CHARACTERIZATION OF THE GEOTHERMAL RESOURCE
AT LACKLAND AFB, SAN ANTONIO, TEXAS.

PHASE I REPORT

Prepared for

United States Air Force
Air Training Command
Lackland Air Force Base
San Antonio, Texas

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1.0 EXECUTIVE SUMMARY

The Phase I study to characterize the geothermal resource under Lackland Air Force Base (AFB), San Antonio, Texas has been completed. It is the conclusion of the investigators that a geothermal well drilled at the site recommended by this study has a high probability of delivering geothermal fluids in sufficient quantity and at adequate temperatures to support a projected space and domestic hot water heating system.

An exploratory production well location is recommended in the southwest sector of the base, approximately 200 ft south of Gott Street and 200 ft east of Hughes Avenue, based upon geologic conditions and the availability of sufficient open space to support the drilling operation. This location is also in reasonable proximity to a portion of the projected utilization load, and provides sufficient separation between the production well and a projected injection well in the northwest sector of the base.

It is projected that a production well drilled at the recommended location would produce geothermal fluid of 130-145°F at a rate of approximately 1000 gpm with reasonable fluid drawdowns.

The Environmental Assessment for the drilling portion of the project has been completed, and no irreversible or irretrievable impacts are anticipated as a result of this drilling program.

The permitting process is proceeding smoothly. Military departments were given the authority to develop geothermal resources within lands under their control by Public Law 97-214. An application for a drilling permit has been filed with the Texas Railroad Commission, the agency which regulates oil, gas and geothermal drilling within the state of Texas.

2.0 INTRODUCTION

The U.S. Air Force has commissioned the Department of Energy, Idaho Operations Office (DOE-ID) to characterize the geothermal resource under Lackland AFB, San Antonio, Texas. DOE-ID in turn has assigned responsibility for this effort to its subcontractors, EG&G Idaho, Inc. and the Earth Sciences Laboratory of the University of Utah Research Institute (ESL/UURI). This characterization is to encompass the siting, drilling and testing of an exploratory geothermal well. The work was split into two phases. Phase I, which is reported here, encompasses the geologic and hydrologic work to assess the probability and quality of the resource, selection of a well site, performance of an environmental analysis and initiation of the permitting process. Phase II, if the Air Force decides to proceed on the basis of this Phase I Evaluation, will consist of completion of the permitting process, development of an addendum to the Environmental Assessment, drilling and testing of the well and performance of an economic analysis to evaluate the potential savings of a utilization project. Subsidiary information in the form of data collection and evaluation of subsurface geology will be produced and reported during the Phase II drilling task, which will have application in defining the potential for oil and gas production under Lackland AFB.

The authors gratefully acknowledge the assistance of the following individuals for their assistance with this project: Mr. Richard Steede and Robert Trevinio of ATC/HQ for initiating and funding the project; Mr. Charles Hewitt of ATC/HQ for assistance in institutional matters; Capt. Dennis Lundquist and John Nepute of Lackland AFB for project coordination; and Dr. Charles Woodruff, Jr. of the Texas Bureau of Economic Geology for his very great contributions, both written and verbal, in the area of geology.

3.0 Geologic Evaluation

3.1 Introduction

This discussion will report on the Phase I geothermal evaluation of Lackland AFB and will provide recommendations for Phase II. The study has been centered on the land under Lackland AFB, but due to the widely-spaced distribution of usable data it has also encompassed much of Bexar County. Since several geological parameters exhibited significant variation across the county, it was necessary to develop a regional understanding of those parameters which were most important to the project on a local scale. The primary oil wells used in this study are shown on Figure 3-1.

The objective of Phase I was to recommend the optimum site to drill a geothermal resource evaluation well under Phase II, based on a detailed analysis of geological and geothermal data. Intermediate stages leading to the primary objective consisted of the evaluation of various geological parameters, including the structural configuration of the target aquifer, the net feet of porous sand to be encountered and the anticipated chemical make-up of the geothermal fluid. A secondary objective was to develop a plan of operations for the recommended well.

3.1.1 Previous Work

Evaluation of geothermal potential in Texas, including Bexar County has been done by the Texas Bureau of Economic Geology (Woodruff and McBride, 1979; Woodruff et al., 1981; Woodruff, Henry and Gever, 1981; and Sorey and others, in press). These studies identified two possible geothermal aquifers in Bexar County, the Edwards Formation and the deeper Hosston Formation which contains hotter fluids. This Hosston is the target horizon at Lackland AFB. Radian Corporation (1982) did an assessment of geothermal utilization which stressed

+ +
Hickock Reynolds
✦ #1 Ewert

✦ General Crude Oil
#1 Talley

✦ General Crude Oil
#1 Rogers Ranch

✦ Gas Ridge Syndicate
#1 Pepper

Pagenkopf
✦ #1 Blum

✦ Mckennon
#1 Fee

West Prod.
#1 Timberlake
✦

✦ Coastal States Gas
#1 Loessberg

Union Prod'g Co.
#1 McKean
✦

✦ Sun Oil Co.
#1 Forbes

+ +
Bur-Kan Petrol
✦ #1 Hubbard

0 1 2 3
scale in miles

+ +
US Enhanced
Oil Recovery
✦
#1 McClain

Figure 3-1

DISTRIBUTION OF OIL WELL DATA POINTS

engineering and economic aspects. Nelson (1978) and Bebout et al. (1981) have discussed the geology of the Hosston Formation. Hydrologic factors of the Hosston have been discussed by Hall (1976), MacPherson (1982), and Ashworth (1983). Near-surface geology of Lackland AFB was discussed by McIntosh and Behm (1967). Many other workers have written about various geologic aspects of the area; these will be cited as needed.

3.1.2 Methodology

Literature review, discussions with base engineers and local geologists, and compilation of petroleum and water well data, were done in order to develop an accurate model of the subsurface geological conditions at Lackland AFB. One extended visit to Texas facilitated accomplishment of these tasks.

Articles in scientific journals and less widely distributed publications of the Texas Bureau of Economic Geology, the U.S. Geological Survey and the Army Corps of Engineers were accessed for their data. Base engineers and local geologists provided information pertinent to the logistics of well location and anticipated subsurface conditions. Petroleum well data were compiled from public records of the Texas Bureau of Economic Geology, the Texas Railroad Commission and private well log libraries in the San Antonio area. These included geophysical logs and core and cuttings descriptions. Water well data were compiled from U.S. Geological Survey offices in San Antonio and Austin, as well as Texas Department of Water Resources files. Hosston Formation cuttings from deep wells in the area were examined at facilities of the Texas Bureau of Economic Geology. Available regional geophysical data did not cover the area of the base, and were not examined.

A model of subsurface geothermal resources was developed by integrating these data, following traditional petroleum exploration practices, to

interpret regional geological conditions, which would permit an evaluation of the subsurface at the base.

3.2 Geology

3.2.1 Tectonic Setting

Lackland AFB is located at the northern edge of the Gulf Coastal Plain and straddles the Ouachita structural belt (Flawn and others, 1961) as shown in Figure 3-2. The Ouachita belt in the subsurface is represented by weakly to moderately metamorphosed Paleozoic sediments, which were eroded to a low relief surface prior to Cretaceous time. In the study area this surface, known as the Wichita paleoplain (Hill, in Flawn and others, 1961, pp. 363-367), dips southeastward about 200 feet per mile (Flawn et al., 1961, p. 128).

The Balcones and Luling fault systems trend northeasterly across the area roughly parallel to the subsurface Ouachita fold belt. The fault systems form a rift across the county, with Balcones faults having a generally down-to-the-coast sense of movement and Luling faults generally having an up-to-the-coast sense of movement. Weeks (1945) has shown that the total throw of the down-to-the-coast faults is about 1000 feet whereas the up-to-the-coast faults exhibit a total throw of about 1500 feet.

The age of movement(s) on these faults is indicated by which formations are offset. Faulting occurred along the Balcones Fault zone in the Cretaceous (Hayward, in MacPherson, 1982), and may have been limited to the Lower Cretaceous in some areas (Nelson, 1978). McIntosh and Behm (1967) identify faults on Lackland AFB that displace Paleocene sediments. Most of the movement on these faults may be Miocene (Woodruff, personal communication, 1983).

Evidence of late Paleozoic and/or early to middle Mesozoic movement along

Figure 3-2
REGIONAL TECTONIC ELEMENTS
 After Woodruff and McBride, 1979

ESL/L AFB-002

some of these rift faults is present in several wells. Immediately south of Lackland AFB, the Pagenkopf #1 Blum well (see Fig. 3-3) penetrated approximately 2600' of unmetamorphosed, variegated sandstone, shale and limestone without encountering Ouachita rocks (Flawn et al., 1961). A similar sequence of rocks was penetrated in the Coastal States #1 Loessberg well 9 miles to the southwest and in the Richardson #1 Hyman Farms well 4 1/2 miles further to the southwest. These unmetamorphosed sediments appear to have been preserved within grabens as the area was peneplained prior to Cretaceous time. The geothermal significance of such a graben will be discussed below.

The San Marcos arch and the Culebra anticline are two additional structural elements that have influenced the geology of the area. The San Marcos Arch extends and plunges southeastward from the Llano uplift in central Texas (Figure 3-2). The San Marcos Arch is considered to be a part of the Gulf Coastal Plain which subsided more slowly than the adjacent areas (Loucks, 1977) during early Cretaceous time. The arch, which was apparently first extant during Paleozoic time (Stricklin and others, 1971), influenced depositional patterns during much of Cretaceous time, and may reflect on the hydrology of this study. The Culebra anticline is a southwest-plunging structure, with the north limb under Lackland AFB.

3.2.2 Structural Geology

Regional faults and folds discussed above under Tectonics are relevant to the structural setting of geothermal resources at Lackland AFB. The faults substantially displace stratigraphic horizons, and the folds complicate interpretation of depth data.

McIntosh and Behm (1967), in drilling test holes for foundation studies, have mapped many faults at Lackland (Figure 3-4). They identify an overall

Figure 3-3
DIAGRAMMATIC GEOLOGIC SECTION THROUGH
THE LACKLAND AFB AREA

Figure 3-4
 GEOLOGIC MAP OF LACKLAND AFB
 (McIntosh and Behm, 1967)

ESL/L AFB-004

pattern of grabens and horsts. Down-to-the-coast displacement of up to 600 feet is suggested for the northeast-trending fault at the north side of the base. Maclay and Small (1983) suggest, based on data from water wells, that at least 500 feet of displacement has occurred along this fault. Two other faults that extend to the near-surface are relevant to siting a geothermal well west of Military Highway. These are an up-to-the-coast northeast-striking fault with approximately 80 feet of displacement adjacent to the south edge of the bast. Woodruff (personal communication, 1983) estimates that most of these faults have dips of 60° - 80° . Figure 3-4 indicates the locations of the 5000 foot depth contour on the major fault along the north side of the base, assuming both 60° and 80° dips.

Basement faults, with unknown extension into overlying rocks, bound the graben discussed under Tectonics above. Flawn and others (1961) depict these faults as steeply dipping, and although they locate a graben-bounding fault north of Lackland, it is possible that the fault may exist in the vicinity of the base.

The Culebra anticline, a relatively small fold, is identified on the basis of surficial mapping (McIntosh and Behm, 1967) and subsurface water well records (Holt, 1956; Maclay and Small, 1983). The anticline plunges to the southwest, with its northern limb beneath Lackland AFB. The dip on the anticline is estimated to be 1° to 3° north, based on cross sections in the above reports. This implies that a maximum of 450 feet of relative difference in elevations of beds can be attributed to the anticline. Figure 3-5 is a contour map of the contact between the Buda and Del Rio Formations in the vicinity of Lackland AFB. The contact indicates the level of subsurface geological complexity at Lackland, in reflecting the faults identified by

Figure 3-5
STRUCTURAL CONTOUR MAP LACKLAND AFB AREA

Datum is Buda/Del Rio Formation Contact
 C.I. 100'

ESL/L AFB-005

McIntosh and Behm (1967) and Arnow (1967), as well as the northward dips of the Culebra anticline.

The role of the faults and fold in the geothermal model are discussed below.

3.2.3 Stratigraphy

Mesozoic and Cenozoic strata were deposited above metamorphosed basement rocks in south-central Texas. Cretaceous and Tertiary periods are represented in the subsurface beneath Lackland AFB (Table 3-1). Much of the Cretaceous stratigraphic section is composed of carbonate and shale formations deposited on a shallow marine shelf. Due to their potential for petroleum production, this sequence of rocks has received substantial study and exploration. By contrast, the basal unit of the Cretaceous, the Hosston Formation of the Trinity Group, is characterized by sandstone and pebble conglomerate, and has not received much detailed study for petroleum exploration. No detailed study of the Hosston Formation near Lackland AFB has been published, although numerous regional studies of it have included Bexar County. The nearest detailed study of depositional environments of the Hosston (Nelson, 1978) involves Guadalupe and Caldwell Counties immediately to the east of Bexar County.

The name of the Hosston Formation was introduced into the literature by Imlay (1940) to describe a shale and sandstone section found in a Dixie Oil Co. well seven miles south of Hosston, Louisiana. The Hosston is known to occur from Florida to Mexico (Rainwater, 1969, in Nelson, 1978). The Hosston and its laterally equivalent Sligo Formation comprise a basal Cretaceous transgressive wedge of carbonates and sandstones.

The Hosston was deposited in a meanderbelt fluvial system landward of the

TABLE 3-1
GENERALIZED STRATIGRAPHIC COLUMN
LACKLAND AFB

<u>System</u>	<u>Formation</u>	<u>Lithology</u>
Tertiary	Alluvium	unconsolidated
	Midway	clay
	Navarro	shaly clay
Cretaceous	Taylor	marl
	Anacacho	argillaceous limestone
	Austin	limestone and chalk
	Eagle Ford	calcareous and sandy shales
	Buda	limestone
	Del Rio	clay
	Georgetown	limestone
	Edwards	limestone
	Walnut	clay
	Glen Rose	limestone
	Pearsall	shale and limestone
Trinity Group	Sligo	limestone and shale
	Hosston	sandstone, shale, limestone
Pennsylvanian?	?	red beds
Pre-Pennsylvanian	Ouachita	metamorphic rocks

Ouachita/Balcones hinge zone. Along the hinge zone, it was deposited in a "high-destructive, wave-dominated delta system" (Woodruff and others, 1981; Hall, 1976). Sediment from source areas to the northwest was transported seaward by Hosston rivers. The rivers were originally confined to major valleys developed on the Wichita paleoplain (Boone, 1968, in Hall, 1976). Filling of valleys by fluvial processes and by transgressive estuarine sediments soon provided an alluvial plain for the rivers to meander upon. The clastic-laden waters discharged into the open-marine waters of the Gulf basin allowing basinward progradation of the shoreline. These sediments were acted on by high energy waves and longshore currents.

We interpret that the Hosston in the Lackland AFB area was deposited in a fluvial meanderbelt depositional environment. This is based on examination of drill cuttings, on electric log characteristics and on comments of the meanderbelt facies in Hall (1976, p. 11). Meanderbelt sandstone facies consist of multilateral sandstone deposits composed principally of medium-to coarse-grained, moderately well-sorted sand, and channel lag gravels. These deposits on electric logs are characterized by abrupt basal contacts and multiple, abbreviated upward-fining sequences. This is favorable as these sands have high water transmissivities.

The Hosston (Hall, 1976) in the Bexar County area ranges in thickness from 287 to 623 feet (Figure 3-6). Of that thickness the portion comprising sand (called net sand values) ranges from 70 to 236 feet (Figure 3-6). This study indicates Lackland AFB is located on the edge of a prominent north-trending thick zone of the Hosston Formation. The net sand value of the oil test nearest to Lackland (Pagenkopf #1 Blum) indicates 156 feet of net sandstone within the Hosston. In addition to there being a significant

Figure 3-6

HOSSTON FORMATION MAP, BEXAR COUNTY, TEXAS

thickness of potential aquifer, microscopic examination of the Pagenkopf well drill cuttings indicates a very well rounded, coarse grained, poorly cemented Hosston section, which should prove to be a very productive aquifer.

3.3 Geothermal Evaluation

3.3.1 Introduction

The development of a geothermal resource is dependent upon three factors: a source of water, a source of heat, and permeability to move the heated water through rock formations to the point of extraction. These factors are discussed in this section, with a likely model for geothermal resources to be developed at Lackland Air Force Base. This model, combined with the results of the stratigraphic and structural studies, allows the selection of a drill site.

Until completion of test drilling (Phase II), details of the geothermal characteristics of the Hosston Formation at Lackland AFB will not be known. As pointed out by Woodruff and others (1981) regional data are lacking because water wells produce from the shallower Edwards Formation, and deeper oil wells in the southern part of the county have not focused on the Hosston. Although many regional groundwater studies have been made (Ashworth, 1983; George, 1962; Holt, 1956; Lang, 1953 and 1954; Maclay and Small, 1983), the Hosston is often only specifically discussed in terms of its relative importance to the Edwards (e.g., Pettit and George, 1956).

3.3.2 Thermal Regime

The temperature of a geothermal system is controlled by the geologic nature of thermal input to the system, and modifications to that thermal input by local geologic or hydrologic conditions. The deeper thermal regime of south-central Texas is not well documented, but several recent studies cited

below allow reasonable explanation to anticipated conditions in the Hosston aquifer beneath Lackland Air Force Base.

Three major sources of heat for geothermal systems are the normal thermal gradient of the earth, the decay of radioactive elements in the crust of the earth, and volcanic or igneous hot spots. In south central Texas, the major source of heat is the thermal gradient of the earth, with perhaps an unknown, but certainly very minor, contribution from elemental decay. No young volcanos or igneous systems exist there.

Specific temperatures at a given depth in a geologic unit are controlled by rock type and hydrologic conditions. Because of their lower thermal conductivity rocks such as shale retain heat better than limestones or sandstones. Water movement in rocks can have either of two effects. If water moves into the desired geologic unit from a usually deeper, warmer place in the earth, it can raise the temperature of the unit. If cold water is moving through the unit, however, it can remove heat. Although there are no specific data at Lackland Air Force Base, a reasonable geologic case is developed below to suggest that warming of the Hosston Formation from deeper waters could be expected.

Thermal gradient is a measure of the rate of increase of temperature with depth. Regional thermal gradients along the Balcones Fault Zone range from slightly under $1.1^{\circ}\text{F}/100\text{ ft}$ ($20^{\circ}\text{C}/\text{km}$) to more than $2.4^{\circ}\text{F}/100\text{ ft}$ ($43^{\circ}\text{C}/\text{km}$) (Kron and Stix, 1982). Woodruff et al. (1981) report two temperature values from the Hosston Formation in Bexar County; these yield gradients of 1.4 and $1.7^{\circ}\text{F}/100\text{ ft}$ (25 and $30^{\circ}\text{C}/\text{km}$). Radian Corporation (1982) estimated formation temperatures at $128\text{--}145^{\circ}\text{F}$ for the Hosston. With an assumed mean annual temperature of 69°F (20.6°C), the gradients required to reach the projected

temperatures at a nominal depth of 4000 ft (1.2 km) are 1.5 to 1.9°F/100 ft (27-35°C/km).

Another method for estimating subsurface temperature is to estimate the temperature of chemical equilibrium for selected constituents in the waters. Assuming that required conditions are met (Fournier et al., 1974), and that chalcedony is the dominant phase of silica (Fournier, 1980), then the estimated temperature of equilibration for the water in the Pagenkopf #1 Blum well (Lang, 1953) is 150°F(66°C). This temperature, which is higher than that estimated from thermal gradients, may or may not represent the aquifer temperature beneath Lackland AFB. If the estimate is accurate, Lackland waters would be similar to those produced at Marlin, Tx from the Hosston Formation. The estimated temperature may be too high, however, if the waters have circulated from a deeper horizon without requilibration in the Hosston, or if silica concentrations are controlled by factors other than temperature dependent water-rock interaction with chalcedony.

Our conclusion is that, based on the regional thermal regime, the range of gradients proposed by Radian Corporation (1982) is reasonable, and their projected temperatures should be attainable at the nominal depth.

3.3.3 Objective Formation Water

The source of water in the Hosston Formation beneath Lackland AFB could be from four possible origins. Three of the four models for water in the Hosston are based on drawing analogies to the movement of water in the overlying Edwards Formation, and the movement suggested by MacPherson (1982) for the Hosston Formation geothermal well at Marlin.

A major source of recharge to the Edwards Formation is presumed to be infiltration from rivers and subsequent downdip flow from the higher plateaus

to the north of San Antonio (Arnow, 1967). This yields a water flow that is primarily to the southeast. A second direction of flow in the Edwards is recharge from the west, with movement primarily along the strike of the Balcones Fault Zone (Arnow, 1967). A possible third direction is updip movement of water from the deeper portions of the Gulf Basin (Woodruff and others, 1981).

Ground water movement in the Hosston Formation could be similar to the three directions postulated for the Edwards Formation, but the position of Lackland AFB adjacent to a deep graben suggests that a component of groundwater that recharges in the Hill County, circulates to depth along faults and fractures in the basement rocks, and flows upward along faults of the Balcones zone. This circulation path has not been demonstrated, however.

MacPherson (1982) suggests that, based on water level and pressure measurements, geothermal waters in the Hosston Formation in the Falls County area could be moving updip from the Gulf basin. Since Bexar county is in a geologically analogous position to Falls County, a similar flow is possible in Bexar County.

Insufficient data exist to reliably predict water quality in the Hosston Formation beneath Lackland AFB. Lang (1953) presents two analyses from wells in structural and stratigraphic setting similar to the base. These are presented in Table 3-2. Water from the Pagenkopf-Blum well is exceptionally clean, but insufficient data are presented to evaluate the reliability of the analysis. Water in the Baker-Von Ormy well has higher TDS, and may have a component of upwelling basin water.

3.3.4 Permeability

Intergranular permeability in the sands of the Hosston Formation may be

TABLE 3-2
Hosston Formation Water Analyses
(from Lang, 1953)

analyses reported in PPM

Source Well-	Pagenkopf-Blum	Baker-Von Ormy
Date of Collection-	1945	1951
SiO ₂	44	28
Fe	-	.07
Ca	55	186
Mg	22	56
Na + K	55	654
HCO ₃	-	320
SO ₄	72	956
Cl	22	580
F	-	2.4
NO ₃	-	0.2
B	-	1.7
TDS	426	2620
temp		132°F (56°C)

enhanced by movement of water along fractures of the Balcones Fault Zone. Although sands in the Hosston have been described as "medium to fine grained...very hard and tightly cemented" (Lang, 1953), cuttings from the Pagenkopf #1 Blum suggest that a coarse grained, uncemented sand may exist beneath Lackland AFB. Such a sand would be more permeable than the water flows reported by Arnow (1963). Diagenetic cements have been reported from the Hosston by Nelson (1978); their presence or absence at Lackland, and their effect on intergranular permeability are unknown.

Many geothermal systems involve movement of water along faults. Secondary permeability generated by fracturing along faults may have two effects: redirecting of horizontal flow (MacLay and Small, 1983) and/or enhancement of vertical flow (MacPherson, 1982). The enhancement of vertical flow by faults, although not documented in the Hosston Formation at Lackland AFB, may be inferred by the findings of MacPherson (1982) in the Falls County area. McIntosh and Behm (1967) document many faults at Lackland AFB, several of which are likely (Woodruff, pers. comm., 1983) to extend to basement, thus providing conduits for water circulating deep in the basement and entering the Hosston.

3.3.5 Geothermal Target Model

Thermal input to the geothermal system is assumed to be from the normal thermal gradient of the earth. The temperature of the system is estimated to most likely be less than 150°F (65.5°C). Upwelling basinal water, moving along faults of the Balcones Fault Zone, expanding horizontally into the basal sands of the Hosston Formation in fault blocks, forms the most attractive model for a target for geothermal resources beneath Lackland AFB. The geothermal waters are likely to be hottest if they can be encountered close to

where they leave the faults and enter the Hosston. This is most likely to occur near the southern part of the base in proximity to a projected Paleozoic graben. Inspection of sands from the nearby Pagenkopf well suggests that good productivity is likely to exist in the Hosston beneath Lackland AFB even without calling on the introduction of water by faults.

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4.0 HYDROLOGIC ANALYSIS

All available data were utilized to estimate the potential productivity of the proposed Lackland well. The estimated productivity will affect project viability and has been factored into the well design. Three different sources were used to evaluate well productivity: lithology and logs of nearby wells, Geological Circular 76-1 by the Texas Bureau of Economic Geology (4-1) and the Radian feasibility report (4-2). Each of these sources and the resulting calculations for well drawdown are discussed below in order of their importance to the project.

4.1 Lithologic and Electric Well Log Evaluations

Lithologic log descriptions and spontaneous potential and resistivity logs were used to estimate drawdowns for four wells near Lackland AFB. The basic input data are summarized in Table 4-1 which lists the oil well name, the approximate distance and direction from the proposed Lackland AFB well and the sand thickness for various grain sizes, estimated from both the lithologic log developed from drill cuttings and the electric logs. The transmissivities were estimated by summing the products of the estimated permeabilities associated with the various grain sizes and the associated sand thickness for all the grain size categories in each well. The permeability estimates were developed using the methods of four references, all of which appear to be based on Davis and DeWiest⁴⁻³ (indicated in tables as "Davis" only). Table 4-2 lists anticipated well drawdowns at a flowrate of 1000 gpm. The drawdowns were evaluated using three methods: Davis (Davis & DeWiest)⁴⁻³ for a confined aquifer, the Dupuit⁴⁻⁴ equation assuming a constant head boundary at a distance of 5000 ft, and the unsteady-state radial flow equation⁴⁻⁵. Conditions of impermeable upper and lower boundaries, isotropism, and a fully penetrating well were applied to each of the three methods. A storage coefficient of 0.000028 was used for the unsteady-state radial flow equation. Calculated drawdowns per log cycle of time are also listed in Table 4-2, as is the log mean drawdown for each well, calculated using all of the available data.

TABLE 4-1

SAND THICKNESSES AND ASSOCIATED TRANSMISSIVITIES

Well Name	Distance & Bearing from Proposed Geo- thermal Well	Sand Thickness, Ft								Estimated Transmissivities, GPD/FT									
		Lithologic Log						Electric Log				Lithologic Log				Electric Log			
		V. Fine	Fine	Med.	Coarse	V. Coarse	V. Fine	Fine	Med.	Coarse	Bouwer	Lindsley	Davis	Todd	Bouwer	Lindsley	Davis	Todd	
Pagenkoff Blum #1	1.1 mi NW	10	55	18	30	-	40	62	18	26	3806	90400	25180	23350	3382	207200	31100	31040	
General Crude Oil #1 Rogers Ranch	6.2 mi NW						60		10	40					4959	88000	44000	40800	
Hickock-Reynolds	9.2 mi NW	45	23	65	51	30	35+ 6 Gravel				18034	199200	129360	243155					
General Crude Oil #1 Talley	10.8 mi WNW	80		22	20	40	30				6184	153600	61694	59840					

1) From Lithologic and Electric Logs

TABLE 4-2
ESTIMATED DRAWDOWNS FOR PUMPING AT 1000 GPM

Data Source for Transmissivities	PAGENKOPF BLUM #1								GENERAL CRUDE OIL #1 ROGERS RANCH				HICKOCK-REYNOLDS EWERT #1				GENERAL CRUDE OIL #1 TALLEY			
	Lithologic Logs				Electric Logs				Electric Logs				Lithologic Logs				Lithologic Logs			
	Method To Estimate Transmissivities				Method To Estimate Transmissivities				Method To Estimate Transmissivities				Method to Estimate Transmissivities				Method to Estimate Transmissivities			
Method Used to Estimate Drawdown	Bouwer	Lindsley	Davis	Todd	Bouwer	Lindsley	Davis	Todd	Bouwer	Lindsley	Davis	Todd	Bouwer	Lindsley	Davis	Todd	Bouwer	Lindsley	Davis	Todd
Davis	461	19.4	69.8	75.3	519	8.47	56.5	56.6	354	20.0	39.9	43.1	97.4	8.81	13.6	7.22	284	11.4	28.5	29.4
Dupuit	512	21.6	77.5	83.6	577	9.42	62.8	62.9	393	22.2	44.4	47.8	108	9.80	15.1	8.03	316	12.7	31.6	32.6
Unsteady State 10 Yr.	774	36.6	12.6	13.5	868	16.44	103	103	600	37.6	73.4	78.9	173	17.1	25.9	14.09	486	22.0	53.0	54.5
Drawdown per Log Cycle of Time (ft/log cycle of time)	69.4	2.92	10.5	11.3	78.1	1.27	8.49	8.51	53.2	3.00	6.00	6.47	14.6	1.33	2.04	1.09	42.7	1.72	4.28	4.41
Log Mean Drawdown	104				79.3				74.5				21.8				51.5			

The log mean data exhibit trends that are expected based on the depositional environment. Hickock-Reynolds Ewert #1 has an unusually low estimated drawdown because this well penetrated a fluvial aquifer at the base of the Hosston and another aquifer near the top. With two main aquifers occurring in the Hosston instead of one as in the other wells, the drawdown was also estimated to be less than at the other wells. The calculated drawdowns also appear to increase towards the southeast, which was the marine environment when the Hosston was being deposited. Based on the lithology and electric logs available, the long term drawdown (10 years) when pumping at 1000 gpm is estimated to be on the order of 100 ft with an estimated range from 20 ft to as much as 500 ft.

4.2 Geologic Circular 76-1, Bureau of Economic Geology

Hall⁴⁻¹ provides some data on well yields from the Hosston Sandstone. The author indicates the average transmissivity is 8000 gpd/ft with a storage coefficient as low as 0.000028. This storage coefficient value is below the value range for most confined aquifers (0.00005 to 0.005 Todd⁴⁻⁶), which will result in higher than normal calculated drawdowns. Using these values, the drawdown after 10 years of continuous pumping at 1000 gpm would be 379 ft assuming that no hydrologic boundaries are encountered that could affect the drawdown. The drawdown changes by 33 ft per log cycle of time, i.e. the drawdown would be $379 - 33 = 346$ ft after 1 year, $379 - 66 = 313$ ft after 0.1 year (3.65 d) and $379 - 99 = 280$ ft after 0.01 yr (3.65 d) of pumping at 1000 gpm. Most of the drawdown can be expected to occur in the first few days of pumping, assuming no impermeable barrier hydrologic boundaries interfere. Thus, the pumping water level can be expected to be near 379 ft below land surface assuming a similar hydrogeologic environment at Lackland AFB as occurs in north-central Texas. Geologic and electric log data in the vicinity of Lackland AFB suggest such a similar hydrogeologic environment in the two areas.

4.3 Radian Report

The Radian Corporation ⁴⁻² utilizes a specific capacity for the Hosston Sandstone of 4.0 gpm/ft of drawdown assuming a net sand thickness of 250 ft. In this report, the Radian Corporation apparently used the same specific capacity of 0.0168 gpm/ft of sand/ft of drawdown for all of the four military sites evaluated in the San Antonio area, and did not make adjustments for the grain size - bed thickness distribution expected at each specific site. For a static water level reported to be at ground level, the specific capacity data suggest a pumping water level of 250 ft below land surface for a constant discharge rate of 1000 gpm at Lackland AFB.

REFERENCES FOR SECTION 4

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- 4-2 Life Cycle Cost Effectiveness Studies for Direct Utilization of Geothermal Energy at Four Military Installations in South-Central Texas, Radian Corporation, January 1982
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5.0 ENVIRONMENTAL ASSESSMENT

Because of uncertainties in the actual water chemistry to be produced from this geothermal well, the method of test effluent disposal and its impacts on surface waters of the region cannot be addressed at the present time. Specifically, the Texas Railroad Commission will not issue a surface discharge permit for well testing until the actual well effluent has been chemically analyzed. As surface discharge of the test effluent is the preferred method, the current issue of the environmental assessment¹ is limited to the actual well drilling and development operations. An addendum to this environmental assessment will be issued following the analysis of the well water and selection of the effluent disposal method.

5.1 Environmental Impacts

No irreversible or irretrievable impacts are anticipated from the proposed well drilling activity. Specific considerations addressed in the Environmental Assessment are briefly discussed below.

5.1.1 Seismicity

San Antonio and the rest of central and south Texas is in an area of very low seismic risk. The physical operation of deep drilling in the this area is not anticipated to induce any additional seismic risk.

5.1.2 Subsidence

Numerous water, gas and oil wells have been drilled and produced in the San Antonio area without any noteworthy consequences of subsidence. The proposed geothermal well will be drilled with standard oil field equipment, and will produce no more risk of subsidence than has any of these existing wells. Further, during testing, insufficient water will be removed to merit concern about subsidence, especially in view of the

1. Appendix A of this report.

depth of the producing zone and the magnitude and strength of the overlying strata.

5.1.3 Groundwater

Groundwater is extremely important to the San Antonio area, as the city is the largest in the U.S. dependent solely upon groundwater for its municipal water supply. Most of this water comes from the Edwards aquifer, which overlies the target Hosston aquifer. Concern exists about contamination of the Edwards aquifer both during drilling and production. However, extensive experience with oil and gas drilling in the area has led to the development of drilling and casing techniques which adequately safeguard the Edwards aquifer. These techniques will be adhered to during the Lackland geothermal project, and no adverse impacts on the Edwards aquifer are anticipated. Groundwater shallower than the Edwards will be protected during drilling by the use of lined ponds and steel tanks so that no fluids will be allowed to seep into the ground. Drilling fluids and geothermal effluent produced during well development will be trucked from the well site to approved disposal sites.

5.1.4 Surface Water

No surface release of fluids will be permitted during the well drilling and development operation, so unfavorable impacts upon surface waters will be non-existent.

5.1.5 Air Quality

The San Antonio region has a low meteorological potential for air pollution due to atmospheric mixing and wind transport characteristics, and there have been no air pollution episodes. The only atmospheric emissions during the brief drilling period (less than 30 days) will be the exhaust from diesel engines on the drill rig. Standard Exemption No. 6 will be applied for and obtained from the Texas Air Control Board for the diesel exhaust.

5.1.6 Flora and Fauna

None of the threatened and endangered plant species listed by the Rare Plant Study Center in Austin, Texas occur on the base. Whitetail deer have occasionally been sighted, but there is no resident population. A significant red squirrel population exists near Leon Creek, but this area will not be disturbed by the drilling operation. A maximum of 50 cottontail and jack rabbits reside in the large fields. Out of a total of approximately 450 acres of undeveloped land on Lackland AFB, only 2 acres will be used for the drill site, and that will be restored following the drilling and testing operation. Predatory birds have been observed on the base from time to time, but they are thought to be non-resident. Other small birds which have occasionally been observed are either non-resident or members of very small resident populations. None of the species listed by the Texas Organization for Endangered Species has ever been sighted at Lackland AFB.

5.1.7 Historical/Archaeological Sites

There were no historical/archaeological sites reported on Lackland AFB in a survey of the region conducted by the Center for Archaeological Research of the University of Texas at San Antonio.

REFERENCES FOR SECTION 5

The references for the Environmental Assessment appear with the full Environmental Assessment in Appendix A.

6.0 PERMITTING

A well site has been selected near the southern edge of the base, 200 ft east of Hughes Avenue and 200 ft south of Gott Street. A drilling permit for a 5000 ft deep geothermal well at this site is in the process of being obtained from the Texas Railroad Commission in the name of the United States Government, U.S. Air Force, Air Training Command, Lackland AFB. This is being done under the authority of Section 2689 of PL 97-214, which grants the Secretary of a military department authority to develop geothermal energy resources within lands under his jurisdiction. This law precludes the necessity of obtaining BLM approval to explore for and develop geothermal resources under Air Force lands. However, the project manager plans to keep the BLM informed of project progress and success, and the well logs will be made available to the Chief of Agreements and Classification Section in the Tulsa BLM office upon project completion.

A permit for temporary surface discharge of the geothermal fluid during well testing cannot be obtained from the Texas Railroad Commission until water chemistry data from the specific well in question is obtained (after drilling and cleaning out the well). This will impact the previously submitted Phase II schedule, and may possibly limit the flowrate and duration of the well test in the event that the actual water quality precludes obtaining a surface discharge permit.

The Texas Air Control Board regulates atmospheric discharges, including exhaust from stationary internal combustion engines and gas turbines of greater than 850 Hp. The type of drill rig which is expected to be used for the Lackland geothermal well will have 3-1000 Hp diesel engines. Therefore, an application for Standard Exemption Number 6 will be filed to allow operation of the drill rig engines at the well location on Lackland AFB.

7.0 CONCLUSIONS AND RECOMMENDATIONS

All of the studies performed to date indicate that the project has a high probability of success, and the investigators strongly recommend that the U.S. Air Force proceed into Phase II of the program.

7.1 Recommended Well Location

This detailed interpretation of the data has led to a very optimistic outlook for geothermal utilization at Lackland AFB. We recommend that a nominally 4200 foot resource evaluation well be drilled through the Hosston formation at the location shown in Figure 7-1. That location was chosen for these geological reasons:

- 1) To avoid the intersection of the deep seated normal fault located at the north of the base as discussed in Section 3.2.2.
- 2) The net sand in the potential aquifer increases to the south, so the well should be to the southern end of the base to be in a position of penetrating a maximum thickness of producing interval.
- 3) A southerly location favors a position over the basement Paleozoic graben, with the potential for graben-bounding faults serving as conduits to bring hot upwelling deep basin water into the Hosston Formation.
- 4) To locate the Lackland well in proximity to the Pagenkopf well just south of Lackland AFB where very good aquifer characteristics were evident in the examination of the drill cuttings.

7.2 Hydrology and Utilization

A well at the recommended location has a high probability of success. It is anticipated that a well drilled at this location will produce approximately 1000 gpm of water with a temperature in the range of

Figure 7-1
RECOMMENDED WELL LOCATION

130-145°F, with a drawdown of approximately 100 ft. It is estimated that a well with these characteristics would be able to supply all domestic hot water and a significant fraction of space heating for the nine 1040 man dorms, the two 624 man dorms and an undefined number of additional buildings on the west side of Lackland AFB.

7.3 Recommended Well Design

Based on the recommendations of local drilling engineering consultant, R. W. Dirks Petroleum Engineer, Inc., we recommend the well design shown in Figure 7-2 and discussed in Appendix B.

It should be noted that proper precautions are included in the well design to protect the Edwards Formation which services as the municipal water supply for San Antonio. These precautions include the use of a native mud drilling fluid during drilling of the Edwards, followed by the installation of properly cemented casing.

The cementing program, Appendix C, is designed to adequately protect the Edwards aquifer and to satisfy requirements of the Texas Railroad Commission for casing/cementing operations.

The drilling fluid program, shown in Appendix B, will provide protection for all formations encountered during drilling of the hole, as well as special protection for the objective Hosston aquifer. The drilling fluid program is based upon recommendations provided by commercial drilling fluid service companies.

In the upper portions of the hole, normal oil field type muds will be used. While drilling in the objective formation, a low-solids biodegradable polymer drilling fluid will be used to minimize any possible damage to the geothermal reservoir.

Figure 7-2
WELL DESIGN DIAGRAM

It should be noted that Lackland AFB is situated in an oil and gas producing area, and standard oil field practices will be followed during drilling operations. A mud logging trailer will be on site during the drilling to monitor the drilling fluid for shows of hydrocarbons. If hydrocarbons are detected in the drilling fluid and/or in the drill cuttings, the show will be evaluated and the formation will be tested as appropriate.

To facilitate Phase II work, a bid invitation letter has been prepared (Appendix D) to distribute to potential drilling companies upon receiving authorization to proceed with Phase II work.

Projected project costs are still being gathered from various service companies as of this writing, so no current estimate of the drilling related costs can be given here. It is anticipated that we will have a reasonable estimate to present at the briefing scheduled for June 17, 1983. It is presently estimated that, due to the depressed activity in the drilling industry, drilling costs will be lower now and in the near future than when project costs were first estimated in mid-1982.

7.4 Environmental Assessment

The current issue of the Environmental Assessment is limited to the well drilling portion of the project. No irreversible or irretrievable impacts are anticipated as a result of the geothermal well drilling on Lackland AFB. Following well completion and chemical analysis of the well effluent, a surface discharge permit for well testing will be requested from the Texas Railroad Commission. Surface discharge is the preferred effluent disposal method for well testing. Following either acceptance or rejection of the request for surface disposal of the test effluent, the test mode will be selected, and an addendum to the EA will be issued covering the well testing phase of the project.

7.5 Permitting

PL 97-214 gave military departments the right to develop geothermal resources within lands under their control. This law significantly reduced the coordination necessary among federal agencies to proceed with this project. An application for a drilling permit has been filed with the Texas Railroad Commission, which controls oil, gas and geothermal drilling within the state of Texas. An exemption for the exhaust emissions from the diesel engines on the drill rig will be requested from the Texas Air Control Board at the initiation of Phase II activities. Following completion of the well and chemical analysis of the effluent, a surface discharge permit for well testing will be requested from the Texas Railroad Commission.

Appendix A

Environmental Assessment

ENVIRONMENTAL ASSESSMENT

**CHARACTERIZATION AND EVALUATION OF GEOTHERMAL RESOURCES
AT LACKLAND AIR FORCE BASE FOR HEATING DOMESTIC
WATER: DRILLING THE EXPLORATORY WELL**

**Lackland Air Force Base
San Antonio, Texas**

June 1983

ABSTRACT

This Environmental Assessment (EA) is for drilling an exploratory geothermal well at Lackland Air Force Base, San Antonio, Texas. The project is part of a program designed to characterize and evaluate geothermal resources beneath the base with the long range goal of utilizing geothermal energy to replace natural gas for domestic water and space heating at a number of buildings on Lackland AFB. Drilling will occur over a 2-3 week period in the summer of 1983 into the Hosston Formation. Surface impacts of this activity will be restricted to the drilling site, a 300 ft by 400 ft (92 m x 122 m) area located on a 4.6 acre (2.1 ha) undeveloped area in the southwest corner of the base. The site requires no grading or road construction, and an all-weather pad will be laid over the portion to be occupied by the drill rig. Adjacent to the rig a reserve pit will be dug and lined for holding excess drilling fluids and solids from the well. Drilling procedures routinely used in the San Antonio area to protect the Edwards Aquifer will be adopted. Upon completion of drilling operations the drill rig and associated equipment will be removed and the well will be shut in thus terminating this phase of the project. The next step in the program is test pumping of the exploratory well, which entails disposal of spent geothermal effluent which cannot be evaluated or initiated until the chemical quality of the effluent is known. An addendum to this EA will be prepared for that phase of the program, characterization of the geothermal resource.

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1. INTRODUCTION

The action addressed by this Environmental Assessment (EA) is the drilling of an exploratory well that subsequently will be used to characterize geothermal resources beneath Lackland Air Force Base (AFB) in San Antonio, Texas. This is part of a program that will provide the U.S. Air Force (USAF) with data to conduct engineering and economic evaluations of the long-term potential for use of geothermal heat on the base. General geological, engineering, and economic investigations performed for the USAF by others^{1,2} suggest potential geothermal sites beneath Lackland AFB and will be supplemented by site specific data on water quality and aquifer productivity characteristics of the exploratory well.

The current program has focused thus far upon developing a well site on Lackland AFB. Available information on the geologic and hydrologic conditions likely to be encountered by the well was compiled which assisted the decision on well siting. Data essential to the USAF decision to utilize geothermal heat will be obtained from an aquifer testing program after the exploratory well is completed.

A drilling site has been selected and well drilling and construction programs have been developed. It is anticipated that drilling will begin during the summer of 1983. The well will require 2-3 weeks to complete, after which aquifer testing will occur over a 1-2 month period in late summer or early fall, 1983.

Following completion of testing, the well will be shut in while data are being analyzed. Should the well not prove suitable for economic use, it will be abandoned in accordance with regulations. If, as anticipated, results of the test and of the feasibility analyses are favorable, the USAF envisions developing a full-scale geothermal heating program at Lackland AFB.

The proposed development program is described in detail elsewhere.² Briefly, it would involve replacing natural gas for domestic water and space heating in recruit dormitories and other buildings by geothermally

heated water. The annual domestic hot water loads in these buildings are large because they house a high density of military personnel. The preliminary economic analysis of switching the domestic hot water heat source from natural gas to geothermal water showed that cost recovery of the investment would occur in seven years.²

It should be kept in mind that this EA addresses only the exploratory well drilling portion of the overall program. This is because too little is known now to assess potential environmental impacts associated with testing the well. These aspects of the program will be the subjects of other assessments and reports as more information becomes available. For example, upon completion of drilling operations, the chemical quality of geothermal water from the exploratory well will be analyzed to provide data for an assessment of testing the well.

The well must be pumped before it can be characterized and evaluated as a geothermal resource, and this will entail disposal of effluent from the test. The means by which the geothermal effluent will be disposed of depends in large part upon the effluent's chemical quality, which cannot be characterized adequately without first drilling the well.

REFERENCES

1. Woodruff, C. M. Jr., C. D. Henry, Christine Gever, 1981, "Geothermal Resource Potential at Military Bases in Bexar, Travis, and Val Verde Counties, Texas;" Geothermal Resource Assessment for the State of Texas; Appendix H, Texas Bureau of Economic Geology, 85 p., U.S. Dept. of Energy Contract DE-A507-79ID12057.
2. Radian Corporation, 1982, Life Cycle Cost Effectiveness Studies for Direct Utilization of Geothermal Energy at Four Military Installations in South Central Texas, U.S.A.F. Contract F41689-81-C-0040, Vol. 1.

2. DESCRIPTION OF PROPOSED ACTIVITY

2.1 Location

The exploratory geothermal well will be located on Lackland AFB in San Antonio (Bexar County), Texas, at approximately 29°22'22" N latitude and 98°37'13" W longitude. A map showing Texas and the locations of Bexar County, San Antonio, and Lackland AFB is in Figure 2.1.1.

Selection of a drilling site for the exploratory well was based largely upon favorable geologic and hydrologic conditions indicating a high probability of finding substantial and dependable quantities of geothermal water. These considerations are addressed in the geological report for this project.¹ It was also necessary to select a site on the base that would accommodate a drilling operation, and this posed no great problem, as there are many undeveloped areas on Lackland AFB of suitable size, configuration, and topography for well drilling. The base and well site selected are shown in Figure 2.1.2.

2.2 Project History

A preliminary geological investigation conducted for the USAF indicated that the Hosston Formation possesses geothermal characteristics of possible economic importance.² A subsequent engineering and economic analysis showed that much of Lackland AFB may be within economic piping distance of potential user sites.³ As a result of these studies, the USAF asked the Idaho Operations Office of the U.S. Department of Energy (DOE) to assist with geothermal exploration at Lackland AFB. The DOE in turn contracted with the Earth Science Laboratory University of Utah Research Institute (UURI) and EG&G Idaho, Inc., in early 1983 to initiate exploration of geothermal resources beneath Lackland AFB.

The UURI compiled and interpreted geologic and hydrologic data on the Hosston Formation beneath the base. Data from the previous studies^{2,3} were supplemented with additional subsurface information from water wells and tests for hydrocarbons in the vicinity of Lackland AFB. Hydrologic and

Fig. 2.1.1. Location of Bexar County, San Antonio and Lackland Air Force Base

Fig. 2.1.2. Lackland Air Force Base and location of the exploratory geothermal well

stratigraphic data were compiled from the files of agencies such as the Texas Bureau of Economic Geology and the U.S. Geological Survey. Oil and gas well data were collected from the files of petroleum libraries and from private geologists familiar with subsurface conditions in the San Antonio area.

The data compilation and interpretation effort provided information used to select the drilling site and to design the well in May 1983. The following section describes details of the drilling program.

2.3 Project Description

A drilling consultant, R. W. Dirks Petroleum Engineering, Inc. of Tuleta, Texas, was employed to assist in designing the well and selecting a drilling contractor. The consultant also is responsible for seeing that all drilling operations comply with state and federal regulations.

Design of the well was a crucial step in the project and has been described in detail in the consultant's report on well design.⁴ Advanced planning of all aspects of well design and construction should minimize the probability of problems arising from unanticipated conditions. Controlling factors that affected the well design were minimum screen and casing sizes necessary to have fluid velocities within acceptable limits for the anticipated well production rates, and to permit a suitable pump to be installed. These considerations, along with knowledge of the stratigraphic section to be penetrated, provided input for drilling and well completion programs.

After a drilling contractor has been selected, preparations can be made for moving the drill rig to the site. This will involve construction of an all-weather pad and a reserve pit for holding drilling fluids and solids.

The exploratory well will be drilled into the Hosston Formation to a nominal depth of 4,500 ft (1,370 m). Surface casing of 13-3/8 in. (40 cm) diameter will be set into the initial 2000 ft (610 m) of the well and

cemented. Drilling fluid for this stage will consist of gel and water containing filtration control additives to restrict water loss. This will form a filter cake on the walls of the well and minimize fluid invasion.

The next phase of the well will be drilled to the top of the production zone (Hosston Formation) at about 3,800 ft (1,200 m). Drilling fluid for this stage will be lignosulfonate based, and 9-5/8 in. (24.5 cm) diameter liner will be hung and cemented from 1,800 ft (558 m). This will protect the Edwards Aquifer from contaminants, the importance of which is explained in Section 3.

A polymer drilling fluid with a zanthium gum base as a viscosifier and starch as a filtration control additive will be used for drilling through the production zone to the final depth of about 4,500 ft (1,395 m). A 7-in. (17.8-cm) diameter screen will be hung from the liner and the annulus between the seven and open bore hole will be packed with gravel.

After the screen and gravel pack is in place, the drilling rig will be moved off the site and a cement bond log run from the bottom of the 9-5/8-in. (24.5-cm) liner to the top of the cement. This will ensure that a good barrier exists between the well casings and the geological formations, such as the Edwards. (Logging and other details of the well design are discussed in the consultant's well design report.⁴)

After cementing is verified, the production zone will be cleaned by air lifting. Water from the Hosston Formation will be obtained for chemical analysis and the well will be temporarily shut in. Determination of chemical characteristics of the geothermal water is necessary prior to testing hydrologic properties of the exploratory well. Testing will require pumping at about 1 ft³/s, or, 0.03 m³/s (cms) for about 30 days. This is equivalent to about 60 acre feet (78,420 m³) of effluent which must be disposed of, and the disposal method depends upon the effluent quality. Thus, there will be a pause in the project between drilling the well and testing it while a means of disposing of the effluent is selected upon.

2.4 Construction and Operation Activities

Construction activities during well drilling will be restricted to the drilling site. This is a 4.6-acre (18.9-ha) field of which an area of 400 ft by 300 ft (92 m by 122 m) will be occupied by drilling operations. Within this area a caliche pad (150 ft by 150 ft by 8 in. deep [47 m by 47 m by 20 cm]) will be laid for situating the drill rig.

Adjacent to the rig a reserve pit will be dug to hold solids and excess drilling fluids. Dimensions of the pit will be 150 ft by 150 ft by 4 ft deep (47 m by 47 m by 1.2 m) and it will be lined with bentonite clay.

It will not be necessary to grade the site as the terrain is level and access will be from existing roads.

Drilling will be performed with a standard rotary rig equipped with three 1,000 horsepower diesel engines, each operating in idle 75% of the time. Drilling operations will require about 25,000 gal (95,000 l) of water for startup during the initial 6-8 h and 2-3 gal/min (8-11 l/min) thereafter for the duration (2-3 weeks). This water will be obtained from the Lackland AFB domestic supply.

Greater detail on drilling operations is in the drilling engineer's report.⁴

2.5 Safety

Because the geothermal resource will not be free-flowing and is expected to be below 140°F (60°C) in temperature, no special or unusual safety problems are anticipated. Oil field blowout prevention equipment will be used on the well, as deposits of natural gas and petroleum occur in the region.⁴

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3. DESCRIPTION OF EXISTING ENVIRONMENT AND POTENTIAL ENVIRONMENTAL CONCERNS

3.1 Physiography

The major physiographic feature in the vicinity of Lackland AFB and San Antonio is the Balcones escarpment which dominates the landscape of south-central Texas.¹ Figure 3.1.1 shows the escarpment in Bexar County and the location of the base relative to it. The general geology and land forms of Bexar County are also shown in the figure.

Portions of two physiographic provinces are involved in the geology of the region: the Edwards Plateau, located northwest of the Balcones escarpment, and the Coastal Plain, located to the southeast of the escarpment.² The Edwards Plateau is underlain principally by limestone beds that dip very slightly to the southeast. Many small streams have dissected this plateau, resulting in a rugged hilly terrain with elevation ranging from 1,100 to 1,900 ft (340 to 580 m) above sea level. The Balcones escarpment trends in a northeast-southwest direction across the northern part of Bexar County and shows an abrupt change in elevation as it changes from the hill country of the Edwards Plateau to the northwest to the rolling Coastal Plain to the southeast. The Coastal Plain is a rolling prairie underlain by beds of marl, clay, and poorly consolidated sands that generally dip toward the southeast at a greater rate than do beds of the Edwards Plateau region.³

3.2 Geology

As part of the site selection and development plan for the exploratory well, an extensive geological survey of Lackland AFB and surrounding area was conducted and reported upon by UURI.⁴ The discussion here is not as extensive as that in the geologic report and focuses instead upon aspects of the environment important to impact assessment. Additional detail on all the geologic considerations relative to the exploratory well and geothermal resources at Lackland AFB can be found in the UURI report. Overburden beneath Lackland AFB is about 20 ft (6 m) thick and consists of

Fig. 3.1.1. Geology and landforms of Bexar County.
Adapted from Woodruff et al (1).

silty clays.³ Chert and limestone gravel beds of varying thickness are present irregularly throughout the area. Clay content in these materials is variable; at some localities they are clay-choked and relatively impervious; whereas, at other localities, the clay is absent and the materials are free-draining.

Numerous subsurface geologic units are represented within the boundaries of Lackland AFB, but only three subcrop the surface clay and gravel.⁵ These are the Taylor Marl and the Navarro Group of Cretaceous age and the Tertiary Midway Group.

The Taylor Marl is a soft to moderately hard, calcareous shale or marl which is found only along the extreme northern edge of Lackland beneath a thin mantle of the Navarro. It attains a maximum thickness of about 315 ft (96 m) at Lackland.

The Navarro Group is a sandy, silty clay shale and, in most cases, exhibits jointing, fracturing, and weathering features to a depth of 70 to 80 ft (21 to 24 m) below the ground surface. The Navarro immediately underlies the overburden in the southern one-third of Lackland AFB with a maximum thickness of approximately 450 ft (138 m).

The Midway Group underlies most of the northern two-thirds of the base, with the exception of the area underlain by the Navarro. This structural discontinuity is a result of faulting. The Midway is divided into upper and lower members to better define structural conditions in the area. Maximum thickness of the combined Upper and Lower Midway at Lackland AFB is 250 ft (76 m) and is located in the northeast section of the base.

The lower Midway, approximately 60 ft (18 m) thick, consists of glauconitic clay with glauconitic sandstone beds up to 5 ft (1.5 m) thick. A relatively pure bentonite bed from 2 to 5 ft (0.6 to 1.5 m) thick is present in the Lower Midway, approximately 8 ft (2.4 m) above the Midway-Navarro contact.

The upper Midway consists of a highly plastic, montmorillonite clay shale. The clay shale shows extensive jointing, fracturing, and weathering (oxidation) to a depth of approximately 50 ft (15 m) below natural ground surface.

The strike of these Cretaceous and Tertiary strata is approximately N30°E, and they have a general dip of approximately 3° to the north. As evidenced by the dip of the beds, it appears that Lackland AFB is located on the north flank of a small anticline that is oriented in an east-west direction with the crest located a short distance south of the base.⁵

3.3 Seismicity

The San Antonio region is within a large portion of Texas that is considered a zero-risk zone for seismic disturbances.⁶ Although the region was heavily faulted during the Paleocene age, none of the faults have been active since that time.^{7,8} Figures 3.1.1 illustrates the extent of faulting associated with the Balcones escarpment in Bexar County.

3.4 Subsidence

Numerous water, gas, and oil wells have been drilled in the San Antonio area without reports of subsidence. It is unlikely that subsidence could result from the exploratory geothermal well as there are overlying strata of sufficient strength to prevent the phenomenon.

3.5 Soils

Soil at Lackland AFB consists of a surface layer of black clay varying in thickness from 5 to 9 ft (1.5 to 2.8 m). Beneath the clay layer to approximately 15 ft (4.6 m) depth is a clayey gravel containing varying amounts of low plasticity clay binder.⁹ The texture is clay with low permeability. The principal minerals in the overburden are montmorillonite mica, chlorite, quartz, and feldspar. Due to the high clay content, the

soil is well compacted and not susceptible to appreciable wind erosion. Water erosion also is limited due to the soil's textural strength and the general lack of slope on Lackland AFB.²

3.6 Ground Water: The Edwards Aquifer

Ground water is extremely important to the San Antonio area, as the city is the largest in the U.S. that is dependent solely upon ground water for its municipal water supply.^{10,11} Although several minor aquifers occur in the area, most of them are insignificant compared to the Edwards Aquifer, which is designated by the U.S. Environmental Protection Agency as the sole-source aquifer for San Antonio's municipal water supply. At least a million people in south-central Texas depend directly or indirectly upon the Edwards Aquifer for their well-being and livelihood.

3.6.1 Geologic Description

Because of its importance, the Edwards Aquifer has been the subject of numerous detailed studies that assess the extent and quality of the resource.^{11,12} The Edwards is a carbonate (limestone and dolomite) formation having mostly secondary (solution) porosity.^{10,11} The aquifer is a tabular rock body ranging in thickness from 450 ft (137 m) to more than 1,000 ft (305 m). It consists of two parts--a water table part (the recharge zone) and an artesian part--that are often separated at the Balcones fault zone. The artesian part of the aquifer generally underlies the surface south of the Balcones escarpment, where San Antonio and Lackland AFB are located. It becomes artesian where overlain by younger, impermeable strata and is progressively deeper to the south and southeast, as shown in Figure 3.6.1.1.

3.6.2 Hydrologic Characteristics

Water in the Edwards occurs in secondary openings formed as the result of dissolution of limestone and dolomite by circulating ground water.^{10,11} The openings thus created range in size from small holes to

Fig. 3.6.1.1. General features of the Edwards Aquifer depicted on structural contours on top of the Edwards. Adapted from Woodruff et al (1).

- EXPLANATION**
- (1) Lackland Air Force Base
 - ▨ "Bad-water line"
 - ▨ Outcrop Edwards and older formations
 - Normal fault (dashed where inferred) turn on downthrown site
 - Datum is mean sea level
 - Contour interval 500 ft (152.5 m)

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large caverns. Natural discharge from the Edwards is principally through springs located on faults along the Balcones escarpment. Recharge takes place both from direct infiltration of precipitation and streamflow. It has been estimated that 46% of runoff from the streams goes to recharge the aquifer.¹⁰

3.6.3 Water Quality

The quality of water in the recharge zone of the Edwards Aquifer is relatively uniform.^{10,11} It is of the calcium bicarbonate type and has a total dissolved solids content of about 250 to 300 mg/l. Along the southern boundary of the aquifer, however, the quality of water deteriorates sharply over a relatively narrow zone.¹ This zone marks the downdip limit of fresh ground-water circulation; very little recharge that enters the aquifer migrates beyond this zone, but instead it moves eastward and northeastward. The southeastern boundary of the aquifer (the "bad water line" shown in Figure 3.6.1.1) is arbitrarily placed in this zone along the line where the total dissolved solids content becomes greater than 1,000 mg/l.

3.7 Surface Water

With the exception of the extreme southern corner, Bexar County is located within the San Antonio River Basin, of which the principal tributary is the Medina River.¹⁰ Another major tributary is Leon Creek, which drains into the Medina River and is of interest here as it flows through the eastward end of Lackland AFB. This short segment of Leon Creek is the only natural surface water inside the base, although a dry creek, Indian Creek, touches the southwestern corner of the base. Indian Creek carries storm runoff into Leon Creek 6 miles (9 km) below the base and 5 miles (8 km) above the confluence of Leon Creek and the Medina River.

3.8 Water Quality

The water quality and flow of Leon Creek are of concern as one alternative for eventual disposal of spent geothermal effluent from the test well is surface discharge into the stream via the storm sewer system at Lackland AFB. The Texas Department of Water Resources (TDWR) conducts

field surveys that include Leon Creek. Eight stations are sampled at roughly monthly intervals, with data available from at least 1976 to the end of 1982. Not all parameters are routinely sampled, and an inspection of the massive amount of data available suggests that no routine sampling program has been maintained. However, there is no paucity of water quality information on Leon Creek. Unfortunately, the large volume of data gathered by TDWR has not been systematized and reduced into a readily available format.

Although up to forty-five parameters are measured from time-to-time by the TDWR, it is more characteristic of the monitoring program to report data on about fifteen to twenty-five parameters. Of interest to this project are those parameters for which there are stream standards that must be conformed to regarding effluents discharged into Leon Creek, i.e., chlorides, sulfates, total dissolved solids, dissolved oxygen, pH, temperature, and fecal coliforms.

There is considerable variation in some of the water quality parameters of concern, depending in part upon time of year and runoff from precipitation. The records show that the TDWR monitoring stations typically report a flow rate of $1 \text{ ft}^3/\text{s}$ ($0.03 \text{ m}^3/\text{s}$). The general overall quality of the water is good.¹³ For example, during summer months, when it is proposed to temporarily discharge spent geothermal effluent, total dissolved solids range from 452 to 532 mg/l, averaging 492 mg/l. Sulfates range from 50 to 138 mg/l and average 73 mg/l., and chlorides range from 25 to 140 mg/l, with an average of 84 mg/l. Temperature of the water in Leon Creek during the summer is high, averaging 79°F (26°C) and ranging from 70 to 85°F (21 to 30°C). Dissolved oxygen and pH remain fairly constant at 7.2 mg/l and 7.4 respectively. Fluctuations in those two parameters during the summer are from 5.7 to 8.4 mg/l dissolved oxygen and from 6.8 to 8.5 for pH.

There are no stream monitoring stations on Indian Creek or on Leon Creek below the confluence with Indian Creek. However, in the confluence area natural stream discharge apparently increases by several cubic feet per second (cfs), and farther downstream the flow is augmented by a 24 cfs

wastewater discharge from the Leon Creek Sewage Treatment Plant.^{12,14} Although water quality parameters and stream flow rates are not available for this portion of Leon Creek there are data available from the U.S. Geological Survey on water quality and flows of the Medina River in the vicinity of its confluence with Leon Creek.¹⁵ These data can be used to evaluate the consequences of surface discharge of geothermal effluent during the test pumping and resource characterization phase of the program. However, this must await determination of the chemical quality of water from the exploratory well.

3.9 Meteorology

San Antonio is located in the south-central portion of Texas on the edge of the Gulf Coastal Plain. Its climate is modified sub-tropical, predominantly continental during the winter months and marine during the summer months.¹⁶

Normal mean temperatures range from 52°F (11°C) in January to a high of 84°F (29°C) in July. The summers are hot with daily maximum temperatures above 90°F (32°C) over 80% of the time. Mild weather prevails during much of the winter months, with below-freezing temperatures occurring on an average of about 20 days each year. Northerly winds prevail during most of the winter, while southeasterly winds from the Gulf of Mexico prevail during the summer.

San Antonio is situated between a semi-arid area to the west and the coastal area of heavy precipitation to the southeast. The normal annual rainfall is 27.8 in. (70.6 cm). Precipitation is fairly well distributed throughout the year with heaviest amounts during May in the spring and September in the fall. Measurable snow occurs only once in 3 or 4 years with the greatest annual amount being 7.4 in. (18.8 cm) in 1926.

Relative humidity averages above 80% during the early morning hours most of the year, dropping to near 50% in the late afternoon. Mean annual evaporation is 43 in. (109 cm), about 15 in. (38 cm) yearly in excess of precipitation.

3.10 Air Quality

The San Antonio region has a low meteorological potential for air pollution due to atmospheric mixing and wind transport characteristics,¹⁷ and there have been no air reported pollution episodes.¹⁸ There are seven air monitoring sites in the area operated by the San Antonio Metropolitan Health District and the Texas Air Control Board, and the annual Pollutant Standards Index (PSI) for 1981 revealed only three out of 251 reporting days with unhealthy conditions.¹⁸ One unhealthy value resulted from elevated total suspended particulate matter during a dust storm on March 18. An unhealthy value for carbon monoxide occurred on December 21, and an unhealthy value for ozone was recorded on May 18.

There are no air quality monitoring stations on Lackland AFB. The base has less than 100 tons (907 kg) per year of all emissions and has received a waiver of requirements from the Texas Air Control Board and is not required to submit an Air Pollution Episode Plan.¹⁹

3.11 Natural Flora

Lackland Air Force Base contains 445 acres of unimproved grounds. This area consists of native brush and grassland composed predominately of mesquite trees (Prosopis juliflora), prickley pear (Opuntia spp.), curly mesquite grass (Hilaria belangeri), side oats gramma grass (Bouteloua curtipendula), prairie coneflower (Ratibida columnifera), devilweed aster (Aster spinosus), buffalo grass (Buchloe dactyloides), Bermuda grass (Cynodon dactylon), and an assortment of less common plants.²⁰ The exploratory well will be situated on 4.6 acres (1.8 ha) of this type of habitat.

Leon Creek includes two acres (0.8 ha) of aquatic habitat containing alligator weed (Alternanthera philoxeroides), watercress (Rorippa nasturtium-aquaticum), cattails (Typha latifolia), and water-hyacinth (Eichhornia crassipes).²⁰

3.12 Native Land Fauna

The only large game animals on Lackland AFB are occasional whitetailed deer (Odocoileus virginianus). The numbers are very small, and there is no resident population. Small game mammals present are red squirrel (Tamiascrurus hudsonicus), cottontail (Sylvilagus floridanus) and jack rabbits (Lepus californicus). The heaviest concentration of squirrels is along Leon Creek that flows through a golf course and picnic area. It is estimated that some 500 squirrels use the 300 acres of this habitat. Rabbits are seen throughout the base on the large fields, but probably no more than 50 reside there.²⁰

3.13 Birds

The only game birds on the base are mourning doves (Zenaidura macroura) that migrate depending upon food availability. Some have been observed nesting in the base's housing area, but the numbers are small.²⁰

From time to time predatory birds are observed on the base, but they are thought to be nonresident. Species sighted are Cooper's hawk (Accipiter cooperii), sparrow hawk (Falco sparverius), screech owl (Otus asio), and great horned owl (Bubo virginianus).²⁰

Other birds that frequently are observed on base are mockingbirds (Mimus polyglottus), black-throated sparrows (Amphispiza bilineata), blue jays (Cyanocitta cristata), boat-tailed grackles (Cassidix mexicanus), cardinals (Richmondia cardinalis), and killdeer (Charadrius vociferous). It is not known whether resident populations exist, but if they do they are small due to limited suitable habitat on the base.

3.14 Fish

Fish known to be present in small pools in Leon Creek are channel catfish (Sctalurus punctatus), suckers (Catostomus spp.), sun perch (Lepomis spp.), and largemouth bass (Micropterus salmoides). None are very large and population sizes are unknown.²⁰

3.15 Threatened and Endangered Species

3.15.1 Plants

A review was conducted in 1976 of plants listed by the Rare Plant Study Center in Austin, Texas.²¹ None of the endangered or rare species listed for the Bexar County portion of the blackland prairie have ever been found on Lackland AFB. If they ever occurred on the site historically, they were eradicated when the base was developed and have not re-established themselves.²⁰

3.15.2 Animals

None of the animals listed by the Texas Organization for Endangered Species²² has ever been sighted at Lackland AFB. Two species of subterranean fish inhabiting caverns of the Edwards Aquifer, the widemouth blindcat (Satan eurystomus) and the toothless blindcat (Trogologlanis pattersoni), are candidates for the national endangered species list.²³

3.16 Historical/Archaeological Sites

There were no historical/archaeological sites reported on Lackland AFB in a survey of the region conducted by the Center for Archaeological Research of the University of Texas at San Antonio.²⁴

3.17 Demography and Socioeconomics

The average total population of Lackland AFB is about 30,000, approximately evenly divided between temporary trainees and permanent personnel. There are about 6,000 permanent residents on the base, one-fourth of which are civilians.²⁵

The base employs almost 9,000 military personnel and about 2,600 civilians. Most of these workers reside within the San Antonio Metropolitan area. The most current available data on incomes (for 1977) show that total annual payroll for military workers was \$107 million and

about \$343 million for civilian workers. These figures compare to about 360,800 employees for the San Antonio area in 1980, with a total annual income over \$3.5 billion. The 1980 population for the area was about 872,000.²⁵

Drilling the exploratory geothermal well will employ about 20 persons from the San Antonio area for no more than a month. These personnel should require no special living accommodations, as they can reside within commuting distance of the drilling site. Funds expected to be put into the local economy as a result of the project are about \$250,000.

Although the site of the exploratory well on Lackland AFB is reasonably remote from routine activities, there is a four-story dormitory situated 900 ft (275 m) to the northwest. The building houses about 1,000 recruits undergoing basic training at the base.

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4. POTENTIAL ENVIRONMENTAL IMPACTS AND MEASURES FOR MITIGATION

Drilling operations for the exploratory geothermal well will occupy a small land area and will be temporary in nature. Measures that might be required to mitigate any consequences of the project are discussed below.

4.1 Ground Water

A major concern regarding drilling in the San Antonio area is protection of the Edwards Aquifer. Wells drilled through the aquifer typically have casing set and cemented in place before drilling deeper to ensure that contamination of the Edwards is avoided. Reserve pits constructed for drilling operations commonly are lined to avoid leaching of contaminants into shallow aquifers. Both the casing plan for the exploratory well and bentonite clay lining for the reserve pit will be used in this project to protect ground water. Additionally, all residues in the pit will be hauled off and disposed of at an approved site. Thus, no impacts to ground-water resources are anticipated.

As this phase of the project does not involve test pumping from the Hosston Formation, there will be no opportunity for impacts to that aquifer at this stage of the overall program. The likelihood of adverse consequences to the Hosston Aquifer resulting from utilization of it as a geothermal resource will be covered in a subsequent assessment.

4.2 Surface Water

There will be no opportunity for impacts from drilling operations to affect Leon Creek because no release of fluids will be permitted during well drilling and development operations. During the subsequent testing phase this will become an important consideration if the creek or its dry tributary, Indian Creek, is used as a surface discharge route for disposal of geothermal effluent.

4.3 Air Quality

During drilling there will be exhausts from a small number of vehicles and the diesel-operated drilling rig. These emissions will be temporary and so small in comparison with other activities nearby that concern is not merited. Consultation with the Texas Air Control Board (TACB) has concluded that the project qualifies for a regulatory waiver.

The generally good atmospheric conditions at Lackland AFB and in the San Antonio region will disperse the minor emissions associated with this project, and no impacts or mitigation steps are anticipated.

4.4 Ecology

The drilling site will be on land previously graded and disturbed during development of Lackland AFB. Disturbances due to drilling operations will be temporary and readily mitigated by restoration measures upon completion of the project, as discussed in Section 6. As there are large areas of undeveloped land on Lackland AFB similar to the drilling site, temporary diversion of the site from its normal condition will not disturb the overall land use system on the base.

4.5 Noise

Potential impacts from noise will depend in part upon the characteristics of the drilling rig yet to be selected. It is unlikely that noise will pose a concern because of the remoteness of the drilling site from normal activities of the base. However, should there be a problem with noise impacts, for example from the dormitory located 900 ft (275 m) from the site, the engine will be muffled.

4.6 Socioeconomics

The small economic scale and short duration of the project will not contribute to socioeconomic impact. There will be no worker relocation associated with drilling operations, which also avoids potential socioeconomic consequences.

5. ALTERNATIVES TO THE PROPOSED ACTION

This project will examine the feasibility of using geothermal water at a low temperature to provide heat currently obtained from natural gas. The reasonably available alternatives to the proposed action are to abandon the project or to delay it. To abandon the project precludes the demonstration of the technical and economic feasibility of utilizing geothermal resources at Lackland AFB and continues the base's dependence upon natural gas, a limited and costly energy resource. A delay in the project would risk eventual cost escalation, and it is unlikely that without further exploration and testing similar to this project that a more suitable site could be found.

6. ABANDONMENT AND RESTORATION

Abandonment and restoration will occur in stages, if at all, depending upon results of geothermal aquifer testing and the outcome of decisions at various points in the overall program to continue or abandon the project. The drilling site will be restored following departure of the rig by removing the caliche pad and cleaning out and filling the reserve pit. Revegetation of the site largely will occur naturally and can be facilitated by reseeding with Bermuda grass, a dominant ground cover at undeveloped sites on Lackland AFB.

7. IRREVERSIBLE AND IRRETRIEVABLE IMPACTS

No irreversible or irretrievable impacts are anticipated from the proposed activity. The geothermal resource to be explored, the Hosston Formation, will not be affected by drilling operations. Neither will other underground resources be affected, because environmental safeguards will protect all vulnerable aspects of that environment. Surface resources likewise will be protected by environmental safeguards applicable to the planned operations at the site.

8. MONITORING PROGRAMS

There are no environmental monitoring requirements for the project at this stage. Monitoring of the exploratory geothermal well and its effluent will occur during testing and characterization of the resource, to be covered in a separate assessment following completion of well drilling operations.

9. REGULATIONS AND PERMITS

Lackland AFB is on federally owned land, and the USAF has full rights to explore, develop, and use geothermal resources on Lackland AFB. A drilling permit will be obtained from the Railroad Commission of Texas, via submission of Form P-5 to the commission's office in Austin and Form W-1 to the San Antonio regional office, prior to initiation of operations.

Upon completion of the well and analysis of the geothermal effluent, application will be made to the Railroad Commission of Texas for a surface discharge permit. An NPDES permit from EPA is not required for short-term discharges such as this will be, and instead a temporary order from the Railroad Commission of Texas will suffice. These steps will be covered in an addendum to this EA.

Emissions from some diesel operated drilling rigs are subject to regulation by the TACB. Based upon prior consultation with the TACB, however, a waiver procedure should suffice in this instance. If the geothermal water is subsequently found to contain hydrogen sulfide or other noncondensable gases in sufficient quantity to merit a permit, application for such will be made prior to the testing and characterization phase of the program.

Appendix B

Well Design

R. W. DIRKS PETROLEUM ENGINEER, INC.
OIL FIELD DRILLING & PRODUCTION SUPERVISION
PHONE 375-2194 P. O. DRAWER 200
TULETA, TEXAS 78162

WELL DESIGN DISCUSSION

It is our recommendation that as soon as a specific location is staked, that a gravel, caliche, or all-weather pad be built to accommodate a drilling rig which will be specified at a later date. The rig capable of drilling and completing this operation, needs to be able to conform to the set of drilling orders included with this report.

As soon as the pad is built, conductor pipe should be set to a depth of 50'. It should be at least 20" in diameter. This will divert fluid returns to metal circulating pits where proper solids control can be monitored.

When the drilling rig is moved on location, the well should commence surface drilling with a 17-1/2" mill-tooth, sealed bearing bit. If the contract for the drilling rig is based on a footage rate, then the responsibility for the bits will lie with the rig and not with the operator. If the responsibility for the bits lies with the operator, then it should be noted that it will require 2 bits to drill the 2000' necessary to set surface casing. The bit type will be decided when the first bit's performance can be evaluated.

The drilling fluid for this stage of the well should consist of gel and water, hereafter referred to as "native mud." This native mud should contain enough filtration control additives to lower the water loss to 6 to 8 cc/ml. by 500'. This will help build a filter cake on the walls of the well bore and minimize fluid invasion. This will also facilitate the evaluation of shallow oil sands which may be present in the surface hole.

After the surface hole is drilled and circulated clean, it should be logged using a dual-induction spherically focused log with a compensated density-neutron log. Side wall cores should be taken in any zones that the logs indicate to be possibly productive.

Upon completion of the log evaluation, surface casing should be set. It should be at least API Grade K-55 with an outside diameter of 13-3/8". It should weigh no less than 54.5 pounds per foot. Proper casing hardware should include a float shoe, float collar, double bow turbolizers, and centralizers. The casing string should be cemented from casing shoe to surface.

While allowing 12 hours for cement to set, the casing head and BOP should be nipped up. Upon completion of nipple up operation, a 12-1/4" mill-tooth sealed bearing drilling bit should be picked up and run in the hole. The

cement plug should be drilled out and drilling into the new formation should continue until the bit dulls. When the bit dulls, it should be replaced with a carbide insert (button) bit and drill to the top of the Hosston. Again, if the drilling contract is based on a footage rate, the drilling contractor will provide the bits.

The drilling fluid for this stage of the well will be similar to the native mud system used in the surface hole. It should be lignosulfonate based drilling fluid. Mud weight should be minimized, and proper flow parameters should be monitored. A 10-12 cc/ml. water loss should be maintained.

The drilled interval from the base of the Edwards to the top of the Hosston should be then logged using the same log program as the surface hole log.

Upon completion of the log evaluation, a 9-5/8" casing liner should be run. It should be no less than API Grade J-55 and should weigh no less than 36 pounds per foot. The liner top should be set at 1800'[±].

Cement should be circulated from the 9-5/8" casing shoe back to 1500'. After allowing 12 hours for the cement to set, the cement on top of the liner should be drilled out with a mill tooth drill bit. After the liner top has been dressed, it should be pressure tested to insure that the liner annulus

does not communicate with the 13-3/8" surface casing. If the pressure test fails, an additional cement job to squeeze the top of the liner will be required. Upon completion of the squeeze job, the cement plug will have to be drilled out and the liner top redressed. The liner top should then be retested. If the pressure test proves satisfactory, a 8-3/4" mill tooth drill bit should be run to the bottom of the 9-5/8" liner and the well bore should be displaced with fresh water. A polymer drilling fluid should be introduced at this stage.

A compatible mud system could be an X-C polymer mud. This polymer uses a zanthium gum base as a viscosifier and uses starch as a filtration control additive. Other mud recommendations are included in this report. The X-C polymer mud is more expensive than some Ben-ex systems, but this polymer is also biodegradable.

Solids control equipment is very important at this stage. Suspended solids and cuttings must be monitored and minimized as much as possible. This may require mud cleaners, dual screen shakers, and mud centrifuges.

When the proper drilling fluid is prepared and in place, then the Hosston Formation can be drilled. The size of bit will be 8-3/4" in diameter. The type of bit will be determined at a later date. Diamond core, mill-tooth, or carbide

insert bits are all available in this size.

After the agreed interval of the Hosston is drilled and evaluated, then the open hole should be underreamed to enlarge the well bore. Then a conventional gravel pack is recommended. A string of API Grade J-55 7" casing is perforated and wrapped with #304 stainless steel wire. The annulus is packed with uniformly sized gravel. The exact size of the screen and sand grains will be designed upon evaluation of the water sand. The method of gravel and screen placement will also depend upon the water sand evaluation.

After the screen and gravel pack is in place, then the drilling rig should be released and moved off location. Once all of the rig equipment is removed, then a cement bond log should be run from the 9-5/8" casing shoe to the top of the cement. This should satisfy all jurisdictional agencies involved and insure that a good cement bond exists between the casing and formation.

Geology

Objective Sands: Hosston Formation

Start Samples: _____ Large _____ Small _____

Start Mud Logger: _____ Mud Logger Co. _____

Send Samples to: _____

Remarks: _____

Logging Depths: 1) 2000' 2) 3850' 3) 4200' 4) _____

Electric Logging Services:

Type	Log Run No.
DI SFL CDL - CNL, SWC, RFT	1
DI SFL CDL - CNL, SWC, RFT	2
DI SFL CDL - CNL, SWC, RFT	3

Required Mud Properties

[illegible]

Approvals:

Manager Drilling & Production

H. Fischer

Exploration Department

R. W. DIRKS PETROLEUM ENGINEER, INC.

DRILLING ORDERS

Well Name: Lackland AFB #1 Total Depth: 4200 Date: 6-3-83
 Prospect: _____ AFE No.: _____
 State: Texas County: Bexar Sec _____ T _____ R _____
 Location: To be determined
 _____ Elevation: _____

Drilling

<u>Hole Size</u>	<u>Depth</u>	<u>Max. Angle</u>
	to	
<u>17-1/2"</u>	<u>0 to 2000</u>	<u>2°, 1°/200'</u>
<u>12-1/4"</u>	<u>2000 to 3850</u>	<u>5°, 2°/500'</u>
<u>8-3/4"</u>	<u>3850 to 4200</u>	<u>5°, 2°/500'</u>

Casing

<u>Size</u>	<u>Description</u>	<u>Setting Depth</u>	<u>Cement Amount</u>
<u>20"</u>	<u>Conductor</u>	<u>50'</u>	
<u>13-3/8"</u>	<u>J-55 54.5 lbs./ft.</u>	<u>2000'</u>	<u>See Remarks</u>
<u>9-5/8"</u>	<u>J-55 36 lbs./ft.</u>	<u>3850'</u>	<u>See Remarks</u>
<u>7"</u>	<u>Wire-wrapped screen</u>	<u>4200'</u>	<u>None</u>

Remarks: Cement amount to be determined based on open hole caliper logs.

Permit No. _____ Serial No. _____

CASING MAKE UP

13-3/8" Surface Casing:

- 1, 13-3/8" float shoe on bottom joint.
- 1, 13-3/8" float collar on top of bottom joint.
- 13-3/8" x 17-1/2" double bow turbolizers spaced 1 per joint through the Edwards Formation.
- 1, 13-3/8" x 17-1/2" cement basket at the top of the Edwards Formation.
- 1, 13-3/8" x 17-1/2" cement basket at the base of the conductor pipe.

Float shoe and float collar must be thread locked in place.

9-5/8" Casing Liner:

- 1, 9-5/8" float shoe on bottom joint.
- 1, 9-5/8" float collar on top of bottom joint.
- 9-5/8" x 12-1/4" double bow turbolizers spaced 1 per joint for the bottom 500'.
- 1, 9-5/8" x 12-1/4" cement basket at the base of the surface casing.
- 1, 9-5/8" x 13-3/8" Liner hanger at 1800'.

Float shoe and float collar must be thread locked in place.

Appendix C

Cementing Program

APPENDIX C

Cementing Program

Surface Casing

Cement 2000' of 13 3/8" casing in 17 1/2" openhole with 70% excess.

Slurry Calculations:

$$\text{Bottom Slurry} = 400' \times .6946 \text{ cft/ft} \times 1.7 \div 1.17 = 405 \text{ sx}$$

$$\text{Filler Slurry} = 1600' \times .6946 \text{ cft/ft} \times 1.7 \div 1.87 = 1010 \text{ sx}$$

Bottom Slurry = 405 sx Class A + 2% S-1

Slurry Weight	15.6 lb/gal
Slurry Yield	1.17 cft/sk
Mix Water	4.94 gal/sk
Compressive Strength	1850 psi - 12 hrs.
	2800 psi - 24 hrs.

Filler Slurry = 1010 sx (25/75 Poz/A) + 6% D-20 + 3% D-44 + 0.2% D-46

Slurry Weight	12.4 lb/gal
Slurry Yield	1.87 cft/sk
Mix Water	10.02 gal/sk
Compressive Strength	375 psi - 12 hrs.
	600 psi - 24 hrs.

Cost Estimate

Cement and Cementing Service	\$10,493
Casing Hardware	3,021
	<u>\$13,514</u>

Production Casing

Cement 9 5/8" casing in 12 1/4" open hole from
3850' - 1800' with 40% excess.

Slurry Calculations:

$$\begin{aligned} 200' \times .3627 \text{ cft/ft} \times 1.4 \div 1.17 &= 90 \text{ sx} \\ 1850' \times .3131 \text{ cft/ft} \times 1.4 \div 1.17 &= 695 \text{ sx} \\ &\underline{785 \text{ sx}} \end{aligned}$$

Main Slurry = 785 sx Class A Neat.

Slurry Weight	15.6 lb/gal
Slurry Yield	1.17 cft/sk
Mix Water	5.19 gal/sk
Compressive Strength	3000 psi - 12 hrs.
	4000 psi - 24 hrs.

Cost Estimate

Cement and Cementing Service	\$5,642
Casing Hardware	1,842
	<u>\$7,484</u>

The volumes used here are a close estimate. The final amounts of cement to be used will be based on hole configuration derived from a caliper log.

Appendix D

Bid Invitation Letter

R. W. DIRKS PETROLEUM ENGINEER, INC.
OIL FIELD DRILLING & PRODUCTION SUPERVISION
PHONE 375-2194 P. O. DRAWER 200
TULETA, TEXAS 78162

BID INVITATION LETTER

TO: Various Drilling Contractors
FROM: R. W. Dirks Petroleum Engineer, Inc.
DATE: June 3, 1983
SUBJECT: Drilling Bid Invitation

The United States Air Force is soliciting drilling bids for the Lackland AFB Geothermal Resource project. The proposed well, hereafter referred to as the Lackland AFB #1, will be drilled to a total depth of 4200', or sufficient depth, to test the Hosston Formation for fresh water production. The bids solicited will be based on a footage rate with daywork charge at total depth, or where appropriate, based on the following parameters found on the attached drilling orders.

Rates will be charged as follows:

The drilling contractor will move in and rig up on an all-weather location built to accommodate the specific rig awarded the contract.

The drilling contractor will charge footage rates from the kelly bushing to 2000'⁺, adhering to the hole size and

mud program attached. Daywork rates will commence when the first electric log reaches total depth. Daywork rates will continue during the log evaluation and continue to be in effect until the casing crew rigs up on the drilling floor.

The daywork rate will cease when the 13-3/8" casing shoe clears the rotary table. The drilling contractor will provide the rig time necessary to run, cement, and nipple up the surface casing.

The drilling contractor will then charge footage rates to 3850'[±], or the top of the Hosston Formation. Daywork rates will then commence at the time the first electric log reaches total depth. Daywork rates will remain in effect until the total depth of 4200'[±], or sufficient depth to test the Hosston Formation, is reached and logging, coring, testing, underreaming, and hanging wire-wrapped screen and gravel packing has been completed.

The operator will provide egress, location, water, mud and chemicals, cement and cementing services, casing crews and casing handling tools, and all tubular goods other than drill pipe and drill collars. All rental tools other than those commonly associated with typical rig equipment will be furnished by the operator.

The drilling contractor will provide rig, crews, and associated equipment necessary for the complete drilling

operation, including BOP stack, bits, and fuel.

The drilling contractor awarded the contract will provide a certificate of insurance to the operator.

Please submit the drilling bid as follows:

Footage rate_____.

Daywork rate_____.

If there are any questions concerning this bid invitation, please call our office and talk to R. W. Dirks or J. R. Fischer.

Sincerely,

J. R. Fischer
R. W. DIRKS PETROLEUM ENGINEER, INC.

R. W. DIRKS PETROLEUM ENGINEER, INC.

DRILLING ORDERS

Well Name: Lackland AFB #1 Total Depth: 4200 Date: 6-3-83
 Prospect: _____ AFE No.: _____
 State: Texas County: Bexar Sec _____ T _____ R _____
 Location: To be determined
 _____ Elevation: _____

Drilling

<u>Hole Size</u>	<u>Depth</u>	<u>Max. Angle</u>	
	to		
<u>17-1/2"</u>	<u>0 to 2000</u>	<u>2°, 1°/200'</u>	°
<u>12-1/4"</u>	<u>2000 to 3850</u>	<u>5°, 2°/500'</u>	°
<u>8-3/4"</u>	<u>3850 to 4200</u>	<u>5°, 2°/500'</u>	°

Casing

<u>Size</u>	<u>Description</u>	<u>Setting Depth</u>	<u>Cement Amount</u>
<u>20"</u>	<u>Conductor</u>	<u>50'</u>	
<u>13-3/8"</u>	<u>J-55 54.5 lbs./ft.</u>	<u>2000'</u>	<u>See Remarks</u>
<u>9-5/8"</u>	<u>J-55 36 lbs./ft.</u>	<u>3850'</u>	<u>See Remarks</u>
<u>7"</u>	<u>Wire-wrapped screen</u>	<u>4200'</u>	<u>None</u>

Remarks: Cement amount to be determined based on open hole caliper logs.

Permit No. _____ Serial No. _____

CASING MAKE UP

13-3/8" Surface Casing:

- 1, 13-3/8" float shoe on bottom joint.
- 1, 13-3/8" float collar on top of bottom joint.
- 13-3/8" x 17-1/2" double bow turbolizers spaced 1 per joint through the Edwards Formation.
- 1, 13-3/8" x 17-1/2" cement basket at the top of the Edwards Formation.
- 1, 13-3/8" x 17-1/2" cement basket at the base of the conductor pipe.

Float shoe and float collar must be thread locked in place.

9-5/8" Casing Liner:

- 1, 9-5/8" float shoe on bottom joint.
- 1, 9-5/8" float collar on top of bottom joint.
- 9-5/8" x 12-1/4" double bow turbolizers spaced 1 per joint for the bottom 500'.
- 1, 9-5/8" x 12-1/4" cement basket at the base of the surface casing.
- 1, 9-5/8" x 13-3/8" Liner hanger at 1800'.

Float shoe and float collar must be thread locked in place.

Geology

Objective Sands: Hosston Formation

Start Samples: _____ large _____ Small _____

Start Mud Logger: _____ Mud Logger Co. _____

Send Samples to: _____

Remarks:

Logging Depths: 1) 2000' 2) 3850' 3) 4200' 4) _____

Electric Logging Services:

Type

Log Run No.

DI SFL CDL - CNL, SWC, RFT

1

DI SFL CDL - CNL, SWC, RFT

2

DI SFL CDL - CNL, SWC, RFT

3

Required Mud Properties

[illegible]

Approvals:

Manager Drilling & Production

H. Zacher

Exploration Department

CASING DESIGN SKETCH