DOE/EA-0013

ENVIRONMENTAL ASSESSMENT

Geothermal Energy Geopressure Subprogram

GCO-DOE
Pleasant Bayou No. 1

Brazoria County Texas

March 1978

U.S. DEPARTMENT OF ENERGY

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U.S. DEPARTMENT OF ENERGY
Assistant Secretary for Energy Technology
Washington, DC 20545

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GLOSSARY AND ABBREVIATIONS

point of drilling	the location of the well bore
well site	the 5 acre area on which support facilities, including separators, cooling towers, tanks, and laboratories will be located; includes point of drilling
Brazoria County Prime Prospect Area	an oval area of 150 km^2 considered by The University of Texas at Austin to be the most desirable zone for geo-pressured-geothermal resource exploration and development
Brazoria Fairway	the high probability area for encountering geothermal-geopressure resources along the north Texas coast (includes BCPPA)
Frio Formation	the wedge of clastic sediments composed of numerous overlapping deltaic and inter-deltaic systems which were built into the Gulf geosyncline (Tertiary age Oligocene series) (includes the Brazoria Fairway).

A-F/yr	acre-feet per year
API	American Petroleum Institute
cfs	cubic feet per second
BPD	barrels per day
BWPD	barrels of water per day
dBA	A-weighted sound levels taken with a sound level meter and expressed as decibels on the scale. The "A" scale approximates the frequency response of the human ear
ERDA	Energy Research and Development Administration
FIA	Federal Insurance Administration
GCO-DOE	General Crude Oil - Department of Energy
hm^3/yr	cubic hectometers per year

GLOSSARY AND ABBREVIATIONS (Continued)

Kh	permeability in millidarcies
md	millidarcy
mgd	millions of gallons per day
MMSCF	millions of standard cubic feet
$\mu g/m^3$	micrograms per cubic meter
ppt	parts per thousand
psi	pounds per square inch
USCE	U.S. Army Corps of Engineers
USDI	United States Department of the Interior
USGS	United States Geological Survey

CHAPTER ONE - DESCRIPTION OF THE PROPOSED ACTION

This Environmental Assessment (EA) has been prepared to assess the environmental implications of the Department of Energy's proposal to drill, complete, and test one geopressure well located in Brazoria County on a 2 hectares (five acre) test site 64 km (40 mi) south of Houston, Abstract 107, Perry & Austin Survey, Brazoria County, Tx (Fig. 1-1). The test well is herein referred to as GCO-DOE Pleasant Bayou No. 1. A maximum of four disposal wells will be located within .8 km (1/2 mi) of the proposed well. The Department of Energy (DOE) and The University of Texas Center for Energy Studies propose to operate the test facility for three years to evaluate the geopressure potential of the subsurface. Tests to be conducted include flow rates, fluid composition, temperature, gas content, geologic characteristics, and the land subsidence potential for subsequent production.

This EA activity falls under the broad subprogrammatic Environmental Impact Assessment, Geopressure Subprogram, EIA/GE/77-3, July 1977, Division of Geothermal Energy, Energy Research and Development Administration; the activity associated with the Frio Formation of Texas and Louisiana.

1.1 Site Location and Surface Features

The proposed action is located in the northernmost geothermal geopressure fairway in Texas in Brazoria and Galveston Counties (Figures 1-1 and 1-2). Within this high potential geothermal geopressure fairway is the Brazoria County Prime Prospect Area (White et al., 1977), the most promising zone for evaluating the physical and chemical characteristics of the resource. One well site (GCO-DOE Pleasant Bayou No. 1) in the Brazoria County Prime Prospect Area was selected for resource analysis on the basis of three parameters

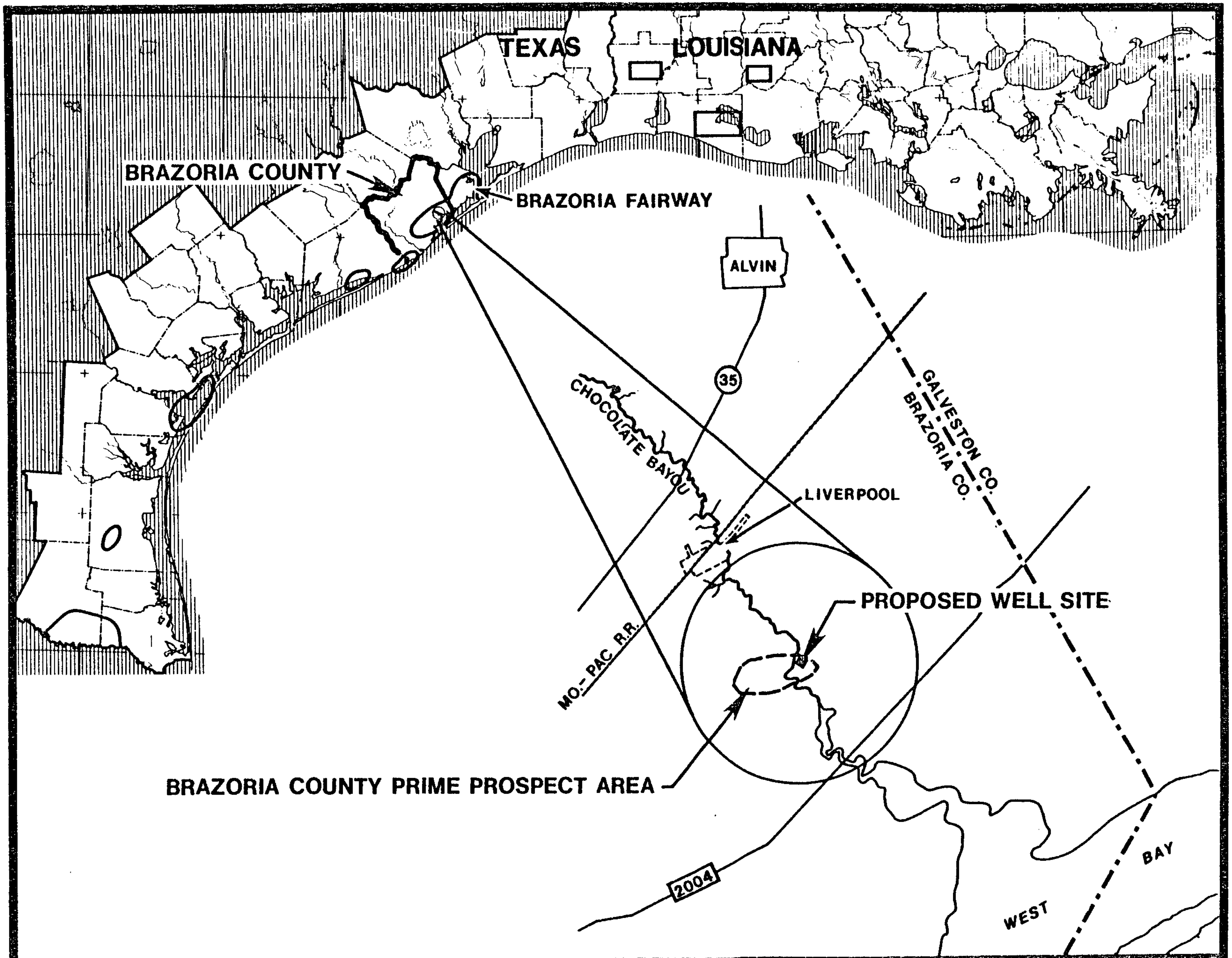

Fig. 1-1. Location of the proposed well site in the Brazoria County Prime Prospect Area and in relation to the Brazoria Fairway of the Frio Formation, Texas.

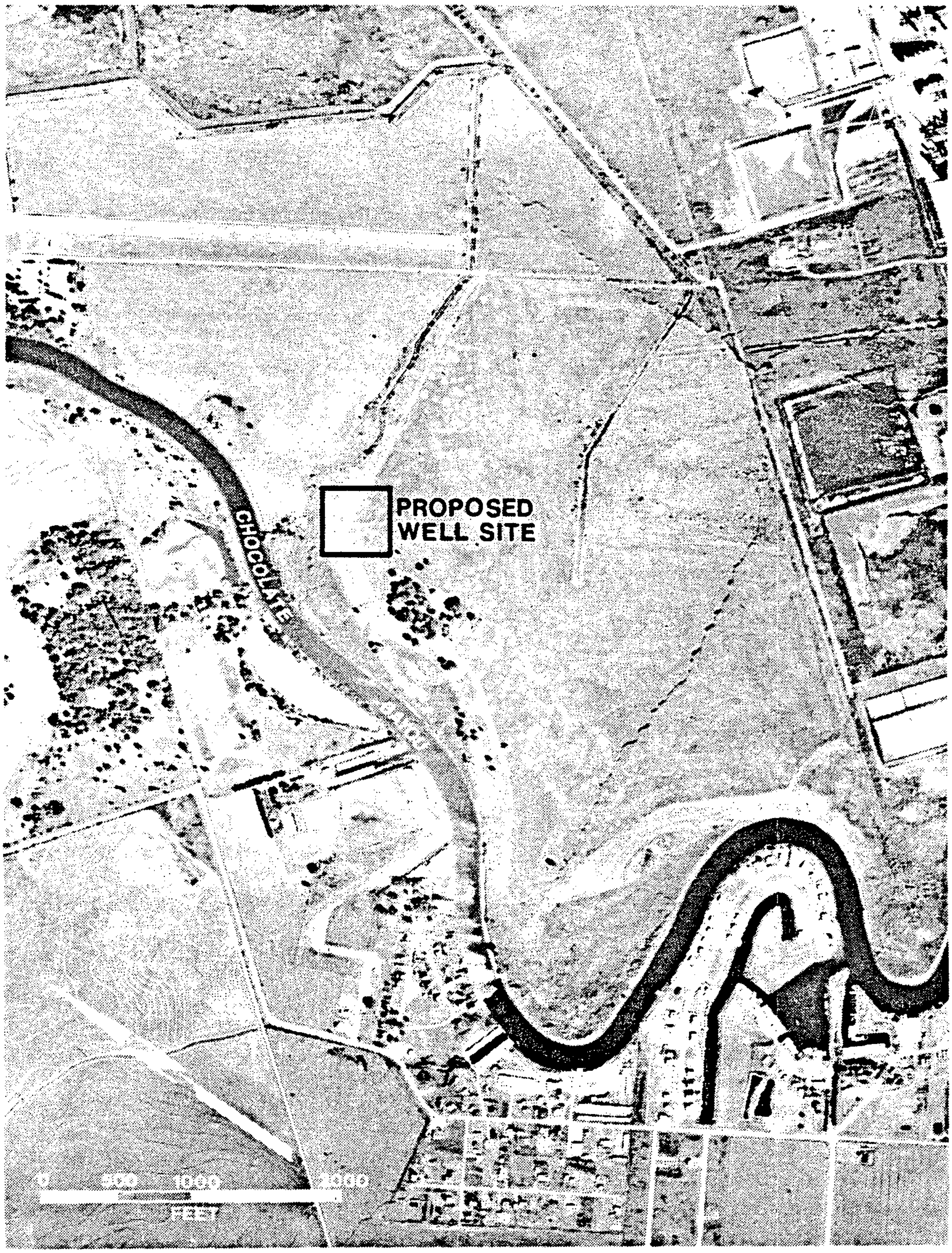

Fig. 1-2. Proposed well site, GCO-DOE Pleasant Bayou No. 1, Brazoria County, Texas.

(Belmont, 1977): sand thickness, temperature, and permeability. GCO-DOE Pleasant Bayou No. 1 well on the General Crude Oil Company lease (Martin Ranch #1) bordering Chocolate Bayou represents a compromise among the ideal locations for any one of the three parameters. Sand thickness and temperature are greater to the southwest near the Danbury Dome and permeability is highest toward the northeast in the Chocolate Bayou field. Temperature will not be a problem as long as the well is located southwest of the minus 4118 m (13,500 ft) depth contour which runs approximately along the airstrip on the northeast end of the prospect. Likewise, sand thickness is not a critical consideration in the prospect area, because of considerable variation expected locally. In spite of this variation, sand thickness should be available at any location in the prospect area. In contrast, however, permeability adequate to provide sustained high flow rates is the major concern. Available data indicate strongly that permeability increases to the northeast. Consequently, the prime area geologically is on the extreme northeastern end of the prospect area where permeability is expected to be highest.

All development of surface facilities and injection wells will take place within .8 km (1/2 mi) of the point of drilling, but not to the west of Chocolate Bayou. All of the land to be used by this test is in private ownership, but is leased to General Crude Oil Company. The approximate latitude and longitude of the well site is 29°15'15"N and 95°14'W. The nearest town is Liverpool, 6.7 km (4.4 mi) to the northwest. The nearest large town is Alvin 19 km (12 mi) to the north while the nearest city is Houston, approximately 64 km (40 mi) to the north. Agricultural fields of rice and sorghum and pastures surround the test site. On the west bank of Chocolate Bayou across from the well site is a recreational community of weekend homes, boat storage sheds, boat launches, and associated recreational services. To the south of the well site is the Chocolate Bayou Plant of Monsanto Corporation, which produces organic and inorganic industrial chemicals.

1.2 Project Description

The proposed project will consist of the drilling of one geothermal fluid well for production testing and a maximum of four injection wells. A test well will be drilled with a 21.6 cm (8.5 in) borehole to an approximate depth of 5,033 m (16,500 ft). Two disposal wells will initially be drilled to provide disposal of lower volume fluids produced during initial testing. Two additional disposal wells will be drilled, logged, completed, tested, and operated prior to commencement of high volume fluid production. Required surface facilities will be constructed and installed in order to conduct the extensive test program which is the objective of the program. The tests will assess the economic viability of the geopressure geothermal resource.

This EA evaluates the potential environmental implications of the drilling, flow testing, abandonment, and restoration of the GCO-DOE Pleasant Bayou No. 1 well site during its three year period.

1.2.2 Construction and Drilling

The initial exploration activities and resource evaluation were conducted by The University of Texas Center for Energy Studies. The environmental implication is evaluated of the activities from well site preparation through site restoration after testing is completed.

1.2.1.1 Site and Road Preparation

Drilling activities require the construction of access roads and level drilling pads for the production well and the injection wells. Where possible, the access road will be constructed to disturb a minimum area by using existing roads when available, by following the natural topography, and by avoiding cut and fill operations. Roads will be 4.2 m (14 ft) wide with a disturbed area of 0.4 ha/km (1.7 acre/mi) of roadway.

The proposed points of drilling will each be cleared, leveled, and compacted for an area of up to 1000 m^2 (1/4 acre) to provide drill pads (Figure 1-3 and 1-4). As many as 1.6 ha (4 acres) will be used with minor disturbances for other equipment, sumps, and laydown areas at each site. A drilling mud sump will be provided to hold the drilling fluids at each well site and each site will be sloped toward the sump to provide a drainage catchment. Figure 1-5 shows the surface facilities at the well site.

1.2.1.2 Well Drilling and Testing

Figure 1-6 shows the proposed well schematic. The well will be drilled, cored, and logged by General Crude Oil Company under contract to DOE.

The well head assembly for the geopressure goethermal well is shown in Figure 1-7. This is the normal combination of casing head and intermediate casing head equipment designed to accommodate 15,000 psi well pressures. The flow will pass through the tubing head and master valves before entering a large radius pipe bend to direct the flow to the high pressure separator without passing through a 90 degree tee. Each casing annulus will be equipped with a pressure gauge to detect tubing leaks or a breakdown in the completion integrity.

Surface equipment will reduce the well pressure to atmospheric pressure. The gas will then be either flared or sold, whichever method proves to be feasible. A flow-through liquid sampler will be located near the well head to collect high

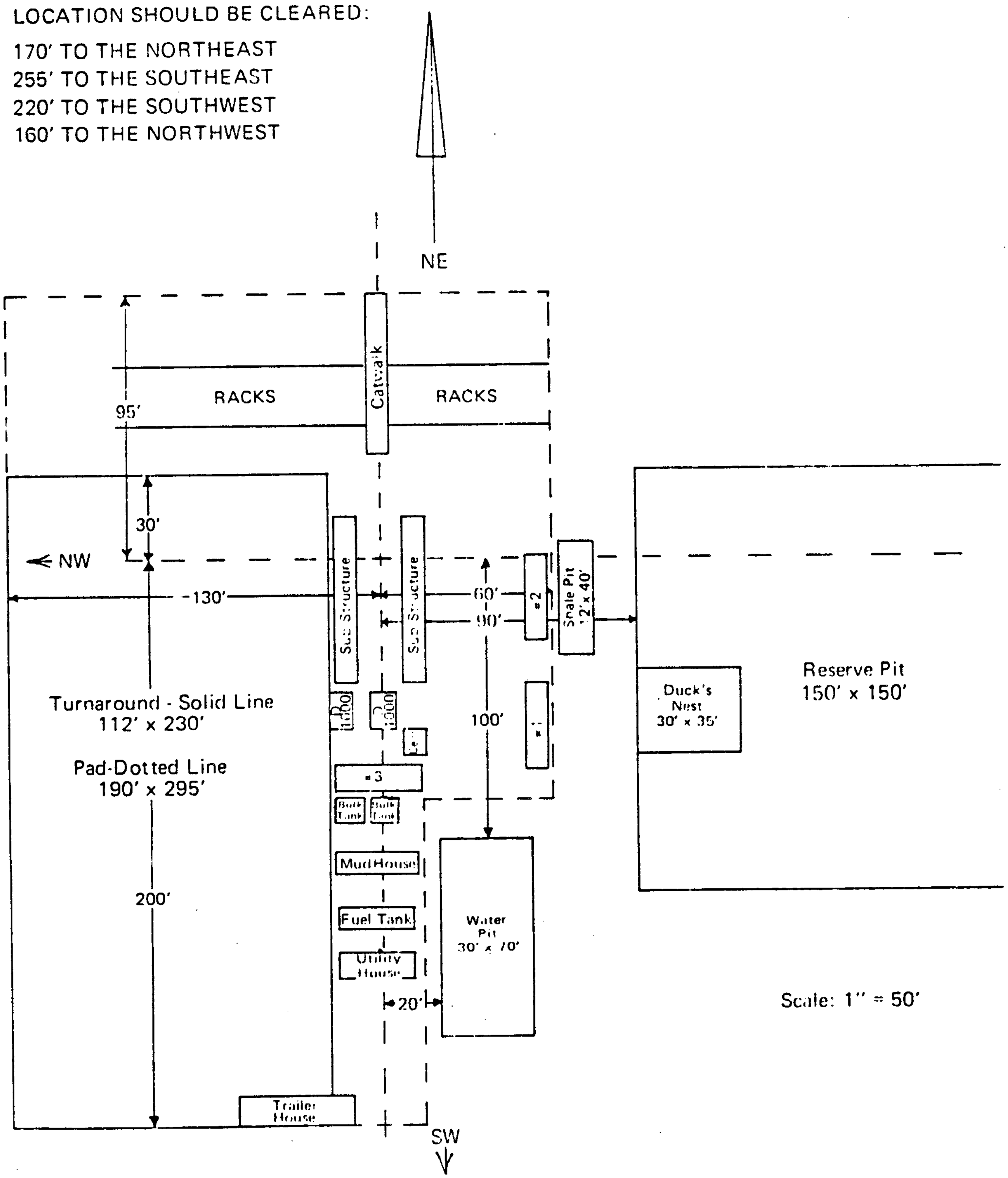

Fig. 1-3. Typical drilling site arrangement (General Crude Oil Company, 1977).

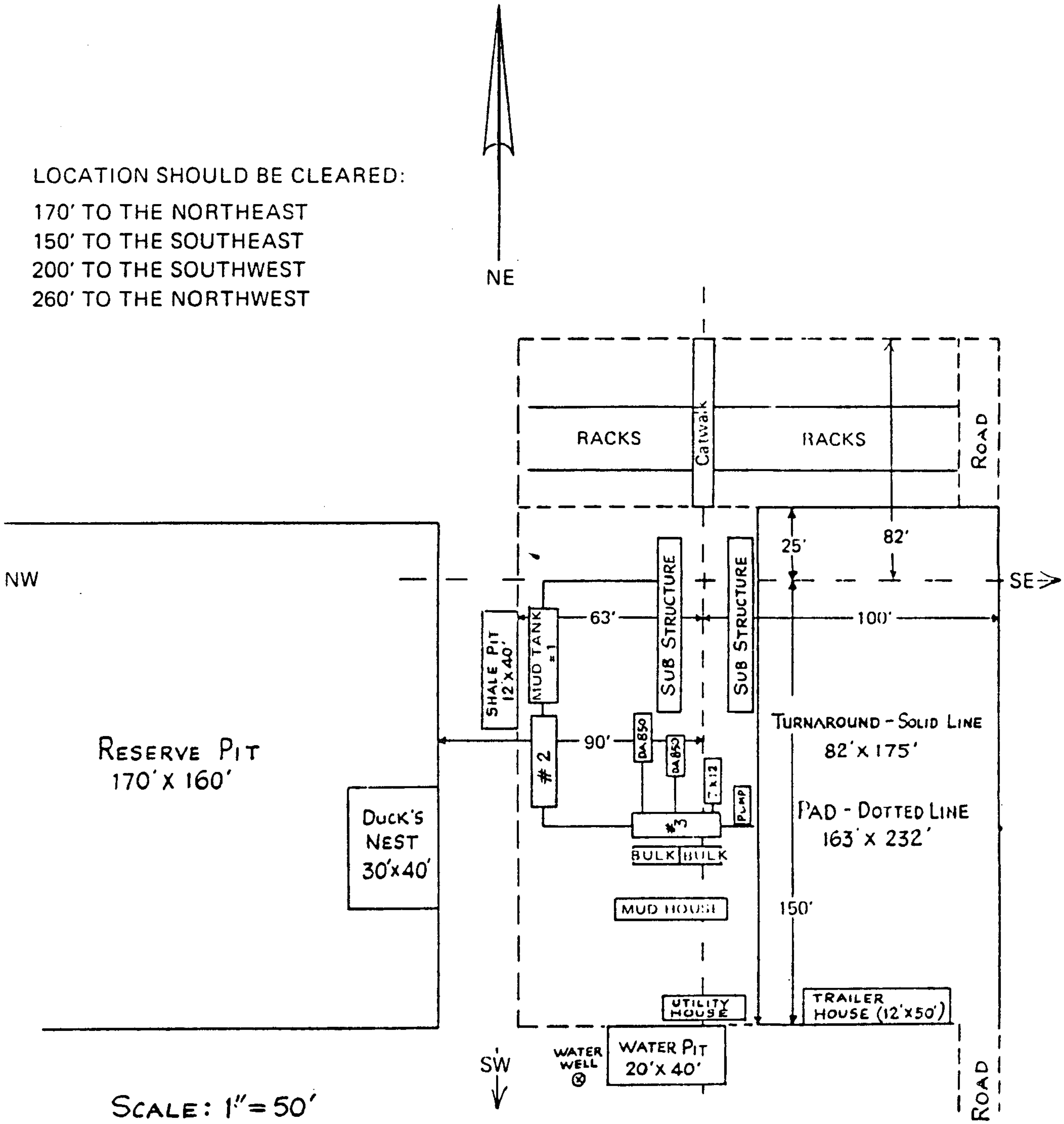

Fig. 1-4. Typical drilling site arrangement (General Crude Oil Company, 1977).

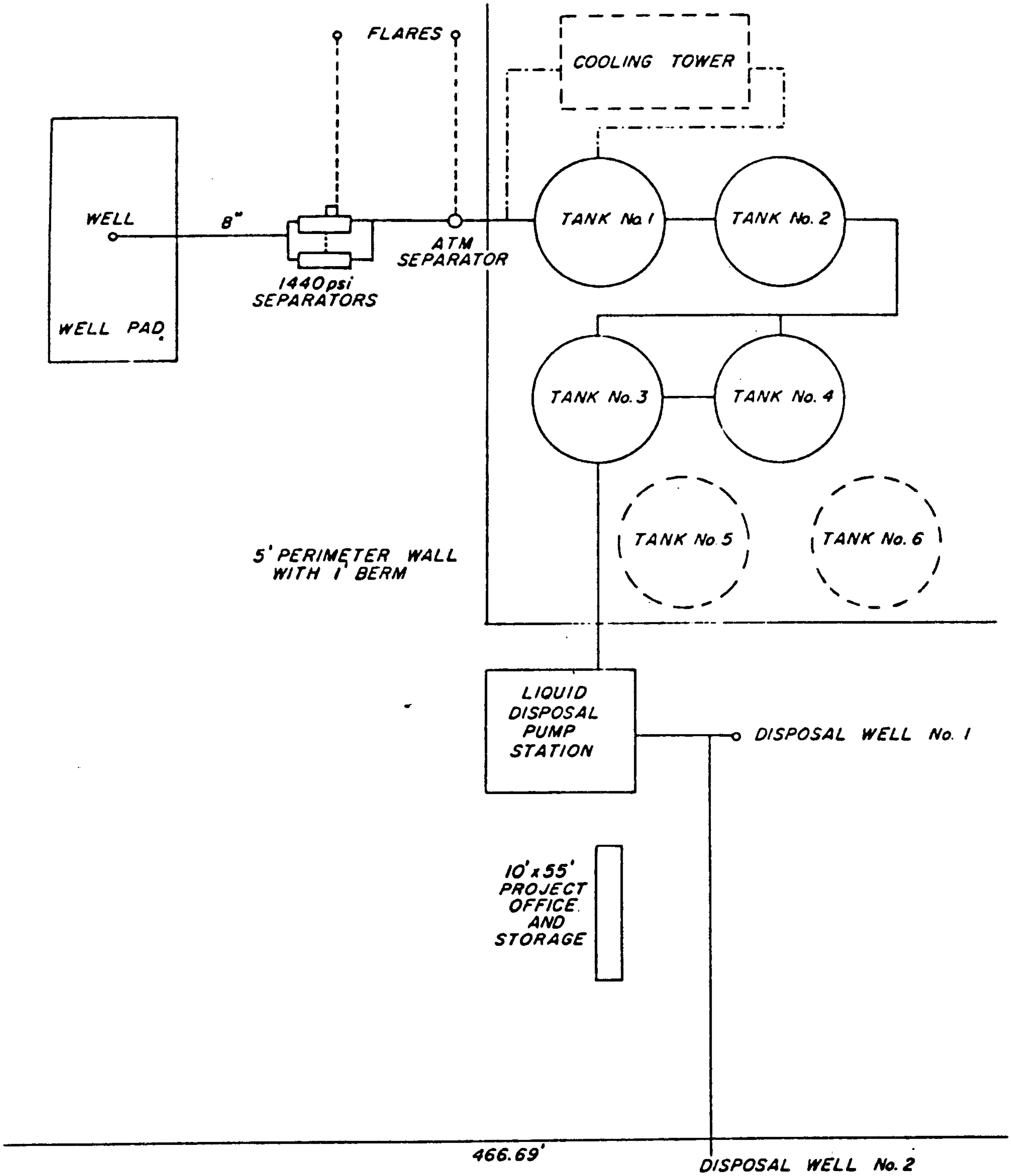

Fig. 1-5. General layout of well site (General Crude Oil Company, 1977).

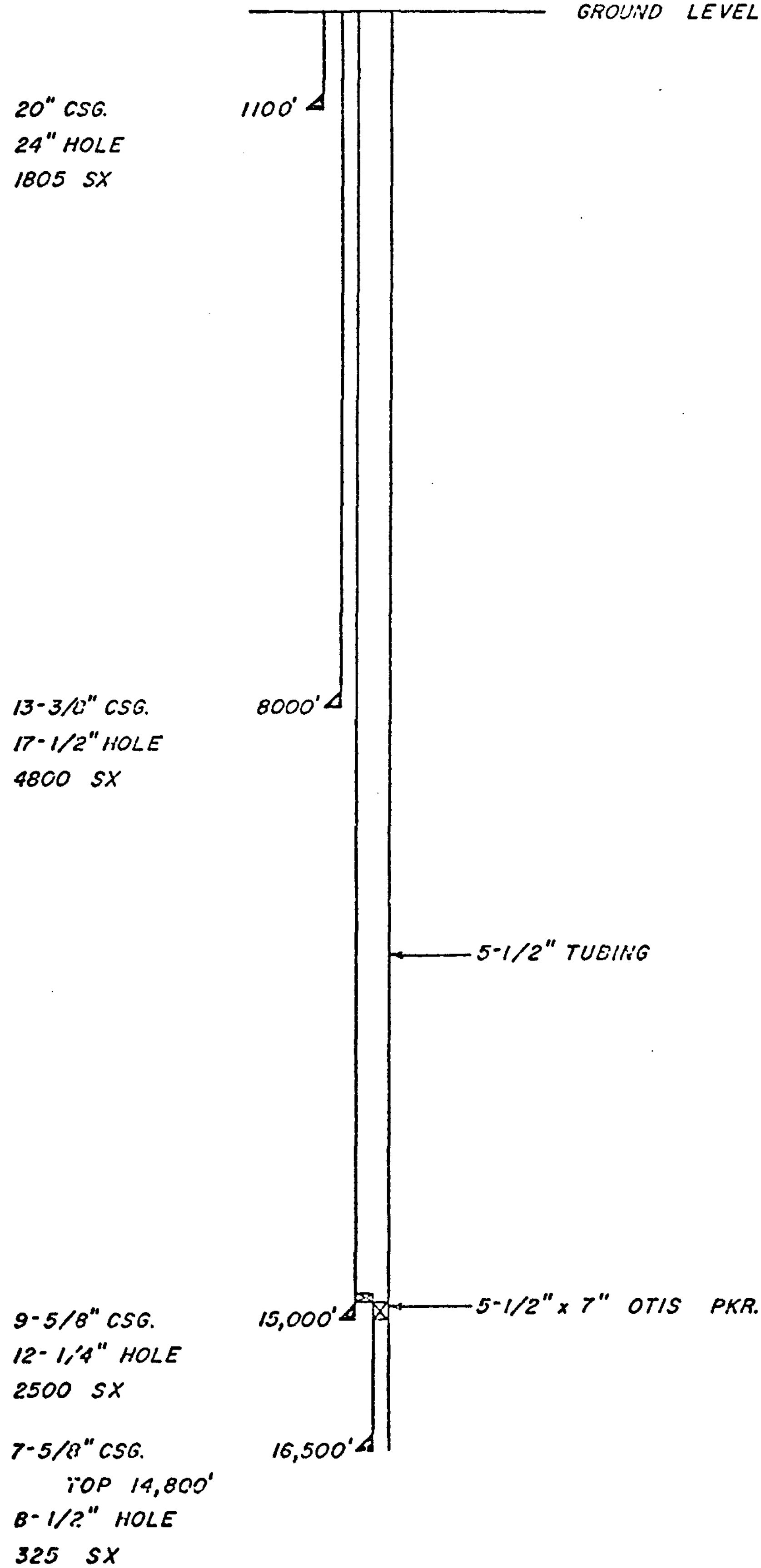

Fig. 1-6. Depth of various pipe sizes (General Crude Oil Company, 1977).

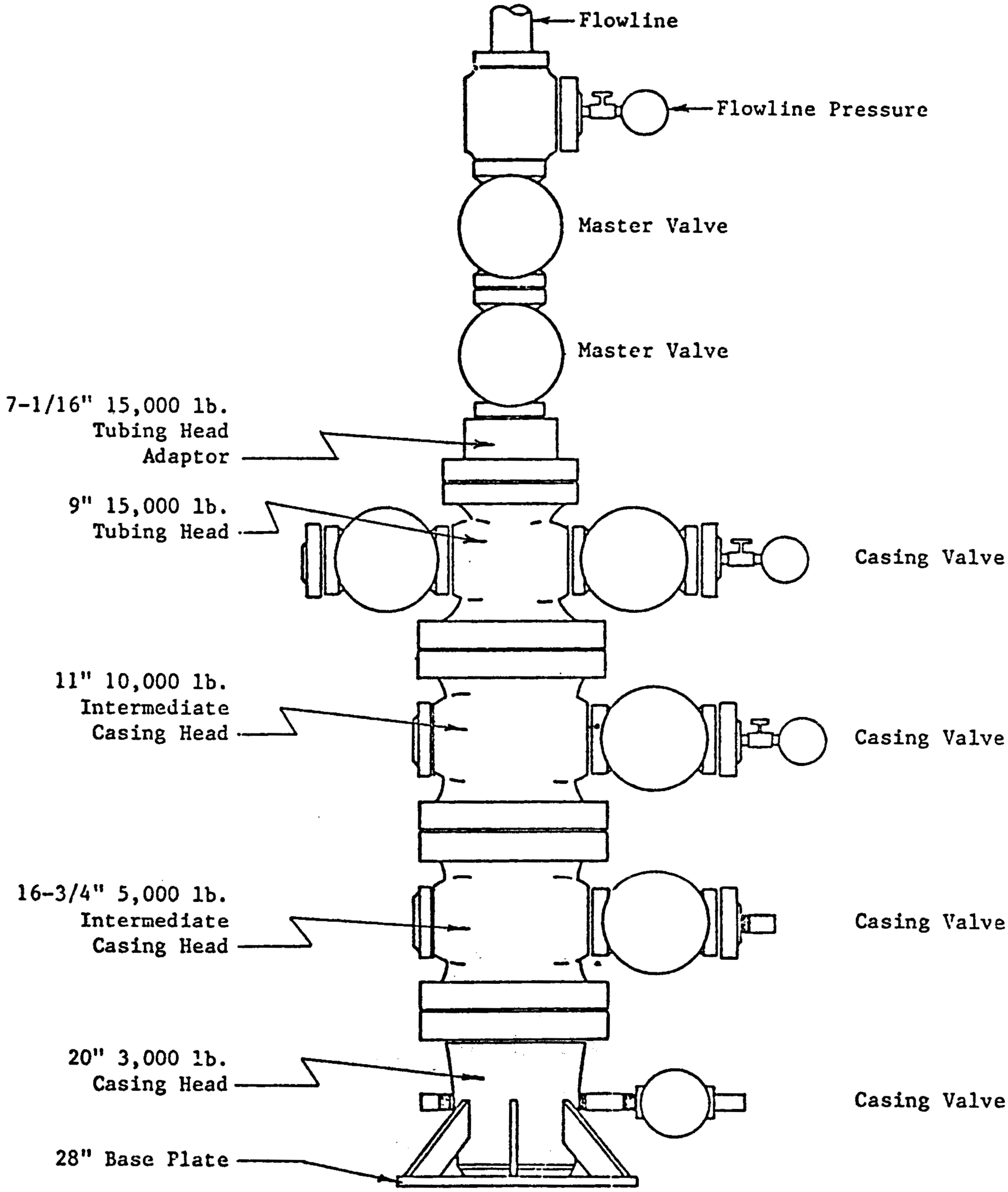

Fig. 1-7. Typical well head configuration for flow testing (General Crude Oil Company, 1977).

pressure samples by isolation of the split stream. Continuous pressure and temperature will be recorded near the well head. A choke will be used to reduce the flow pressure to 1000 psi just before entering two high pressure separators. Gas released from solution will be sold or flared through an orifice meter. Down stream to the high pressure separators, a second flow through liquid sampler will be used to compare chemical analysis between the high pressure and low pressure lines. A second choke will reduce the stream pressure to approximately 50 psi just before entering a low pressure separator. Any gas production at this point will be either vented or dehydrated to remove the water and sold. Gas contract negotiations will have to be completed before concrete estimates on gas sales may be obtained. Presently, estimated gas sales will amount to 1.6 MMSCF per day from both separators. Gas from the high pressure separator will be cooled to between 38° and 50° C (100° and 200° F). Gas from the low pressure separator will be dehydrated and compressed to 800 psi to meet sales line pressure and cooled to between 38° and 50° C (100° and 120° F). It is anticipated that compression equipment be rented on a year lease. Figure 1-5 is a plan view of the facility layout showing the separators as well as the tank area used to cool the production before it enters the injection pumps for disposal. The four 10,000 barrel holding tanks will be adequate during the initial phase of the project for cooling the produced fluids. However, as the flow rates are increased, a cooling tower may be required to reduce the flow temperature before the disposal stream enters the pump station. Only two disposal wells will be drilled initially, but a total of four disposal wells will be needed when the flow rate reaches the designed 40,000 BPD rate. Three pumps will be used to dispose of the water. The disposal station will be housed to protect it from weather since the pumps are electrically driven and have a high horse-power rating. Electrical supply to these pumps will be 2300 volts and each pump motor will draw approximately 100 amps. A well test schedule has been formulated as shown in Table 1-1. Initial test will be static pressure test after the well is perforated. The well will be circulated clean with salt water and pressured up to 10,000 psi to test surface equipment. The pressure will then be bled to 5,000 psi and the hole will be logged for perforating depth control. The perforating gun will then be lowered to shoot the first permeable interval between about 16,000 and 16,500 feet. Perforation will continue until 125 ft of zone is open or a Kh product of 5,000 millidarcy per foot (md/ft) is obtained based on core analysis. The total perforated interval may be increased to 220 ft if the permeability is on the order of 10 md and the logs show the sand development to be this extensive. After perforation the well will be brought on stream in steps of 250 BWPD each day over a five day period to clean the well bore. During this period, quart samples will be taken daily and checked for sand and tracer ion concentration. If sand production is not a problem and the tracer ion concentration has changed significantly, then the well will be shut in. The well will be sampled with a bottom hole sampler, the static pressure will be measured and a high resolution thermometer log will be taken along with other logs given in Table 1-2 for a cased hole completion. A continuous bottom hole pressure measuring instrument will be calibrated to agree with the static pressure test obtained with the Amerada gauge. The well then will be brought on production at 1,000 BPD and increased by 1,000 BPD each day after sampling the flow stream for sand production. If sand production is detected, rate increases will be suspended while the sand production is observed. If the well cleans up then the rate increase may resume; however, if the sand production stays constant or increases, the rate will be adjusted downward in 500 BPD increments until the sand production stops. Once a rate is established with less than 1/2% volume

Table 1-1. Test Schedule.

Test Period	Test Duration	Cumulative Test Time At End Of Period	Test Rate BPD	Cumulative Fluid Prod. MBbl
Initial Static	3 Days	3 Days	0	0
Initial Dynamic				
Phase 1a	63 days	69 days	0 - 10,000	315
Phase 1b	40 days	116 days	10,000	715
Phase 2a	28 days	134 days	10,000 - 20,000	1,135
Phase 2b	40 days	174 days	20,000	1,935
Second Static	3 days	177 days	0	1,935
Second Dynamic				
Phase 1a	22 days	199 days	0 - 30,000	2,346
Phase 1b	30 days	229 days	30,000	3,246
Phase 2a	12 days	241 days	30,000 - 40,000	3,626
Phase 2b	30 days	271 days	40,000	4,826
Final Static	3 days	274 days	0	4,826

Table 1-2. Major Services and Equipment.

HOLE:

Depth Feet	Diameter Inch	Mud Weight Pounds per Gallon
1,100	24	10
8,000	17½	10
15,000	12¼	16.5
16,500	8½	18.5

WELL LOGGING:

Depth	Interval	Log
8,000	to 1,100	Dual Induction Laterolog Bore Hole Compensated--Sonic Integrated Compensated Neutron Log Formation Density Compensated Caliper High Resolution Thermometer Velocity Survey
15,000	to 8,000	Dual Induction Laterolog Bore Hole Compensated--Sonic Integrated Compensated Neutron Log Formation Density Compensated High Resolution Dipmeter Caliper High Resolution Thermometer Velocity Survey
16,500	to 15,000	Dual Induction Laterolog Bore Hole Compensated--Sonic Integrated Compensated Neutron Log Formation Density Compensated High Resolution Dipmeter Caliper High Resolution Thermometer Velocity Survey

Table 1-2. Continued.

WELL CORING:

Depth	Interval	Core
8,000	to Surface	100—Sidewall Samples
15,000	to 8,000	100—Sidewall Samples
16,500	to 15,000	100—Sidewall Samples
16,500	to Surface	1000 feet Conventional Core

CASING, LINER, TUBING, AND CEMENT:

	Size	Weight	Grade	Length	Collar/Thread	Cement
CASING	20	94	H40	900	ST&C	
	20	106.5	K55	200	ST&C	
Total				1,100		1805 Sx
	13-3/8	72	N80	300	Buttress	
	13-3/8	72	N80	3,950	ST&C	
	13-3/8	72	S95	1,500	ST&C	
	13-3/8	81.4	S95	2,250	ST&C	
Total				8,000		4800 Sx
	9-5/8	53.5	S95	1,950	Buttress	
	9-5/8	47	S95	3,950	Buttress	
	9-5/8	53.5	S95	2,200	LT&C	
	9-5/8	59.2	S105	2,000	LT&C	
	9-5/8	62.8	S105	4,900	LT&C	
Total				15,000		2500 Sx
LINER	7"	38	P110	1,700	LT&C	325 Sx
TUBING	5-1/2	23	P110	1,000	Buttress	
	5-1/2	23	P110	7,400	LT&C	
	5-1/2	23	P110	8,100	SFJ	
Total				16,500		---

sand production at or below 10,000 BPD, the well's producing pressure will be recorded for an indefinite period not to exceed 40 days. The bottom hole pressure and surface pressure should stabilize and be recorded. The well's productivity index can then be calculated. A second dynamic test period will be run, resuming step size increases in the well production rate at 2,000 BPD increments each day up to a total rate of 20,000 BPD, and checking the flow stream for sand. This test period will also last for 40 days and the productivity index for the zone will be calculated at each rate. At the end of the second test period, the well will be shut in and the pressure allowed to stabilize while measuring the bottom hole pressure. A second set of cased hole logs will be run at this time. At this point it may be desirable to open twice as much permeable sand and test the potential of the combined zones in the same manner. Ultimately, if sand production is not a problem, the well's final flow rate should be 40,000 BPD sustained for a 30 day period to allow stabilization as determined from pressure measurements and calculation of the Productivity Index. At the end of this flow test, the well should be shut in for a second build-up to a test static pressure.

During the dynamic test on reservoir production, surface samples of the produced fluid will be collected daily and checked for pH, hardness, chloride and sand cut at the test site. Once a week a sample shall be checked by a laboratory for the standard API ion analysis. The static bottom hole samples will be checked by a laboratory for the API ion analysis in addition to selected heavy metal determination with the spectrograph. Gas analysis for CO_2 and light hydrocarbon gas content and composition may be run routinely at the test site on a weekly basis. Each month a gas sample will be submitted to a laboratory for light hydrocarbon gas content and composition and CO_2 and total sulfur. These analyses may be reduced in frequency if they are determined to be consistent and repetitive. Ions and heavy metals that are not present in the produced fluids will not be included in subsequent tests. Correspondingly, gas components that are not present in the initial test will be dropped from remaining tests. Scaling is a typical problem with mineral laden waters from the Frio Formation. A typical well water analysis for scaling tendency is given in Table 1-3. This is a flowline sample taken from a well in the Chocolate Bayou area. Barium sulfate creates the scaling problem by precipitating in the well's tubing, flowline, and surface equipment. Regular chemical tests will be made to determine the severity of, and to devise control of the expected scaling problem.

1.2.2 Site Restoration

Indications of an inadequate resource at any stage in the testing activities may result in abandoning the project. Abandoned wells will be plugged with cement or welded shut below ground level and will be in compliance with appropriate state rules and regulations. Once the three year test program is completed, the disturbed area will be back-filled and replanted with species native to the area. Mud pits and reserve pits will be drained of free water and this water will be pumped into the disposal well prior to its abandonment. Residue will be buried in the impervious pits.

1.3 Known Environmental Issues

Geothermal exploration and development are being carried on extensively throughout the United States. Therefore, several environmental issues are well established. These include water use, surface and groundwater contamination, subsidence, air pollution, noise, land use changes, and wildlife disturbance. These and other potential environmental impacts will be treated in Section 3.

Table 1-3. Brazoria County Prime Prospect Area, Typical Well Water Analysis.

Component	Composition Mole Percent
Ba SO_4	64.6
Ca CO_3	13.3
Na_2 CO_3	7.0
Na_2 SO_4	6.3
Fe S	2.8
Sr SO_4	1.4
Siliceous Material	3.2
Moisture and Volatile	0.4
Loss at 900° C.	1.0
	100.0
Chloride Concentration	80,000 ppm

CHAPTER TWO - DESCRIPTION OF THE EXISTING ENVIRONMENT

The GCO-DOE Pleasant Bayou No. 1 is located on the Texas Coastal Plain, in the Chocolate Bayou drainage basin in Brazoria County, Texas. The site is above the Frio Formation. This is an area with very little natural subsidence. Soils are primarily loams and clays. Annual precipitation ranges from 1120 to 1220 mm (44-48 in). Boating, fishing, and weekend homesites are recreational activities near the well site. Biologically, the area falls within Coastal Short-Grass Prairie. The climate is humid subtropical. There are three archeological sites in or near the study area.

This GCO-DOE Pleasant Bayou No. 1 Environmental Assessment is one aspect of the Geopressure Subprogram. An Environmental Assessment of the Geopressure Subprogram, EIA/GE/77-3, July 1977, was prepared by the Division of Geothermal Energy, Energy Research and Development Administration. The GCO-DOE Pleasant Bayou No. 1 well test is consistent with the goals and objectives of the subprogram as directed by the Assistant Secretary for Energy and Technology.

2.1 Geology

The geology of the proposed project site is typical of the Texas Coastal Plain and is the overriding factor in the origin of geopressured aquifers. Cenozoic deposits beneath the Texas Gulf Coastal Plain are primarily noncarbonate clastic rocks. They include medium- to fine-grained sandstones and mudstones (clay or shale) of fluvial, deltaic, delta fringe, or near-shore marine origin, complexly interbedded with transgressive marine shales and siltstones (turbidites) of outer shelf, or upper slope origin

(Murray, 1961). Contemporaneously with rapid progradational sedimentation along the Gulf margin, regional shear zones developed in the direction of the coast and parallel to it. Differential compaction of deltaic sandy deposits landward, and less competent prodelta and marine clay deposits gulfward, resulted in regional "growth faults" along which displacements of hundreds and even thousands of feet occurred (OCamb, 1961). Great depositional masses of the gulfward downthrown block were rotated into the fault plane as deltaic loading of their landward margin continued; fault planes are concave gulfward and flatten with depth, in response to downward increase in pore pressure (Bruce, 1973). Reversal of stratigraphic dip seals the landward ends of sand-bed aquifers where they abut against prodelta clay of older depositional cycles.

Sedimentary tectonics restricted upward drainage and resulted in increased geothermal gradients and thermal diagenesis of sediment minerals and interstitial waters as the deposits were geopressured. Salt movement altered depositional patterns; salt diapirs upwarped and faulted peripheral deposits, and resulted in rapid downbuilding as enormous masses of sediment filled in nearby belts called "salt withdrawal areas." The effects of these events on the geology of the test well area are shown on the structure map of the top of the Frio Formation in the area of the Brazoria Fairway (Figure 2-1); by the map of the top of the Andrau sand where it occurs deep in the geopressure zone (Figure 2-2); and on the map showing major growth faults and oil-field structures near the Brazoria County Prime Prospect Area (Figure 2-3) in which the GCO-DOE Pleasant Bayou No. 1 well is to be drilled.

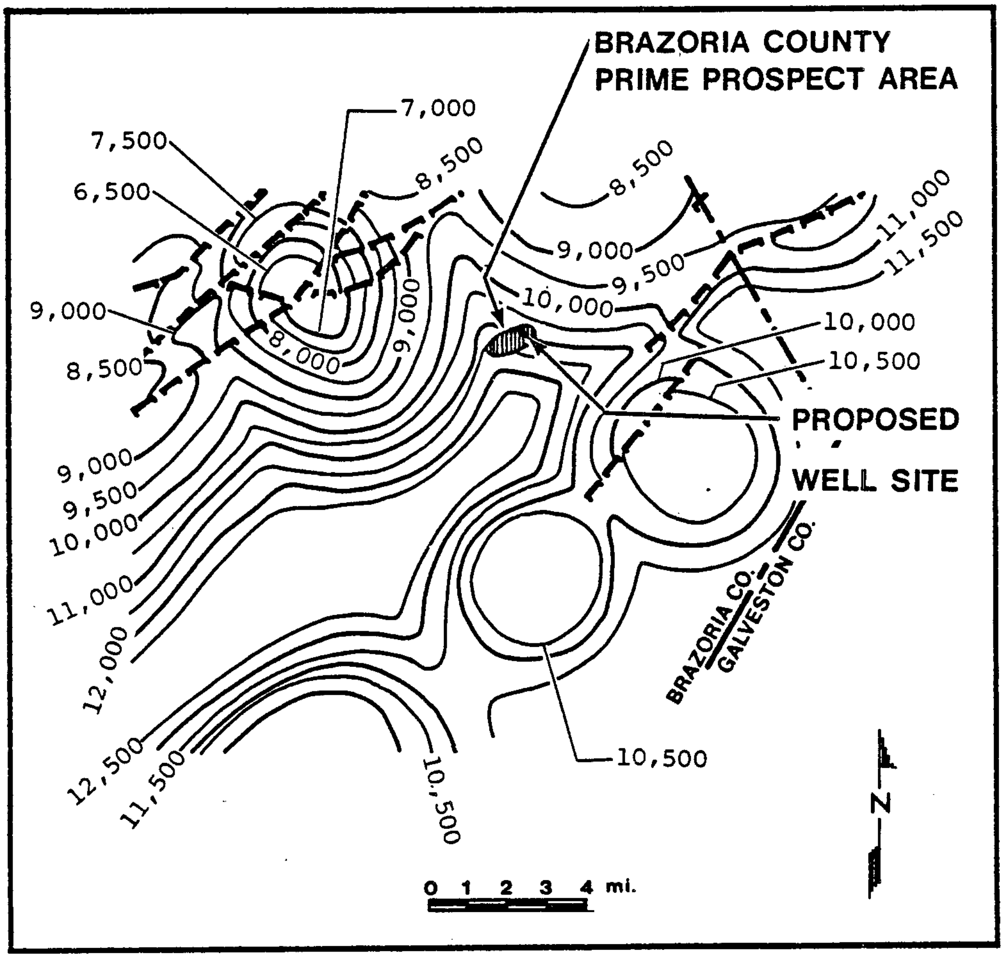

Fig. 2-1. Geologic structure of Brazoria Fariway; depth to the top of the Frio Formation, and location of the well site area, Brazoria County, Texas (After Humble Oil and Refining Co., 1962).

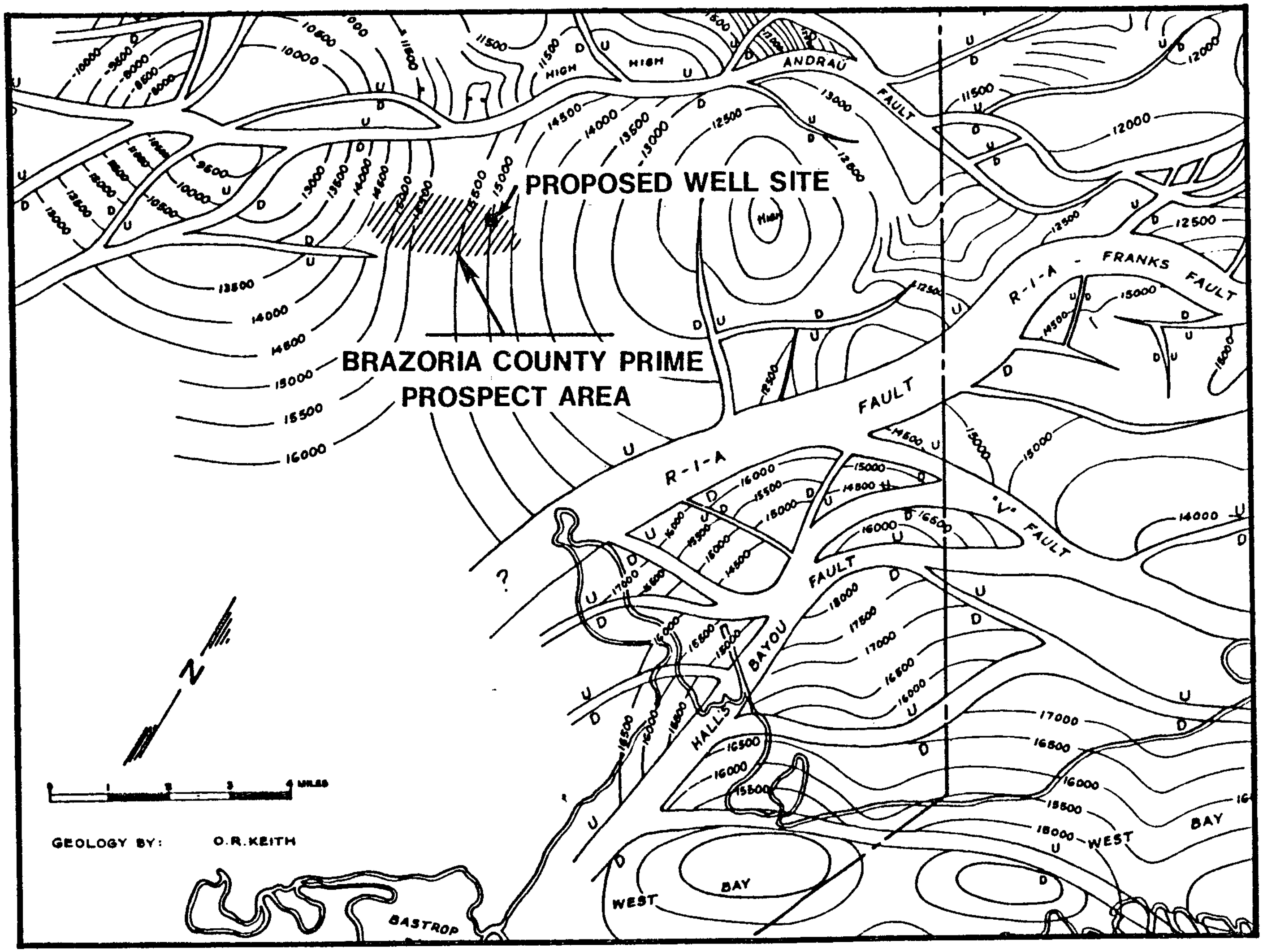

Fig. 2-2. Lower Andrau structure, Chocolate Bayou area, Brazoria and Galveston Counties Texas; and location of well site area (After unpublished manuscript, W. A. Fowler, 1967).

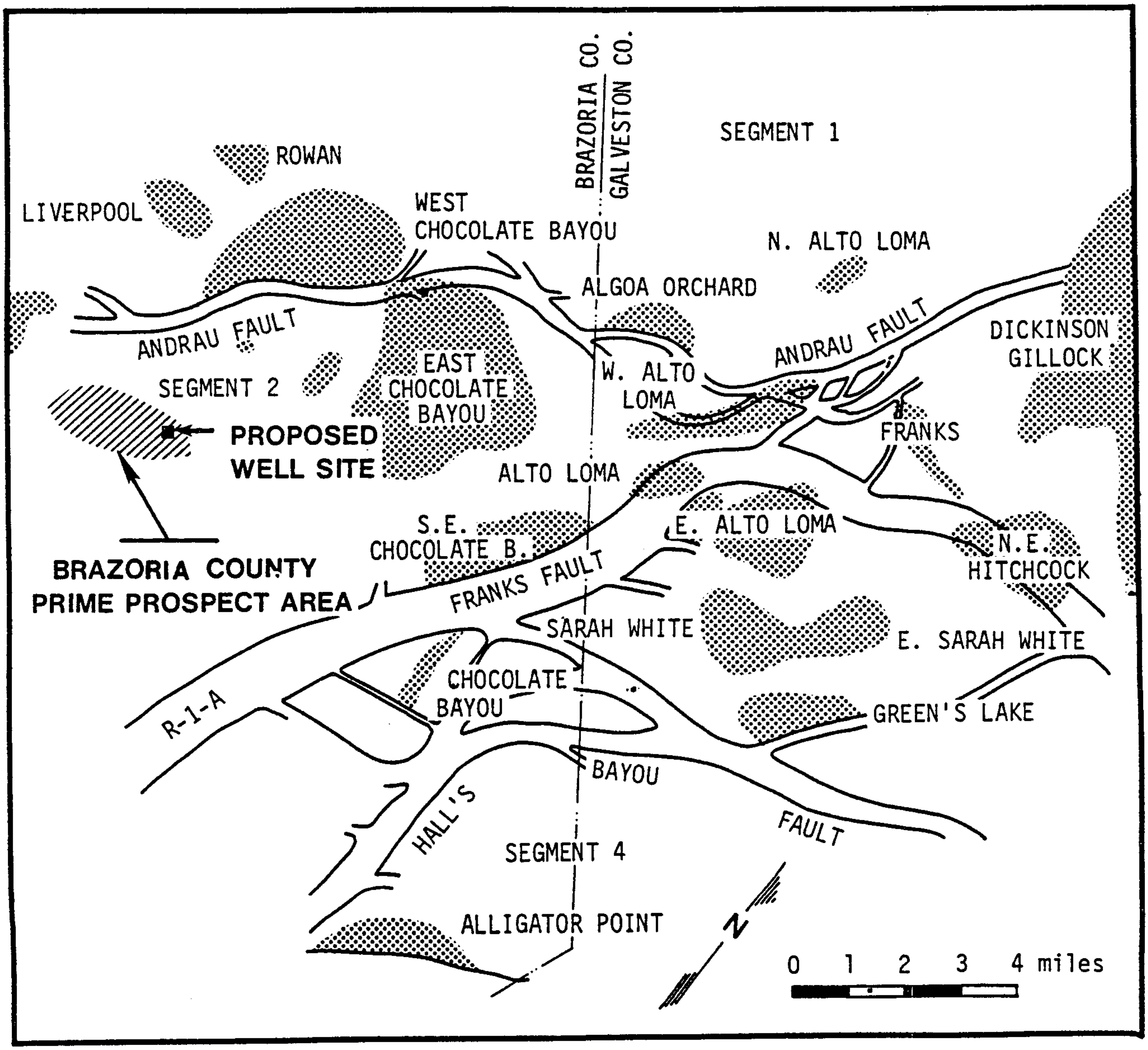

Fig. 2-3. Location of proposed well site area in relation to nearby oil fields and major faults bounding geopressured zone reservoir segments, Chocolate Bayou area, Brazoria and Galveston counties, Texas (After unpublished manuscript, W. A. Fowler, 1967).

Depositional patterns and the areal extent of the "stacked" deltaic and delta front sand-bed aquifer systems proposed for testing and possible development at the well site are shown in Figure 2-4. The deposits of these systems grade upward into distributary-mouth bar and delta plain sandstones, overlain by prodelta clay-shale of the next younger deltaic system.

The lithology and mineral composition of sandstones in this sequence are described by Bebout, Loucks, and Gregory (1977) as midway between the feldspathic litharenites of the Lower Texas Gulf Coast and the quartzose feldspathic volcanic litharenites of the Upper Texas Gulf Coast. Sandstone aquifers to be tapped by the GCO-DOE Pleasant Bayou No. 1 test well occur about 1200 m (4,000 ft) below the top of the geopressure zone and have undergone extensive leaching of cements, feldspar alteration to kaolinite, and precipitation of iron-rich calcite and dolomite cement. The net increase in porosity of sandstones leached by influx of alkaline, low-salinity waters from interbedded shales during their thermal dehydration may result in porosity increase of 10% to 20% (Lindquist, 1976). Porosity of 5% to 25% and permeability of 2 to 20 md are expected in the 750 m (2,500 ft) depth interval to be tapped by the well. Formation temperature will exceed 144°C (300°F) and fluid pressure will be between 7031 and 8789 kgs/m^2 (10,000 and 12,500 psi)

The lithology and mineral composition of shales (mudstones) interbedded with sandstone aquifers in this sequence have received relatively little study. Powers (1967) and Burst (1969) examined dehydration as a function of thermal diagenesis of montmorillonite in the clayey sediments of the Gulf Coastal Plain and developed a consistent pattern of montmorillonite conversion to illite and

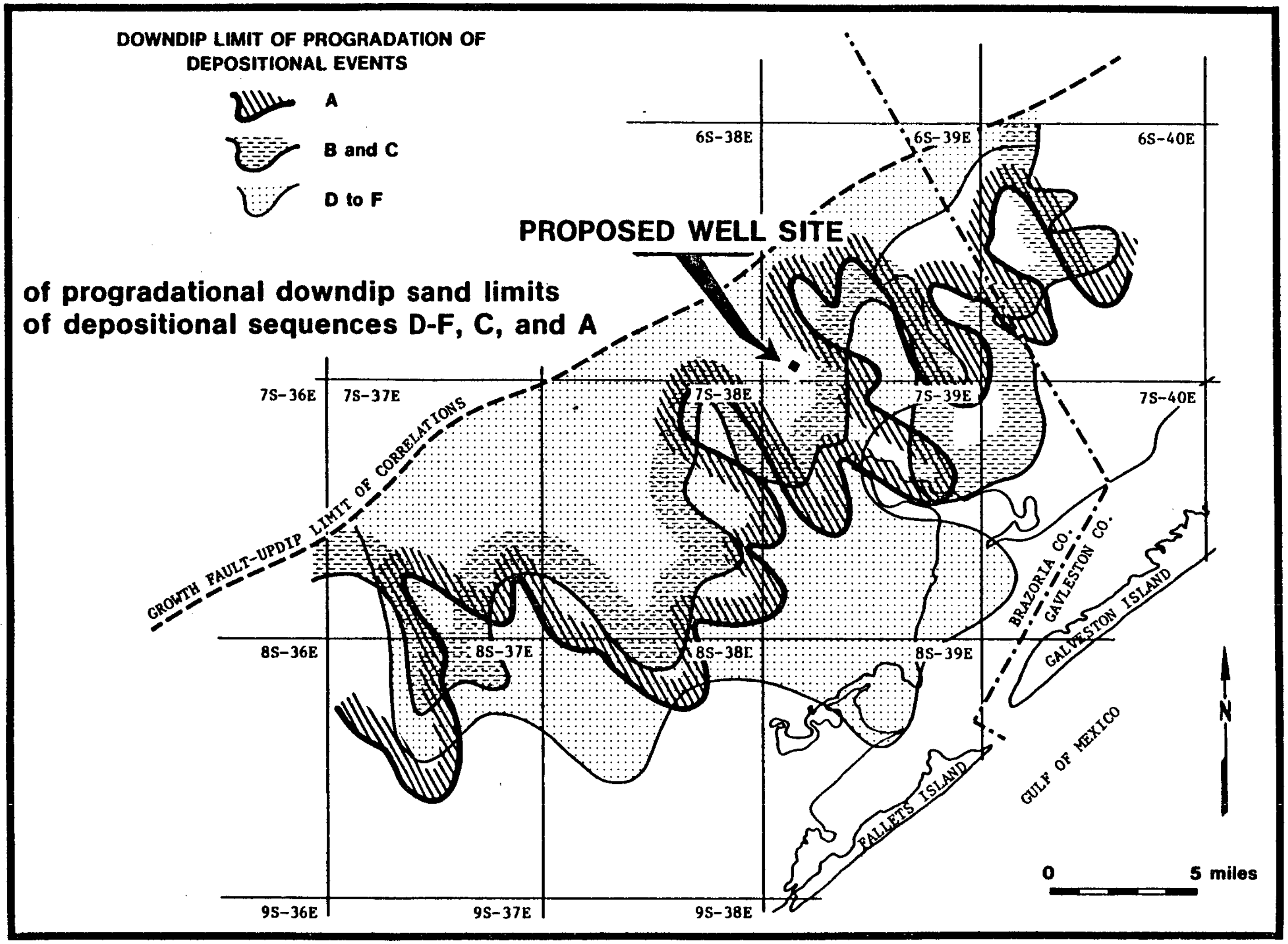

Fig. 2-4. Limits of progradational deltaic and delta front deposits in the vicinity of the Brazoria County Prime Prospect Area (After Bebout, Loucks, and Gregory).

mixed-layer clay minerals with depth and geothermal gradient (Figure 2-5). This conversion of clay minerals and the accompanying release of bound and intracrystalline water is accompanied by an increase in porosity. Stuart (1970) shows that porosity increases below the top of the geopressure zone in both sandstone and shale (Figure 2-6).

2.1.1 Natural Land Subsidence

Local mass movement that involves principally the gradual downward sinking of the solid earth's surface is called land subsidence. The immediate cause of land subsidence, independent of crustal tectonics, is the removal of support caused by a reduction of pore pressure of interstitial fluids in a porous layer beneath the surface (Poland and Davis, 1969). Pressure reduction will occur with the withdrawal of fluids in the course of geothermal resources development. A direct consequence could be acceleration of the natural processes of sediment compaction, already in progress in young, deep sedimentary basins such as the Gulf Basin.

Most field studies of sediment compaction due to natural processes are based upon indirect information, mainly porosity data from well logs or bulk density measurements on drill cuttings or cores. A very comprehensive mathematical analysis of shale compaction was made by Smith (1973), who concluded that tens or even hundreds of millions of years are required for shales to drain under natural loading stress with deepening burial, and that reduced porosity and permeability occur only near sand-shale boundaries, where the pore-water pressure gradient is very large. Smith's calculations are supported by the work of Bourgoyne, Hawkins, Lavaquial, and Wickenhauser (1972) who state that little or no shale water influx to sand-bed reservoirs in the geopressure zone will occur with reservoir pressure decline for shale with initial permeability of

Diagenesis of Gulf Coast Clayey Sediments

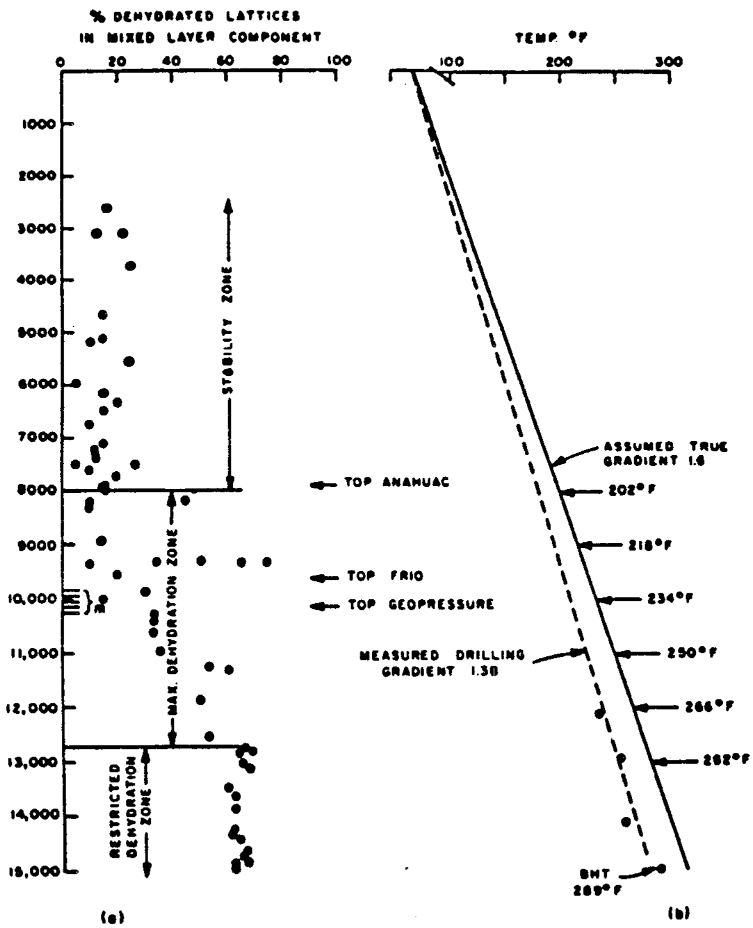

Fig. 2-5. Stepwise dehydration of clay in a Gulf Coast well, Chambers County, Texas (After John F. Burst, 1969).

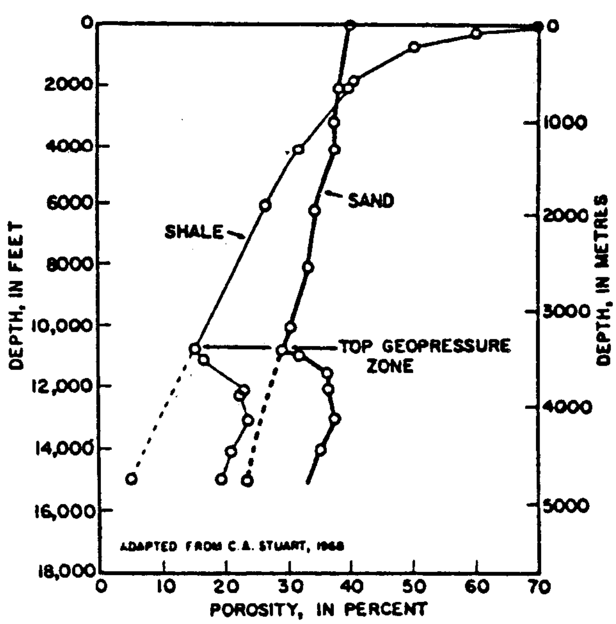

Fig. 2-6. Relation of porosity to depth of burial in sand beds and in shale beds of Cenozoic Age in the hydropressure zone and in the geopressure zone in the Gulf Basin (After Charles A. Stuart, 1970).

10^{-7}md; and that, although shale-water influx would have a significant effect upon reservoir pressure depletion at initial shale permeabilities of 10^{-5} to 10^{-6} md, only the first few feet of shale adjacent to the reservoir would contribute materially to the water influx during reservoir pressure depletion.

Detailed studies of pore-space reduction in sandstones, primarily using mathematical models, have been made in recent years. Rittenhouse (1973) notes that "the average porosity of Gulf Coast Tertiary sandstones commonly decreases more than 1% for each 1,000 ft of burial." The causes he identified are: (1) grain rearrangement, (2) pore filling with crystalline material, and (3) physical and/or chemical modification of the original sand grains. Grain modification is a factor related to (1) sand composition, (2) fluid composition and movement, (3) effective stress, (4) temperature, (5) time, and (6) the extent to which early pore filling has strengthened the rock. Grain rearrangement and grain modification change both the porosity and thickness of the sandstone. Rittenhouse states that a fluid pressure reduction of 1758 kgs/m^2 (2,500 psi) in a deeply buried sandstone reservoir could result in a bed thickness reduction of 8.2%, unless pore filling prior to application of this stress enables it to withstand the increased effective stress. He further states that actual thickness reduction under such a fluid pressure reduction--accomplished in 30 years, for example (an instant in geologic time)-- would have far less effect.

If the bed has experienced an effective stress greater than it now bears, as a consequence of deeper burial in the past than now, or by having been hydropressured at its present depth before now being geopressured, its thickness reduction as a consequence of reservoir pressure reduction might be negligible. If, however, leaching of mineral grains occurred after geopressuring, without appreciable depth change, thickness reduction as a result of fluid pressure reduction could be appreciable--or it might be negligible, depending upon the mineral composition of grains and the leached component of the matrix.

The region has undergone considerable subsidence as a result of groundwater and oil and gas withdrawal by municipalities and petroleum companies. Subsidence as a result of groundwater withdrawal measured between 1943 and 1964 is shown by Jorgensen (1975). Lowering of surface elevations has lead to flooding problems in the areas around Galveston Bay and in the Houston area where subsidences over 1.5 m (5 ft) have occurred. In the vicinity of the geothermal well site, if subsidence has occurred it has been less than 15 cm (6 in). Subsidence in the Chocolate Bayou Field has been associated with oil and gas production from the geopressured zone (Gustavson and Dreitler, 1976). Subsidence of more than .3 m has occurred in the field and coincides with periods of maximum gas production from the geopressured horizon. Subsidence resulting from oil production shows a lag time before it is felt at the surface.

2.1.2 Physiography

The GCO-DOE Pleasant Bayou No. 1 well test site is in southeast Brazoria County, Texas, on the east side of Chocolate Bayou. Two geologic surfaces form the study area, a flat to rolling Pleistocene surface above 3 m (10 ft) in elevation, and the Holocene-Modern alluvium at lower elevations along Chocolate Bayou. The Pleistocene surface is probably part of the Beaumont Formation, a fluvial-deltaic system of distributary sands in the study area. The soils are thin and are moderately susceptible to erosion. The Holocene-Modern Alluvium, flat and composed of mud, is a permanent and ephemeral fresh water marsh. These fluvial systems are still undergoing deposition. Except for oil, there is no mineral production in the vicinity of the study area. (St. Clair et al., 1975).

2.1.3 Soils

Figure 2-7 shows the distribution of the soils of the study area, which are primarily loams and clays, with slow to very slow runoff and slow to very slow permeability. Table 2-1 summarizes these and other characteristics. Permeability of the soils is very slow. However, the Pleistocene soils are moderately permeable and recharge the shallow aquifers.

2.2 Hydrology and Water Use

In the area, the important fresh groundwater sources are the Chicot and Evangeline aquifers. These sands extend along the entire coastal area of Texas into Southwestern Louisiana. The surface water of the project area is located within the Chocolate Bayou drainage basin. Surface drainage is sluggish, but generally northwest to southeast.

2.2.1 Groundwater

Fresh groundwater (less than 100 parts per million dissolved solids) occurs from near the surface to a depth of approximately 290 m (950 ft) at the proposed well site (Figure 2-8). The base of fresh water slopes generally northwestward to a local maximum depth of more than 365 m (1200 ft), 8 km (5 mi) from the site. Locally, the minimum depth of fresh water occurs 6.4 to 12.9 km (4 to 8 mi) west of the site where local contamination by salt from Danbury salt dome causes an abrupt rise in the fresh water-salt water contact to within 60 m (200 ft) of the surface (Sandeen and Wesselman, 1973). Slightly saline water (1000 to 3000 parts per million dissolved solids) extends to about 30 m (100 ft) deeper than the fresh water base in the area.

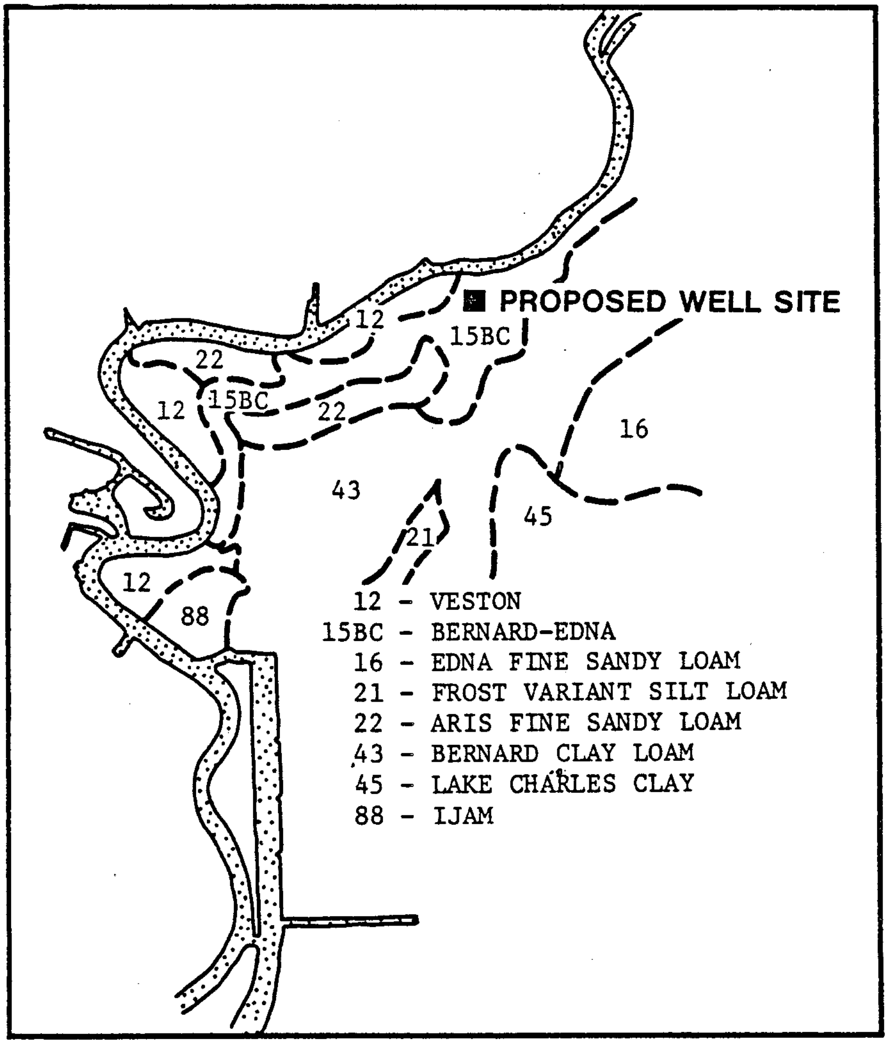

Fig. 2-7. Soils of the study area (After Texas Bureau of Economic Geology).

Table 2-1. Characteristics of Soils in the Study Area (SCS 1973-1977)

Name	Description	Runoff	Permability	pH	Suitability for pond or reservoir area	Suitability for buildings and roads	Uses
Veston (12)	dark gray fine sandy loam horizons and gray loam and silty clay loam; nearly level coastal flats inundated by storm surge	very slow; poorly drained	slow	moderately alkaline	severe, floods, wetness	poor	native range
Bernard-Edna (15 BC)	see Bernard and Edna						
Edna (16)	dark gray loam horizons and very firm clayey horizons; broad nearly level coastal prairies	very slow	very slow	slightly acid	severe, wet slight	severe, wet	rice and native range
Frost (21)	silty loam; silty alluvium or loess deposits in broad depressions late Pleistocene terraces	very slow	slow		severe, wet	severe, wet, floods	hardwood forest or pasture
Aris (22)	dark grayish brown fine sandy loam and gray sandy clay loam and clay; level on Pleistocene terraces	slow	very slow		slight	severe, wet	crops
Bernard (43)	dark gray clay loam to clay; fine textured, unconsolidated sediments of Pleistocene age	very slow	very slow	slightly acid to alkaline	slight	severe, wet	rice and native pasture
Lake Charles (45)	clayey soils; broad level uplands on Beaumont formation	very slow	very slow	slightly acid to alkaline	slight	severe, wet	rangeland
Ijam (88)	dark gray to gray clays; dredged material	very slow	very slow	alkaline	slight	severe, wet	

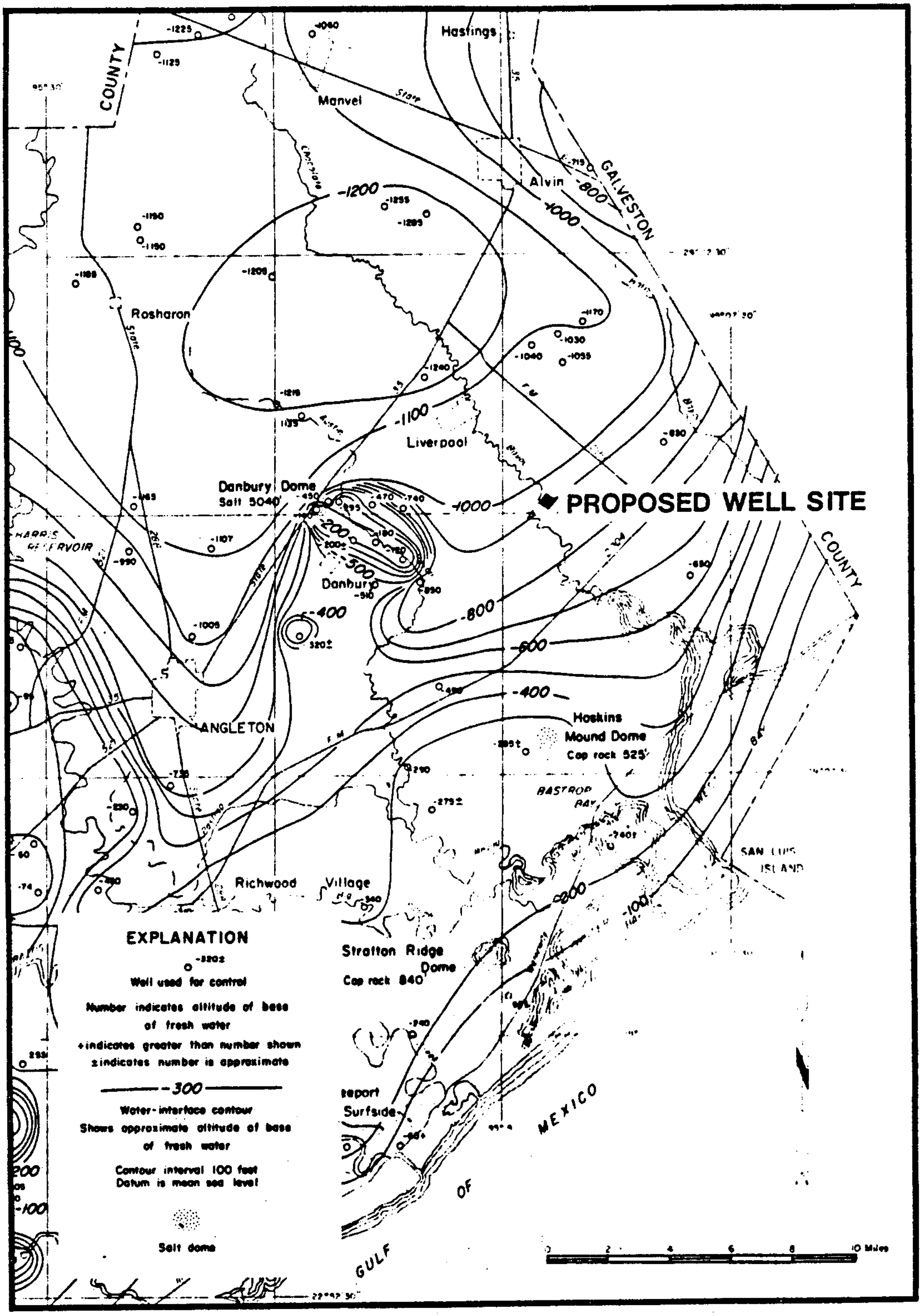

Fig. 2-8. Approximate altitude of the base of fresh water, Brazoria County, Texas (After Sandeen and Wesselman, 1973).

The important fresh ground-water sources are the Chicot and Evangeline aquifers. These sands extend along the entire coastal area of Texas into southwestern Louisiana (Table 2-2). The major recharge occurs at the aquifer outcrops 50 to 60 km (35 mi) north of the test site. The relatively impermeable overburden of Beaumont Clay prevents significant recharge from the surface at the site.

The proposed location of the GCO-DOE Pleasant Bayou No. 1 well is at the boundary between fresh water and salt water in the Evangeline aquifer. Because of the proximity of salt water the Evangeline aquifer has not been developed as a water supply here. The overlying Chicot aquifer yields fresh water at the site. Table 2-3 lists chemical constituents from two wells completed in the Chicot aquifer. Well 703 is 1.6 km (1 mi) north and well 702 is 1.6 km east of the site. The closest ground-water use is on the west bank of Chocolate Bayou at Peterson's Landing. Four wells were reported by Sandeen and Wesselman (1973) completed within 107 m (350 ft) of the surface and supplying small quantities of water for limited public and domestic use. A well drilled to 282 m (924 ft) is located at the Monsanto plant more than 2 km (1 mi) east of the site and pumped 2 cubic meters per minute (524 gal/min) in 1961.

The closest larger centers of pumping in the Chicot aquifer are at Angelton, 21 km (13 mi) west southwest, Alvin, 19 km (12 mi) north, and Danbury, 9.6 km (6 mi) west southwest. None of these sites appear to affect water levels at the well site. Maps of water levels in wells screened in the Chicot aquifer in 1967 indicate the local ground-water flow direction is east to southeast at the well site.

Between the base of fresh ground-water and the top of the geopressure zone occur extensive deposits of Miocene and Pliocene sands and clays containing

Table 2-2. Geologic and Hydrologic Units of the Texas and Louisiana Coastal Plain

		Hydrologic Unit		
System	Series	Southwest Texas Coastal Plain[1]	Northeast Texas and Southwest Louisiana Coastal Plain[2]	Mississippi River Area, Louisiana[3]
Quaternary	Recent	Alluvium	Chicot Aquifer[4]	Mississippi Alluvium
	Pleistocene	Beaumont Clay Lissie Formation		Older Delta Deposits
Tertiary	Pliocene	Willis Sand (Pliocene?) Goliad Sand	Evangeline Aquifer	Deposits Miocene Pliocene
	Miocene	Lagarto Clay (Miocene?) Oakville Sandstone Catahoula Sandstone (Miocene?)	Burkville Aquiclude Jasper Aquifer[5]	
	Oligocene (?)	Frio Clay	Not Mapped	

[1]Wood, Gabrysch and Marvin, 1963.
[2]Wesselman, 1971.
[3]Cardwell and Rollo, 1960; Long, 1965.
[4]Becomes Chicot-Atchafalaya Aquifer in Southcentral Louisiana (Harder and others, 1967).
[5]Wesselman, 1972.

Table 2-3. Chemical Analyses of Water from the Chicot Aquifer Near the GCO-DOE Pleasant Bayou No. 1 Well Site (Sandeen and Wesselman, 1973).

WELL	WATER BEARING UNIT	DEPTH (ft)	DATE OF COLLECTION	TEMPERATURE (°C)	SILICA (SiO_2)	IRON (Fe)	CALCIUM (Ca)	MAGNESIUM (Mg)	SODIUM AND POTASSIUM NA	SODIUM AND POTASSIUM K	BICARBONATE (HCO_3)	CARBONATE (CO_3)
702	CL	924	May 25, 1967	--	--	--	--	--	--	--	406	0
703	CU	30	May 17, 1939	--	--	--	--	--	394	--	508	--

SULFATE (SO_4)	CHLORIDE (Cl)	FLUORIDE (F)	NITRATE (NO_3)	BORON (B)	DISSOLVED SOLIDS	HARDNESS AS $CaCo_3$	RESIDUAL SODIUM CARBONATE (RSC)	SODIUM ABSORPTION RATIO (SAR)	SPECIFIC CONDUCTANCE (MICROMHOS AT 25°C)	pH
1.6	890	--	--	--	--	150	3.65	--	3,330	7.9
122	945	--	--	--	2,106	1,020	--	--	--	--

Source: Sandeen and Wesselman, 1973.

saline water. The general relationship between depth and salinity is shown in Table 2-4.

Table 2-4. Relation Between Depth & Salinity in the Study Area.

Depth Interval	Average Dissolved Solids Content	Net Sand
0 to 610 m (0-2,000 ft)	5,000 to 10,000 ppm	122 m (400 ft)
610 to 1220 m (2,000-4,000 ft)	20,000 to 40,000 ppm	213 m (700 ft)
1220 to 1830 m (4,000-6,000 ft)	20,000 to 40,000 ppm	244 m (800 ft)
1830 to 2440 m (6,000-8,000 ft)	60,000 to 80,000 ppm	122 m (400 ft)
2440 to 3050 m (8,000-10,000 ft)	80,000 to 100,000 ppm	30 m (100 ft)

(Interpreted from Maps: Core Laboratories, Inc., 1972).

The sequence of saline sands available for brine injection is shown in Figure 2-9. Bebout, Loucks, and Gregory (1977) evaluated nearby electric logs and found that the potential disposal interval contains an average of 34% sand with an average net sand thickness of 525 m (1725 ft) (Figure 2-10). Limited drilling data and seismic data indicate major faulting is not expected in the area of the production test well and the disposal wells (Bebout, Loucks, and Gregory, 1977). The nearest oil and gas production is at Chocolate Bayou Field, more than 4.8 km (3 mi) north of the test site. The shallowest production there is -2438 m (8,000 ft), stratigraphically deeper than the deepest proposed brine injection zone of -2130 m (7,000 ft).

The saline aquifers above the Frio are used for disposal of oil field brines and for industrial waste injection. Brine disposal wells listed in Table 2-5 are located in fields surrounding the structural syncline where the test well is to be located (Figure 2-11). No brine injection wells are closer than 8 km (5 mi) to the site. However, three waste injection wells (for disposal of a waste stream containing various hydrocarbons including ether, phenols, and nitrite) are located at the Monsanto Plant within about 1.6 km (1 mi) of the proposed site

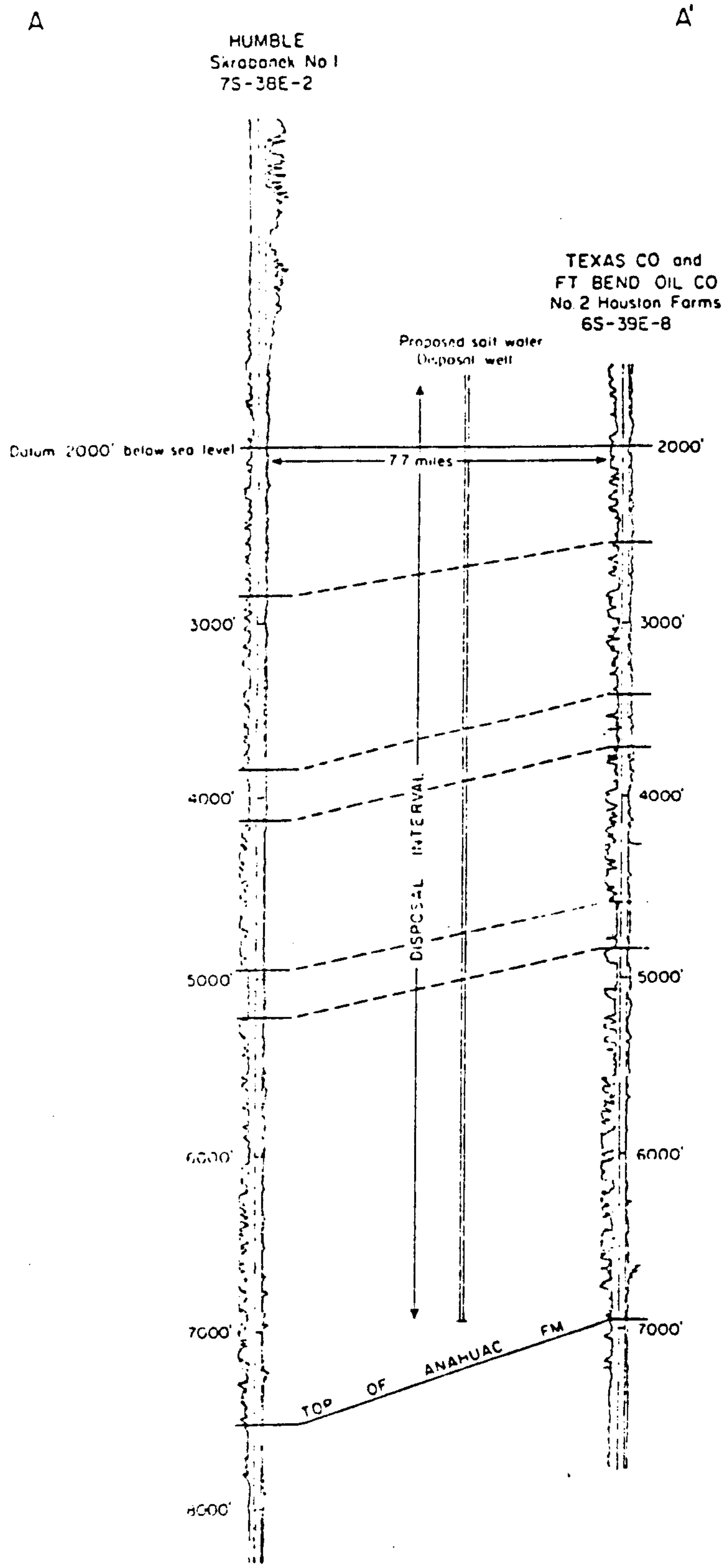

Fig. 2-9. Cross section of potential geothermal waste water disposal sands. Well locations for A and A' are shown on Figure 2-10 (After Bebout, Loucks, and Gregory, 1977).

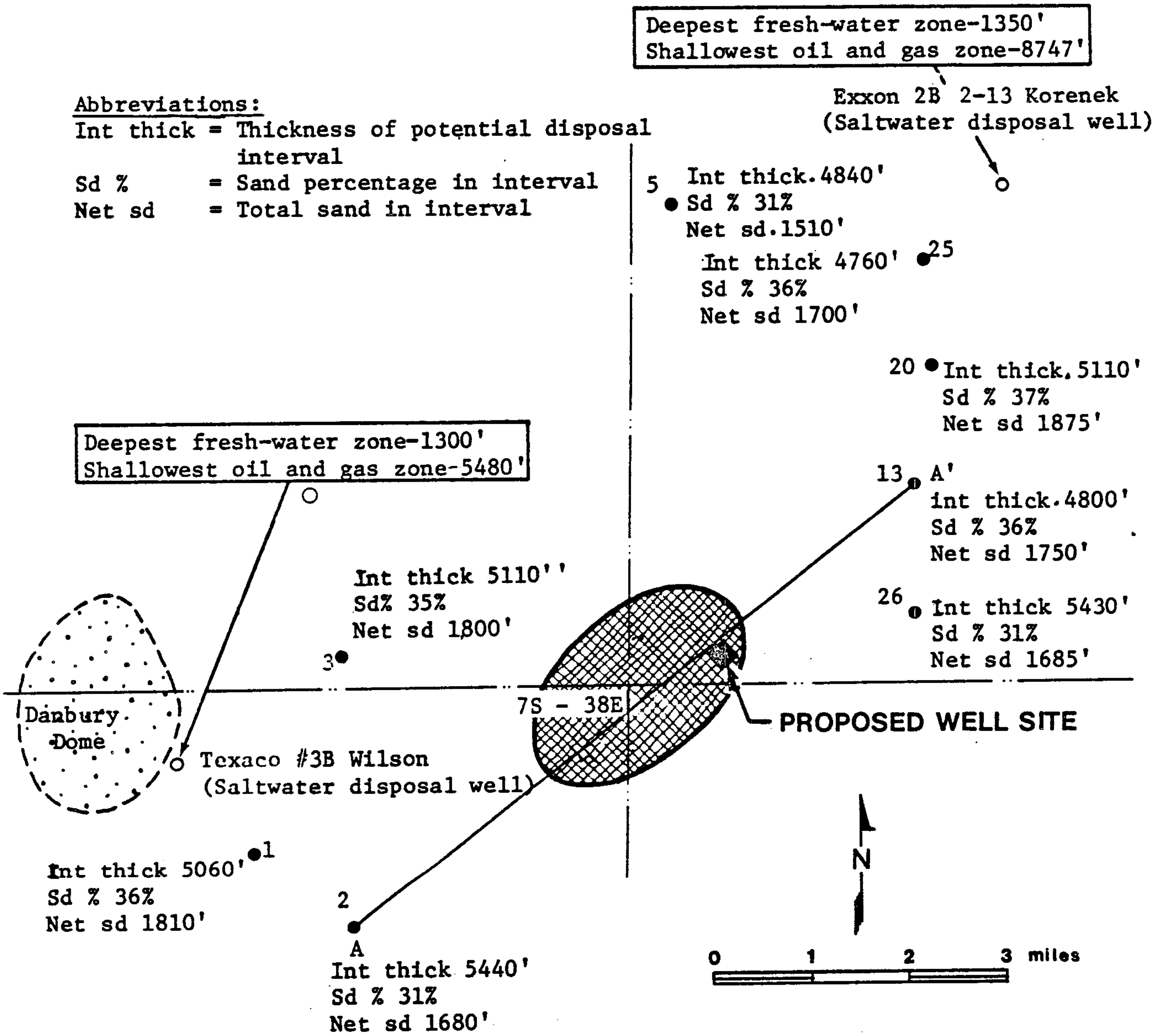

Fig. 2-10. Thickness of sandstone suitable for disposal of geothermal waste water near proposed well site. Details of Section A-A' are shown on Figures 2-9 and 3-1 (After Bebout, Loucks, and Gregory, 1977).

Table 2-5. Oil Field Brine Injection Wells Nearest the Proposed Well Site.

Well No.	Field	Approved Injection Zone (meters)	Anticipated Injection Volume (Maximum-minimum) (Barrels/day)	Base of Fresh Water (meters)
D-62	Chocolate Bayou	610 - 2030	0 - 8000	411
D-11	Chocolate Bayou	807 - 1829	0 - 3000	396
D-98	Danbury	701 - 1600	1000 - 5000	396
D-60	Danbury	580 - 915	200 - 1000	335
D-106	Danbury	1103 - 1295	400	320

data compiled by the Texas Bureau of Economic Geology, 1977.

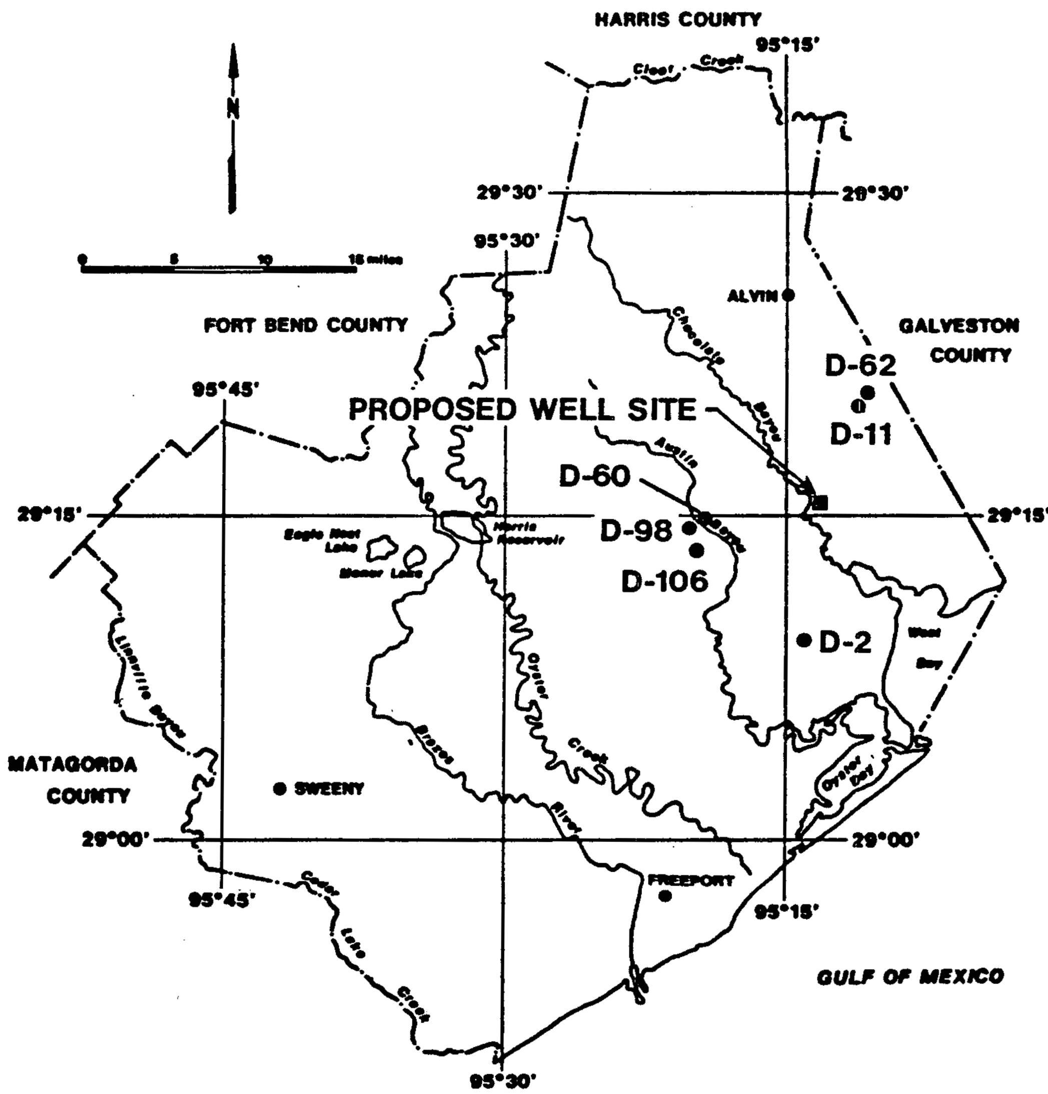

Fig. 2-11. Existing brine injection wells near the proposed well site (data compiled by the Texas Bureau of Economic Geology, 1977).

(Texas Department of Water Resources, personal communication, 1977). The injection zones are basal Miocene sands, between 1781 and 2103 m (5842 to 6900 ft) deep. Details filed with the Texas Department of Water Resources concerning these wells are presented in Table 2-6 and are available from the Texas Water Quality Board, Austin, Texas.

2.2.2 Surface Water

The most obvious part of the hydrologic cycle is surface water. Water that falls on the surface and eventually drains into streams represents a residual element whose quantity and quality is governed by the many physical and cultural features of the surface environments. In this section the resulting runoff, stream regime, water quality, and development of the water resource are described as they pertain to the proposed action in the study area.

2.2.2.1 General Hydrology

The project area is located within the Chocolate Bayou drainage basin (Figure 2-12). Chocolate Bayou drains an area of approximately 414 km^2 (160 mi^2). Surface drainage in the basin is generally northwest to southeast in response to surface gradient. Elevation grades from about 20 m (65 ft) at the upper end of the basin to sea level in a distance of about 45 km (28 mi), a slope of about 0.4 m/km (2.3 ft/mi). Therefore the flow is sluggish and is subject in lower parts of the basin to distortion from the effects of tides and weather conditions.

The proposed well site is located in the lower part of the basin, in the tidally influenced reach of the stream. Conversations with local residents established a highly variable tidal regime at the site. A range of 0.1 to 0.9 m

Table 2-6. Monsanto Waste Disposal Wells Near the Proposed Well Site.

Well No.	Operator	Injection Zone (meters)	Maximum Injection Rate (Cu m/sec)
WDW - 1	Monsanto	1839 - 1924 1930 - 1978	3.7×10^{-2}
WDW - 1A	Monsanto	1781 - 1919	2.76×10^{-2}
WDW - 13	Monsanto	1905 - 2103	6.43×10^{-2}

data compiled by the Texas Department of Water Resources, 1977.

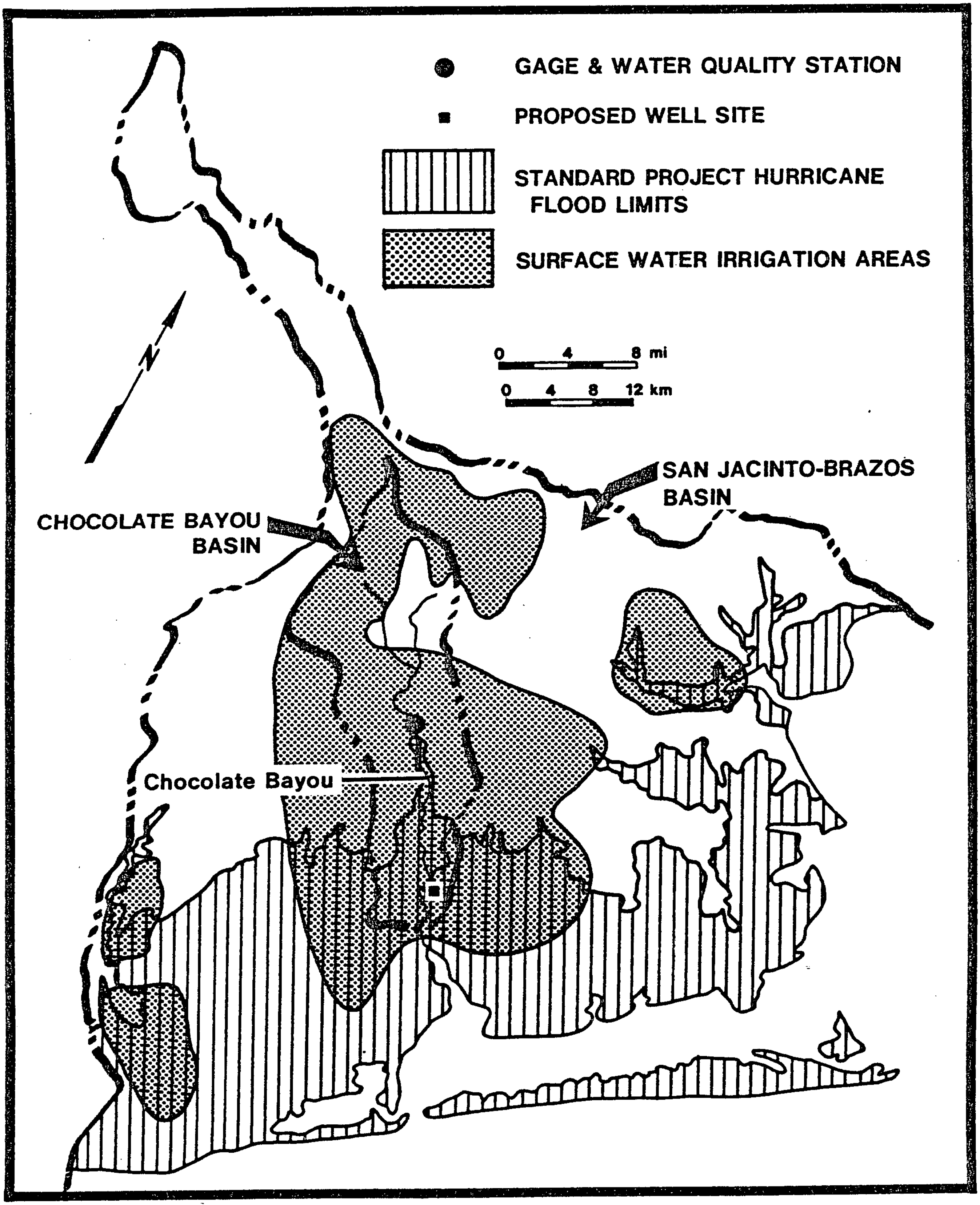

Fig. 2-12. Chocolate Bayou Drainage Basin; relationship to San Jacinto-Brazos Coastal Drainage Basin (After Texas Parks & Wildlife Dept., 1975; Blakely & Kunze, 1971).

(0.5 to 3 ft) daily fluctuations in water level at the site indicates strong influence of weather events on water level and tidal action. Strong southerly winds evidently produce large rises in water levels, whereas northerly winds effectively damp out the tidal fluctuations. The well site itself is located out of the floodplain at an elevation that will keep it from being influenced by these normal fluctuations. However, as Figure 2-12 clearly shows, the well site is within the area of flooding expected from the standard project hurricane (flooding expected to occur from the most severe combination of meteorological and hydrological conditions that are considered reasonably characteristic of the drainage basin).

2.2.2.2 Physical Characteristics of Basin Hydrology

A hydrograph using 17 years of average monthly discharge (Q) shows a regime which does not fit the geographical pattern anticipated for streams in this region (Figure 2-13). The low flow in March and the high flow in June may be related to irrigation return flow in the basin - low in March when irrigation use is low and high in June when use is high. (Figure 2-12 shows that Chocolate Bayou drains the largest irrigation area in the coastal basin). It should be noted that these data are measured in the upper part of the basin (location in Figure 2-12) at a point on the stream that drains about 50% of the basin. Therefore the regime depicted may be more erratic than and less representative of conditions lower in the basin at the well site.

Average annual precipitation in the basin ranges from 1170-1220 mm (44-48 in). Minimum annual precipitation recorded is 533 mm (21 in) and maximum is 2108 mm (83 in) (Texas Park and Wildlife Department, 1975). Runoff averages about 93.8 hm^3/yr (76,070 A-F/yr) (USGS, 1976). Runoff characteristics are governed

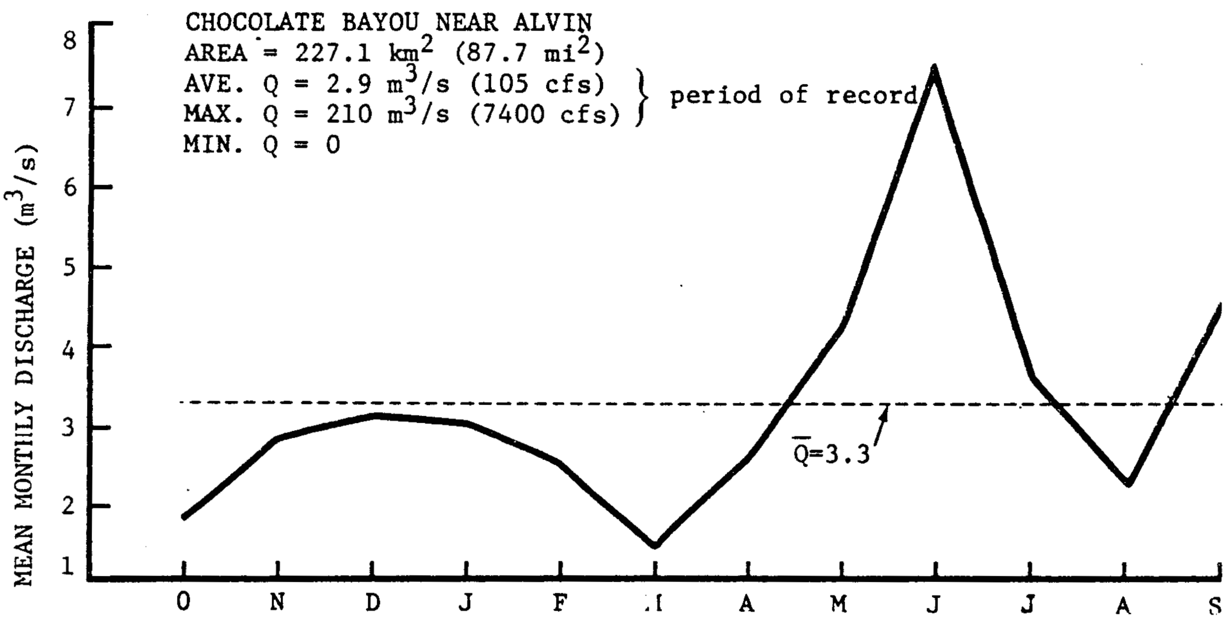

Fig. 2-13. Mean monthly discharge, 1960-1976, Chocolate Bayou near Alvin (After USGS, 1960-1976).

by soil type, vegetation, and land use in the basin. Table 2-7 lists the percent of precipitation expected as runoff from different surfaces. Reference to the soil type, vegetation, and land use sections of this assessment points out the pertinence of these differences around the well site.

Table 2-7. Runoff as a Percent of Precipitation on Various Surfaces.

Surface	% Runoff
Urban Residential	
single houses	30
garden apartments	50
Commercial and industrial	90
Forested areas (depending on soil)	5-20
Parks, farmland, pasture	5-30
Asphalt or concrete pavement	85-100

(source: Linsley and Franzini, 1972)

Discharge of Chocolate Bayou at the gage site averages $2.9m^3/s$ (105 cfs). Sixty-four percent of the monthly mean flows in the 17-year period analyzed are below $2.8m^3/s$ (100 cfs), 75% are below $4.2m^3/s$ (150 cfs), and 98% are below $14m^3/s$ (500 cfs). Assimilative capacity of the stream may therefore be judged as consistently low.

Figure 2-14 shows the flood hazard expected in the vicinity of the proposed action and at the well site itself. The well site is located between the 19 and 20 ft base flood elevation lines. Flood stages in excess of 20' have occurred 7 times during the period of record (Table 2-8). The proposed well site is in the 100 year floodplain. Compliance with E.O. 11988 is being undertaken by the Department of Energy and will apply to this subprogram once the DOE regulations have been formulated.

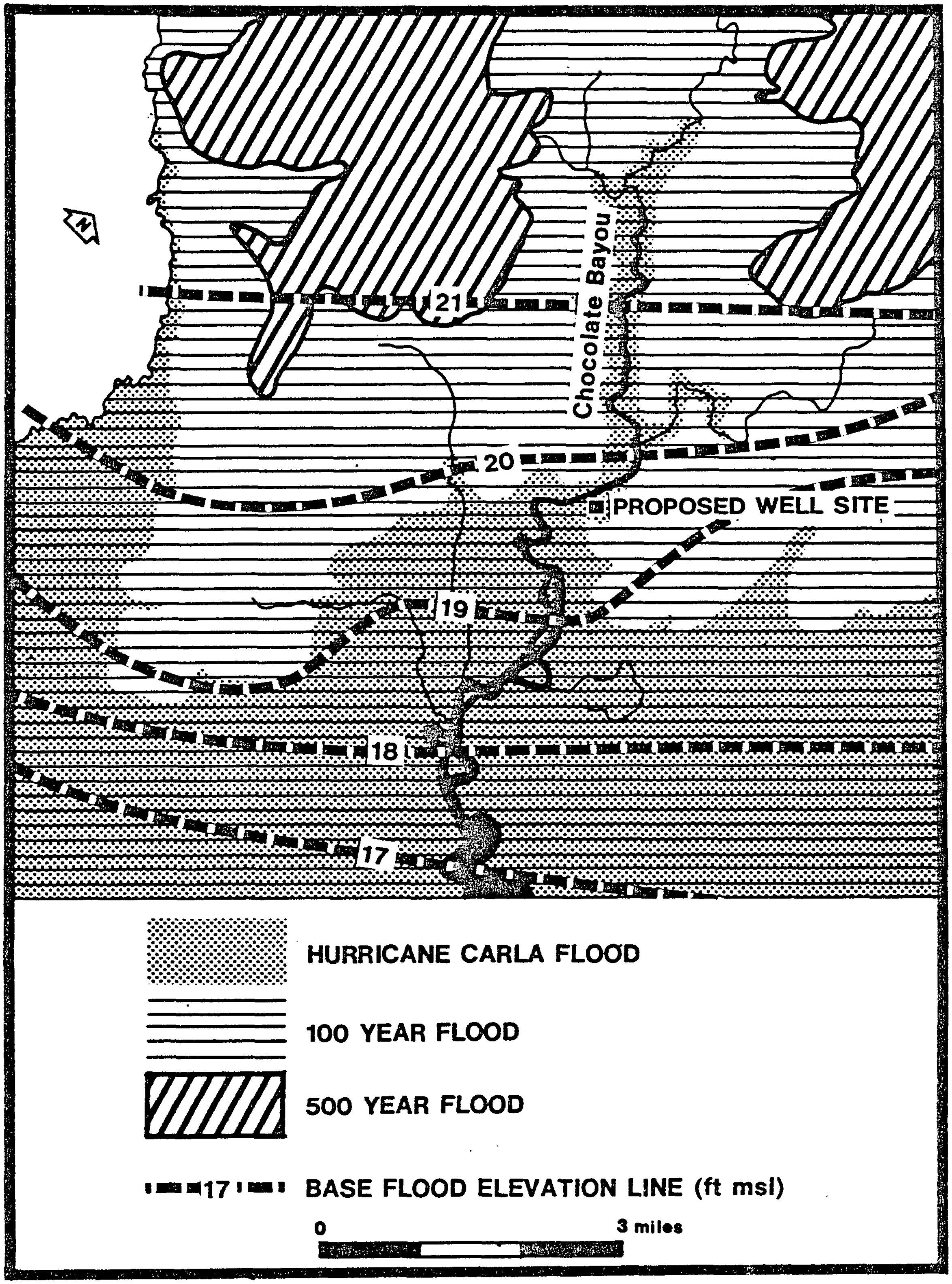

Fig. 2-14. Flood hazard map (After USCE, 1970; FIA, 1977).

Table 2-8. The Highest Floods in Order of Magnitude for Chocolate Bayou Near Alvin, Texas.

Order No.	Date of Crest	Gage Heights: Stage m	(ft)	Elevation m	(ft)msl	Estimated Peak Discharge m^3/s	(cfs)	
1	July 14, 1939	6.9	(22.90)[1]	10.1	(33.21)	326	(11,500)	(2)
2	October 8, 1949	6.6	(21.80)	9.8	(32.11)	210	(7,400)	
3	March 18, 1957	6.3	(20.60)	9.4	(30.91)	121	(4,280)	
4	June 24, 1968	6.2	(20.52)	9.4	(30.83)	118	(4,160)	
5	October 16, 1957	6.2	(20.47)	9.4	(30.78)	116	(4,100)	
6	June 19, 1961	6.2	(20.37)	9.3	(30.68)	112	(3,970)	
7	July 12, 1961	6.1	(20.00)	9.2	(30.31)	99	(3,510)	
8	Sept. 13, 1961	6.1	(19.94)	9.2	(30.25)	98	(3,460)	
9	August 27, 1959	6.0	(19.85)	9.2	(30.16)	95	(3,370)	
10	Nov. 14, 1961	5.9	(19.48)	9.1	(29.79)	86	(3,050)	

(1) Estimated from flood mark.

(2) Estimated by Corps of Engineers.

source: Data compiled by Texas Bureau of Economic Geology from USCE, 1970.

Note: Elevations in the area of the test well site range from about 1.5 m (5 ft) above msl near Chocolate Bayou to a maximum of about 4.5 m (15 ft) above msl on the terrace surface. White, *et al*.(1977) show that a comparison of land surface elevations and potential flood level elevations (Figure 2-14) suggests a possible minimum depth of flooding of about 1 m (3.3 ft) in the well area.

2.2.2.3 Water Quality Characteristics

Table 2-9 summarizes available information on water quality parameters. Locations for which there are existing water quality data near the well site are shown on Figure 2-15. At stations 1 and 2 average values for chlorides, total dissolved solids, and temperature are within the acceptance level as set by the Texas Water Quality Board, but the average sulfate value (54 mg/l) exceeds the accepted level at station #1 (Table 2-10). These data were collected upstream from the well site.

Table 2-10. Water Quality Standards, Selected Parameters.

Segment	Chloride (mg/l) average not to exceed	Sulfate (mg/l) average not to exceed	TDS (mg/l) average not to exceed	Temperature (%) maximum not to exceed
Chocolate Bayou (Tidal)	-	-	-	35
Chocolate Bayou (Above tidal)	150	50	600	32.2

(source: Texas Water Quality Board, 1976a).

Water quality data sampled below the well site indicate that water quality grades rapidly into brackish and saline between stations #2 and #3, documenting that the well site is close to the boundary between the tidal and non-tidal segments of the stream. No specific standards have been set for the tidal reaches of the stream (Table 2-10).

The tidal segment of the stream has been designated "effluent limited" (capable of meeting water quality standards using point source controls by 1977) and the non-tidal segment has been designated "water quality limited" (more stringent controls needed to meet standards) (Office of Water Planning and Standards, 1974). Two chemical plants located below the well site, Monsanto Chemical Co. and Amoco

Table 2-9. Water Quality Data (ranges of values in mg/ℓ).

Parameters	Sampling Stations**				
	1	2	3 Surface	3 Depth 0.9-3.6m (9-12ft)	4
TDS	272-666	300-1,000*	1,400-15,500*	10,500-17,500*	13,000-20,500*
NA	38-160				7,200
K	2.4-6.8				
NH_3	0.01-0.14	0.01-0.48	0.01-1.0		0.03-0.08
Mg	10-30				
Ca	43-84				
Mn	0-0.01				
Cl	49-260	30-266	725-9,300		
HCO_3	138-341				
SO_4	23-89	22-53	117-1,250		
SiO_2	3.9-32				
B	0.11-0.4				
pH (units)	6.4-8.0	7.0-8.1	7.70-8.30	7.60-8.60	8.0-8.4
Temp (°C)	15-29	15.6-28.3	18.5-30.0	19.0-29.5	9.5-15.5
Conductivity (micromhos)	502-1,400	600-2,000	2,800-31,000	21,000-35,000	26,000-41,000

** See Figure 15 for location of sampling stations.
* Calculated as 50% of conductivity

(Source: White *et al.*, 1977).

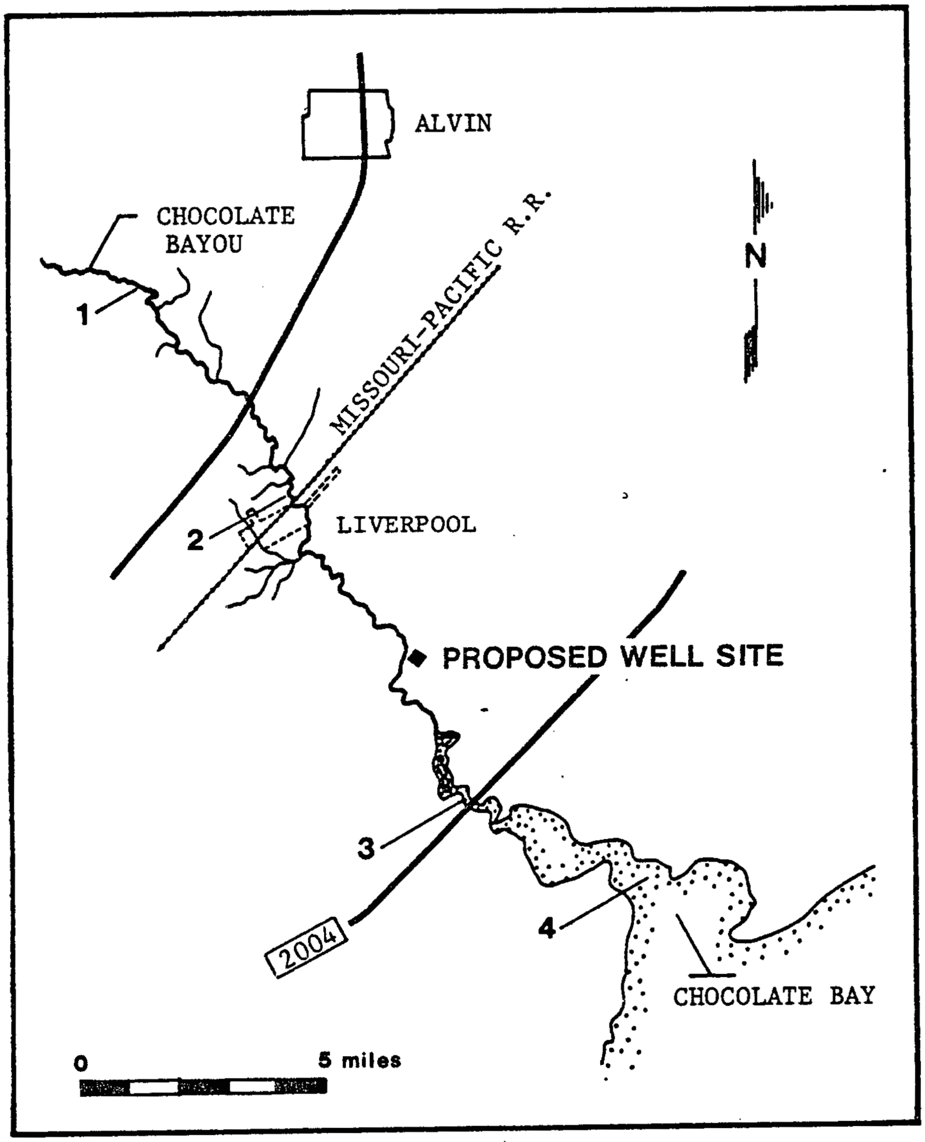

Fig. 2-15. Location of surface water quality sampling stations along Chocolate Bay, reported in Table 2-9 (After White _et al_., 1977).

Chemicals Corp., have permits for regulated discharge into the bayou cumulatively totaling to a maximum of 19.5 mgd of industrial process water, storm water, and domestic sewage. The specifications of the permits are on file at the Texas Department of Water Resources. At present the largest water quality problem in the stream and estuary is that of fecal coliform, probably originating from raw sewage discharged from the small communities and recreational establishments along the stream.

2.2.2.4 Water Resource Development

Chocolate Bayou tidal segment is approved for contact recreation, and both tidal and non-tidal segments are approved for non-contact recreation and propagation of fish and wildlife (Texas Water Quality Board, 1976). Boating, fishing, and weekend homesites are well-developed recreational activities near the well site. No domestic supply is taken from the stream.

Although the area is a high irrigation district, most of the surface water used is imported from the Brazos River by the Chocolate Bayou Water Company. The company sells water in the area for both irrigation and industry. Future development in the region may necessitate use of Chocolate Bayou as a water supply source. Table 2-10 shows irrigation figures for Brazoria County. Chocolate Bayou receives much of the return flow.

Table 2-11. Brazoria County Irrigation Statistics.

	All Irrigation				Surface Water Only				% Surface Water	
Year	ha	(Acres)	hm^3	(Acre-feet)	ha	(Acres)	hm^3	(Acre-feet)	Acre	Acre-feet
1958	20,759	(51,295)	206	(167,389)	17,786	(43,950)	181	(146,775)	86	88
1964	22,799	(56,335)	165	(133,783)	21,307	(52,650)	156	(126,318)	93	94
1969	28,151	(69,560)	269	(218,068)	23,946	(59,170)	237	(192,303)	85	88
1974	24,026	(59,368)	195	(158,315)	20,396	(50,399)	166	(134,397)	85	85

(source: Texas Water Development Board, 1975).

The Texas Parks and Wildlife Department has nominated the Chocolate Bayou area as an "area of particular concern," relative to recreational and industrial use of the water resource and relative to critical habitat areas dependent upon the existing hydrologic regime (General Land Office of Texas, 1975).

2.3 Terrestrial Flora and Fauna

The flora and fauna of the Pleistocene Terrace is quite diverse, with local conditions such as rainfall, soil fertility and salinity, topography, and land use determining community constituents. The well site falls within the broad classification of the Coastal Short-grass Prairie (St. Clair et al., 1975). During a field reconnaisance of the area of the proposed well site in September 1977 and from aerial photographs, six plant communities were delineated. These communities, named by their dominant components with locations and associated animals (see Appendix Table 2-10 for probability of occurence) were:

1. Quercus Community extending down the natural levee of Chocolate Bayou above all but the highest flood or tidal surges. This community provides nesting habitat for mourning doves (Zenaidura macroura), habitat for fox squirrels (Sciurus niger), nesting and resting habitat for numerous non-game birds and acorns as high quality food for a wide variety of wildlife.

2. Eupatorium - Andropogon - Axonopus Community maintained on infrequently flooded areas which were lightly disced and recently grazed. The bobwhite (Colinus virginius) and the eastern cottontail (Sylvilagus floridanus) make considerable use of this type. A number of small rodents and ground nesting and feeding non-game birds also occur here.

3. Cultivated Communities dominated by agricultural row crops (rice, milo, corn, or cotton and their respective, associated weed species) which are usually determined by soil capabilities, expected market demand, and

availability of equipment. Crop residues and the seeds of annual herbs and grasses provide food for wildlife, principally birds. Geese possibly make some use of this type with White-fronted geese (Anser albifrons) and Canada geese (Branta canadensis) using the crop residues. Lesser snow geese (Chen caerulescens) occasionally use burned stubble or saturated fields in their feeding.

4. Typha Community (aquatic) found in the water-saturated, abandoned meanders of Chocolate Bayou. Nutria (Myocastor coypus) and swamp rabbit (Sylvilagus aquaticus) utilize this plant community. The mink (Mustela vison) and the river otter (Lutra canadensis) may, on occasion be found here. The king rail (Rallus elegans) uses this type habitat and the common gallinule (Gallinula chloropus) may nest in shrubs at the bayou edge.

5. Baccharis - Spartina - Distichlis Community located along the edge of Chocolate Bayou in a zone frequently inundated by tidal or rain-induced flood surges, or wave action from boats; here faunal distribution is similar to that of the preceeding type.

6. Juncus Community (aquatic) existing in the shallow, permanently flooded edge of Chocolate Bayou. The racoon (Procyon lotor) forages in all habitat types of the area.

Various raptors course over the area and a large variety of small rodents occupy the various niches of the project area (See appendix Table 2-10). Several species of snakes are thought to occur in the vicinity of the well site. These include the poisonous southern copperhead (Agkistrodon contortrix), western cottonmouth (A. piscivorous), canebrake rattlesnake (Crotolus horridus), and the Texas coral snake (Micrurus fulvius). Prominent non-poisonous snakes are the diamond-backed water snake (Natrix rhombifera), glossy water snake (Regina rigida), checkered garter snake (Thamnophis marcianus), eastern coachwhip

(Masticophis flagellum), and the Texas rat snake (Elaphe obsoleta) (USCE, 1974, Thomas, 1976, and Conant, 1975).

Areas inhabited by humans were not recognized as separate plant communities because the vegetation is often selected or modified by the inhabitants. A list of species found associated with most of the vegetative communities is included in Appendix (Table 2-10). Plant communities distribution is shown in Figure 2-16. The proposed well site is to be located in the Eupatorium - Andropogon - Axonopus Community (Figure 2-16).

While Brazoria county has the second highest annual duck harvest and the seventh highest goose harvest of all Texas counties (USDI, 1975), no appreciable waterfowl value is present at the proposed well site.

The 52 x 49 m (170 x 160 ft) reserve pit to be built at the well site will provide additional aquatic habitat. However, this relatively small addition is not expected to provide sufficient food and/or cover necessary to attract many waterfowl; and the well structure as well as the nearby chemical plant and residences will act to deter waterfowl usage of the reserve pit. Although occasional individuals may stray into the area, most waterfowl are expected to seek or choose to remain in the more secluded and productive coastal marshes nearby. Therefore, the effects of toxic substances in the reserve pool are expected to be insignificant.

The Brazoria National Wildlife Refuge, located 19 km (12 mi) southwest of the site, is managed primarily as a refuge for wetland wildlife, but regulated sport hunting is allowed on a portion of the area.

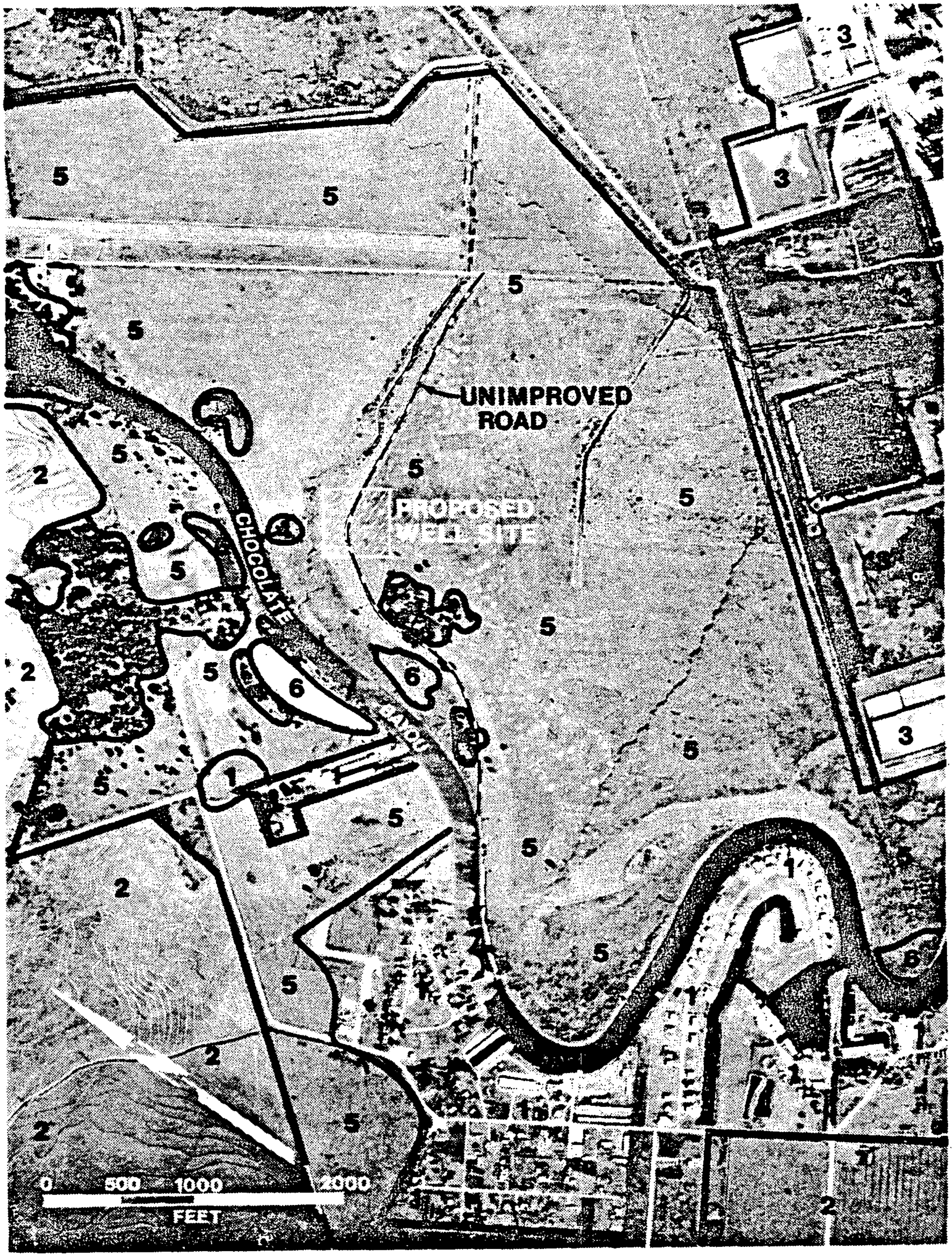

Fig. 2-16. Distribution of plant communities within the area of the proposed geothermal well site in Brazoria County, Texas, as delineated from a 20-21 September, 1977, field reconnaisance and aerial photographs.

1 INHABITED AREAS

2 CULTIVATED COMMUNITIES

3 CHEMICAL PLANTS

4 QUERCUS COMMUNITIES

5 EUPATORIUM-ANDROPOSAN-AXONOPUS COMMUNITIES

6 TYPHA COMMUNITIES

7 BACCHARIS-SPARTINA-DICTICHLIS COMMUNITY (along bayou banks)

Fig. 2-16. Continued: Key to distribution of plant communities in Brazoria County, Texas.

2.4 Aquatic Flora and Fauna

The Typha and Juncus communities were the only aquatic plant communities observed. Common cat-tail (*Typha latifolia*) and rush (*Juncus* sp.) clearly dominated their respective communities. (Scientific nomenclature after Correll and Johnston, 1970).

These communities are generally recognized as being highly net productive (Westlake, 1963), that is, they export organic detritus that is the basis for the detrital food chain. Despite pollution from industrial and domestic discharges, Chocolate Bayou carries this detritus and the nutrients necessary to make the bayou highly productive and is an important component of the Chocolate Bay estuary. Sport fishing, sport shrimping, and sport crab fishing all take place in the area (Moffett, 1975). Principal saltwater fish include red drum (*Sciaenops scellata*), spotted seatrout (*Cynoscion nebulosus*), and southern flounder (*Paralichthys lethostigma*). Fresh water catfish (*Ictaluridae*) and sunfish (*Centrachidae*) are also caught in Chocolate Bayou in the vicinity of the site. See Appendix Table 2-11.

Moffett, 1975, concludes that the Chocolate Bayou estuary is a major marine nursery habitat, and recommends, "...stringent reviews by Texas Parks and Wildlife Department officials of all proposals for oil exploration, channel dredging, waste disposal, spoiling and land development...careful monitoring of coliform bacteria, pesticides, trace metals and other pollutants in the watershed by the responsible state departments..." According to the same author the harvest of oysters is prohibited because the area is classified as polluted by the Texas State Health Department, Division of Marine resources.

2.5 Endangered Flora and Fauna

The Texas Parks and Recreation Department cites "Rare and Endangered Plants Native to Texas," compiled by the Rare Plant Study Center, The University of Texas at Austin, and the Resource Management section, Texas Parks and Wildlife Department (1975). The only plant on this list thought to have occurred within 0.8 km (0.5 mi) of the well site is bulb gromwell (Lithospermum tuberosum), and the last known collection of this species was in 1914 (Texas Parks and Wildlife Department, 1975). Since the vegetative portions of this plant are visible only in the spring, no specimens would have been observed even if it did occur. However, since the last known collection was made 63 years ago, and because much of the area is disturbed by agriculture, and because its natural habitat is "low often dry woods" (Correll and Johnston 1970: 1305), bulb gromwell is not expected to occur on the site.

One mammal and four birds that once occurred on or near the project area are currently classed as endangered (Federal Register October 28, 1976) to provide federal protection for them and for their essential habitats. However, the area of the proposed well site is agricultural fields and not suited for wildlife habitat. There are no long term surveys of the proposed well site planned because of the low probability of finding endangered species.

The red wolf (Canis rufus) once ranged throughout this region but now the project site is not considered as part of the 36,855 ha (91,000 acre) red wolf habitat projected for Brazoria County (Texas Parks & Wildlife Commission, 1975).

The Attwater's prairie chicken (Tympanuchus cupido attwateri) was once a common bird of the coastal praries (Lehmann and Mauermann, 1963). Habitat alteration and the associated populations decline has caused the present "endangered species" status. No prairie chickens are presently nearer the site than 28 km (18 mi) west near Angleton. Other small populations are located 48 km (30 mi) west-northwest and 33 km (21 mi) east-northeast of the site (Texas Parks and Wildlife Commission, 1975). The plant associations of the former coastal prairie, now in pastures and fields, were noted to contain the plants regarded as important prairie chicken foods (Texas Parks and Wildlife Commission, 1975). Present industrial development probably limits the attractiveness of this area for transplanting or natural dispersal of this bird into the area.

Two Southern Bald Eagle (Haliaeetus leucocephalus leucocephalus) nesting sites are known from Brazoria county, with the nearest site approximately 65 km (43 mi) west of the site (Brownlee, 1977).

The Peregine Falcon (Falco peregrinus) is probably a winter visitor to the vicinity of the project; however the lack of concentrations of prey species proximate to the site makes it unattractive as a hunting area for these endangered raptor.

The Whooping Crane (Grus americana) winters to the west of the area although the saline marshes of Chocolate Bay were once a part of its winter habitat.

The American alligator (Alligator mississippiensis) occurs in Chocolate Bayou and in the upper parts of the downstream estuary. The Alligator was formerly classed as endangered, but with state and federal protection has made substantial population gains in principal habitats, such as Calcasieu, Cameron, and Vermilion Parishes, Louisiana. More recently (Federal Register, January 10, 1977) the classification has been changed to threatened over much of the range including the study area.

The Houston toad (Bufo hustonensis) occupies mixed pine-hardwood forest and has been reported from the vicinity of Alvin 16 km (10 mi) north of the project site. No other animals of special status are known to occur in or immediately proximate to the project area.

All of the endangered animal species are either indigenous to unaltered habitat, causing their populations to be adversely affected by man's encroachment into their environment, or do not currently exist in the area of the well site due to man's role in disruption of their niche. Therefore, no further searches of the well site for endangered species will be made because of the agricultural, residential, and industrial development at and surrounding the well site.

2.6 Land Use

The existing land use surrounding the proposed well site is classified into four main types. These four main land use types are Agricultural, Industrial, Recreational Development, and Undeveloped open space. The criteria for classification of land use types is selfexplanatory with the exception of recreational development. This land use type is characterized by numerous residential dwellings which are primarily used in conjunction with leisure time activities such as boating and fishing.

2.6.1 Existing and Projected Land Use

The existing land use in the vicinity of the well site is indicated in Figure 2-17. The predominant land use, by acreage, is agricultural with much of the land being used for rice and soybean cultivation. Those agricultural areas which are not utilized for producing croplands are currently being utilized as range and pasture.

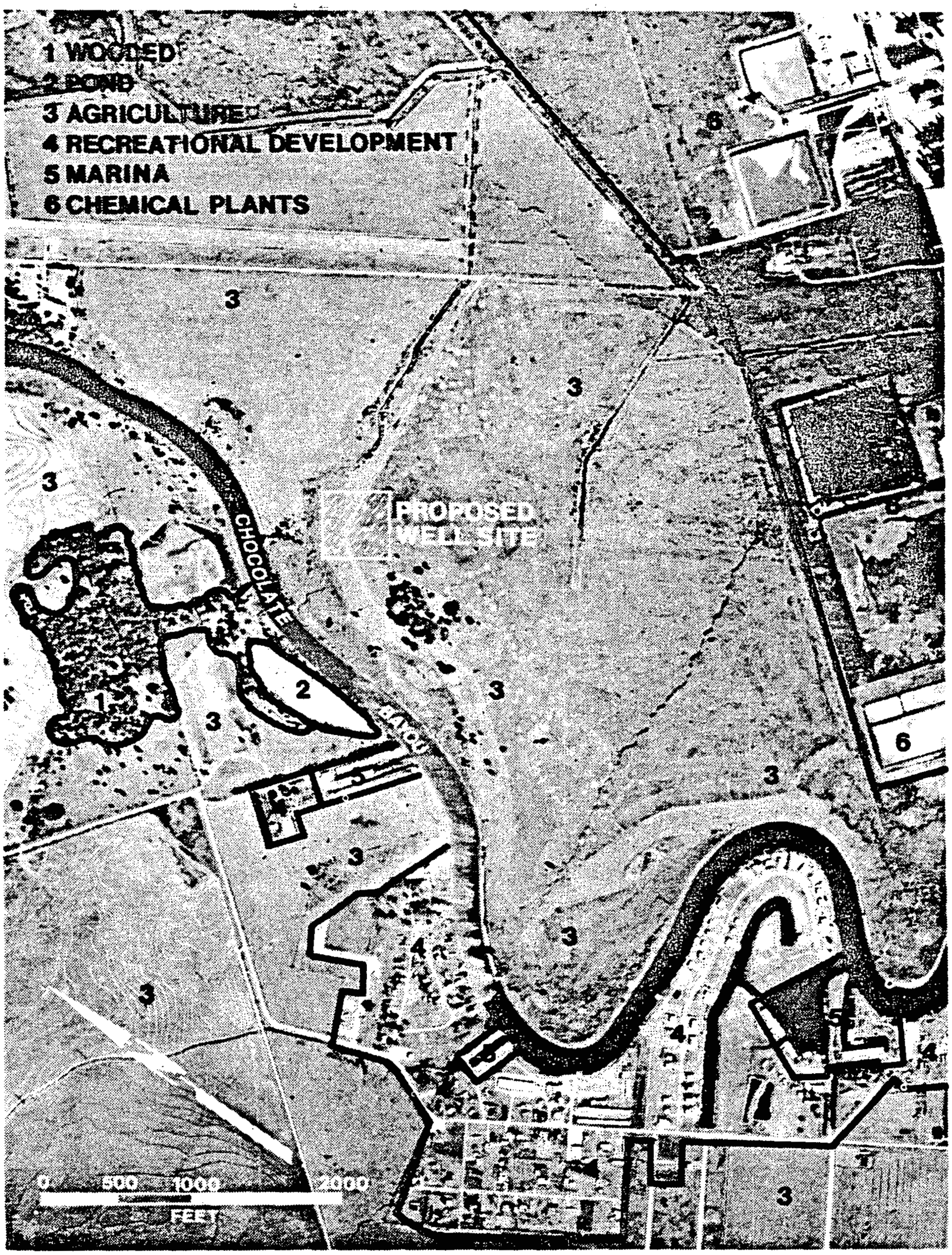

Fig. 2-17. Existing land use in the study area.

Land immediately surrounding the well site is presently being utilized as agricultural land. However, a large concentration of recreational homes [approximately 671 m (2200 ft) south-southwest; another 854 m (2800 ft) south; another 210 m (700 ft) south} and related facilities such as small boat marinas [one approximately 671 m (2200 ft) south-southwest; another 1250 m (4100 ft) south] exists on the west side of Chocolate Bayou. Water-related recreational activities appear to be a major interest adjacent to the well site (HGAC land use map for Year 2000).

An examination of projected land use in the vicinity of the well site indicates that industrial development will increase markedly [presently there is a chemical plant approximately 793 m (600 ft) east of the well site}, while agricultural land will decrease. Additionally, the proposed dredging of Chocolate Bayou to 8 km (5 mi) north of the existing Monsanto Plant will aid in future industrial expansion. This action may also impact the existing recreation in the area by increasing the amount of larger vessel traffic (Texas Parks and Recreation Department, 1975). While this change in the land use pattern will have no substantial effect on the proposed action, it does represent a change from the existing commitment of recreational related land use.

Two major pipelines pass near the well site. One is immediately west of the high power transmission line. The other is south of the well site. Both pipelines cross Chocolate Bayou in the vicinity of Peterson's Landing and the adjacent recreation community.

2.6.2 Prime and Unique Farmlands

Prime farmland is land best suited and available for producing food, feed, forage, fiber, and oilseed crops. This land may presently be classified as cropland, pastureland, rangeland, forest land, or other land. Urban builtup land and water areas larger than 4 hectares (10 surface acres) are considered unavailable for prime farmland. Prime farmland has the soil quality, growing season, and moisture supply needed to produce sustained high yields of crops economically when treated and managed, including water management, according to modern farming methods. The vehicle used to evaluate a tract of land for prime farmland is the soil mapping unit.

Unique farmland is land other than prime farmland that is used for the production of high-value food and fiber specialty crops. This land has the special combination of soil quality, location, growing season, and moisture supply needed to produce sustained high quality and/or high yields of a specific crop when treated and managed according to modern farming methods. The total acres of specialty crops presently being grown but NOT ON PRIME FARMLAND must equal or exceed 1,012 hectares (2,500 acres) in the county. Unique farmland delineations are the same as soil mapping unit boundaries; therefore, if .41 hectares (one acre) of a specialty crop is presently being grown on a soil mapping unit, the entire county acreage of that mapping unit becomes unique farmland.

Table 2-12 gives the status of soils in the vicinity of the proposed-well site. The soil distributions are shown in Figure 2-7.

Table 2-12. Prime and Unique Soils.

SOIL	PRIME	UNIQUE
Veston		
Bernard-Edna		
Edna		X
Frost		X
Aris		X
Bernard	X	
Lake Charles	X	
Ijam		

Source: Wheeler, 1977.

2.6.3 Noise

Noise is defined as any undesirable sound; for analytical purposes, it is assumed to decrease in desirability as loudness increases. Loudness (intensity) of sound is measured in decibels (dB) using a logarithmic scale of comparative intensity with respect to the threshold of human hearing. Using this scale, an increment of 1 dB corresponds to an increase of 26% in intensity. Table 2-13 gives some common sound levels.

The human ear perceives sounds of higher frequency at lower intensity than those of intermediate and low frequency; therefore, noise measurements are usually weighted to account for this by using the "A" (dBA) scale. Noise impacts on humans depand to a high degree on individual variation in acuity and personal experience as well as on intensity and frequency of the noise. Wildlife also differs greatly in their sensitivity to various frequencies and intensities.

Table 2-13. Common Sound Levels.

Typical "A"-weighted sound levels and human responses

Sound source	dBA[a]	Response criteria	Intensity (W/m^2)
Carrier deck jet operation	150		10^9
	140	Painfully loud; limited amplified speech	10^8
	130		10^7
Jet takeoff (200 ft)		Maximum vocal effort	
Unmuffled geothermal well			
	120		10^6
Discotheque			
	110		10^5
Jet takeoff (2000 ft)			
Shout (0.5 ft)			
	100		10^4
Heavy truck (50 ft)		Very annoying, hearing damage (8 hr)	
	90		10^3
Pneumatic drill (50 ft)		Annoying	
	80		10^2
Freight train (50 ft)			
Freeway traffic (50 ft)		Telephone use difficult; intrusive	
	70		10^1
Air conditioning unit (20 ft)			
	60		1
Light auto traffic (50 ft)		Quiet	
	50		10^{-1}
Living room			
Bedroom			
	40		10^{-2}
Library			
Soft whisper (15 ft)		Very quiet	
	30		10^{-3}
	20		10^{-4}
Broadcasting studio		Just audible	
	10		10^{-5}
		Threshold of hearing	
	0		10^{-6}

[a]Typical A-weighted sound levels taken with a sound level meter and expressed as decibels on the scale. The "A" scale approximates the frequency response of the human ear.

Source: *Environmental Quality – The First Annual Report of the Council on Environmental Quality,* Council on Environmental Quality, transmitted to Congress August 1970.

An unmuffled venting geothermal well may cause noise levels of 120 dBA 30m (100 ft) away. A large proportion of the sound energy (intensity) emanating from geothermal well venting is in the lower frequency range of the noise spectrum. Because of this, the A scale tends to minimize potential noise impacts on wildlife whose level of perception is generally unknown but is often broader than that of humans. Also, low-frequency, high-intensity noise may have sub-subliminal or psychological effects on humans. The A Scale weighting is nonetheless used for all standards and criteria and is the only index that can be used to assess noise impact.

Noise levels at the well site have not been monitored. However, agricultural equipment, power boats, and the nearby Monsanto Chemical plant produce a background noise level that is higher than a pristine area (30 dBA). Noise levels probably fall in the range of 45-60 dBA (See Table 2-12). Provisions have been made to monitor noise levels at the site both before and during project activities.

2.6.3.1 Noise Regulations

This assessment is concerned with community noise. The province of worker habitat and its relationship to tools and machinery is administered by the Federal Department of Labor under the Occupational Safety and Health Act (May 29, 1971). Neither the State of Texas nor Brazoria County has specific regulations regarding community noise. In the absence of local guidelines, the Environmental Protection Agency (EPA) has recommended that maximum sound levels be maintained between 78 and 82 dB or as low as practicable. Because of the danger to health, sound levels above 90 dB are prohibited. The following Department of Housing and Urban Development rating system for noise levels at residences also provides guidance.

1. Clearly unacceptable: exceeds 80 dBA for 60 min in a 24-hr period, or exceeds 75 dBA for 8 hr in a 24-hr time span.
2. Normally unacceptable: exceeds 65 dBA for 9 hr in a 24-hr time span, or loud repetitive sounds onsite.
3. Normally acceptable: exceeds 65 dBA for less than 8 hr in a 24-hr period.
4. Clearly acceptable: does not exceed 45 dBA for more than 30 min. in a 24-hr period.

2.7 Meteorology and Air Quality

The climate of the proposed well site (near Alvin in Brazoria County), located in the flat coastal plains of southeast Texas about 40 km (25 mi) from the Gulf of Mexico, is predominantly humid subtropical, influenced during much of the year by the anticyclonic circulation of the Azores-Bermuda high-pressure system. Winters are generally short and mild, with an occasional incursion of continental polar air bringing cooler temperatures and northwest winds. Summers are long, hot, and humid, with maritime tropical air masses predominating over the area. The site is principally affected by storms originating in late winter and early spring over the western Gulf of Mexico. The last occurrence of freezing temperatures in the spring is usually in early February, and the first occurrence of freezing temperatures in the fall usually is in mid-December.

Since there is no on-site meteorological measurements, the following data were taken from observations made at Houston (U.S. Dept. of Commerce, 1972 et seq) as a first approximation. Mean monthly temperatures may be expected to range from about 12°C (54°F) in January to about 28°C (83°F) in July and August. Temperatures may be expected to reach 32°C (90°F) or higher about 95 days per year, while reaching 0°C (32°F) or lower about 8 days per year. The record maximum temperature in the Houston area was 42°C (108° F) in August 1909, and the record minimum temperature was -15°C (5°F) in January 1940.

The annual average precipitation of almost 1168 mm (45.6 in) is well distributed throughout the year. The minimum monthly average precipitation of about 69 mm (2.7 in) occurs in February, while the maximum monthly average of about 109 mm (4.3 in) occurs in May, July, August, and September. The recorded maximum monthly precipitation was 5-66 mm (.2-2.6 in) in October 1949. The maximum 24 hr rainfall was 398 mm (15.5 in) in August 1945. Snowfall is negligible in the area, averaging about 10 mm (.4 in) per year. The maximum monthly and maximum 24 hr snowfall in the Houston area was 112 mm (4.4 in) in February 1960.

Relative humidity is generally high throughout the year, averaging almost 75% in Houston. Heavy fog occurs frequently and may be expected on an average of 42 days annually.

During summer months winds are expected to be predominantly from the southeast when the Azores-Bermuda high pressure system is strong, otherwise, diurnal clockwise rotation of the wind direction is expected due to the sea breeze system. Wind speed of the sea breeze is about 15 to 25 km/hr (10 to 15 mph) and occurs in most afternoons. For more detail about this coastal air-circulation system along the Texas Coast, see Hsu, 1969. Northerly winds are expected during winter season after the passage of cold fronts. Since winds are related to the atmospheric dispersion characteristics, more about winds will be discussed in a later section. If cold fronts and sea breezes are absent, winds are expected to blow out of the southeast to south most of the time yearly.

Types of severe weather expected in this area are thunderstorms, tornadoes, and hurricanes. As a result of circulation patterns that bring warm, moist, unstable air from the Gulf of Mexico in all months of the year, thunderstorms can be expected in all months. At Houston, thunderstorms can be expected on about 59 days annually, being most frequent in July with an average of 10 thunderstorm days. Two-thirds of the expected thunderstorm days occur from May-September. Thunderstorms are least frequent from October-March, with November, December, January, and March averaging two thunderstorm days.

Since the well site is located in a two-degree latitude-longitude square where the tornado information is available, tornado occurrences were examined for the two-degree square. During the period 1955-1967, 139 tornadoes were reported in this two-degree square (SELS Unit Staff, 1969), given a mean annual tornado frequency of 2.7 for a comparable one-degree square containing the site. The computed recurrence interval for a tornado at the site is about 540 years (Thom, 1963).

Hurricanes are usually weakened somewhat from moving inland before reaching the proposed well site. In the period 1871-1973, about 34 tropical storms, hurricanes, and depressions have passes within 80 km (50 mi) of the site (Thom, 1963; Cry, 1965; U.S. Dept. of Commerce, 1973). The fastest speed of wind reported for the Houston area was 135 km (34 mph) in March 1926.

In the period 1936-1970, there were about eight atmospheric stagnation cases totalling about 25 days (Korshover, 1971). The highest monthly frequency of these cases is in October.

Major characteristics involving air pollutant dispersion are atmospheric stability classes and inversion potentials. Stability classes and their associated wind speeds have been measured from August 1972 through July 1973 by the Houston Lighting & Power Co. (1974) and listed as follows:

Stability Classes	Percent Frequency	Average Wind Speed (M/S)
A	2.49	4.25
B	3.15	4.71
C	7.20	4.25
D	34.95	4.38
E	29.13	3.17
F	14.14	1.80
G	8.94	1.64

Note that the site for the Allens Creek Nuclear Generating Station is located in southern Austin County, Texas, immediately west of the center of Houston. Note also that stability class A represents extremely unstable conditions, B unstable, C slightly unstable, D neutral, E slightly stable, F moderately stable, and G extremely stable (Slade, 1968).

Inversion frequency in the area of the well site is expected about 25% for annual average. It ranges about 20% in Spring and Summer and 35% in Fall and Winter (Hosler, 1961).

Isopleths of total number of forecast-days of high meteorological potential for air pollution in a five-year period is shown in Figure 2-18. It can be seen that in our study area the forecast-days of high pollution potential are about 1-2 days. For the state of Texas and two stations near the proposed well site area, i.e. Alvin and Clute, some air quality data are available. These are shown in Table 2-14 and Figure 2-19 which were supplied by the Bureau of Economic Geology of The University of Texas at Austin. It can be seen that some improvement of air quality has been made since 1974. Except ozone and non-methane hydrocarbons, other pollutants are below ambient standards. Air quality due to equipment operation and release of geothermal gases will be discussed in Impact sections.

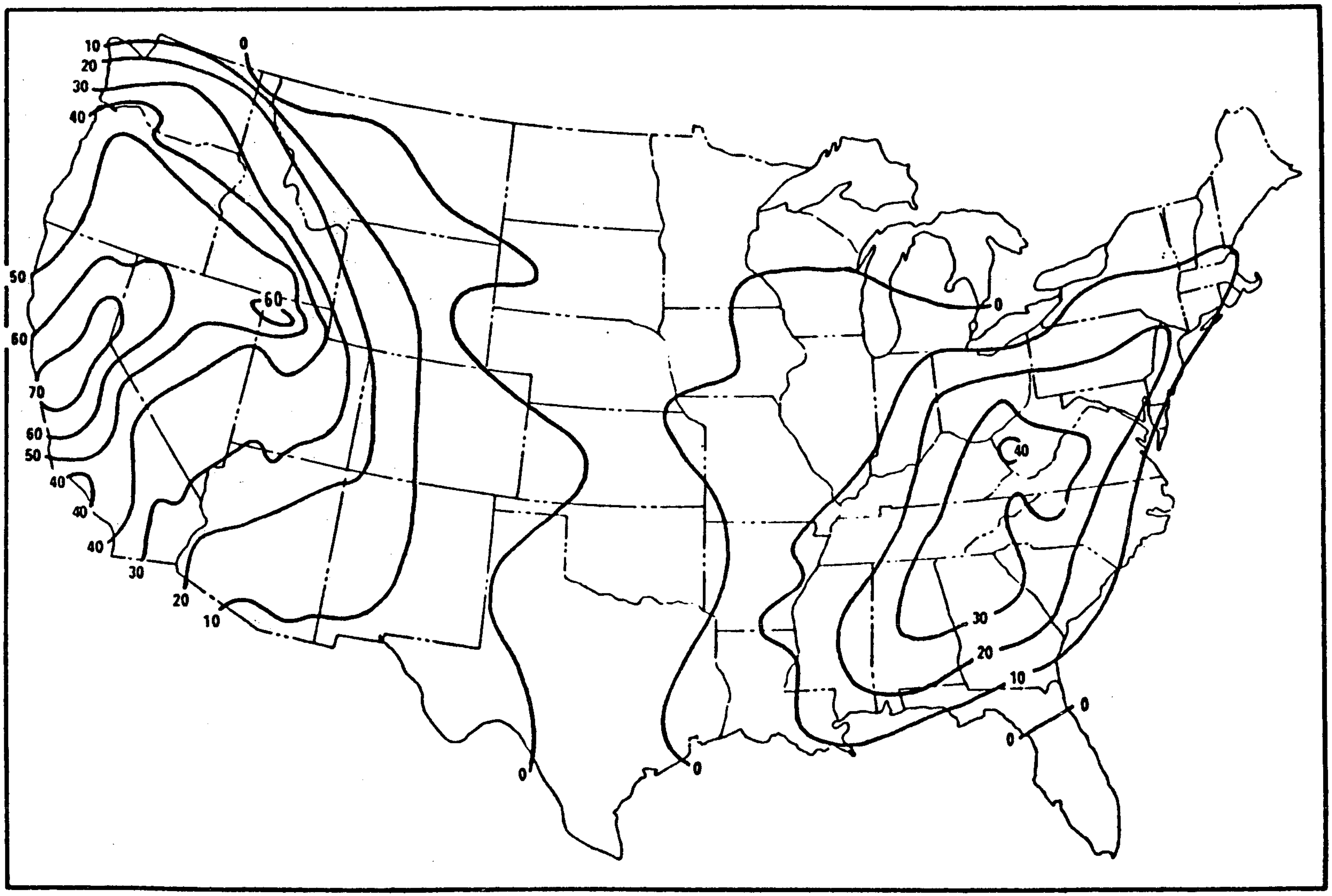

Fig. 2-18. Isopleths of total number of forecast-days of high meteorological potential for air pollution in a five year period (After G. C. Holzworth, 1972).

Table 2-14. Comparison Summary of Area Data with Ambient Standards.

Air Quality Control Region Number	Station Location	Ozone - Second Highest Hour	Ozone - Percent of Time > 0.08 ppm	Carbon Monoxide 2nd Highest Hour	Carbon Monoxide 2nd Highest 8 Hrs.	Nonmethane Hydro-carbons 6-9 AM High	Sulfur Dioxide 2nd Highest 24 Hrs.	Sulfur Dioxide Annual Mean	Sulfur Dioxide 2nd Highest 3 Hrs.	Nitrogen Dioxide Annual Mean
	Maximum Allowable By Ambient Air Standards (parts per million)	0.080	0.0 %	35	9	0.24	0.14	0.03	0.50	0.05
3	Austin, North	0.138	2.1	9.8	4.1	1.3	0.02	0.00	0.16	0.01
	Downtown[1]	0.062	0.0	8.4	4.7	4.9	-	-	-	-
	Waco[2]	0.079	0.1	-	-	-	-	-	-	-
5	Corpus Christi	0.139	2.8	8.8	5.1	3.1	0.00	0.00	0.12	0.01
6	Odessa	0.139	2.1	8.1	3.7	3.6	0.00	0.00	0.01	0.01
7	Houston, East	0.267	4.2	8.6	6.7	3.4	0.00	0.00	0.07	0.02
	Harris County (Aldine)	0.255	7.7	7.9	6.2	3.9	0.00	0.00	0.00	0.02
	Texas City	0.203	5.1	5.5	2.6	3.8	0.00	0.00	0.21	0.01
	Clute	0.186	4.0	5.2	2.3	4.5	0.00	0.00	0.03	0.01
8	Dallas, North	0.164	5.8	6.0	3.2	1.6	0.00	0.00	0.01	0.02
	Fort Worth, Northwest	0.180	5.3	7.0	2.6	3.8	0.00	0.00	0.00	0.01
	Fort Worth, Downtown[3]	0.146	3.1	8.4	5.2	2.6	-	-	-	0.02
9	San Antonio, Northwest[4]	0.177	2.0	17.3	6.2	2.4	0.00	0.00	0.00	0.02
10	Nederland	0.192	5.5	5.1	2.0	5.5	0.00	0.00	0.03	0.01
	West Orange	0.170	5.5	6.4	4.3	3.8	0.00	0.00	0.01	0.01
11	El Paso, Downtown	0.140	0.7	17.5	12.2	6.8	0.00	0.00	0.19	0.02
	El Paso, East	0.157	2.9	19.0	11.1	7.1	0.00	0.00	0.12	0.01

Notes: 1 Operation began 11/08/76
2 Operation began 10/22/76
3 Operation began 7/30/76
4 Sulfur Instrument Removed after 4/26/76

Source: Holzworth, 1972.

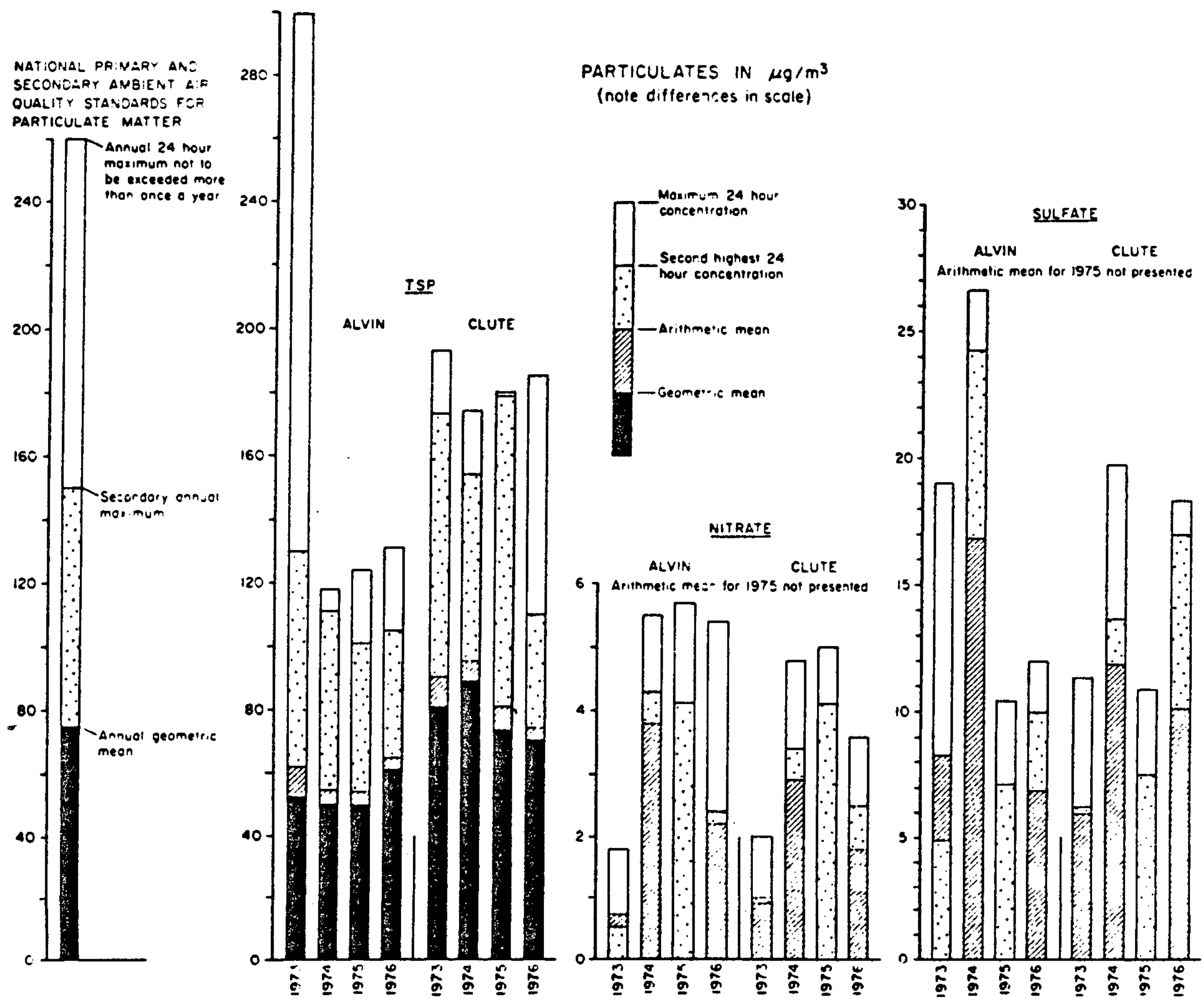

Fig. 2-19. Particulates in µg/m^3 (After The University of Texas at Austin, 1977).

2.8 Recreational, Archaeological, and Historic Sites.

Recreational opportunities in the Chocolate Bayou area are considered a resource. The area offers a significant amount of opportunities for outdoor and water oriented recreational activities.

2.8.1 Recreational Sites

The area of Chocolate Bayou including Chocolate Bay and more or less flanking the bayou's banks on both sides to a point about 3 km (2 mi) south of Liverpool has been nominated by Texas Parks and Wildlife Department (1975) as one of the areas of particular concern of the upper Texas Coastal Region. It is considered to be an area of substantial recreational value and opportunity, and as an area of high natural productivity or essential habitat for living resources including fish and wildlife.

On the west bank of Chocolate Bayou and approximately 1 km (3281 ft) from the site there is a recreational community. In Figure 2-20 the recreational features such as launching facilities and boat sheds can be appreciated. The nearest State Park is on Galveston Island, southwest of Chocolate Bay.

2.8.2 Archaeological Sites

The well site was surveyed for archaeological artifacts and any evidence of prehistorical significance. The survey was conducted on December 19, 1977, under the direction of Dr. Edward T. Baxter of the Texas A&M Research Foundation, College Station, Texas. No evidence at all of human habitation was found within the area of the well site.

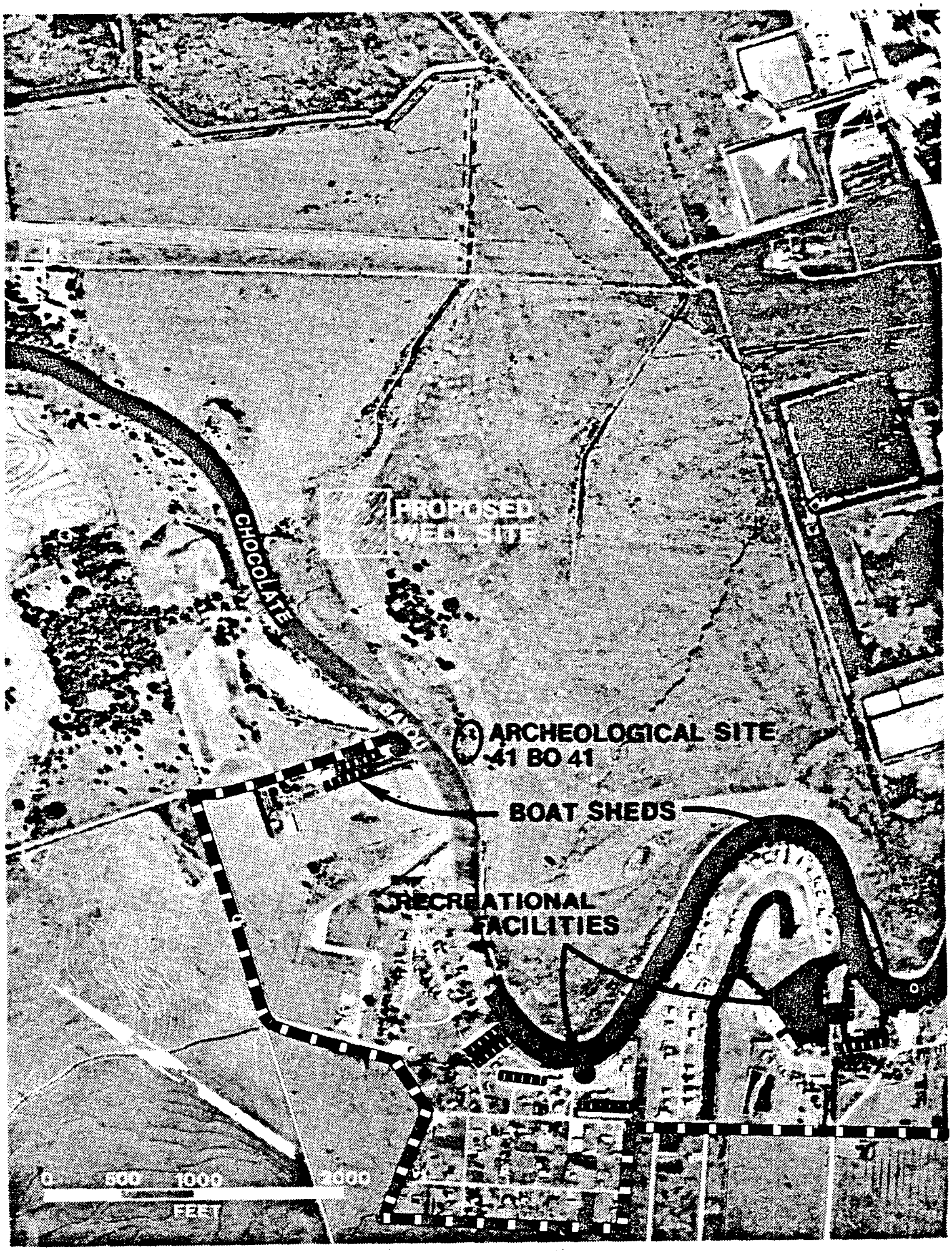

Fig. 2-20. Recreational community west of Chocolate Bayou and archaeological site 41 BO 41.

Further archaeological studies of the project area were conducted separately. One site of archaeological signifiacnce approximately 350 m (1150 ft) southwest of the proposed well site was located. The archaeological site covers 2 hectares (5 acres). A records check of the area revealed three archaeological sites located near the proposed well site: 41 BO 40, 21, and 43. 41 BO 40 was off the well site as it was on the south bank of Pleasant Bayou. Records showed that 41 BO 41 was located on the east side of Chocolate Bayou across from Peterson's Landing. The third site was on the east bank of Chocolate Bayou, south of Pleasant Bayou and north of 41 BO 41.

The Beaumont Terrace overlooks the floodplain. The area around the bayou was overgrown by trees and mixed herbaceous growth (see section on vegetation). The rest of the area was in a plowed field but it also was overgrown. Surface examination was possible only around part of the bankline and along cow paths. These cow paths were located on the highest land that would lead to the bayou. The rest of the area was so heavily overgrown that surface examination was impossible. No new sites were found in the project area but there was no subsurface testing.

A shell midden was located in the Beaumont Terrace area (Figure 2-20) along a cow path. The midden appeared to be 10-14 cm (4-6 in) in depth. The extent of the site could not be determined due to ground cover, but it extended at least 30 m (98 ft) N-S by 10 m (33 ft) E-W. Material was eroding out of the bank onto the floodplain. At this Rangia and Crassostrea shell midden two potsherds (Goose-neck Plain), one core, one flake, a piece of burnt clay, and a piece of unidentified bone were recovered. A Corps of Engineers survey benchmark, "Station CB 16," was located on the south end of the site.

After talking to local inhabitants, it became clear that the U.S.G.S. had mis-located Peterson's Landing. The correct location is directly across the bayou from the archaeological site located during the survey. It appears that the archaeological site located during the survey was 41 BO 41. It was reported to The University of Texas by Mike O'Brien in 1972. He reports the site is approximately 20 cm (8 in) deep and 25 m (81 ft) by 10 m (32 ft) in area. He found bone, sherds, and points at the site when he excavated the site in 1977. Further questioning of local informants revealed that someone had dug at the site several years ago. The site information and location agrees with the description given by O'Brien.

The boundaries of this archaeological site (i.e., a shell midden) were staked clearly in order that all personnel could see them and avoid disturbing the area.

2.8.3 Historical Sites

There are no National Register Sites on the proposed well site or in the vicinity.

2.9 Demography and Socio-economics

The 1975 population of Brazoria County was 133,000 persons; the population has grown 21% since 1970 (1970 population was 108,312). Reference forecast population for the year 1980 is 156,500 persons. The rate of growth forecast for 1970 to 1980 is 36%. For the year 2000, population is expected to reach 269,600 persons.

The two areas within the county more likely for continued rapid growth and development are the Brazos port area and the northern part of the county which is already experiencing rapid growth in both population and employment resulting from spillover from Harris County.

The population of the county is young with 53.9% being 25 years and younger.

Manufacturing and services are the biggest employers in the industrial sector, followed by wholesale and retail trade and construction (Table 2-14).

Industrial development associated with the imminent construction of a deep water port is very likely to occur. Several oil companies have expressed their interest in locating refinery plants in the Brazos port area. However, a radical increase in total employment from this industrial development is not expected, unless "a significant petrochemical manufacturing industry was to develop" (Bureau of Business Research, 1974). Table 2-15 shows employment for the year 1975 and forecasts to the year 2000 by sector (Bureau of Business Research, 1974).

The county offers housing ranging from houses for sale through renting them. There are apartments, trailer courts, hotels, and motels. All of these opportunities for housing are also found in the City of Alvin only 19 km (12 mi) away from the project area. Water supplies and sewage treatment facilities are also available in the area.

Table 2-15. Brazoria County Employment Forecasts By Sector, 1975-2000.

Sector	1975	1980	1985	1990	1995	2000
Agriculture, Forestry, and Fisheries	1,053	980	947	914	869	823
Mining	1,105	1,236	1,205	1,175	1,145	1,116
Construction	5,531	5,760	5,969	6,179	6,797	7,415
Manufacturing	11,962	12,159	13,435	14,712	16,330	17,949
Transportation, Communication, and Utilities	3,386	4,551	5,341	6,131	6,621	7,112
Wholesale and Retail Trade	8,262	9,817	10,896	11,976	13,413	14,851
Finance, Insurance, and Real Estate	1,260	1,433	1,598	1,764	1,764	1,764
Services	11,008	13,207	15,056	16,905	19,356	21,807
Public Administration	1,772	2,077	2,357	2,638	3,033	3,429
Total	45,339	51,220	56,804	62,394	69,328	76,266

Source: Bureau of Business Research, 1974.

CHAPTER THREE - POTENTIAL ENVIRONMENTAL IMPACTS

This chapter evaluates the environmental impacts that could occur from the drilling and testing of the GCO-DOE Pleasant Bayou No. 1 well. The impacts that will occur specifically as a result of drilling and maintenance will be considered first, followed by those impacts that will occur specifically as a result of flow-testing or operation of the well.

3.1 Impacts Due to Drilling and Maintenance

The specific procedures involved in drilling and maintenance are described in Chapter One. The impacts that could occur from these procedures are given below.

3.1.1 Geological Impacts of Drilling and Maintenance

In the GCO-DOE Pleasant Bayou No. 1 well, the log of which is interpolated between two nearby wells for which logs and data are available (Figure 3-1), a 1,406,200 kgs/m^2 (2,000 psi) drop in reservoir pressure is expected; the vertical interval to be perforated is from 4270-5033 m (14,000-16,500 ft), in which 14 sandstone aquifers are expected to be firmly-cemented sandstones with porosities ranging from 5 to 25%, and the reservoirs are deeply buried. Furthermore, they are geopressured, and the uppermost aquifer is some 1220 m (4,000 ft) below the top of the geopressure zone. During the drilling of this well, it is probable that no geological impacts will occur.

3.1.2 Impacts to Physiography of Drilling and Maintenance

Since no subsidence will result from the drilling, there will be no basic change in physiography as a result of it.

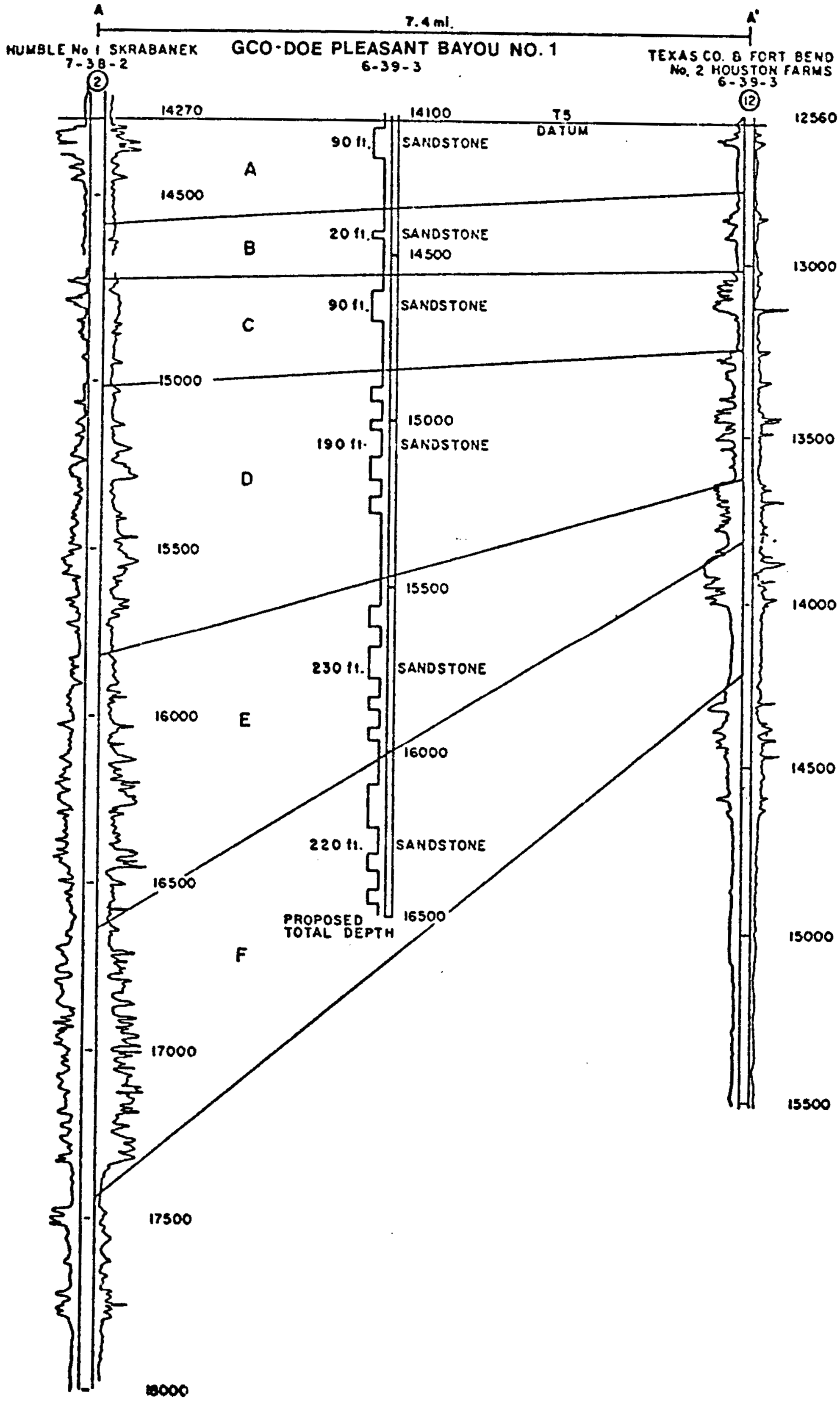

Fig. 3-1. Interpolated log and predicted test well data, GCO-DOE Pleasant Bayou No. 1, Brazoria County, Texas. Well locations for A and A' are shown on Figure 2-10 (After Bebout, Loucks, and Gregory, 1977).

3.1.3 Impacts to Soils from Drilling and Maintenance

The well site will not remove any prime or unique soils of the study area from productivity. There will be some erosion caused by the road construction and drill pad facilities. This can be mitigated by seeding the base areas as soon as possible and returning them to the natural state once the facilities are removed.

3.1.4 Impacts to Groundwater of Drilling and Maintenance

The current facility design does not call for the use of the fresh water aquifers at the site. Thus, the resources of the Chicot and Evangeline aquifers should not be intentionally disturbed. Furthermore, because the well site is more than 4.8 km (3 mi.) from the nearest oil and gas field and associated brine disposal wells, these operations should not be disturbed by either the well or waste water disposal wells planned. However, the three waste disposal wells at the Monsanto plant are completed in the basal sands of the proposed disposal interval for the geothermal waste water. This should not present problems for geothermal waste water disposal as many suitable shallower, saline sands are expected to occur beneath the well site which can receive injected brine without interfering with the ongoing waste injection operations at Monsanto. A potential adverse impact could occur if these waste disposal reservoirs are penetrated during drilling of the test well or brine disposal wells and significant amounts of the contained toxic fluid enter the drilling fluid. The drilling mud and the surface pits would be contaminated and would require special clean-up measures. If these waste disposal sands extend to the test well area, their pressures are likely to be equivalent to that of other undisturbed (unused) aquifers, despite the volume of waste they contain. Thus it is unlikely these aquifers will present any special problems to the drilling contractor in safely completing the new wells.

3.1.5 Impacts to Surface Water of Drilling and Maintenance

Land clearing, levelling, road and drill pad construction, and possibly construction of reserve ponds and flood walls will increase erosion and runoff rates, increasing turbidity of the surface water. Runoff from construction and operation will contain lubricants from vehicles and equipment and chemicals from the drilling muds. Drainage patterms may be altered by road, pond, and levee construction.

Because of the actual site of the project and its elevation, flood threat is a danger. Flooding of the site could wash toxic materials and pollutants from the well site and storage pits.

3.1.6 Impacts to Terrestrial and Aquatic Flora and Fauna of Drilling and Maintenance

Installation and maintenance of the proposed well site will involve habitat loss of up to 0.4 ha/km (1.7 acre/mi) for roads and 1000 m^2 (1/4 acre) for drill pads with an additional 1.6 ha (4 acres) temporarily committed for equipment, sumps, and laydown areas during installation. Improvement and use of existing unimproved roads can reduce the habitat loss due to road construction. Vegetation and wildlife presently existing on those areas to be used for roads and drill sites will be lost or displaced.

Additional vegetative impacts will include decreased growth of terrestrial plants due to dust accumulation on leaves during dry periods and slightly lower aquatic production due to increased surface water turbidity from erosion. Production in both terrestrial and aquatic vegetation will be adversely affected by runoff of vehicle and equipment lubricants and chemicals from drilling muds. Similar effects can be expected in fish and wildlife production. These impacts should, however, be local and insignificant, especially if precautions to retard dust, erosion, and spillage are maintained.

Drilling mud, discharged at the surface and held in an impervious sump, will contain toxic chemicals and pollutants but should present only a localized impact to the storage areas.

3.1.7 Impacts to Land Use due to Drilling and Maintenance

Direct impacts on existing land use will be limited to the east side of Chocolate Bayou. The initial impacts will be the removal of crop and pasture land not designated as prime or unique farmland from production for the development of drill sites. This initial action will remove an estimated 0.4 ha (1.7 acre) for each kilometer (0.6 mi) of access road built and 1000 m^2 (0.25 acre) for each drilling part. In addition to the primary areas of drilling, ancillary areas adjacent to each well will remove, during well drilling, an additional 1.6 ha (4 acres) per drill site. These areas will be returned to natural (pre-project) conditions upon the completion of each well.

The extent of impact on the land use should be limited, excluding the possibility of well blowouts, to removal of drill site lands and roadways for the duration of testing, and the removal of ancillary areas during well drilling. Pipelines to the injection wells will be laid next to the access roads to minimize land use changes and environmental impacts.

In addition to removal of agricultural land from production, the noise generated during both drilling and testing phases may affect developed areas on the western side of Chocolate Bayou. While the noise factor will, in all probability, have no adverse impacts to agricultural land use, it may provide an adverse impact on the recreational and residential land uses along the western side of Chocolate Bayou if mitigation measures (e.g. muffling engines) are not taken.

During the three-year study period, noise will be produced by the drilling and testing of the new well and the drilling of the injection wells. The major source of noise is the operation of heavy equipment which produces sound levels in the range of 70 to 100 dBA at a distance of 15 m (50 ft) from the source. Measurements of noise during well drilling include levels of 90 dBA at 15 m (50 ft) and 68 to 71 dBA at 30 m (100 ft). At various stages during drilling and following completion of drilling, the wells are allowed to flow through flasher/separator to the atmosphere and reserve pit. Noise levels may reach 80 dBA at 15 m (50 ft) from an unmuffled steam vent.

The nearest houses are on the west bank of Chocolate Bayou, approximately 305 m (1000 ft) from the well site. Most of the recreation community along Chocolate Bayou is more than 1 km (3281 ft) from the well site. At these distances, noise levels from drilling activities will be reduced to a level of 66 dBA and 54 dBA, respectively, by normal attenuation calculations. For well venting, the noise levels at 305 m (1000 ft) will be 56 dBA and 44 dBA at 1 km (3281 ft). These estimates do not include effects of intervening objects or atmospheric conditions, but the low vegetation and even topography of the area will add little to noise attenuation. Drilling will continue 24 hours a day for a period of from three weeks to two months per well. Well venting will occur at irregular intervals for periods of several hours.

While these noise levels are routinely accepted by residents of cities, they may be obtrusive in the rural environment of this project. The very low frequency noise produced by well testing is particularly obtrusive because it is unusual and is not greatly diminished by shutting doors and windows. These noise levels approximate the noise criteria established by the U.S. Department of Interior and HUD, and are under EPA guidelines (Table 3-1). The noise levels from the well test project will be reduced to an acceptable level as necessary by instituting mitigating techniques such as mufflers or other sound proofing devices.

Table 3-1. Noise Criteria Not to be Exceeded for Geothermal-Related Activities (U.S. Department of the Interior, 1973)

Land Use	Daytime	Evening	Night
Residential (Rural)	45 dBA	40 dBA	30 dBA
Agricultural	70 dBA	65 dBA	55 dBA
Recreational	45 dBA	40 dBA	30 dBA
Uninhabited or Rangelands	70 dBA	65 dBA	60 dBA

3.1.8 Socio-Economic Impacts of Drilling and Maintenance

The project will require a work force of about 30 to 50 persons at any one time at the proposed well site. The majority of workers and personnel involved is expected to be from within Brazoria County, or neighboring counties. They will probably commute to the well site from surrounding communities during construction and testing operations.

Because of the short duration of the construction phase of the work, approximately 6 weeks, and its small size, 2 ha (5 acres), few economic impacts in the local communities are expected. The impact on public services will be relatively small or nil during the testing period since no large migration of workers or technicians is expected into the area as a result of the proposed geothermal well testing. There are temporary housing facilities as well as houses for sale or rent available in the town of Alvin located about 19 km (12 mi) north of the well site. Liverpool, a smaller town about 6.7 km (4.2 mi) to the northwest of the site, also offers temporary housing facilities.

From the previous discussion, it can be concluded that the economic effects of the proposed action will not be significant in the area's economy.

3.1.9 Impacts to Air Quality Caused by Drilling and Maintenance

Since there are only very limited studies (ERDA, 1977) relating to the impacts on air quality due to geothermal exploration and production, the following sections are given only as a first approximation.

Construction-related impacts on air quality will result from dust, exhaust emissions from construction machinery, and noncondensable gases released from geothermal fluids during preconstruction flow-testing. Since the land will be disturbed in connection with construction of additional drill pads, access roads, pipelines, and other related activities, dust will be inevitably generated. Because the concentration of total suspended particulate in air is already high as given in Section 2-7, construction areas will be graveled or sprinkled to control dust.

Exhaust emissions from drilling and construction machinery will include SO_2, NO_X, CO, hydrocarbons, and particulates. Diesel drives for the drilling rigs typically consume 2000 liters/day (550 gal/day) of fuel, resulting in emissions of approximately 23 Kg/day of CO, 9 Kg/day of exhaust hydrocarbons, 107 Kg/day of NO_X, 7 Kg/day of SO_X, and 7.5 Kg/day of particulates (ERDA, 1977a). The emissions associated with the operation of diesel-powered equipment for 5 days to prepare a well pad would be equivalent to those associated with a single day of drilling. A small amount of polluting emissions will also result from the operation of delivery trucks and private vehicles. These releases are expected to be minor, short-term, and should be readily dispersed because about 64% of the time the atmospheric stability classes are in D and E (cf. preceding sections on atmospheric dispersion characteristics). The accumulated level of impacts due to exhaust emission from drilling and construction machinery is negligible.

Noncondensable geothermal gases will be released during drilling (ERDA, 1977a). Although the weight of the drilling mud should prevent a large release of gases to the surface during drilling, the mud will carry some gases to the surface. These gases will be released to the atmosphere from the water/steam separator at the well, from the drilling-mud cooling tower, and from the liquid sump. Maintenance of sufficient pressure within the well to protect against blowouts should result in acceptably low levels of gases emissions during drilling. Impact on air quality due to blowout will be discussed later.

3.1.10 Potential Impacts to Recreational and Archaeological Sites from Drilling and Maintenance

There are recreational sites on the west bank of Chocolate Bayou. These sites will be impacted by the noise of drilling and maintenance. See Section 3.1.7 for specific measurements. Although no indication of human habitation exists on the proposed well site, there is an archaeological site, 41 BO 41, located nearby [350 m (1150 ft) southwest]. Precautions will be taken to avoid disturbing this site. If the site is disturbed, the state historic and preservation office will be contacted. Road construction, borrow disposal, drilling mud disposal, pipeline construction, and other activities will be undertaken so as to avoid this known site. If during site preparation, well drilling, or flow testing any artifacts are found by personnel, these finds will be reported to the Texas State Historical and Preservation Office.

3.2 Impacts Caused by Flow-Testing or Operation of the Well

Specific descriptions of the flow-testing procedures are given in Chapter One. The impacts likely to occur from the normal operation of the well are listed below.

3.2.1 Impacts to Geology from Flow-Testing

The geological impacts that create the most concern in geopressure well operation are subsidence and fault activation. Neither is considered likely in the proposed action. Activation of movement along existing faults in the Brazoria County Prime Prospect Area is not considered likely for the following reasons:

1. Rock properties (described in preceding section) that make subsidence unlikely under test conditions also mitigate against bed thickness reductions that would induce movement on faults.
2. The test well is located 1.6 km (1 mi) or more from any known fault trend.

3. The withdrawal rate is moderate, the discharge will be intermittent, and the total volume of fluid to be produced is not large, compared to volumes produced from thousands of reservoirs in the geopressure zone of the Gulf Coastal Plain, over periods of many years, without fault activation.

Proposed rates and volumes of withdrawal from the GCO-DOE Pleasant Bayou No. 1 well will be relatively small, and flow will be intermittent (Bebout, Loucks, and Gregory, 1977). Land subsidence, regional or local, over and above that which is already taking place will not occur as a consequence.

In a comprehensive analysis of land subsidence above compacting oil and gas reservoirs, Geertsma (1973) concludes that..."some or all of the following conditions are fulfilled when considerable subsidence is observed...":

1. A significant reduction in reservoir pressure takes place during the production period,
2. Production is effected from a large vertical interval,
3. Oil or gas, or both are contained in loose or weakly cemented rock, and
4. The reservoirs have a rather small depth of burial.

3.2.2 Impacts to Groundwater caused by Flow-Testing

The potential impacts to groundwater that will be caused by flow testing are covered in Section 3.3.2 below. Should an accident occur, the well will be immediately shut down until the problem is solved.

3.2.3 Impacts to Surface Water Caused by Flow-Testing

Impacts to surface water from routine operation of the test well result from disposal of the fluid brought to the surface, and from possible environmental changes such as land surface subsidence or seismic activity. Thermal and chemical pollution could alter surface water quality. Elevation changes could alter surface flow patterns, disrupting existing environmental systems dependent upon established water regimes. However, since no disposal will be allowed in surface water, and no subsidence is predicted, the impacts to surface water should be restricted to runoff from the drilling operation and the associated machinery.

3.2.4 Impacts to Terrestrial and Aquatic Flora and Fauna Caused by Flow-Testing

Geothermal effluents are extremely hot, moderately saline to brine, and may contain concentrations of toxic elements. If released into the environment, any one of these properties could cause adverse biological impacts. However, proper containment, insulation, and disposal (reinjection into saline aquifers) of geothermal products during normal operation should assure a minimal effect on the plant and animal life. Noise, another product of geothermal wells, should have no effect on the plants (numerous high school science projects to the contrary) and cause only temporary movement of animals away from the well site.

3.2.5 Impacts to Air Quality Caused by Flow-Testing

Well-testing will result in the direct release of steam and a variety of other gases and particulates for approximately 70 days (ERDA, 1977). The contaminant of greatest concern is hydrogen sulfide. Other gases that may be emitted are CO, NO_X, NH_3, CH_4, N_2, and H_2, based on typical noncondensable gas content for pressure fluids. Particulates released with the geothermal fluids or raised by equipment should not add significantly to the high background level of particulates in the proposed well site area. The local dust problem should be controlled by spraying as suggested previously. The short duration of these emissions makes it unlikely that the air quality will be significantly affected outside of the immediate area of the well.

The impact of flaring the gases from a single plume is expected to be small based on the experiences from similar geothermal well tests (ERDA, 1977). This particular project is miniscule when compared to the many flares which exist in major refineries such as Exxon in Baton Rouge where the air quality is still within standards (Hsu, 1978).

The impact of the cooling tower is expected to be negligible because of the small size required for the single well operation. The possible impact would be the increased occurrence of fog or the formation of steam fog during freezing temperatures in winter, but the frequency is small.

3.3 Accidents

Accidents which could occur during drilling and maintenance or during flow-testing include well blow-out, surface or subsurface spills due to scaling and clogging or loss of control of a well during drilling, and accidental discharge of effluents into the atmosphere. The impacts of these accidents on the surrounding environment are evaluated below.

3.3.1 Potential Impacts of Accidents on Geology

In the event of a blowout of the worst possible order, cratering could modify the land surface elevation considerably. In time this will lead to modification of the surface water patterns and plant and animal communities.

3.3.2 Potential Impacts of Accidents on Groundwater

Subsurface leaks of brine from the geothermal or injection wells, although unlikely, would cause contamination of groundwater resources if the leaks occurred in the fresh water zones within 335 m (1100 ft) of the surface. The impact would be limited because (1) local groundwater development is limited to a few shallow wells, (2) the lost brine would tend to move to the bottom of the aquifer due to its greater density and would be diluted by diffusion and dispersion as it moves through the aquifer, and (3) brine leaks would probably be limited to test periods. Brine losses could result from leaks in casings of the geothermal well and/or brine disposal wells, brine leaks through abandoned well casings connecting disposal reservoirs with fresh ground-water aquifers, and leaks of brine from the disposal aquifer due to aquifer fracture during brine injection.

Proper well construction will assure that potential brine leaks due to well casing failures will be minimal. The casing program for the geothermal well calls for 335 m (1100 ft) of casing to be cemented to the surface to protect the freshwater zone. This satisfies state requirements and should isolate freshwater aquifers from potential well failures during deeper drilling and during well operation. Similar casing programs for the brine disposal wells should likewise provide adequate protection of fresh groundwater resources at these well sites. An adequate well casing program and well monitoring program is required to assure brine is not injected into the freshwater zone without detection.

A maximum of four disposal wells will be constructed to inject geothermal waste daily into sands between approximately 610 and 2130 m (2000 to 7000 ft) deep during flow tests of the geothermal well. A potential adverse impact would result if injection pressures were to reach aquifer fracture levels. Brine could then migrate vertically into shallower, possible fresher groundwater.

This possibility will be avoided if injection pressures are maintained below fracture pressure (about 75% of overburden weight) and if the injection zone is sufficiently deep to separate it from the fresh groundwater by several hundred feet of sand and clay.

Surface spills of brine could occur during a failure of surface pipelines and pits or as a result of loss of control of a well during drilling or completion. The impact on groundwater resources at the site would be minimal because the freshwater aquifers are separated from the surface by the only slightly permeable soils of the Beaumont clay, because the proximity of Chocolate Bayou and the local site relief would assure the majority of the effluent would run off the site, and because ground water development at the site is limited to a few small wells west of the bayou. The impact of a brine spill would probably not be significantly different from the impact of natural flooding at the site.

3.3.3 Potential Impacts of Accidents to Surface Water

Accidental discharge of geothermal fluids to the surface poses the greatest environmental impact to surface water. High temperatures and pressures of the geothermal geopressured resource increase the possibility of accidents. Blowouts, thermal well-head and casing cracks, scaling and clogging of injection wells, leaks, spills, and human error all could result in discharge of geothermal fluids to the surface where they could be introduced into surface waters by natural drainage, seepage, or flooding.

Dorfman and Deller (1976) list the following possible impacts from surface disposal, whether routine or accidental:

1) contamination of shallow groundwater aquifers, recharge areas, and soils from leaks or flooding;
2) destruction of non-salt-tolerant vegetation adjacent to water courses;

3) interruption of animal migration patterns by hot saline courses;
4) disruption of food chain and ecological balance in bays and estuaries where discharge is allowed;
5) possible air pollution from release of toxic gases in the brines; and
6) thermal pollution.

Produced geothermal fluids range in temperature from 150°C to 260°C (Dorfman, 1976). Temperature distributions are entirely dependent on formation structure, making accurate prediction impossible (Jones, 1975). The highest recorded temperature in the Gulf Coast region is 273°C at a depth of 5859 m (Dorfman, 1976).

Chemical composition of the produced fluids varies from formation to formation. Because of the ability of certain plants and animals to concentrate these elements, total water quality analyses of the produced waters are needed to determine concentrations of the constituents and to detect what parameters are present. Sabadell and Axtmann (1975) report a high probability of environmental pollution by trace metals from geothermal sources.

Table 3-2 lists tolerance levels suggested by EPA (1976) for selected constituents. Comparing this information with the information on chemical constituents in geothermal fluids in the Gulf Coast region (Table 3-3), selected constituents are evaluated in terms of range of relative hazard with respect to water supply (Table 3-4). When more information is available, similar evaluation can be performed for heavy metals and other possibly hazardous constituents of the produced fluids. The range of relative hazard is calculated by dividing the observed minimum and maximum concentrations by the appropriate limit (Schieler, 1976). This gives a number which indicates how much, if any, a given concentration exceeds the maximum allowable concentrations.

Table 3-2. EPA Suggested Water Quality Criteria (After EPA, 1976)

Constituent	Domestic	Aquatic
Alkalinity ($CaCO_3$)	20 mg/l	
Ammonia	0.02 mg/l	
As	50 ug/l	
Ba	1 mg/l	
Be	1100 ug/l	
B	750 ug/l	
Cd	10 ug/l	
Chlorides	250 mg/l	
Cr	50 ug/l	100 ug/l
Cu	1 mg/l	0.1 96-hr. LC_{50}*
Cn	5 ug/l	
total dissolved gasses	110% saturation value	
Fe	0.3 mg/l	1 mg/l
Pb	50 ug/l	100 ug/l
Mn	50 ug/l	100 ug/l
Hg	2 ug/l	0.1 ug/l
Ni	0.01 96-hr. LC_{50}	
N	10 mg/l	
Phenol	1 ug/l	
P	0.01 ug/l	
Se	10 ug/l	0.01 96-hr.LC_{50}
Ag	50 ug/l	0.01 96-hr.LC_{50}
Sulfates	250 mg/l	
TDS	500 mg/l	
Turbidity	limit 10% reduction in photosynthetic activity point	
H_2S	2 ug/l	
Temperature	a) increase in weekly average no greater than 1 C (1.8 F) b) daily cycle not altered in amplitude or frequency, summer maximum not exceeded	
Zn	5000 ug/l	0.01 96-hr. LC_{50}

*LC_{50} - the concentration of a toxicant which is lethal (fatal) to 50% of the organisms tested in a specified time.

Table 3-3. Chemical Composition (mg/l) of Formation Waters from Wells in the Chocolate Bayou Oil and Gas Field, Brazoria County

Well Number	Kitchen #1	Cozby #2	Gardner #1
Perforation Interval (m)	2,648-51	3,324-64	3,588-92
Measured Temperature °C (°F)	100(212)	114(237)	129(264)
Pressure, OBHP (PSI)	4,000	6,770	7,589
Total Dissolved Solids	42,000	3,100	68,500
Na	16,500	1,075	24,000
K	130	8.5	300
Rb	0.35	<0.2	0.80
NH_3	9.8	8.8	26
Mg	60	3.0	235
Ca	290	100	2,000
Sr	22	5.8	380
Fe	0.15	11.0	8.0
Mn	0.52	----	2.7
Cl	23,200	1,740	40,500
HCO_3	1,660	90	520
SO_4	39	12	0.6
SiO_2	1.6	0.85	0.32
B	42	1.8	30
pH	7.0	5.2	6.3

NOTE: Formation waters analyzed in Cozby #2 and Gardner #1 are from the geopressured zone. Low salinities of water from Cozby #2 are the result of condensed vapor which is thought to have diluted formation water by a factor of 20.

Source: Kharaka *et al*, 1977.

Table 3-4. Range of Relative Hazard of Known Geothermal Fluid Constituents

Constituents	Range of Concentration (ppm)	Tolerance Level for Domestic Supply (ppm)	Range of Relative Hazard
Na	1075-24,000	270	4-89
Cl	1740-40,500	250	7-162
SO_4	0.6-39	250	0.002-0.16
TDS	3100-68,500	500	6-137
Fe	0.15-11	0.3	0.5-37
B	1.8-42	0.750	2.4-56

On the basis of these available data, chlorides and total dissolved solids appear to present the greatest potential hazard. Unknown hazards from toxic trace elements whose concentrations are not known may prove to be far more hazardous, however. All species of fish and other aquatic life must tolerate a range of dissolved solid concentrations in order to survive. Estuarine species are tolerant of changes from fresh to brackish to sea water. Abrupt changes could result from effects of the excess dissolved solids, primarily through the elimination of desirable habitat. Rapid salinity changes cause plasmolysis of leaves and stems because of changes in osmotic pressure. The following limits in salinity variation from natural salinity have been recommended to protect wildlife habitats (EPA, 1976):

Natural Salinity (ppm)	Variation Permitted (ppm)
0 to 3,500	1000
3,500 to 13,500	2000
13,500 to 35,000	4000

Agricultural uses of water are also limited by excessive dissolved solids concentrations. A general classification of salinity hazards for irrigation has been prepared (EPA, 1976):

Dissolved Solids Hazard for Irrigation Water (mg/l)	
Water from which no detrimental effects will usually be noticed	500
Water which can have detrimental effects on sensitive crops	500-1,000
Water that may have adverse effects on many crops and requires careful management practices	1,000-2,000
Water that can be used for tolerant plants on permeable soils with careful management practices	2,000-5,000

Industrial requirements regarding dissolved solids content of raw waters are quite variable. Table 3-5 indicates maximum values accepted by various industries for process requirements.

Table 3-5. Total Dissolved Solids Concentration of Surface Waters that Have Been Used as Sources for Industrial Water Supplies (After EPA, 1976)

Industry/Use	Maximum Concentration (mg/l)
Textile	150
Pulp and Paper	1,080
Chemical	2,500
Petroleum	3,500
Primary Metals	1,500
Copper Mining	2,100
Boiler Make-up	35,000

Future expansion of recreational, urban, agricultural, and industrial activities in the vicinity of the well site is predicted. Water resource development will increase accordingly. Potential threats to water quality could adversely affect each of these categories.

Undetected or accidental venting of effluents through surface or subsurface faults could occur for several reasons. Faulty installation of casing, choice of hydraulically unsuitable disposal aquifers or reinjection well sites, and wells improperly plugged during abandonment could allow the fluids to escape undetected at some distance from the well site through faults or sand lenses with surface outcrops. Contamination of soils, reduction of water quality, and consequent threats to terrestrial and aquatic biota could result.

3.3.4 Potential Impacts of Accidents on Aquatic and Terrestrial Flora and Fauna

Some of the expected constituents of the geothermal fluids include calcium, sodium, chloride, fluoride, boron, and sulfide

(Gustavson and Kreitler, 1976). Their biotic toxicity is dependent upon their concentration. Accidents induced from blowouts, cracks in the well head or pipes, human error, or natural hazards (hurricanes or floods) could cause the release of these toxicants into the environment. The range and seriousness of the resulting impacts are dependent upon the type, composition, and quantity of biologically degrading material released and various environmental factors such as wind speed and direction, air temperature, light, and moisture. Major fish kills can be anticipated downstream in Chocolate Bayou and Chocolate Bay with large scale releases of toxicants into waterway.

Plants have evolved in harmony with their environment. When pollutants are introduced, sensitive members of the plant communities are killed out entirely, while further from the source their metabolic activity may be impaired. Modification of growth and reproductive potential of species will reduce their ability to compete with more tolerant plants and thereby alter the population. The significance of this to the biotic community will depend upon the importance of the sensitive species to the stability of the community (Treshow, 1970).

Depending on moisture conditions at the time, accidental fires could spread through the area east of Chocolate Bayou until extinguished. This should have little impact on the vegetation of the immediate area since it is currently kept in early successional stages through normal agricultural practices. Fire should, however, be prevented and kept in check.

Accidental spills of lubricants and chemicals directly on vegetation would probably kill exposed plants. When washed into the water they could damage the aquatic habitat for food chain organisms and higher aquatic forms. Such spills should be contained to assure a minimum of damage. However, in the event of a flood or rain of such intensity as to overflow and purge the sump areas or well sites, various adverse biotic damage could result in the surrounding environment.

3.3.5 Potential Impacts of Accidents on Land Use

In the event of a well blowout during the drilling phase of the study, it is conceivable that hypersaline geopressured fluids could be forced onto adjacent agricultural lands. In regard to land use such an accident would have an immediate impact of killing the vegetative cover which the geopressured fluids contacted. Depending on the volume of fluids discharged during a blowout, agricultural productivity could be disrupted for a long period of time. Such an accident would completely remove land from cultivation, leaving it barren and unproductive.

During the first and second blowout of Edna Delcambre #4 well in south Louisiana (335 km or 210 mi to the east) fluid was blown about 30 m (100 ft) into the air. As a result of winds, brine fallout occurred at a maximum distance of 610 m (2000 ft) from the well site (ERDA, 1976). The nearest residence to the proposed well is approximately 300 m (900 ft) west. Should a similar blowout occur at the proposed well site and should the winds be from the northeast, geothermal fluids could reach individual residences on the west bank of Chocolate Bayou, but are not expected to reach the recreational community. The extent of disruption of recreational or domestic activities is unknown, although it may be necessary to evacuate if a blowout occurs. Some damage to the exterior of structures is possible.

3.3.6 Potential Impacts of Accidents to Air Quality

By standards of normal oil field operation, extraordinary precautions will be taken in the proposed project to prevent blowout of the test well. Yet the possibility of a blowout should be considered in view of the high pressures anticipated in the geopressured zone. Some documentation exists on blowout occurrences at various geothermal fields (ERDA, 1977).

Very little air quality impact data as a result of blowout is available in the literature. Some preliminary information may be inferred from the blowout of the Edna Delcambre #4 gas well in the Tigre Lagoon area in Louisiana (ERDA, 1976). The blowout took place on July 13, 1971, and resulted from negligence during workover as rams were changed on the blowout preventers. Depth of the producing interval at the time of blowout (July 13, 1971) was between 13,380 and 13,880 ft., with three to four thousand pounds flowing pressure. The well caught fire ten hours after blowout and the fire lasted for 10 days. Discharge of the highly saline (± 150 ppt) formation fluid continued for approximately three months until the well was made inactive. The well was finally plugged and abandoned on November 4, 1971, by pumping cement through the relief well.

Since the emission rate of H_2S due to possible blowout from the proposed project is not known, one may calculate the impact on air quality as the result of the oxidation from H_2S to SO_2 from the experience gained by Edna Delcambre #4 well (ERDA, 1976).

The computation of SO_2 is based on the following assumptions:

A. Emission height is assumed to be about 30 m (100 ft). This is based on data that during both the first and second blowout of Edna Delcambre #4 well, saline formation fluid was blown about 30 m (100 ft) vertically into the air.

B. Emission rate of H_2S is assumed to be about 6.8 Kg/hr. This is based on a Union Oil Co. well testing, which produced a total flow of 22,500 Kg/hr., of which 3% was noncondensable gases. Ninety-nine percent of this was CO_2. If the remaining percent is assumed to be entirely H_2S, the total emissions of H_2S would equal 6.8 Kg/hr.

C. Atmospheric stability is assumed to be F, the moderately stable condition commonly used as the air pollution computation for safety analysis.

D. Wind speed during stability F in the proposed project area is 1.80 m/s. This is given in the Section of Atmospheric dispersion characteristics.

E. Blowout will result in the burning of the gas, which in turn will result in oxidation of the H_2S to SO_2. Available data showed that 620 grams of H_2S would produce 1136 grams of SO_2.

On the basis of the preceding information the maximum concentration of SO_2 may be computed to be about 192 $\mu g/m^3$, which is below national ambient air quality standards of maximum 24 hr concentration of 365 $\mu g/m^3$. The distance of this maximum concentration is expected to be about 1.7 km (1 mi) downwind from the blowout well. Although the concentration of SO_2 is below air quality standards, because of the unusual odor of H_2S the area within 3.2 km (2 mi) radius from the blowout well (such as campsites in the proposed project area) should be warned and necessary precautions taken.

In summary, the impacts of the proposed project on air quality are insignificant during construction and operation. However, should blowout occur, the most important pollutant will be SO_2, and its maximum concentration is below national ambient air quality standards. No adverse effect on air quality is anticipated even under conservative estimates during stable atmospheric conditions. The effect of inversion layer is also small, because the minimum height of that layer is about 400 m (1310 ft) above ground (Holzworth, 1972).

3.4 Impact Control Programs

Physical changes to the land surface which could impact surface water will be controlled by construction techniques as described in Section 1 of this assessment. These procedures should minimize adverse impacts to water circulation, water quality, wildlife, vegetation, recreational use, and aesthetic value of surface water in the study area.

Potential impacts from well installation, maintenance, and accidents have been extensively encountered by the oil and gas industry in the region. Technology has advanced to a high degree; equipment has been designed to cope with pressures, and personnel have been trained in all aspects of well drilling and operation. Additionally, numerous state and federal agencies regulate well operation, especially in areas affecting discharge or other use of surface waters.

Problems associated with routine disposal of produced fluids (brine, condensate) or production wastes (drilling muck, lubricants) into surface waters are nonexistent in the proposed action. State laws prohibit any such non-regulated disposal to protect air quality. The reinjection procedure has been in use by the oil industry for many years in the region, and technology has been refined so that no problems are anticipated with the amounts of effluent expected to be produced in the test well. These precautions should protect surface water during the project and should lead to nearly complete restoration of the site to its original condition after completion of the project, enhancing rapid recuperation to the previous hydrologic setting.

Standing water in mud pits and reserve ponds will be pumped into the disposal wells and the solid residue will be buried in the impervious pits. A potential impact exists in the procedure. Toxic materials are buried, subject to leaching, erosion, seismic activity, and runoff. Some materials used in drilling fluids and muds may reach surface or gourndwater through any of the natural processes listed or through cultural changes such as future plowing, ditching, grading, or digging in the area. Any or all of these activities will occur in the area if future development takes place as planned. Once the materials such as calcium and chrome derivatives, crude oil, oil emulsions, and asbestos, are in the environment they will affect plants and the resulting food chain. A more detailed explanation of the consequences of this subject is in the Environmental Assessment, Geothermal Energy, Geopressure Subprogram, Gulf Coast Well Testing Activity, Frio Formation, Texas and Louisiana (February 1978).

Primary biological impacts are expected to result from dust and erosion, release of toxic chemicals purged from sump areas of the well site during floods, tidal surges, or hurricanes, fires, and/or accidents. Exposed mineral soil will be covered with such material as shell or gravel to minimize dust and erosion. Frequent checking of well heads and pipes for cracks will help prevent accidents. A restoration program includes replanting all exposed soil on the well site with plants native to the area of the well site.

CHAPTER FOUR - COORDINATION WITH FEDERAL, STATE, AND REGIONAL AGENCIES

Several Federal, state, local and regional agencies have been contacted and asked to identify any conflicts or potential conflicts that might result from the proposed action with any active or proposed plans and regulations that they may have, and also for any thoughts they may have regarding the proposed action in the study area. No conflicts were found.

The agencies contacted include:

Federal

*Geological Survey, Water Resources Division, Austin, Tx., U.S. Dept. of the Interior
Department of Housing and Urban Development
*National Parks Service, Southwest Region, Santa Fé, New Mexico, U.S. Dept. of the Interior
*Geological Survey, Denver Colorado, U.S. Dept. of the Interior
*National Marine Fisheries Service, NOAA, U.S. Dept of Commerce, St. Petersburg, Fla.
United States Environmental Protection Agency
*Bureau of Land Management, Santa Fé, New Mexico, U.S. Department of the Interior
*U.S. Coast Guard, Eighth Coast Guard District, New Orleans, La., Dept. of Transportation
*Bureau of Outdoor Recreation, Albuquerque, New Mexico, U.S. Dept. of the Interior
*U.S. Department of Commerce - Maritime Administration, New Orleans, La.
*U.S. Corps of Engineers, Dept. of the Army, Galveston District, Galveston, Tx.
*Fish & Wildlife Service, U.S. Dept. of the Interior, Wash., D.C.

State

*Texas Railroad Commission, Oil and Gas Division, Austin, Tx.
*Texas Dept. of Water Resources
*Texas Parks and Wildlife Dept.
Texas Office of the Governor - Interagency Council on Natural Resources and the Environment
*Texas Dept. of Health, Austin, Texas

Regional and Local

*Houston-Galveston Area Council, Houston, Tx.
*Brazoria County Engineers Office, Angleton, Tx.
*City of Alvin Design Office, Alvin, Tx.
*Brazoria County Health Unit, Angleton, Tx.

The accompanying Table 4-1 shows agencies at the Federal and state levels of government which have regulations or permit requirements concerning geothermal or geopressure resource activities.

*Agencies that responded.

Table 4-1. Matrix of Federal and State Actions on Geopressure-Geothermal Well Testing Activities and Related Oil Activities

FEDERAL AGENCIES	Coastal Const. Activites	Navigable Waters	Mineral Leasing on Public Lands, O.C.S. Oil, Gas, Other Mining Leases, Permits & Other Act. Management Programs	Dredging and Filling Disposal of Dredge Material	Activities on Marine Sanctuar-Coastal Zones	Noise & Air Emissions	Effluent Disch. & Water Quality & Water Resources	Oil Pipelines (Interstate)	Fish & Wildlife Resources	EIS Review	Historic Sites Bldg. & Objects National Register	
Bureau of Land Management (Department of the Interior)			● ○							x		43 USCA p.1 et seq. 30 USCA p. 351 et seq. OCS Land Sec, 43 USCA pp 1331-1342
Bureau of Outdoor Recreation (Department of the Interior)										x		16 USCA p. 460, 1; 16 USCA p. 460 1-4
U. S. Army Corps of Engineers	● ○	● ○		● ○				● ○		x		33 USCS sec. 408(1960); 33 USCS sec. 404(1960); FWPCC see 404-33 USCS: Sec. 1344 (Supp 1976).
Department of Commerce Coast & Geodetic Survey, NOAA	● ○				● ○					x		Coastal Zone Management Act (1972)P.L.No. 92-583,86 Stat.1280, & U.S.C. pp. 1431 et seq. 16 USCA p. 1361 et seq.; 15 USCA pp. 311, 330a; 15USCA p.1501 et seq.
Environmental Protection Agency		● ○		● ○		● ○	● ○			x		FWPCA Sec. 402(1976) 42 USCA Sec. 1857,1858,3521 et seq. 4901 et. seq.; 21 USCA p.346a; 33 USCA pp. 1251 et seq.; 14011 ? USCA p.135 et seq.
Federal Power Commission								● ○				16USCA pp.791-825r; 49 USCA pp.1671-1684; 15 USCA p.717 et seq.
Geological Survey			● ○							x		43USCA p.1334,1337; 43 USCA p.31 et seq.; 30 USCA p.351 et seq.
Interstate Commerce Commission								● ○				49USCA p.1 et seq.; 49 USCA p.302 35 seq.; 49 USCA p.901 et seq 49 USCA p.1001 et seq.
U. S. Coast Guard	● ○	● ○							○	x		33USCA p.1221; 46 USCA p.526; 33USCA p.14d; 33 USCA p.1002; 14USCA p.81 et seq.; 14 USCA p. 1 et seq.
U. S. Fish & Wildlife Service (Department of the Interior)			○	○					● ○	x		16USCA pp.742a-742k; 16 USCA p.1361 et seq.
Water Resources Council							○			x		42 USCA p. 1962 et seq.; Fed.Non-nuclear Energy Res. & Dev. Act, 1974 Sec. 13
Energy Research and Development Administration (ERDA)			● ○							x		42 USCA p.5812 et seq.; 42 USCA p.2011 et seq.; Fed. Non-nuclear Energy Res. Dev. Act. 1974, Sec. 3, 30 USCA pp. 661-668.
Advisory Council on Historic Preservation										x	● ○	16 USCA 461-67,1970; 16 USCA 470-470m as ammended, 1973; 42 USCA 4321 et seq. 1970.

● Agency Requires Permits

○ Agency has Rules and Regulations Applying to Action

x Agency Reviews EIS and EA or Reviews Applications

The following Table 4-2 shows the drilling form submissions required.

Table 4-2. Drilling Form Submissions Required in the State of Texas (ERDA, 1977b)

Agency	Division	Form No.	Description
Texas Railroad Commission (TRRC)	Oil & Gas	GT-4	Certificate of compliance and authorization to transport Geothermal Energy
TRRC	"	W-1	Application for permit to drill
TRRC	"	P-5	Organization Report
TRRC	"	GT-2	Producers monthly report of Geothermal wells
TRRC	"	W-2	Oil Well potential test or recompletion report and log
TRRC	"	GT-3	Monthly geothermal Gatherer's report

CHAPTER FIVE - ALTERNATIVES

The reasonably available alternatives to the proposed action are delayed or no action and considering an alternative site within the geopressured resource region.

5.1 Delayed or No Action

This project is designed to drill a well into a geopressure reservoir at an optimum location as determined by exploration procedures and to evaluate the reservoir potential over a sustained period of flow testing. Previous well tests have been confined to testing wells that were originally drilled as oil or gas wells and were not necessarily in the best location for geopressure resource evaluation. The delay or abandonment of this project will therefore preclude the availability of geopressured reservoir data based on geopressure exploration techniques and will severely restrict the amount of information available on the geopressured resource.

5.2 Location

Several productive drilling sites are available within the Brazoria County Prime Prospect Area. This particular site was selected because it combined environmental acceptability and economic considerations with the most desirable geopressured-geothermal resource potential zone. This site is part of the Geothermal Energy Geopressure Subprogram of the DOE which is evaluated in an EA(DOE/EA-0023) dated February 1978. Studies of the subsurface resource (Bebout, 1977) and the environment (White _et al._, 1977) were conducted by DOE contractors and used to plan the proposed action. A detailed analysis of the study area was undertaken by a DOE contractor to provide the basis for the preparation of the environmental evaluation. The exact well-site location was further refined to avoid known archaeological sites and to reduce adverse physical and cultural impacts to an acceptable level.

APPENDIX A

Mammals Whose Recent Range Included Brazoria County, Texas
(From Davis, 1974)

Common Name	Scientific Name	Status in Project Area
Opossum	Didelphis virginiana	2
Eastern Mole	Scalopus aquaticus	2
Short-tailed Shrew	Blarina brevicauda	2
Least Shrew	Cryptotis parva	2
Southeastern Bat	Myotis austroriparius	3
Georgia Bat	Pipistrellus subflavus	2
Red Bat	Lasiurus borealis	2
Greater Yellow Bat	Lasiurus intermedius	3
Evening Bat	Nycticeius humeralis	3
Guano Bat	Tadarida mexicana	3
Racoon	Procyon lotor	1
Long-tailed Weasel	Mustela frenata	3
Mink	Mustela vison	3
River Otter	Lutra canadensis	3
Eastern Spotted Skunk	Spilogale putorius	2
Striped Skunk	Mephitis mephitis	2
Gray Fox	Urocyon cinereoargenteus	3
Coyote	Canis latarans	3
Red Wolf	Canis rufus	4
Ocelot	Felis pardalis	4
Cougar	Felis concolor	4
Bobcat	Lynx rufus	4
Eastern Gray Squirrel	Sciurus carolinensis	4
Fox Squirrel	Sciurus niger	3
Eastern Flying Squirrel	Glaucomys volans	3
Plains Pocket Gopher	Geomys bursarius	3
Hispid Pocket Mouse	Perognathus hispidus	2
Beaver	Castor canadensis	3
Fulvous Harvest Mouse	Reithrodontomys fulvescens	2
Dwarf Harvest Mouse	Reithrodontomys humulis	3
Pigmy Mouse	Bariomys taylori	3
White-footed Mouse	Peromyscus leucopus	2
Northern Rice Rat	Oryzomys palustris	2
Hispid Cotton Rat	Sigmodon hispidus	2
Florida Wood Rat	Neotoma floridana	3
Muskrat	Ondatra zibethicus	3
House mouse	Mus musculus	3
Roof Rat	Rattus rattus	3
Norway Rat	Rattus norvegicus	3
Nutria	Myocastor coypus	1
Eastern Cottontail	Sylvilagus floridanus	1
Swamp Rabbit	Sylvilagus aquaticus	2
White-tailed Deer	Odocoileus virginianus	4
Nine-banded Armadillo	Dasypus novemcinctus	1

1 - known to occur on or near site
2 - very likely to be present on or near site
3 - Unlikely to be present on or near site
4 - Almost certainly absent from vicinity of site

APPENDIX B

An alphabetical List of Some of the Plants in the Plant Communities Observed Near the Proposed Geothermal Well Site in Brazoria County, Texas on 20-21 September, 1977

Community	Growth Habit	Scientific Name[1]	Common Name
Quercus	Trees	Celtis laevigata	Texas sugarberry
		Diospyros virginiana	common persimmon
		Parkinsonia aculeata	retama
		Prosopis glandulosa	mesquite
		Quercus drummondii	post oak
		Quercus virginiana	live oak
		Sapium sebiferum	Chinese tallow tree
	Shrubs	Bumelia sp.	ironwood
		Ilex vomitoria	yaupon
		Myrica cerifera	wax myrtle
	Vines	Ampelopsis arborea	pepper-vine
		Campsis radicans	trumpet creeper
		Lonicera japonica	Japanese honeysuckle
		Rubus spp.	blackberry
		Smilax bona-nox	cat greenbrier
		Vitis mustangensis	mustang grape
	Herbs and Grasses	Amaranthus sp.	pigweed
		Stenotaphrum secundatum	St.Augustine grass
Eupatorium-Andropogon-Axonopus	Trees	Parkinsonia aculeata	retama
		Prosopis glandulosa	honey mesquite
		Quercus drummondii	post oak
		Sapium sebiferum	Chinese tallow tree
	Shrubs	Ilex vomitoria	yaupon
		Myrica cerifera	wax myrtle
		Rosa bracteata	Macartney rose
		Zanthoxylum clava-herculis	toothache tree
	Vines	Clematis crispa	blue jasmine
		Ipomea sp.	morning glory
		Mikania scandens	climbing hempweed
		Rubus spp.	blackberry

[1] Scientific nomenclature after Correll and Johnson (1970).

APPENDIX B (Continued)

Community	Growth Habit	Scientific Name	Common Name
	Herbs and Grasses	Agalinis sp.	gerardia
		Ambrosia artemisiifolia	lesser ragweed
		Amorpha fruticosa	bastard indigo
		Andropogon spp.	bluestem
		Aster spp.	aster
		Axonopus sp.	carpet grass
		Baptista sp.	wild indigo
		Callirhoe sp.	poppy-mallow
		Caperonia palustris	birdeye
		Cassia fasciculata	partridge pea
		Coreopsis sp.	coreopsis
		Croton capitatus	wolly croton
		Croton glandulosis	croton
		Cynodon dactylon	Bermuda grass
		Diodia teres	poor joe
		Diodia virginiana	buttonweed
		Eupatorium capillifolium	dog fennel
		Eupatorium coelestinium	blue mistflower
		Eupatorium compositifolium	yankeeweed
		Eupatorium maculata	spurge
		Eupatorium sp.	boneset
		Euphorbia bicolor	snow-on-the-prairie
		Eustoma exaltatum	catchfly-gentian
		Gaura sp.	
		Gnaphalium sp.	rabbit tobacco
		Helenium amarum	bitterweed
		Hypericum sp.	St. John's-wort
		Iva annua	sumpweed
		Lepidium virginicum	peppergrass
		Liatris elegans	gay-feather
		Liatris sp.	gay-feather
		Linum sp.	flax
		Ludwigia spp.	water-primrose
		Monarda sp.	horsemint
		Oxalis spp.	wood-sorrel
		Panicum spp.	panic grasses
		Paspalum dilatatum	Dallis grass
		Paspalum floridanum	Florida paspalum
		Paspalum notatum	bahia grass
		Paspalum plicatum	brownseed paspalum
		Paspalum setaceum	fringed-leaf paspalum
		Paspalum urvillei	vasey grass
		Perilla frutescens	beefsteak plant
		Physalis angulata	ground cherry
		Phytolacca americana	pokeweed
		Pluchea purpurascens	camphorweed
		Polygonum sp.	smartweed
		Rhexia spp.	meadow beauty
		Rhyncospora sp.	beakrush
		Ruellia caroliniensis	wild petunia

APPENDIX B (Continued)

Community	Growth Habit	Scientific Name	Common Name
		Ruellia sp.	ruellia
		Rumex sp.	dock
		Schrankia sp.	prairie mimosa
		Sesbania vesicaria	bladder pod
		Setaria glauca	yellow foxtail
		Solidago sp.	goldenrod
		Sorghum halepense	Johnson grass
		Sporobolus indicus	smutgrass
		Tragia urens	noseburn
		Triodanis biflora	Venus' looking-glass
		Verbena sp.	vervain
		Xanthium strumarium	cocklebur
Baccharis-Spartina-Distichlis	Trees	Fraxinus pensylvanica	green ash
		Ulmus crassifolia	cedar elm
	Shrubs	Baccharis halimifolia	sea myrtle
		Lycium carolinianum	salt matrimony vine
	Trees and Shrubs	Cynodon dactylon	Bermuda grass
		Distichlis spicata	saltgrass
		Eleocharis sp.	spikerush
		Iva annua	sumpweed
		Iva frutescens	marsh elder
		Juncus sp.	rush
		Lippia alba	lippia
		Paspalum notatum	bahia grass
		Phragmites communis	roseau cane
		Scirpus sp.	bulrush
		Solanum pseudocapsicum	Jerusalem-cherry
		Spartina spp.	cordgrass
		Vigna lutea	deer pea

APPENDIX C

Important Aquatic Fauna of Chocolate Bayou and Chocolate Bay

Blue Crabs	(Callinectes sapidus)
Brown Shrimp	(Penaeus azcetus)
White Shrimp	(Penaeus setiferus)
Eastern Oyster	(Crassostrea virginica)
Gulf Menhaden	(Brevoortia patronus)
Gizzard Shad	(Dorosoma cepedianum)
Bay Anchovy	(Anchoa mitchilli)
Sea Catfish	(Arius felis)
Gafftopsail Catfish	(Bagre marinus)
Warmouth	(Lepomis gulosus)
Bluegill	(Lepomis macrochirus)
Longear Sunfish	(Lepomis megalotis)
Largemouth Bass	(Micropterus salmoides)
Sheepshead	(Archosargus probatocephalus)
Silver Perch	(Bairdiella chrysura)
Sand Seatrout	(Cynoscion arenarius)
Spotted Seatrout	(Cynoscion nebulosus)
Southern Kingfish	(Menticirrhus americanus)
Spot	(Leiostomus xanthurus)
Atlantic Croaker	(Micropogon undulatus)
Black Drum	(Pogonias cromis)
Red Drum	(Sciaenops ocellata)
Striped Mullet	(Mugil cephalus)
White Mullet	(Mugil curema)
Southern Flounder	(Paralichthys lethostigma)
Fringed Flounder	(Etropus crossotus)

(From Moffet, 1975).

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