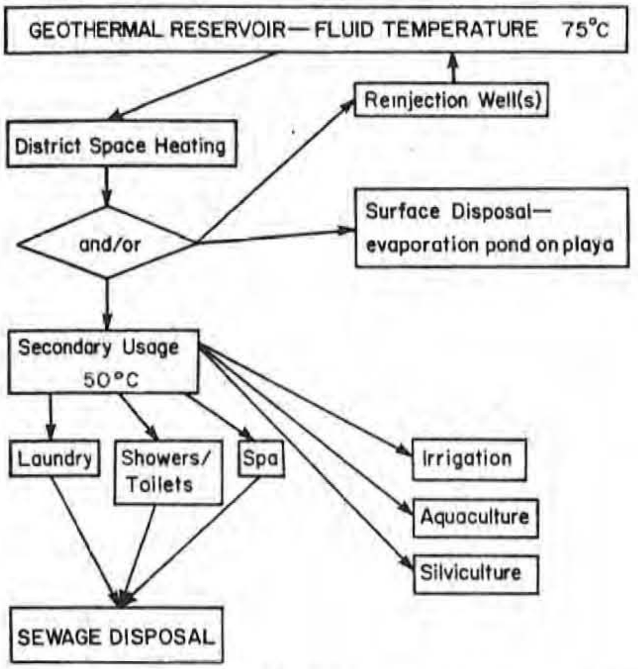

Figure 5.

Direct Utilization of Geothermal Energy
MCAGCC Twentynine Palms, CA.

Table 2.

2,000 ft. production well & pump	$ 150,000
20,000 ft. 8" insulated pipe $25/ft.*	500,000
2,000 ft. 6" insulated pipe $30/ft.	60,000
250 retrofits @ $1,200/unit	300,000
10,000 ft. disposal line @ $4/ft.**	40,000
Estimated Total	$1,050,000

*Installed on surface
**Buried

of 12 years. If the geothermal well can be located adjacent to Ocotillo Heights, the conversion cost is $500,000 less and the corresponding simple payback time is 6 years.

If the new construction is located in the vicinity of hole No. 5, then these new buildings would be ideal candidates for geothermal space heating. Supply line costs will be minimized and "retrofit" costs would be limited to the cost differential between heat exchangers and conventional furnaces.

CONCLUSIONS AND RECOMMENDATIONS

This report demonstrates the utility of integrating data from those well defined parameters that most influence the success of geothermal resource utilization. The temperature, depth and approximate areal extent of a low-temperature geothermal resource (70°C) was determined on the basis of data derived from geological, geophysical, and temperature gradient hole drilling surveys carried out by the Geothermal Division at China Lake Weapons Center and the Division of Earth Sciences, UNLV. Data from those studies were used to develop use-scenarios that included heat and water utilization in a framework that was consistent with existing military operations and environmentally beneficial.

Data are presently being collected that will help determine the engineering and economic feasibility of offsetting all or part of the Center's energy demand with geothermal heat. A report by Bakewell and Renner (1982) included an economic analysis of using geothermal fluids for MCAGCC which was based on assumptions which have been found to be totally misleading. The important data are listed in Table 3:

Table 3.

Resource Character	Bakewell & Renner 1982	Trexler and Others 1984
Location	unknown	between #5/6 on map
Temperature	63°C	70°C - 85°C
Depth	90 m	350-600 m

The conclusion that the attractiveness of geothermal utilization is sensitive to co-locating the resource and end use is correct. The report differs, however, in assuming the location of the resource, in ignoring optional uses for the fluids, and for not considering separating isolated heat loads from the entire base heat load.

The principal recommendation of this report is to define the eastern-most limit of accessible and usable geothermal fluids by drilling temperature gradient holes. A series of 2-3, 600 m holes in the area of Ocotillo Heights and west will provide the required data. Following this, a pump test on a properly sited well will complete the resource definition phase of the program.

Detailed engineering and economic feasibility studies using the most accurate resource data would then be warranted. Preliminary estimates show that economic benefits may be realized within 6 years if the Ocotillo Heights residential area is retrofitted for space and water heating. More significantly, new construction located at the site of the geothermal reservoir would achieve a payback in a shorter time period if geothermal heating systems were included during construction.

ACKNOWLEDGEMENTS

Many people participated in the successful completion of this project and the authors would like to acknowledge their contributions. John Crawford and Bill Holman, of the San Francisco Operations Office of the U.S. Department of Energy, provided pertinent suggestions during site selection review and the drilling phase of the program. Geothermal Utilization Division, Naval Weapons Center, China Lake, personnel were instrumental in conceiving the project, providing geophysical data used in drill site selection, and assisting in temperature gradient measurements and site restoration. Individuals of the Geothermal Utilization Division who provided this support are Al Katzenstein, Jack Neffew and Ted Mort. Carl Halsey's critical review of the drilling report showed that the characterization of specific mission contraints must utilize and be functionally interwoven with the preliminary qualification limit.

Logistical support during activities at the Marine Corps Center was provided by Lt. Col. C.E. Schaffer and the staff of the Installations Division, specifically Staff Sgt. William Flummerfelt, who provided assistance in acquiring necessary permits for drilling activities at the MCAGCC, and baseline data for the fluid disposal study. Stu Hammonds helped secure data for the engineering feasibility study, and Charles Miles and David Holmes of the Naval Civil Engineering Laboratory were instrumental in funding this program.

We would also like to acknowledge the drilling contractor, Fred Anderson and Son Exploration Drilling, Inc., for a job well done and for their patience while drill site locations and depths were changed because of data acquired during drilling.

Without the assistance and support provided by these individuals and organizations, this project would not have been completed.

This work was funded under the following contracts: DOE Contract No. DE-AC03-83SF11956; Navy Work Order No. N60530-M-23BQ; DOE Grant No. DE-FG03-85SF15555.

Finally, many thanks to U.R. Bearmatt for keeping the lines of communications at MCAGCC open. 10-4.

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