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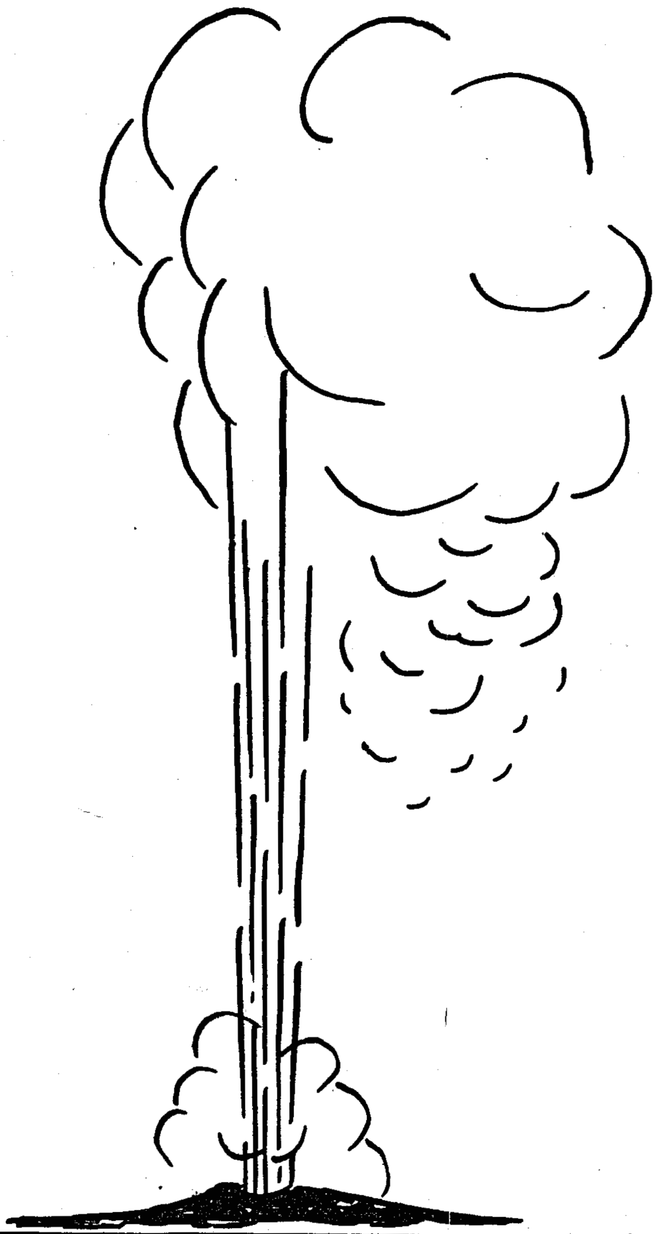

ENVIRONMENTAL ANALYSIS OF GEOPRESSURED-GEOTHERMAL PROSPECT AREAS, BRAZORIA AND KENEDY COUNTIES, TEXAS

By
William A. White
Maryann McGraw
Thomas C. Gustavson

Work Performed Under Contract No. EG-77-S-05-5401

Bureau of Economic Geology
University of Texas
Austin, Texas

U. S. DEPARTMENT OF ENERGY
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ABSTRACT

Preliminary environmental data, including current land use, substrate lithology, soils, natural hazards, water resources, biological assemblages, meteorological data, and regulatory considerations have been collected and analyzed for approximately 150 km^2 of land: (1) near Chocolate Bayou, Brazoria County, Texas, where a geopressured-geothermal test well is being drilled in 1978, and (2) near the rural community of Armstrong, Kenedy County, Texas, where future geopressured-geothermal test well development may occur. The study was designed to establish an environmental data base and to determine, within spatial constraints set by subsurface reservoir conditions, environmentally suitable sites for geopressured-geothermal wells.

In Brazoria County, preliminary analyses of data revealed the need for focusing on the following areas: potential for subsidence and fault activation, susceptibility of test well and support facilities to fresh- and salt-water flooding,

possible effects of produced saline waters on biological assemblages and ground-water resources, distribution of expansive soils, and effect of drilling and associated support activities on known archeological-cultural resources.

Based on predicted values of bulk compressibilities, declines in reservoir pressure, well drainage radius, and depth and thickness of reservoir sandstones, preliminary estimates of surface subsidence resulting from reservoir sand compaction range from 6 cm/yr (0.2 ft/yr) during the first two years of fluid production, to 3 cm/yr (0.1 ft/yr) during a 5-year period. These rates do not include possible subsidence resulting from compaction of shales associated with reservoir sands. Differential subsidence may occur across known growth faults which, when projected to the surface, strike near the proposed well site. Although current land use maps show an agriculturally-dominated region, facilities that could be adversely affected from significant amounts of subsidence and/or fault activation include: two petrochemical plants; a small unincorporated community along Chocolate Bayou; several gas, crude, and product pipelines; and paved highways.

Flood distribution maps, which project "100-year" flood levels between 2.4 and 4 meters above ground surface (approximately 1.8-3.4 m or 6-11 ft in elevation) indicate the need to institute flood-protection measures at the well site. In addition to the possibility of fresh-water flooding, salt-water flooding accompanying passage of a hurricane must be considered, as indicated by flood levels associated with Hurricane Carla.

Probable locations of fluid production and disposal facilities should have little direct impact on important biological assemblages and habitats; however, accidental discharge of geothermal brines that may contain significant amounts of boron could affect small areas of fresh-water marshes near the well sites and larger areas of fresh- to brackish- and salt-water marshes with their associated estuary habitats along Chocolate Bayou and Chocolate Bay gulfward of the well sites. These biologically productive areas provide nurseries for commercial shrimp, blue crabs, and game fish.

Although fresh-water aquifers underlie the geothermal prospect area, contamination from properly managed temporary emergency surface storage of saline waters is unlikely because of low permeabilities of clay substrates at or near the surface. High shrink-swell potentials which characterize the clays, however, should be considered in the construction of pipelines, roads, and other facilities.

A preliminary investigation of archeological-cultural resources in the prospect area has revealed that production activities may affect known cultural resources which are potentially eligible for inclusion within the National Register of Historical Places. A detailed investigation of the archeological-cultural resources was conducted.

The Kenedy County geopressured-geothermal prospect area is not as promising as the Brazoria County Prospect in terms of known and suspected reservoir characteristics. Environmental problems associated with geopressured-geothermal resource development in this relatively unpopulated South Texas area, however, will be fewer than those in the Chocolate Bayou area. Estimates of surface subsidence resulting from reservoir sand compaction range from 11.2 cm to 13.7 cm for pressure declines of 275 psi and 340 psi, respectively. Although these amounts of subsidence are similar to those estimated for Brazoria County (after two and five years of fluid production, respectively) the remoteness of the Kenedy County prospect from industrial and urban development significantly mitigates the importance of subsidence and fault activation.

Poor surface drainage in the Kenedy County prospect area can lead to extensive flooding by heavy rainfall which is sometimes associated with hurricane aftermath storms such as those that accompanied Hurricane Beulah in 1967. Improperly selected well sites could be flooded or isolated by ponded water for many days following intensive rain storms.

Geomorphic processes are dominated by eolian activity as reflected by the numerous eolian features including active and stabilized sand dunes, sand and loess (silt) sheets, deflation areas, and accretionary clay-sand dunes. Devegetation of sand dunes should be avoided to prevent the formation of active blowouts and dunes.

Important fresh ground water resources are present in the western two-thirds of the prospect area. The fresh water lens is:

(1) under artesian conditions, (2) recharged in areas west of the prospect area, and (3) sandwiched between ground water of moderate to high salinity. These conditions provide a measure of protection to usable ground-water resources because geothermal fluids inadvertently discharged at the surface would be unlikely to infiltrate the deeper fresh water aquifer. Moderately to highly permeable sands and silts that characterize shallow substrates in much of the prospect area, however, will allow relatively rapid infiltration of fluids into the shallow more saline aquifer.

Perhaps the most important biological assemblage in the Kenedy County prospect area is that associated with the live oak mottes that have been established on sand dunes. The mottes represent climax vegetation and have been established only after many years of orderly plant succession. These vegetated areas serve a double purpose: (1) habitat for a variety of plants and animals, and (2) physical stabilizer of underlying dune sand. These areas should be left undisturbed in the development of test wells.

Prevailing southeasterly winds in this dry subhumid region suggest that production wells should be placed west of U. S. Highway 77 and the small community of Armstrong. Location of wells on the west side of U. S. Highway 77 would be in agreement with the recommended location of water-dominated geothermal energy system as noted by Muehlberg and Shepard (1975).

INTRODUCTION

Information presented in this report was collected and analyzed as part of a preliminary environmental analysis of potential geopressured-geothermal energy resource areas in Brazoria and Kenedy Counties, Texas (fig. 1). Although specific geopressured-geothermal prospect areas and environmental problems associated with location of a specific test well are considered, the report is not, nor was it intended to be, an environmental impact assessment. Approximately 150 km^2 (60 mi^2) were analyzed within each of the Brazoria and Kenedy County geopressured-geothermal prospect zones, with the objectives of: (1) conducting a comparative environmental analysis of candidate sites for geopressured-geothermal test wells, and (2) providing an environmental data base for future well development with the possibility of full scale energy production.

Part of the study of the prospective areas involved producing a series of large scale maps (1:24,000) or, where appropriate, tables in order to depict and describe selected environmental characteristics concerning current land use, environmental geology, natural hazards, soils, biologic assemblages, water resources, meteorologic conditions, and regulatory agencies (Appendix C). In addition, a methodology (Appendix A) was devloped employing transparent-translucent overlay maps and matrices for the purpose of identifying and classifying possible detrimental interactions between geopressured geothermal development

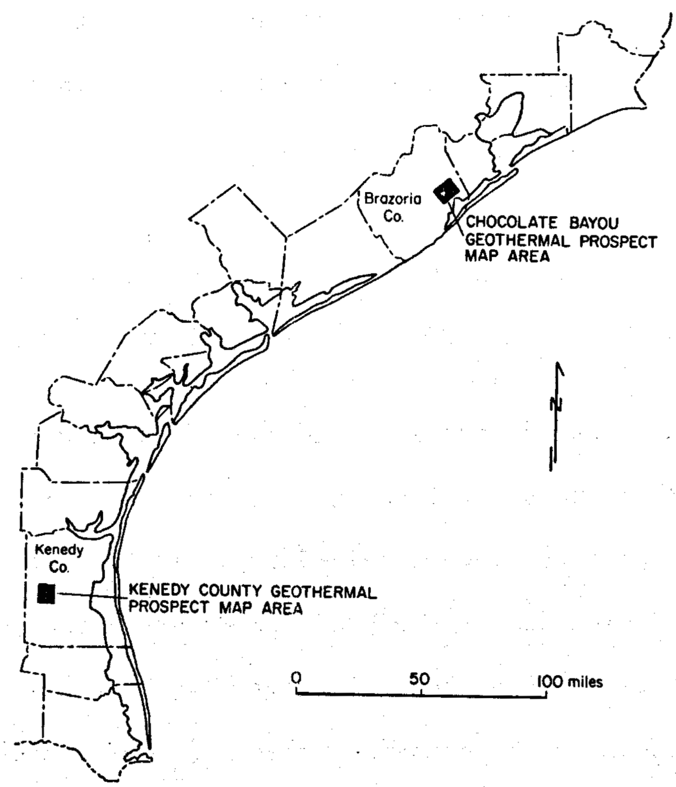

Figure 1. Location of geopressured-geothermal prospect areas, Brazoria and Kenedy Counties, Texas.

activities and selected environmental characteristics. Possible detrimental interactions were evaluated by considering both the potential effect of a test well and associated activities on the environment, and the potential effect of the environment on the test well and associated activities. Stated another way, activities were evaluated in terms of (1) their probable effects on environmental quality and natural processes, and (2) their capability for effective utilization of the environment with minimal loss or damage from natural processes or events.

PART I: PRELIMINARY ENVIRONMENTAL ANALYSIS OF A GEOPRESSURED-GEOTHERMAL TEST WELL IN BRAZORIA COUNTY, TEXAS

Because the first geopressured-geothermal test well (Austin Bayou Prospect*) is to be drilled in Brazoria County in 1978, the Brazoria County prospect area received emphasis in this environmental study. Evaluation of the Brazoria County area and the prospect well in terms of expected reservoir characteristics and potential as a geopressured-geothermal energy resource are reported by Bebout and others (1978).

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* The geopressured-geothermal test well is referred to as the Austin Bayou Prospect by Bebout and others (1978), but because of its final proposed location adjacent to Chocolate Bayou, it is sometimes referred to in this report as the Chocolate Bayou Prospect.

GENERAL SETTING--BRAZORIA COUNTY PROSPECT AREA

The area for which environmental data were collected and analyzed in Brazoria County encompasses about 150 km^2 (60 mi^2). The center of the area, which is near the proposed site of the test well, is located approximately 56 km (35 mi) south of Houston and 22 km (14 mi) inland from the Gulf shoreline of Galveston Island (fig. 2). Liverpool, with a population of 340 in 1974 (Dallas Morning News, 1976) is the only incorporated community within the mapped area. Two cities with populations of 10,000 or greater that are near but off the mapped area are Alvin, with a 1974 population of 12,500 located about 16 km (10 mi) north of Liverpool, and Angleton, with a 1974 population of 10,000 and located 19 km (12 mi) southwest of Liverpool (fig. 2).

The area within which the first test well is to be located--as determined through analyses of geopressured-geothermal reservoir characteristics including temperature or geothermal waters, net sand thickness, and permeability (Bebout and others, 1978)--lies near the center of the 150 km^2 area. The actual test well and proposed surface support facilities, including separators, cooling tower, tanks, and disposal wells, will encompass only about .02 km^2 (5.5 acres) (Draper and others, 1977). Although in the following sections, environmental data maps and tables are presented for the entire area of analysis (150 km^2), emphasis is placed on a smaller central area (area of detailed analysis) of approximately 13 km^2

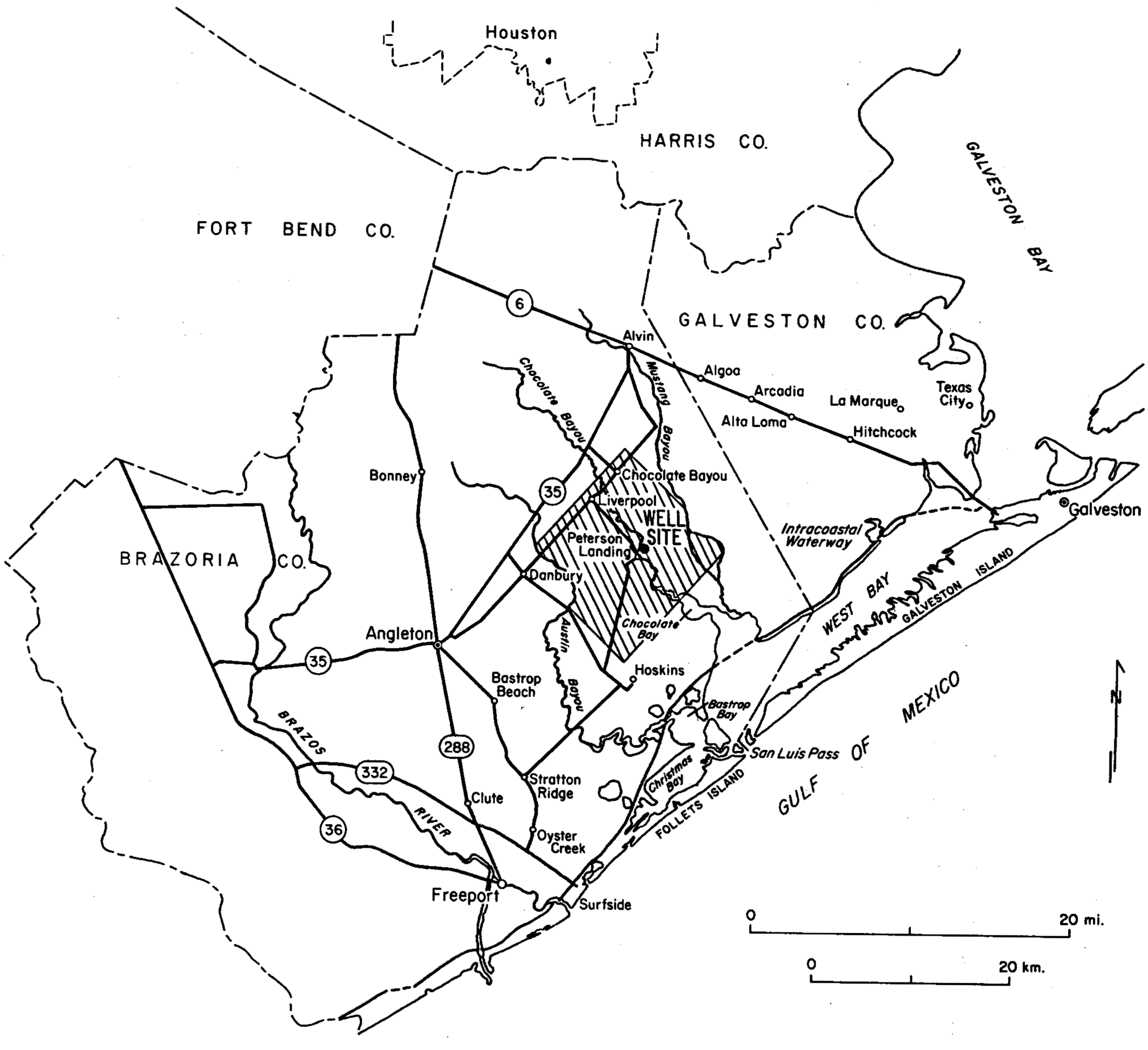

Figure 2. Location of Brazoria County geopressured-geothermal prospect area. Various environmental characteristics were mapped in the area shown by line pattern.

($5\ mi^2$) in discussing and evaluating possible locations for the test well and future wells in terms of environmental characteristics.

ENVIRONMENTAL CHARACTERISTICS

Environmental characteristics that are described and analyzed for the geopressured-geothermal prospect area were identified on the basis of: (1) their relevance and applicability to development of geopressured-geothermal energy resources, (2) their relevance and applicability to the specific geopressured-geothermal prospect area in Brazoria County, and (3) the availability of existing environmental data describing the prospect area.

In the following sections, various environmental characteristics are discussed, followed by a more specific analysis and evaluation of environments located in the area of detailed analysis (fig. 3), in terms of selecting environmentally suitable locations for test wells.

CURRENT LAND USE

Current land use patterns were mapped using 1975 color IR aerial photographs, scale 1:120,000, supplemented locally with large scale (1:20,000), 1975 color IR aerial photographs. Mapping was updated where possible through field reconnaissance during the summer of 1977.

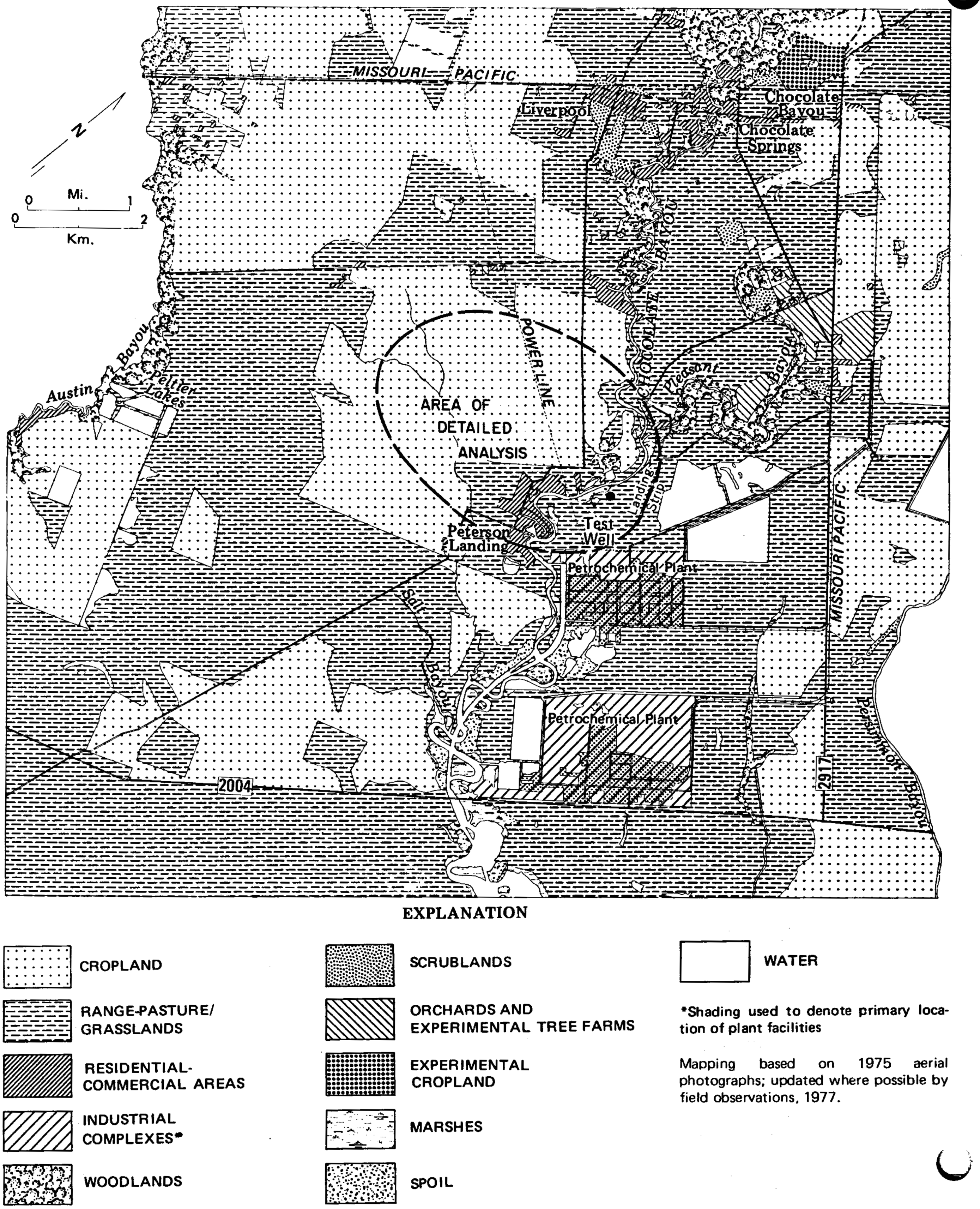

Figure 3. Current land use in the Brazoria County prospect area.

Current land use patterns in the Brazoria County prospect area are dominated by agricultural lands which include cropland and range-pasture/grasslands (fig. 3). Dominant crops in the area include rice, grain sorghum, and soy beans. The distribution of cropland and grassland varies from year to year as areas may be placed in or out of crop production. The map unit, range-pasture/grasslands, includes (in addition to those areas that appear to be permanently utilized and maintained as grassland, improved pasturelands, etc.) areas of cropland that were out of production and supporting other than cropland-type vegetation during the mapping period.

Current residential-commercial developments shown on the land use map include the incorporated community of Liverpool, located in the northern part of the map area, an unincorporated community on the west bank of Chocolate Bayou in the vicinity of Peterson Landing; and several permanent and second home developments along or near Chocolate, Pleasant, and Austin Bayous.

Industrial development is dominated by two petrochemical plants, Monsanto Chemical Intermediates Company and Amoco Chemical Corporation, located on the east bank of Chocolate Bayou, gulfward of the residential-commercial developments. The Monsanto Company (northernmost plant in fig. 3) manufactures intermediate hydrocarbon products and organic chemicals, and the Amoco plant, principally polyolefins. The petrochemical plants are serviced by a dredged canal that dissects natural meanders formed along the lower reaches of Chocolate Bayou;

the canal, approximately 3.7 m (12 ft) deep and capable of handling barge traffic, connects with the Intracoastal Waterway in West Bay about 14 km (9 mi) gulfward of the Monsanto plant.

Several farm to market roads are present in the area, some of which connect to State Highway 35 which is located just off the map (fig. 3) about 3 km (2 mi) northwest of Liverpool. Spurs off the Missouri-Pacific Railroad (located along the northwest edge of the map area) connect with facilities at the two petrochemical plants. A major power transmission line passes through the heart of the map area providing power to the petrochemical plants. Many gas, crude, and product pipelines also cross the area (fig. 4).

Other land use categories depicted on the current land use map include woodlands, located primarily along Chocolate, Austin, and Pleasant Bayous; experimental cropland where research is conducted on experimental plantings such as rice; orchards, and experimental tree farms and nurseries, most of which are no longer maintained and are presently overgrown with understory; scrubland which includes a mixture of scrubs and local patches of grassland; dredge spoil which outlines the dredged canal along the lower reaches of Chocolate Bayou; marshes; and known archeological-cultural resources* located along Chocolate and Pleasant Bayous. Records and location maps maintained at the Texas Archeological Research Laboratory at Balcones

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* Archeological-cultural resources are not shown on maps published in this report.

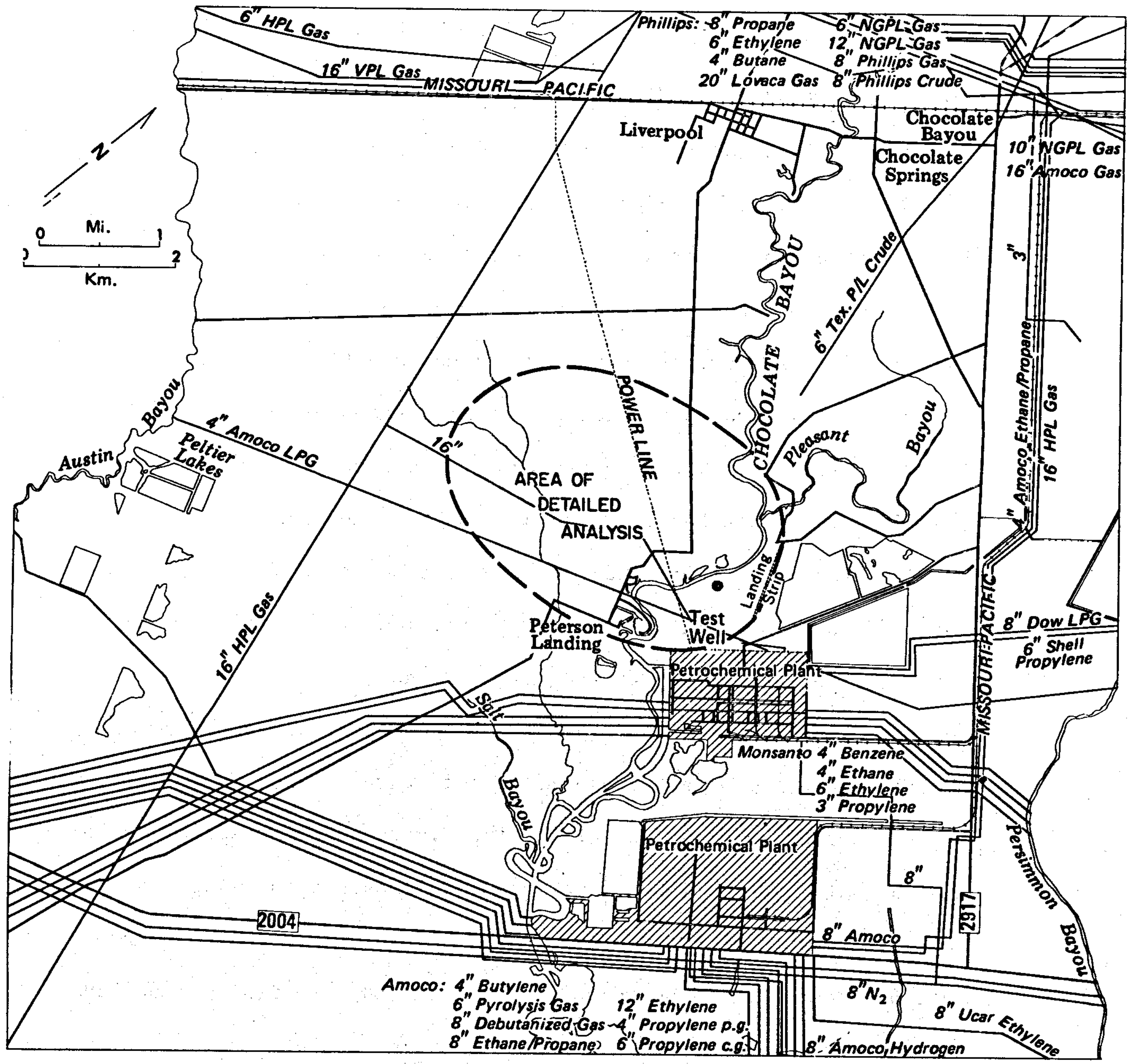


Figure 4. Approximate location of product, crude, and gas pipelines in the Brazoria County prospect area. (Modified from Dewitt and Company Inc., Houston, Texas)

Research Center (Austin, Texas) show seven known archeological sites (Indian shell middens) in the Brazoria County prospect area.

Selection of Test Well Site on the Basis of Current Land Use

Current land use in the area of detailed analysis (fig. 3) is dominated, areally, by range-pasture/grasslands and cropland, but also occurring in the area are: (1) the unincorporated community development along the west side of Chocolate Bayou near Peterson Landing, (2) small areas covered by marshes and trees (treated in the section on biological assemblages), and (3) known archeological-cultural resources. The Monsanto Company petrochemical plant is located near but southeast of the area of detailed analysis.

In terms of current land use, the most suitable areas for development of the test well and support facilities are those areas presently utilized as range-pasture/grasslands and, as a second choice, cropland. The least suitable areas, of course, are those occupied by community development and archeological-cultural resources.

Range-pasture/grassland areas (the first choice for development) exist on both sides of Chocolate Bayou. Although areas mapped as range-pasture/grasslands may be alternately in and out of crop production, recent field checks and interpretation of aerial photographs indicate that areas mapped as range-pasture/grasslands on the east side of Chocolate Bayou (in the area of detailed analysis) have been more permanently maintained as grasslands than on the west side where cultivation is more commonly practiced. Permanent removal of 5 to 6 acres (approximate area of one test well and support facilities) of cropland is, realistically, inconsequential. So, for a test well, there should be little advantage in choosing grassland over cropland areas. Should the area eventually be developed for full scale energy production with development of additional wells and construction of a power plant, however, larger amounts of cropland would be permanently removed from production. In addition, areas of cropland surrounding geopressured surface facilities could be affected inadvertently by accidental discharges of geopressured-geothermal fluids which may be brines containing high concentrations of boron.

The fact that industrial facilities have already been established on the east side of Chocolate Bayou adds support to the choice of locating the test well on the east side in an area mapped as range-pasture/grasslands, near the existing petrochemical plant facilities and away from community development. This location would also be favorable for the eventual construction of a power plant because of the established industrial facilities.

A factor which has not yet entered the discussion, however, is the direction of expansion of the geopressured-geothermal resource should the test well indicate favorable reservoir conditions for energy development. Expansion is likely to occur in the area west of Chocolate Bayou (personal communication, Robert Loucks, 1977). Drilling additional wells in the western part of the map area, farther and farther away from a power plant constructed on the east side of Chocolate Bayou, may lead to inefficiencies in fluid transmission in the form of heat loss between the production well and power plant. The possibility of eventual expansion west of the bayou warrants additional analysis.

Because the area of detailed analysis extends about 3.6 km (2.3 mi) west of the bayou, location of the test well on the west side would allow placement of the well at a greater distance from community development than on the east side. In addition, there would be more area (open space) for energy development in the area of detailed analysis, but there remains the problem of the permanent loss of some amount of cropland. Surface facilities for a 25 megawatt power plant should require about 10 acres (Riemann and others, 1976). Removal of that amount of cropland (assuming there are no additional losses from accidental fluid discharges) is probably insignificant because it represents less than .01 percent of the cropland acreage harvested in Brazoria County in 1976 (table 1). Should additional industries locate in the area to take advantage of the geothermal fluids, however, additional cropland would be lost. Nevertheless, there is sufficient area (open space) for development of the 25 megawatt plant and additional industrial facilities on the west side of Chocolate Bayou as well as on the east side.

An area initially selected as a possible site for the test well and surface support facilities, prior to the analysis of existing environmental characteristics, included an archeological site known

TABLE 1. HARVESTED ACRES FOR BRAZORIA COUNTY, 1976

(from Texas Crop and Livestock Reporting Service, 1976 Texas County Statistics)

CROP		HARVESTED ACRES
Upland Cotton		3,250
Rye		800
Sorghums		
(Grain)		37,200
(Hay)		1,400
Corn (Grain)		8,900
Soybeans		7,400
Rice		57,700
Other Hay-Excluding Sorghums		7,000
	TOTAL	123,650

as Three Oaks (41BO41)--which is one of two archeological sites located in the area of detailed analysis (fig. 3). The Three Oaks site is an Indian Shell midden which archeologists believe may have been a principal Indian camp related to a burial site and fishing camp which were excavated from an area known as Shell Point along the east side of Chocolate Bay southeast of the test well site (Hole and Wilkinson, 1973). An investigation of the Three Oaks site (41BO41) by staff archeologists from the Anthropological Research Laboratories, Texas A&M University, indicated the shell midden is oval in shape with a diameter of about 9 to 12 m (30 to 40 ft) and a depth (as indicated by one soil auger test) of approximately 50 to 60 cm (20 to

24 in). In addition to numerous oyster (Crassostrea virginica) and clam (Rangia cuneata) shells, materials collected at the site during the investigation included two 20th century stoneware plate shards, 11 specimens (shards) of San Jacinto-like aboriginal ceramics, and 8 bone fragments from various animals.

The location of the test well as shown in figure 3, is approximately 440 m (1450 ft) from the Three Oaks site. A search by archeologists, of an area of about 5 acres surrounding the staked location of the test well revealed no archeological site indicators of any kind (written communication, Edward P. Baxter, Jan. 6, 1978).

In conclusion, in terms of current land use, there are advantages when considering future potential and development of geopressured-geothermal resources for locating the test well on either side of Chocolate Bayou in areas away from existing community development and known archeological-cultural resources. The fact that there are areas currently utilized as range-pasture/grasslands near existing industrial developments with ready access to power transmission lines and rail and water transportation routes supports the prospect of locating the test well on the east side of Chocolate Bayou at the eastern extremes of the area of detailed analysis and near the petrochemical plant.

POTENTIAL FOR SUBSIDENCE AND FAULT ACTIVATION IN THE BRAZORIA COUNTY PROSPECT AREA

Subsidence and in some cases fault activation have been attributed to the production of oil and gas, ground-water, and geothermal fluids, although they can also be attributed to natural, on-going processes associated with sediment deposition, compaction, and contemporaneous growth faults. In the Houston area, land surface subsidence resulting from both oil and gas and shallow ground-water production has been well documented (Pratt and Johnson, 1926; Snider, 1927; Winslow and Doyel, 1954; Gabrysch and Bonnet, 1975; Kreitler, 1977b; and Gustavson and Kreitler, 1976). In addition, activation of faults from fluid withdrawals and fluid pressure declines has been documented (Gustavson and Kreitler, 1976; Kreitler, 1977a, 1977b). "The Houston area has more than 240 km of active faults, making it the most active area for faulting in the Coastal Zone," (Gustavson and Kreitler, 1976, p. 23). Gustavson and Kreitler (1976) and Kreitler (1976) also note that subsurface faults projected to the surface are commonly coincident with active surface faults indicating a relationship between the two. Surface expression of many faults, however, is commonly very subtle to non-existent.

Several subsurface faults have been detected in the Brazoria County prospect area (fig. 5) (Bebout and others, 1978). The faults are similar to others along the Texas Gulf Coast in being

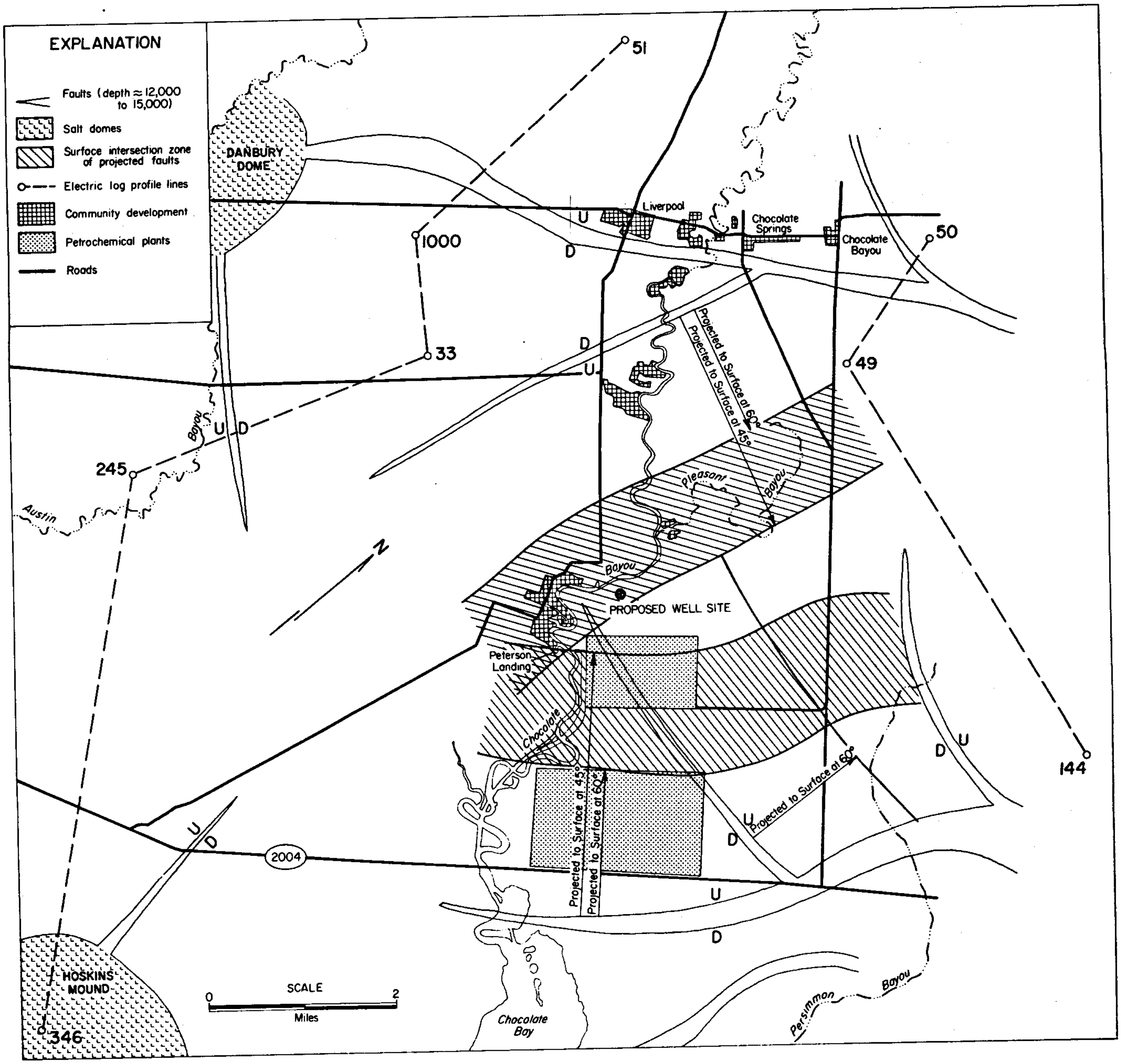


Figure 5. Location of subsurface growth faults and zone of expected surface intersection when faults are projected upward at 45 and 60 degrees. (Location of subsurface faults from Bebout and others, 1978)

mostly down-to-basin growth faults that strike subparallel to the coast and flatten and converge at depth (Bruce, 1973). Fault patterns in the prospect area have been complicated to some extent by the occurrence of salt domes (Danbury Dome and Hoskins Mound).

Because the fault planes are curvilinear with the angle of dip increasing toward the earth's surface, subsurface faults were projected upward at angles of both 45° and 60° in an effort to locate a zone within which any surface expression of the faults would likely occur (fig. 5). The range in angles of projection are in agreement with angles of faults reported by Quarles (1953) and Bruce (1973) as well as with calculated angles for faults which cross two subsurface horizons in the prospect area. Kreitler (1976; 1977b) extrapolated faults at 45° and found good coincidence between extrapolated faults and surface faults and lineations.

Although active surface faults have not been located in the Brazoria County prospect area, there is some evidence of surface and near-surface fault activity. Construction of profiles from electric logs of relatively shallow Pleistocene sedimentary units along two lines shown in figure 5 reveals sediment thickening toward the coast that cannot be explained by depositional slope alone; the variation in sedimentary sequences indicates the presence of growth faults between wells at points 245 and 346 along the southern most profile and between points 49 and 144 along the northern most profile (C. W. Kreitler, personal communication, 1977). The location of a growth fault(s) between points 49 and 144 coincides with surface projections of the eastern subsurface fault as shown in figure 5.

Surface expressions of faults have also been related to rectilinear drainage patterns in Houston and surrounding areas (Kreitler, 1977a). The approximate north-south trend of Chocolate Bayou within the western most fault projection zone follows the general trend of the projected fault (fig. 5). Furthermore, the northeast-southwest trend of Chocolate Bayou in the area of the 60° projection line of the eastern most fault is in agreement with the fault trend. Moreover, the fault projection (at 60°) coincides in part with aerial photographic lineations mapped by Fisher and others (1972). It is possible that these patterns of channel development in Chocolate Bayou are fault related. An abandoned Pleistocene channel located southwest of Chocolate Bayou also shows patterns that are possibly fault related.

As noted previously, fault activation in some areas may be related to fluid production. In fact, there is evidence that fault planes control fluid migration and subsequently, the area over which pore fluid pressure reduction and subsidence occur (fig. 6); thus, the faults, which are planes of weakness that may be activated with fluid pressure declines and reservoir compaction, become boundaries across which there may be differential compaction effectively compartmentalizing subsidence (Kreitler, 1977a, 1977b).

Surface facilities that could be adversely affected by signifi-

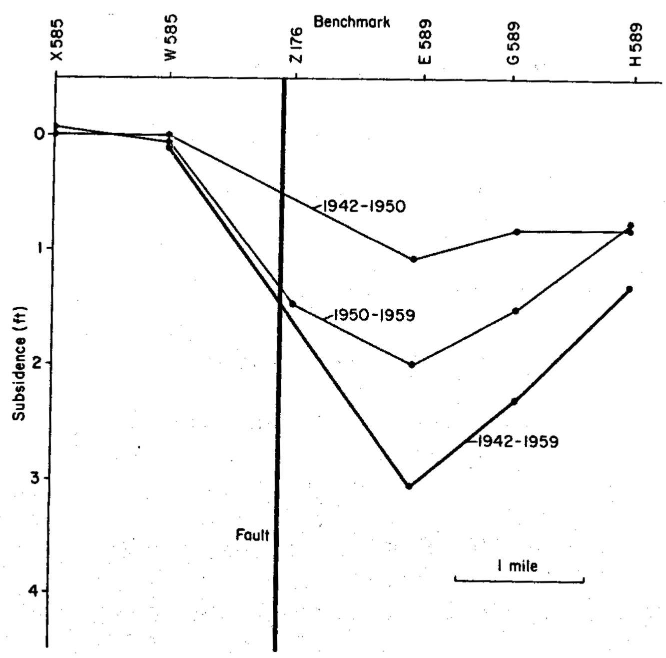


Figure 6. Land subsidence over Chocolate Bayou oil and gas field. Note coincidence of differential subsidence with lineation and surface trace of extrapolated fault. (From Gustavson and Kreitler, 1976)

cant amount of subsidence and faulting are depicted in the map of current land use (fig. 3) and include two petrochemical plants, numerous product, gas, and crude pipelines (fig. 4), residential-commercial developments, and paved roads.

Two important questions need to be addressed: (1) how much subsidence is likely to occur from geopressured-geothermal fluid production, and (2) will varying the location of the test well within the area of detailed analysis significantly reduce the chances of damage to surface structures if significant subsidence and fault activation do occur?

Difficulty of Accurate Prediction

Accurately predicting the potential and the amount and rate of subsidence that may accompany production of geopressured-geothermal fluids in the Brazoria County Chocolate Bayou prospect area is a complex problem. The problem is demonstrated in the case of the Wilmington oil field in California where subsidence prediction models were unsuccessful until the field had undergone 65 to 75 percent of its probable ultimate subsidence; the field subsided approximately 9 m (29 ft) in 27 years before subsidence was arrested by water injection programs (Allen and Mayuga, 1969).

A comparison of those factors which contribute to subsidence versus those which contribute to stability may help simplify the problem (table 2). Through this analogy process, one might conclude that the chances for subsidence in the Brazoria prospect area are high, on

TABLE 2. FACTORS TENDING TO INFLUENCE GEOTHERMAL SUBSIDENCE (FROM ATHERTON AND OTHERS, 1976) COMPARED TO FACTORS THAT CHARACTERIZE THE BRAZORIA COUNTY PROSPECT AREA

FACTOR TYPE (• major; φ minor)	FACTORS WHICH MAY CONTRIBUTE TO SUBSIDENCE SUSCEPTIBILITY	FACTORS WHICH MAY CONTRIBUTE TO SURFACE STABILITY	FACTORS CHARACTERIZING PROSPECT AREA
1. RESERVOIR FLUID			
• Phase	All-liquid	Vapor-liquid mixture (vapor dominated, to a lesser extent)	● Liquid dominated
Pressure	Geopressured (overpressured)	Low (below hydrostatic)	● Geopressured
Density	High	Low	● High
φ Dissolved Solids			High
φ Temperature			>300°F
2. PRODUCTION FLUID			
• Volumes	Large	Small	● Large
• Fluid levels[1]	Large drops, long time, extensive areas	No drops	?
• Pore pressures[1]	Large drops, long time, extensive areas	No drops	● Large drops, long time, extensive areas
Formation flashing	None	Extensive, continual flashing	?
3. GEOHYDROLOGY			
Natural recharge[1]	Low rates	High rates	?
4. RESERVOIR MATERIALS			
• Type	Sediments	Igneous or metamorphic	● Sediments
Predominant grain size	Coarse	—	Fine
Grain shape	Angular	Rounded	● Angular
Porosity - Primary	25-40%	Very low	Low
- Secondary	High	Low	● Secondary, 5-25%
• Consolidation/cementation	Unconsolidated, lacking cementation (loose or friable)	Consolidated, cemented	Cemented
• Preconsolidation[2]	None	Much	?
Hydrothermal alteration	Present	Absent	● Present
Admixed clay content (sorting)[3]			?
Admixed mineral content	High mica, montmorillonitic clays	None	● Mixed-layer illite and montmorillonite in shales
Age	Miocene and younger	Older than Miocene (22 million years)	Oligocene
• Thickness (in communication)	Great vertical section	Small vertical section	● Great vertical section
• Deformation properties[4]	Highly deformable	Slightly deformable	?
5. ASSOCIATED MATERIALS			
Type	Clays, siltstones, shales	Volcanic flows and shallow instructions	● Sandstones, shales, interbedded sandstones and shales of moderate thickness; intercommunication between sands impaired by shales
Occurrence	Many thin strata of large total vertical thickness, interbedded with reservoir materials but not impairing communication between them (less susceptible if distributed in few thick strata)		
6. RESERVOIR GEOMETRY			
Width/thickness ratio[5]	Large	Small	● Large (for several wells)
7. OVERBURDEN			
• Thickness	Small (<3000 ft)	Great	Great, >14000 ft
• Competence	Incompetence, unconsolidated sediments	Competent, consolidated	Possibly competent
• Deformation properties[6]	Highly deformable	Slightly deformable	?
Density	High	Low	Low
8. SITE GEOLOGY, STRUCTURE			
Folding	Gentle, broad, synclinal	Sharp, anticlinal (arched)	● Gentle broad synclinal
Flank dips	Less than 25°	Greater than 25°	● Less than 25°
Faulting	Normal, graben blocks	Reverse or thrust	● Normal, graben blocks
Fracturing	Much, recent	Little, old, sealed	?
Regional stresses	Tensional	Compressional	● Tensional
Stratigraphy			

[1] Depend(s) upon formation properties, which may be studied by preliminary well tests.
[2] Preconsolidated materials have previously experienced loads greater than their present load.
[3] If high pressures did not always accompany the presence of admixed clays in geopressured zones, they will be preconsolidated.
[4] Elastic constants, compaction coefficient, yield stress, etc.
[5] Of the producing zone.
[6] Can the overburden materials possible respond more slowly than the reservoir materials below.
● Characteristics similar to those listed in column 2.

the basis that over 60 percent of the factors that characterize the prospect area are similar to those factors which may contribute to the susceptibility of subsidence (table 2). Many of these factors, such as thickness of production interval and pressure declines, are major ones, but two factors that can have substantial influence and perhaps overriding control over other factors regarding potential for significant subsidence in the area of Chocolate Bayou are: (1) the amount of cementation in reservoir sands and in overburden sands, and (2) the depth from which production will occur which determines the overburden thickness.

The importance of these two positive factors--cementation and overburden--has been noted by Allen and Mayuga (1969) who state that in addition to a decline in reservoir fluid pressures, the following conditions are necessary for subsidence (of the Wilmington type):

1. "The reservoir rocks must be compactable (uncemented) and unable to effectively resist deformation upon transfer of load from the fluid phase to the grain to grain contacts."
2. "The overburden must lack internal self support and be of such a nature as to easily (deform) downward and supply a constant load to the underlying formation."

<u>Cementation of Reservoir Sands</u>

The degree of cementation has a significant influence over reservoir compaction and ultimately subsidence. According to Allen and Chilingarian (1975), cementation is by far the single most important factor controlling (limiting) mechanical sand compaction. Without significant compaction in the sands in the prospect area, subsidence would be dependent on compaction of mudstone (shale) associated with the producing sand reservoirs. This may be an important consideration because below depths of about 300 m, as pore fluid pressure is reduced, sands may compact more than shales (Allen and Chilingarian, 1975). In the Wilmington field, cumulative compaction was 67.6 percent in the sands and 32.4 percent in the shales (siltstones) (Allen and Mayuga, 1969). The sands, however, were not cemented.

In the area of detailed analysis, the net thickness of sandstone within the proposed production interval (the total interval which is about 730 m (2400 ft) thick includes interbedded shales) is expected to be approximately 225 m (840 ft); these sandstones apparently have undergone a rather complex history of cementation, leaching, and recementation at moderate to intermediate and geopressural depths as noted below (Bebout and others, 1978).

The area of detailed analysis lies between two regions that can be characterized by differences in depositional and compactional histories that were operative during and after the time (Oligocene) the prospective reservoir sands (Frio Formation) were deposited (Bebout and others, 1978). One area to the west and southwest, south of Danbury Dome, has a history of rapid sedimentation and accompanying subsidence which resulted in little early cementation and relatively complete compaction by burial of sediment. The other area to the northeast (Chocolate Bayou oil and gas field) has less rapid sedimentation and subsidence, instituting a longer period of early cementation which inhibited complete sediment compaction. Later periods of leaching and cementation ended in higher porosities and permeabilities in the reservoir rocks to the northeast where sediment accumulation was less rapid and compaction less complete than to the west where sands became well compacted and cemented yielding much tighter reservoir rocks with lower porosities and permeabilities. Characteristics of the prospective geopressured-geothermal reservoir sandstones, expectably, lie somewhere in between characteristics of sandstones in these two opposing areas.

Some of the changes in reservoir properties regarding secondary-leached porosity have occurred after the sands were under geopressured condition. This (geopressured condition) may be a particularly important factor because secondary pore spaces produced under geopressured conditions could be maintained by the abnormal pore fluid pressures which counteract effective stress (grain to grain stress caused by the overburden) thereby preventing closure or deformation of the pore spaces. Furthermore, late stage cementation that has occurred includes (in addition to Fe-rich carbonates) precipitation of the clay mineral--kaolinite, which may fail as effective stress is increased. Thus, even if reservoir sands are moderately-well cemented, it is possible that alterations under hydrothermal and geopressured conditions, coupled with locally incomplete grain to grain cementation, may leave "room" for compactional deformation in sandstones when fluid pore pressures are reduced. Until cores have been taken and detailed compressibility tests conducted, the question about cementation and compactional deformation cannot be adequately answered.

Overburden

Thickness. The depths, -4,115 to -5,030 m (-13,500 to -16,500 ft) (Bebout and others, 1978), from which geopressured-geothermal fluids will be produced in the prospect area, far exceed the production depths of most areas that have subsided in response to fluid withdrawal (tables 3 and 4). The importance of overburden thickness in resisting subsidence is noted by Atherton and others, 1976:

> "Two factors contribute to the significance of overburden thickness in determining the amount of reservoir compaction which is expressed at the surface as subsidence. In terms of engineering mechanics, the structural resistance to bending of a slab or disc representing the overburden is proportional to the cube of its thickness (Timoshenko and Woinowsky-Krieger, 1959). Thus, a very small increase in overburden thickness substantially reduces its tendency to deform. Second, expansion may occur within the overburden to compensate for the contraction of the reservoir materials (Allen, 1968). The thicker the overburden, the less

TABLE 3. MAXIMUM SUBSIDENCE AND PRODUCTION DEPTHS FOR PETROLEUM, GROUND WATER, AND GEOTHERMAL SUBSIDENCE AREAS

(Modified from Atherton and others, 1976)

Ground Water Subsidence Areas		
	Maximum Subsidence	Production Depth
San Joaquin Valley California	9.15 m	90-900 m
Santa Clara Valley California	4 m (1969)	50-300 m
Houston-Galveston Texas	1-2 m (1969)	50-600+ m
Denver Colorado	.4 m (1962)	?-760 m
Ely-Picacho Arizona	2.3 m (1969)	100-300+ m
Las Vegas Nevada	1 m (1969)	60-300? m
Savannah Georgia	.2 m (1969)	
Baton Rouge Louisiana	.3 m (1969)	40-900(?)
Osaka Japan	3-4 m (1969)	10-200? m
Mexico City Mexico	8 m (1969)	chiefly 10-50m
Taipei Basin Taiwan	1 m (1969)	30-200?
London England	.7 ft ?	90-? (1969)

Petroleum Subsidence Areas		
	Maximum Subsidence	Production Depth
Wilmington California	8.8 m (1928-1970)	600-2,300 m (most 600-1,100 m)
Long Beach California	.75 m (1925-1967)	median 1,690 m
Inglewood California	1.73 m (1911-1963)	median 900 m
Huntington Beach California	1.22 m (1933-1965)	median 930 m
Goose Creek Texas	1 m (1918-1925)	200-1,400 m
Lake Maracaibo Venezuela	.3-3.3 m (1926-1954)	
Po Delta Italy	~2 m	? (one well~700 m)
Nigata Japan	.8 m (1900-1960)	?-1,000 m

Geothermal Subsidence Areas		
	Maximum Subsidence	Production Depth
Wairakei New Zealand	4.7 m (1956-1974)	150-1,360 m
Broadlands New Zealand	.175 m (1969-1975)	430-1,200 m
Kawerau New Zealand	.028 m (1970-1971)	460-915 m

Proposed Production Depth of Geopressured-geothermal Test Well: -4,300 to -5,030 m

TABLE 4. LAND SUBSIDENCE AND SURFACE FAULTING ASSOCIATED WITH OIL AND GAS FIELDS, HARRIS COUNTY, TEXAS*

(From Kreitler, 1977b)

Field No.	Field Name	Producing Horizon (m)	Total Production (10^6bbl)	Subsidence (m)	Faulting (m)
1	South Houston	1,460	39.3 (1974)	0.3 (1942-1958)	0.45 (1972)
2	Clinton	915-2,134	2.7 (1974)		0.7 (1972)
3	MyKawa	1,483-2,645	4.1 (1974)	0.5 (1942-1973)	0.5 (1942-1973)
4	Blue Ridge	1,420-2,381	21.0 (1974)	0.2 (1942-1973)	0.15 (1966-1972)
5	Webster	1,481-2,564	41.3 (1974)		0.45 (1942-1975)
6	Goose Creek	200-1,400	60.3 (1926)	1.0 (1917-1926)	0.43 (1917-1926)

* Harris County is adjacent to and northeast of Brazoria County.

compaction is likely to be transmitted to the ground surface."

The purpose of tables 3 and 4 is not to imply that production depth is the controlling factor over subsidence susceptibility, but to point out that fluid production in the prospect area will be from reservoirs more than twice the depth of those reservoirs associated with subsidence listed in the tables.

The additional overburden, more than 2000 m, should be influential in limiting the amount and rate of subsidence but apparently will not necessarily prevent it. Gustavson and Kreitler (1976) note that over the Chocolate Bayou oil and gas field (north of the prospect area), where production is from -2438 to -3962 m, the surface has undergone more than 0.3 m of subsidence. The subsidence appears to be associated primarily with gas production from geopressured sediments (fig. 7). This is the same geopressured-geothermal fairway from which the test well will produce at a down dip location. One difference between these two areas is that reservoir porosities are expected to be lower in the prospect area than in the Chocolate Bayou oil and gas field (Bebout and others, 1978). The lower porosities, although detrimental in terms of fluid production, are beneficial in terms of mitigating compaction and subsidence.

<u>Cementation in the Overburden</u>. In addition to the positive factor of having a thick overburden, the amount of cementation in overburden sands at moderate to intermediate depths may help prevent

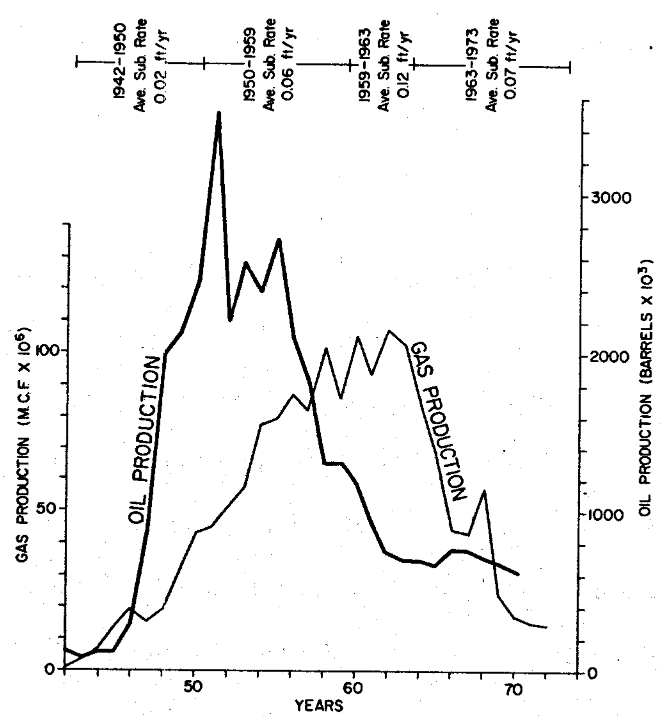


Figure 7. Comparison of rates of subsidence to oil and natural gas production from Chocolate Bayou oil field between the years 1942 and 1973. Production rates of oil and gas from the Railroad Commission of Texas. (From Gustavson and Kreitler, 1976)

deformation and subsequent translation of reservoir compaction into surface subsidence. Bebout and others (1978) note that precipitation of calcite and quartz has reduced porosity to less than 5 percent in sands at shallow to intermediate depths. This high degree of cementation should provide relatively rigid sedimentary layers above the production zone.

The factor that will counteract and perhaps override the resistance to deformation by well-cemented overburden sedimentary layers is the presence of growth faults which are planes of weakness in the prospect area (fig. 5).

Possibility of Subsidence Based on Expected Reservoir Characteristics

According to Geertsma (1973, p. 735), "a sizable degree of compaction can be expected even in hard rock for the particular conditions of large pore-pressure reductions and a sufficiently large producing interval." The amount of reservoir compaction that is translated to the surface as subsidence, however, must also be related to the production depth and the radius of the production zone. To estimate the order of magnitude of subsidence resulting from reservoir sand compaction that may accompany geopressured-geothermal fluid production from a single test well, the following equations from Geertsma (1973) were used:

$$u_z\,(r, o) = -\,2\,c_m\,(1-\nu)\,\Delta_p\,H\,A\,(\rho, \eta) \qquad (1)$$

where u_z = vertical displacement; z = vertical coordinate

r = radius from the vertical axis through the nucleus

c_m = uniaxial compaction coefficient

ν = Poisson's ratio

Δ_p = pore (reservoir) pressure reduction

H = height of production interval

A = $R \int_0^\infty J_1\,(\alpha R)\,J_0\,(\alpha r) e^{-D\alpha}\,d\alpha$ for ranges of values ρ and η

ρ = r/R

η = D/R

R = reservoir radius

D = depth of burial

and $$c_m = \tfrac{1}{3}\,\frac{(1+\nu)\,(1-\beta)c_b}{(1-\nu)} \qquad (2)$$

where c_m = uniaxial compaction coefficient

ν = Poisson's ratio

c_r = rock matrix compressibility

c_b = rock bulk compressibility

β = c_r/c_b

Values used to solve equation 2 are as follows: Poisson's ratio, 0.25 (Geertsma, 1973); rock matrix compressibility (quartz) $0.18X10^{-6}$ psi^{-1} (Gardner and others, 1974); and rock bulk compressibility, $1.2X10^{-5}$ psi^{-1} (estimated value for sandstone in geopressured zone, Gregory, 1977). Substituting these values into equation 2 yields a uniaxial compaction coefficient of $6.58X10^{-6}$ psi^{-1}.

To solve equation 1, the following estimated values (from Gregory, 1977) which characterize the prospect area are used in conjunction with the uniaxial compaction coefficient (c_m) as shown above, and a value for A as determined from Geertsma's (1973) tables (approximately 0.17 when r/R = 0 and D/R = 1.5):

Δ_p = 275 psi (after 2 year production period)*

Δ_p = 340 psi (after 5 year production period)*

H = 840 ft (net sand thickness within proposed perforated interval)

R = 10,500 ft

D = 15,300 ft (mean depth of perforated interval between - 14,100 and - 16,500 ft)

*Reservoir pressure declines (Δp) of 275 psi and 340 psi, representing 2-year and 5-year production periods, respectively, are substantially lower than the Δp's of 428 and 708 used in subsidence calculations for the initial draft report submitted in November, 1977 (White and others, undated). The new pressure decline figures from Bebout and others, 1978, reflect a correction in reservoir drainage areas used in the reservoir similation program. Original pressure decline values were based on a drainage area of 4 sq. miles (see Gregory, 1977) which was corrected to 16 sq. miles in the final program (Bebout and others, 1978). The change in reservoir pressure substantially reduces the estimates on subsidence resulting from compaction of sandstone. The original estimates of subsidence were 18.3 cm and 30.7 cm after 2 years and 5 years of fluid production, respectively.

The following amounts of surface subsidence from sand compaction at the site of the test well are indicated by solving equation 1: 11.9 cm (4.7 in) after two years of fluid production and 14.7 cm (5.8 in) after a five year period of production. The rate of subsidence for the 5-year period is about 3cm/yr (0.1 ft/yr); the rate of subsidence attributed to gas production from the geopressured zone in the Chocolate Bayou oil and gas field north of the test well site is 3.7 cm/yr (0.12 ft/yr) for a comparable period (1959-1963) (Gustavson and Kreitler, 1976).

It should be emphasized that many assumptions were made with respect to both the above equation and the values used in solving it. Some of the assumptions inherent in the equation were noted by Geertsma (1973) and include: (1) a disc-shaped reservoir, (2) uniform pressure reduction throughout the reservoir, and (3) homogeneous deformation with respect to the reservoir and its surroundings. Nevertheless, in theory, the equation provides a method for estimating the potential magnitude of subsidence related to reservoir sand compaction by using parameters relevant to geopressured fluid production, such as potentially large declines in pore pressure, relatively thick production intervals, a large drainage radius, and deep production zones.

Although not considered in the above calculations, potential subsidence accompanying compaction of shales interbedded with reservoir sandstones could be more significant than that associated with reservoir sands. In a theoretical treatment of geothermal fluid production from geopressure zones in Kenedy County, Texas, Gustavson and Kreitler (1976) estimated subsidence resulting from potential mudstone compaction to range from 0.3 m to 6.3 m for pressure declines of 100 to 500 psi; the net thickness of mudstone used in estimating the maximum value of subsidence (6.3 m) was 146 m. The net thickness of shale (mudstone) within the proposed perforated interval of the test well may be as much as 400 m (Gregory, 1977). With such a large sequence of shale, subsidence accompanying shale compaction could be critical.

Although there are many uncertainties, perhaps the single most important indicator that some subsidence will occur as pore pressures are reduced in the Chocolate Bayou geopressured reservoir is that subsidence has already occurred with fluid (gas) production from the same geopressured fairway updip to the northeast in the Chocolate Bayou oil and gas field (Gustavson and Kreitler, 1975).

Location of the Test Well in Terms of Potential Subsidence and Fault Activation

As previously mentioned, surface facilities in the Brazoria County prospect area that could be adversely affected by subsidence (which can increase the extent of flooding by fresh and salt water) and by fault activation (which can have a direct effect on various structures) include two petrochemical plants, numerous pipelines, a community development along Chocolate Bayou, paved roads and railroad tracks (see discussion of current land use). But the question that remains is: if subsidence and fault activation do accompany geopressured fluid production, can varying the location of the test well within the area of detailed analysis reduce the potential impact to the surface facilities?

In most cases, subsidence bowls produced by subsurface fluid withdrawal are centered around areas of maximum production; the Wairakei geothermal field in New Zealand is a notable exception (Atherton and others, 1976). The size of the bowl is affected by many variables.

Using equation 1 (presented on a preceding page), theoretically it is possible to determine variations in the amount of subsidence for given distances from the test well by varying r (the radius from the vertical axis through the nucleus). Table 5 shows how the amount of subsidence may vary depending on the horizontal distance from the test well. If the test well is located along the western extremes of the area of detailed analysis, distances between the well and the nearest petrochemical plant and the well and the western edge of community development along Chocolate Bayou would be approximately 4.8 km (3 mi) and 3 km (1.9 mi), respectively. If the test well is located on the east side of the Bayou, maximum distances from the petrochemical plant and from the community development would be approximately 1.5 km (1 mi). According to table 5, there are definite differences in expected subsidence with respect to the relevant distances. The theoretical treatment is complicated, however, by the possibility that subsidence may be compartmentalized by faults which affect fluid migration and pressure declines, and by the possibility of higher amounts of subsidence than shown in the table.

Although it is impossible to know how much the potential impact of subsidence and fault activation can be mitigated by location of the test well at the western extremes of the area of detailed analysis, the western area would still have to be first choice when

TABLE 5. ESTIMATED SUBSIDENCE ACCOMPANYING RESERVOIR SAND COMPACTION AT SELECTED DISTANCES FROM THE TEST WELL AFTER FIVE-YEAR PRODUCTION PERIOD

Determined from equation 1 (see text) by varying r (radius from vertical axis through nucleus)

Distance from Test Well (radius from vertical axis through nucleus)		Estimated Subsidence	
Miles	Kilometers	Inches	Centimeters
0.	0.	5.8	14.7
0.4	0.64	5.7	14.5
0.8	1.29	5.6	14.2
1.2	1.93	5.1	13.0
1.6	2.57	4.7	11.9
2.0	3.22	4.1	10.4
2.4	3.86	3.6	9.1
2.8	4.51	3.0	7.6
3.2	5.15	2.5	6.4
3.6	5.79	2.0	5.1

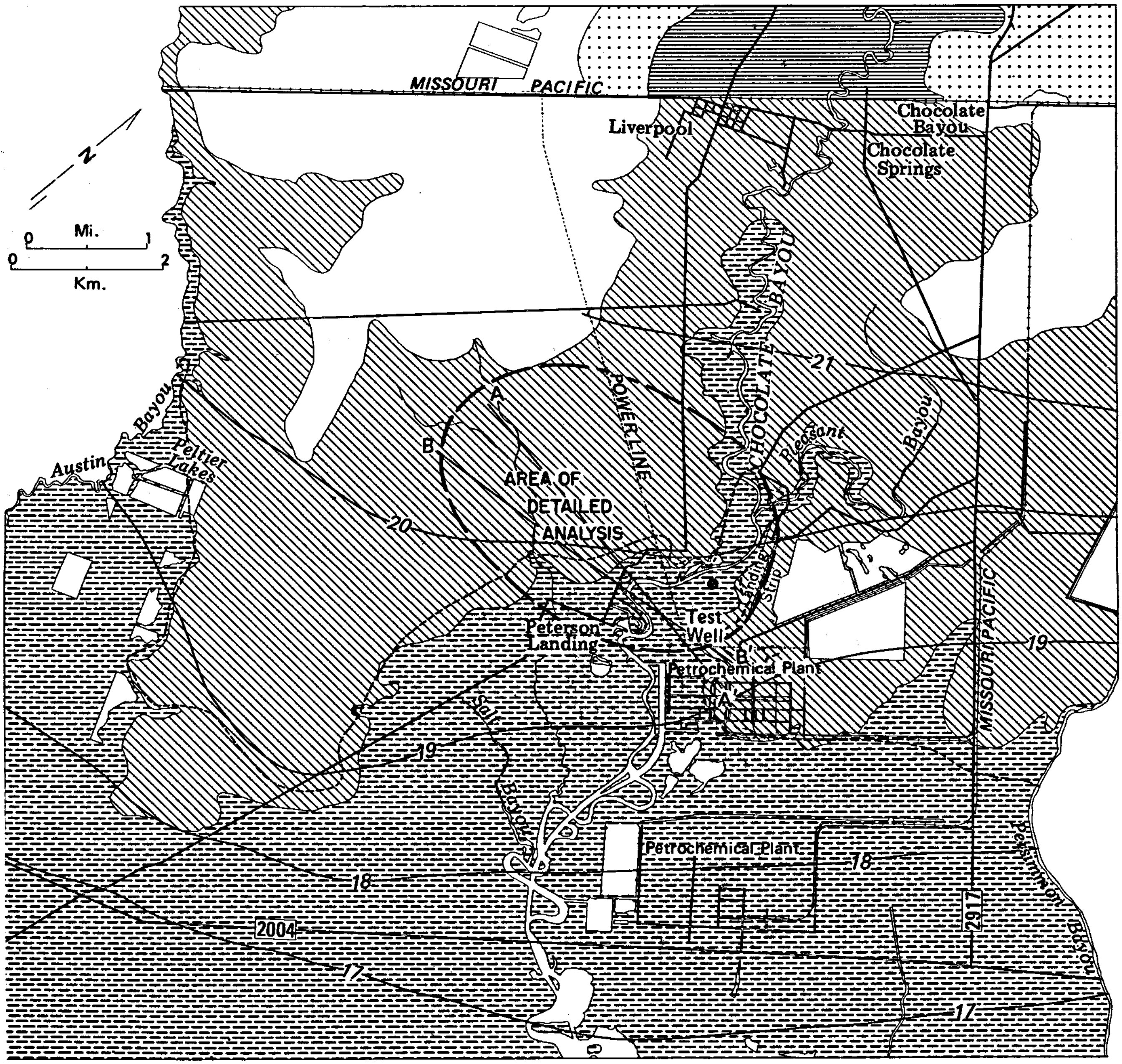
considering the potential subsidence and fault activation that may accompany geopressured-geothermal fluid production from a single test well. Wherever the well is located, however, the possibility of subsidence coupled with the presence of growth faults, when viewed in the context of current land use, emphasize the need to institute detailed monitoring programs (including precise leveling and seismic monitoring surveys) before and during the time of production of geopressured-geothermal fluids.

FLOOD POTENTIAL--BRAZORIA COUNTY PROSPECT AREA

Relatively large portions of the Brazoria County prospect area are susceptible to inundation by flood waters along bayous that drain the area and by salt-water flooding associated with hurricane storm surge (fig. 8). The extent and levels of inundation accompanying periods of flooding and possible effects on the location of the geopressured test well and support facilities, were determined from reports and/or maps on: (1) flooding along Chocolate Bayou north of the Missouri Pacific Railroad (U. S. Army Corps of Engineers, 1971), (2) flood hazard boundary maps for Brazoria County (Federal Insurance Administration), and (3) flooding associated with Hurricane Carla (U. S. Army Corps of Engineers, 1962; Fisher and others, 1972).

Potential for Fresh-water Flooding along Chocolate Bayou

Precipitation records, runoff, historical and current flood levels, and other relevant data indicate a potential for extensive flooding along Chocolate Bayou (U. S. Army Corps of Engineers, 1971). The bayou has a total drainage area of about 407 km^2 (159 mi^2). Discharge data from a U. S. Geological Survey gaging station along Chocolate Bayou near Alvin Texas, indicate that flood stages in excess of 20 ft have occurred 7 times during the period of record (table 6).



EXPLANATION

Standard Project Flood*	Area of "100-year" flood, includes area flooded by Hurricane *Carla*
Intermediate Regional Flood* (equivalent to "100-year" flood)	—20— Base flood elevation line with elevation in feet
Approximate area of storm-surge tidal flooding by Hurricane *Carla*	------- Line delineating areas of 100-year coastal flooding with velocity (wave action); velocity hazard applies to areas gulfward (southeast) of line.

*Shown only above Missouri-Pacific Railroad at top of map.

Figure 8. Areas susceptible to flooding in the Brazoria County prospect area. (Modified from U. S. Army Corps of Engineers, 1962, 1971; Federal Insurance Administration flood hazard boundary maps; and Fisher and others, 1972) (Surface water features can be identified by referring to figure 13.)

TABLE 6. THE HIGHEST FLOODS IN ORDER OF MAGNITUDE FOR CHOCOLATE BAYOU NEAR ALVIN, TEXAS

(From U. S. Army Corps of Engineers, 1971)

Order No.	Date of Crest	Gage Heights Stage feet	Gage Heights Elevation feet, msl	Estimated Peak Discharge cfs
1	July 14, 1939	22.90 (1)	33.21	11,500 (2)
2	October 8, 1949	21.80	32.11	7,400
3	March 18, 1957	20.60	30.91	4,280
4	June 24, 1968	20.52	30.83	4,160
5	October 16, 1957	20.47	30.78	4,100
6	June 19, 1961	20.37	30.68	3,970
7	July 12, 1961	20.00	30.31	3,510
8	September 13, 1961	19.94	30.25	3,460
9	August 27, 1959	19.85	30.16	3,370
10	November 14, 1961	19.48	29.79	3,050

(1) Estimated from flood mark.

(2) Estimated by Corps of Engineers.

General flood characteristics of Chocolate Bayou are shown in table 7. Although these characteristics were determined for an area upstream from the map area, they provide an approximate assessment of conditions that may be expected in the Brazoria County prospect area during periods of fresh-water flooding.

Land that would be inundated by Intermediate Regional Floods and Standard Project Floods (U. S. Army Corps of Engineers, 1971) are

TABLE 7. GENERAL FLOOD CHARACTERISTICS OF CHOCOLATE BAYOU

(Compiled from U. S. Army Corps of Engineers, 1971)

Flood Seasons	Spring and summer (intense local thunderstorms of short duration--past flooding has occurred mostly during these times)
	Winter-general storms extending over periods of several days
	June-Oct.--Tropical disturbances that may produce torrential rainfall
Flood Velocities During Major Storms	
Channel	0.8 m/sec (2 mi/hr) in unobstructed reaches
Floodplain	0.3 m/sec (0.7 mi/hr) generally, although varies widely
Duration	Commonly several days due to flat terrain and small conveyance capabilities
Rate of Stage Change from Bankfull to Extreme Flood Peak	About 2 days following intense rainfall

shown along the upper margin of the flood hazard map (fig. 8). Intermediate Regional Floods are those that have a recurrence interval of about once in every 100 years. It is possible, though, for a "100-year" flood to occur during any year and even during successive years. The flood that occurred along Chocolate Bayou in 1939, (table 6) was about 0.15 m (0.5 ft) lower than the computed Intermediate Regional Flood (U. S. Army Corps of Engineers, 1971).

The Standard Project Flood as defined by the U. S. Army Corps of Engineers represents the "flood that can be expected from the most severe combination of meteorological and hydrological conditions considered reasonably characteristic of the geographical area in which the drainage basin is located, excluding extremely rare conditions." Assumptions with respect to storm rainfall used to estimate the extent of the Standard Project Flood at the Chocolate Bayou gaging station are: 20.0 cm (7.88 in) of rainfall in three hours, 29.9 cm (11.76 in) in six hours, 53.0 cm (20.86 in) in 24 hours, and a total of 65.2 cm (25.68 in) in 96 hours (U. S. Army Corps of Engineers, 1971). Flood levels expected during the Standard Project Flood are approximately 0.6 m (2 ft) above levels of the 1939 flood (table 6).

The areal extent of the Intermediate Regional Flood and the Standard Project Flood upstream from the Missouri Pacific Railroad (fig. 8) (railroad marks lower limit of area studied by Corps of Engineers) indicates the probability of significant fresh-water flooding downstream in the area of detailed analysis during such floods. Estimated levels of flooding in the prospect area, however, cannot be adequately treated without also considering floods associated with hurricanes.

Potential for Storm-Surge Tidal Flooding during Hurricanes

The Brazoria County prospect area lies within an area along the coastal zone that is susceptible to storm-surge tidal flooding during passage of tropical storms and hurricanes. Destructive hurricanes can be expected to make landfall along the Texas Coast on the average of about once every three years (Bodine, 1969). Hurricane frequency studies by Simpson and Lawrence (1971), indicate that for an 80 km (50 mi) segment of the Gulf shoreline that centers approximately on Chocolate Bay, the probability (percentage) that a tropical storm, hurricane or great hurricane will occur in any one year is as follows:

All tropical cyclones (Winds 40 mph or higher)	18%
All hurricanes (Winds 74 mph or higher)	14%
Great hurricanes (Winds greater than 125 mph)	4%

The earliest and latest dates of tropical cyclones making landfall within the 80 km (50 mi) segment of shoreline that centers on Chocolate Bay, are June 17 and October 17 (Simpson and Lawrence, 1971).

Although hurricane winds can be extremely damaging, even more destructive with respect to man and his activities along the coastal zone, are storm-surge tides that accompany passage of a hurricane. Hurricane Carla which made landfall near Port O'Connor (approximately 160 km (100 mi) southwest of the Brazoria County prospect area) in 1961, flooded about 1.7 million acres of coastal land, including entire communities, and caused damage in excess of $408 million

(U. S. Army Corps of Engineers, 1962). The level of storm surge flooding associated with Carla reached a high of about 6.7 m (22 ft) above mean sea level at Port Lavaca, on Lavaca Bay, southwest of Brazoria County. In Chocolate Bay maximum surge elevations associated with Carla were about 5 m (17 ft) (Reid and Bodine, 1968). The high still-water elevation determined for one point near Peterson Landing was 4.5 m (14.7 ft) (U. S. Army Corps of Engineers, 1962). The approximate areal extent of land inundated by Carla in the Brazoria County prospect area is shown in figure 8. Flooding would have been much more extensive had Carla made landfall at a point nearer Chocolate Bay.

Because torrential rainfall can accompany hurricane passage and aftermath storms, (rainfall associated with Hurricane Beulah was in excess of 76 cm (30 in) for a 4 to 5 day period; Brown and others, 1974), the most extensive flooding along coastal areas may result from a combination of fresh-water flooding along streams and bayous and salt-water flooding by storm surge. To determine flood levels and the extent of inundation expected with a recurrence interval of about 100 years (based on statistical probability), Federal Insurance Administration flood hazard boundary maps of Brazoria County were used. The areal extent and levels of flooding expected during such events (100-year floods) for the Brazoria County prospect area are depicted in figure 8.

Selection of Test Well Site on the Basis of Flood Potential

Land surface elevations (as indicated by U. S. Geological Survey topographic maps) in the area of detailed analysis range from a high of about 6 m (20 ft) above mean sea level along the western margin of the area to less than 1.5 m (5 ft) along Chocolate Bayou. Maximum elevations on the east side of the Bayou in the area of detailed analysis are slightly in excess of 4.5 m (15 ft).

A comparison of land surface elevations with flood level elevations expected during 100-year floods suggests that the minimum depth of flooding would be about 0.2 m (0.5 ft) on the west side of Chocolate Bayou in the area of detailed analysis as compared to a minimum of about 1 m (3.3 ft) on the eastern side (fig. 9). Furthermore, almost all of the area of detailed analysis on the east side of Chocolate Bayou was inundated by Hurricane Carla, whereas over 60 percent of the land in this area on the west side of the bayou was not affected. The area flooded by Carla correlates closely with areas designated zone "V" on Federal Insurance Administration flood hazard boundary maps. The "V" designation identifies areas affected by a "100-year coastal flood with velocity (wave action)." Flood insurance rates in areas designated zone "V" are substantially higher than in areas designated zone "A" which also lie within 100-year flood zones but are not affected by the "velocity" hazard.

In the area of detailed analysis, the most suitable site for the test well in terms of flood potential, or more precisely, in terms of

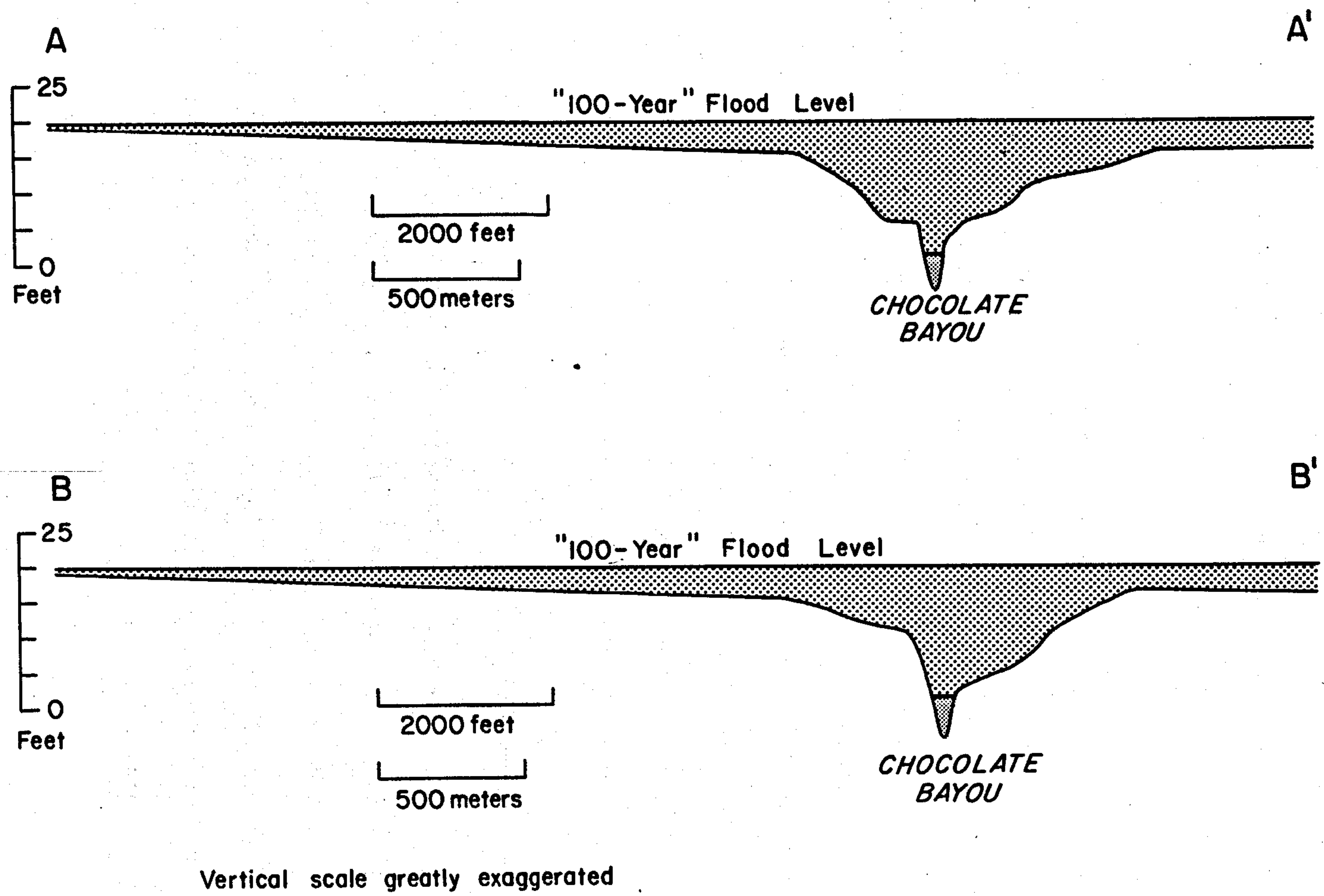


Figure 9. Cross sections indicating 100-year flood levels along lines A-A' and B-B' (fig. 8) in the area of detailed analysis.

avoiding flood-prone areas, is along the western margin where high land surface elevations would afford some degree of natural flood protection for the test well and surface support facilities. Location of the test well and support facilities on the east side of Chocolate Bayou will require implementation of flood protection measures including the placement of surface facilities on land with naturally high elevations and the construction of dikes. Surface elevations at the site of the proposed test well as shown in figure 8, range from about 1.8 to 3.4 m (6-11 ft) according to U. S. Geological Survey topographic maps. Recent leveling data show that the staked location of the well is at an elevation of 2.5 m (7.9 ft) above mean sea level. Levels of inundation during the 100-year flood at this site would range approximately between 2.4 and 4 m (8 and 12 ft).

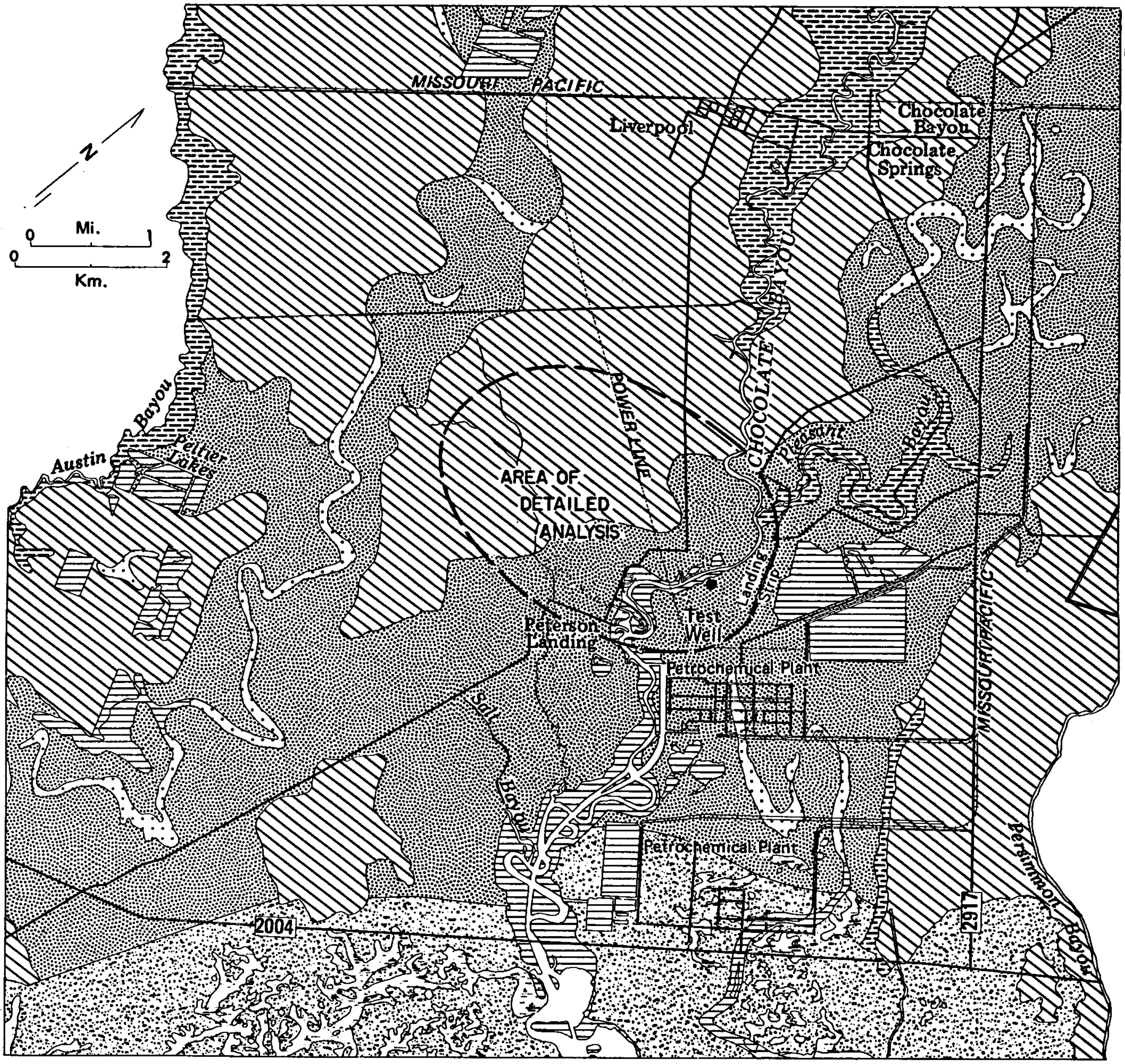
SUBSTRATE LITHOLOGY AND SOILS

Knowledge of shallow substrate lithology and soils helps to differentiate areas on the basis of factors such as permeability, potential for ground-water recharge, expansive clays, corrosivity, and drainage characteristics, which in turn aid in evaluating possible problems associated with construction and geopressured fluid handling and disposal activities.

The Brazoria County prospect area lies within a Pleistocene fluvial-deltaic system composed of: (1) distributary and fluvial sands and silts, including levee and crevasse splay deposits, (2) interdistributary mud including bay and flood-basin facies, (3) marine deltaic sand that is reworked and locally veneered by thin marsh and lacustrine mud, and (4) mud-filled abandoned channels and tidal creeks (fig. 10) (Fisher and others, 1972). Modern-Holocene features, present in the map area include: (1) tree-covered areas of alluvium, sand, silt, and mud along active headward-eroding streams, (2) mud filled and locally marsh covered abandoned channels and courses, and (3) marshes primarily along bayous and around natural ponds.

Areas underlain by substrates composed of sand and silt such as those associated with distributary and fluvial channel sands and silts and marine deltaic sands, are considered potential ground-water recharge areas because of moderate to high permeabilities that characterize the sands. Areas underlain by interdistributary and flood-basin muds are much less permeable because of the high clay content. The clay content can create problems for man-made structures because of high shrink-swell potentials.

To provide a more detailed look at expected surface conditions with respect to permeability, shrink-swell potential, corrosivity and other factors, a soils map was constructed from unpublished soils maps prepared by the United States Department of Agriculture Soil Conservation Service (fig. 11). Characteristics of various soil series that occur in and near the area of detailed analysis are summarized in table 8.



EXPLANATION

- Distributary and fluvial sands and silts, including levee and cravasse splay deposits
- Interdistributary mud, including bay and floodbasin facies
- Marine deltaic sand, delta front and reworked delta facies; may be veneered by thin marsh or lacustrine mud
- Abandoned channel and course, mud filled
- Tidal creek, fresh to brackish-water marsh-covered, mud-filled
- Small active headward-eroding streams, tree-covered, alluvium, sand, silt, mud, alluvium absent locally
- Undifferentiated reservoirs, ponds, spoil, fresh to brackish marsh, mud and local sand substrate

Figure 10. Environmental geologic map of the Brazoria County prospect area. Map units depicted are Pleistocene to Recent. (Modified from Fisher and others, 1972)

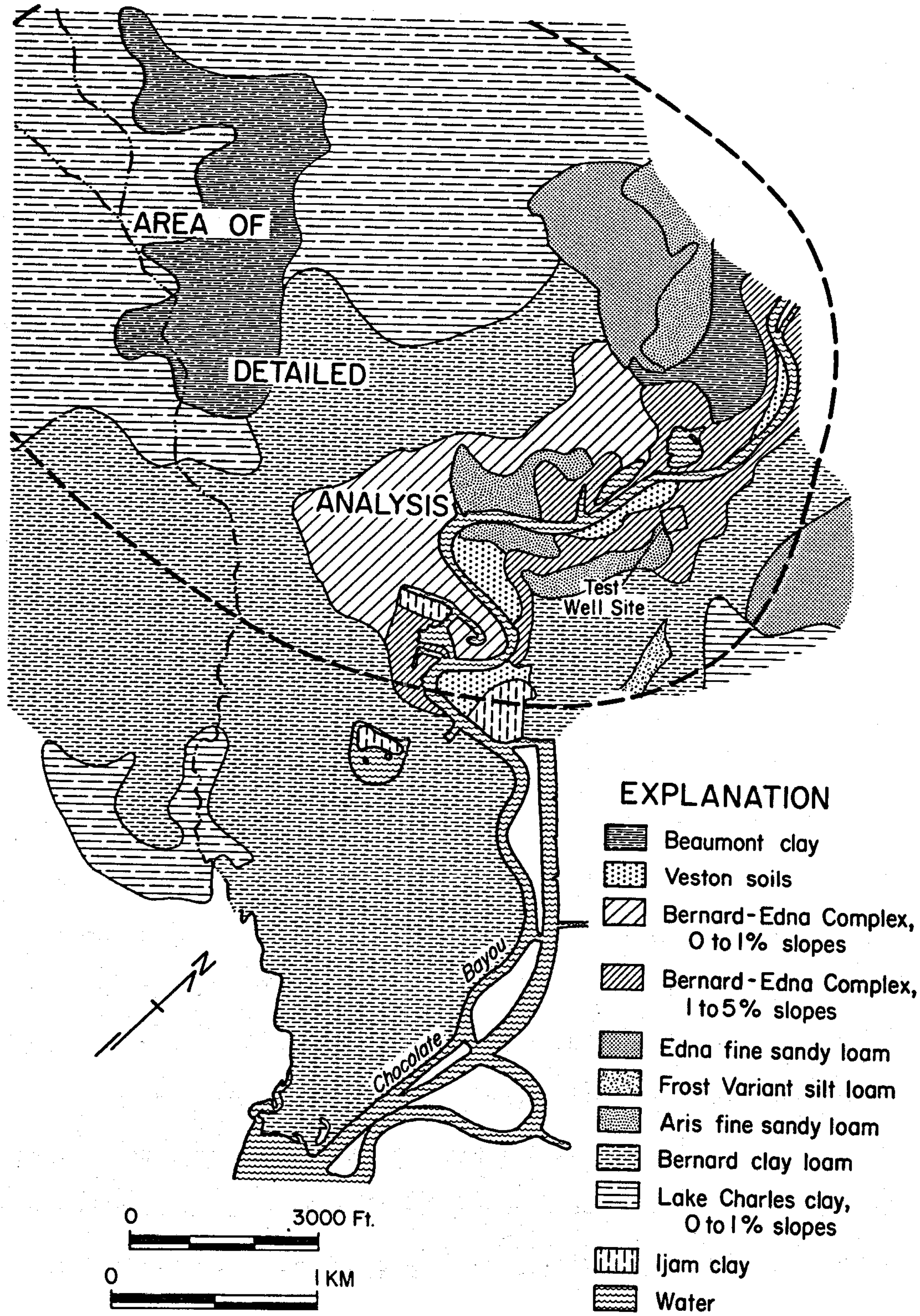


Figure 11. Distribution of soils in the vicinity of the Brazoria County prospect area. (Modified from U. S. Department of Agriculture, Soil Conservation Service, unpublished maps)

Selection of Test Well Site on the Basis of Substrate Lithology and Soils

Interdistributary and flood-basin muds underlie the western half of the area of detailed analysis; the eastern half, which includes a portion of Chocolate Bayou, is dominated by fluvial and distributary sands and silts, and locally marshes with muddy substrates (fig. 10). In terms of lithology as indicated by these map units, the more permeable substrates, which are potential ground-water recharge areas, lie along both sides of Chocolate Bayou. Discharged (whether by accident or design) hypersaline geopressured-geothermal waters would more likely enter shallow ground-water aquifers in these areas of higher permeability than in areas underlain by impermeable to low permeability mud. Thus, containment of inadvertently discharged fluids could best be realized within the western half of the area of detailed analysis where interdistributary and flood-basin muds occur. Evaluation of permeabilities associated with various soils mapped in the area, however, indicates relatively low permeabilities for most of the soils at depths of approximately 70 to 150 cm (28 to 60 in). These low-permeability soil zones will offer some protection to ground water because they will inhibit infiltration of potentially harmful fluids. Evaluation of possible test well sites with regard to permeability and potential ground-water recharge is also treated in an analysis of ground-water resources in a later section.

Clay-rich soils such as the Lake Charles clay, Bernard clay loam and Beaumont clay which characterize much of the area (fig. 11), have high shrink-swell potentials. Expansive clay soils such as these can cause damage to surface and near surface facilities such as paved roads, buildings, power lines, and buried pipelines (Gustavson, 1975). By locating surface support facilities on fine sandy loams of the Aris series (fig. 11), some degree of protection against expansive soils should be realized. At depths below 71 cm (28 in), however, clay content increases in the Aris series, resulting in higher shrink-swell potentials than at the surface (table 8). Corresponding with the increase in clay content is a decrease in permeability and internal drainage which can produce a shallow perched water table and, subsequently problems for construction activities. Because of the extent of expansive soils (fig. 11, table 8), the use of engineering techniques may be more appropriate in mitigating damage from soils with high shrink-swell potentials, than trying to locate surface support facilities on naturally stable soils. Current engineering techniques employed to reduce damage to surface structures include using lime in subbase material for surface stabilization, and reinforcing concrete slabs with steel bars or post-tension cables (Gustavson, 1975).

All soils in the area of detailed analysis have high corrosivity with regard to steel (table 8). Soils of the Ijam and Veston series have high corrosivity with respect to concrete. These two soils can easily be avoided because of their limited areal extent along Choco-

TABLE 8. GENERAL CHARACTERISTICS OF SOILS

IN THE VICINITY OF THE BRAZORIA COUNTY PROSPECT AREA

(Compiled from descriptions of soil series established by U. S. Department of Agriculture Soil Conservation Service)

SERIES	DEPTHS (inches)	LITHOLOGY	SLOPES	PERMEABILITY (inches/hour)	SOIL REACTION (pH)	SALINITY (MMHOS/cm)	SHRINK-SWELL POTENTIAL	CORROSIVITY STEEL	CORROSIVITY CONCRETE	HIGH WATER TABLE DEPTH (ft)	HIGH WATER TABLE KIND	HIGH WATER TABLE MONTH
Aris fine sandy loam	0-21	fine sandy loam	mainly less than 1% but up to 3%	0.6-2.0	5.6-7.3		low	high	moderate	0-2	perched	Nov-Mar
	21-28	sandy clay loam		0.2-0.6	5.1-6.5		moderate	high	moderate			
	28-60	clay		<0.06	5.1-6.5		high	high	moderate			
	60-70	clay loam		<0.06	5.1-7.3		high	high	moderate			
Beaumont clay	0-20	clay	0 to 1%	0.06-0.2	4.5-6.0		high	high	moderate	0-2	apparent	Nov-Mar
	20-40	clay		<0.06	4.5-5.5		high	high	moderate			
	40-60	clay		<0.06	5.1-7.8		high	high	moderate			
Bernard clay loam	0-6	clay loam	mainly less than 1% but up to 3%	0.06-0.2	6.1-7.3		moderate	high	low	0-3	apparent	Dec-Feb
	6-60	clay		<0.06	6.1-7.8		high	high	low			
	60-78	clay loam		<0.06	6.6-8.4		high	high	low			
	78-90	sandy clay loam		---	---							
Edna sandy loam	0-9	loam	0 to 5%	0.6-2.0	5.6-7.3		low	high	low	0-1.5	perched	Dec-Mar
	9-38	clay		<0.06	5.6-7.3		high	high	low			
	38-50	clay loam		<0.06	6.6-8.4		high	high	low			
	50-65	sandy clay loam		<0.06	6.6-8.4		high	high	low			
Frost silt loam	0-11	silt loam	0 to 1%	0.2-0.6	4.5-6.5		low	high	moderate	0-1.5	apparent	Dec-Apr
	11-68	silt loam, silty clay loam		0.06-0.2	4.5-8.4		moderate	high	low			
Ijam clay	0-8	clay	mainly less than 1% but up to 10%	0.10-0.12	6.6-9.0	4-16	high	high	high	0-3.0	apparent	Sep-May
	8-62	clay		0.10-0.12	6.6-9.0	4-16	high	high	high			
Lake Charles clay	0-20	clay	mainly less than 1% but up to 8%	0.06-0.2	6.1-7.8		high	high	low	0-2.0	apparent	Dec-Feb
	20-70	clay		<0.06	6.6-8.4		high	high	low			
	70-80	clay		<0.06	6.6-8.4		high	high	low			
Veston loam	0-12	loam, sandy clay loam, fine sandy loam	0 to 1%	0.6-2.0	6.6-8.4	>4	low	high	high	0-2.0	apparent	Jan-Dec
	12-24	loam, fine sandy loam, clay loam		0.6-2.0	7.9-9.0	>8	low	high	high			
	24-60	silty clay loam, loam, silty loam, fine sandy loam		0.06-0.2	7.9-9.0	>8	moderate	high	high			

late Bayou within the area of detailed analysis (fig. 11).

The test well and surface support facilities, if located at the proposed site as shown in figure 10, will be in an area depicted as Pleistocene fluvial and distributary channel sands and silts on the environmental geology map. Soils that occur at this site are the Aris fine sandy loam and a complex of the Bernard clay loam and Edna fine sandy loam (fig. 11). Shrink-swell potentials characterizing the soils are low to moderate near the surface but increase to high below depths of about 0.6 m (2 ft) in the Aris and 15 to 23 cm (0.5-0.75 ft) in the Bernard-Edna complex (table 8). Corrosivity of the soils with respect to concrete is moderate to low. Slopes of up to 5 percent in the Bernard-Edna complex will need to be a consideration in designing and constructing surface facilities which include perimeter dikes.

WATER RESOURCES

The necessity of producing and disposing of large quantities of hot saline waters in geopressured-geothermal energy development emphasizes the need for mapping and describing ground- and surface-water resources in order to analyze and evaluate how they may be affected should geothermal fluids come into contact with them. Chemical analyses by Kharaka and others (1977) of water from wells in the Chocolate Bayou oil and gas field in Brazoria County indicate high salinities and high concentrations of potentially harmful chemicals such as boron in formation waters from the geopressured zone (table 9). Although essential to plant growth, boron can be toxic at concentrations slightly above the optimum value; concentrations of only 1 mg/l and 3 mg/l are permissible for irrigating most boron-sensitive and boron-tolerant crops, respectively (Scofield, 1936; Sandeen and Wesselman, 1973). Current plans with respect to the geopressured-geothermal test well call for fluid production rates of up to 40,000 barrels a day. The water will be disposed of by injecting it, via disposal wells, into salt-water bearing formations that do not contain oil, gas, or geothermal resources. This method of disposal is considered environmentally the most acceptable because the produced saline waters will be less likely to affect surface and near-surface water resources. The possibility of inadvertent spills and discharges of geothermal fluids points out the need for mapping and describing ground-water and surface-water characteristics in the Brazoria County prospect area.

Ground-Water Resources

The following discussion of ground-water resources in the Brazoria County prospect area is based primarily on a report by Sandeen and Wesselman (1973).

Fresh and slightly saline ground water in the Brazoria County prospect area are produced from two major aquifers: the Chicot and the Evangeline. The Chicot which is the shallower of the two aquifers has been subdivided into an upper and lower unit. The upper unit in

TABLE 9. CHEMICAL COMPOSITION (MG/L) OF FORMATION WATERS FROM WELLS IN THE CHOCOLATE BAYOU OIL AND GAS FIELD, BRAZORIA COUNTY

(Modified from Kharaka and others, 1977)

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 (Kharaka and others, 1977).

the Brazoria County prospect area consists of interconnected shallow sands and stream alluvium and ranges in depth from near the surface to about 30 to 90 m (100 to 300 ft) below mean sea level. The upper unit is either a water table or an artesian aquifer. Water levels of wells screened in this unit are shown in figure 12.

The lower unit of the Chicot aquifer, which is generally separated from the upper unit by clay, is an artesian or leaky artesian aquifer. In the Brazoria County prospect area, the base of the lower unit of the Chicot dips toward the southeast and ranges in depth between approximately 260 m (850 ft) and 320 m (1050 ft) below mean sea level.

An unconformity separates the base of the Chicot from the underlying Evangeline aquifer. Distinction between these two aquifers is based on differences in stratigraphic position, lithology, permeability, and water level. The Evangeline aquifer consists of alternating sands and clays that range in thickness from approximately 610 m (2,000 ft) to 1,065 m (3,500 ft) at the northern edge and southern edge of Brazoria County, respectively. The maximum thickness of the zone containing fresh to slightly saline water in the Evangeline aquifer, however, is about 335 m (1,100 ft).

The quality of the water in the Chicot and Evangeline aquifers varies with location, partly as a result of salt domes that are present in the area. The distribution of the fresh water (less than 1,000 mg/l of total dissolved solids) and slightly saline water

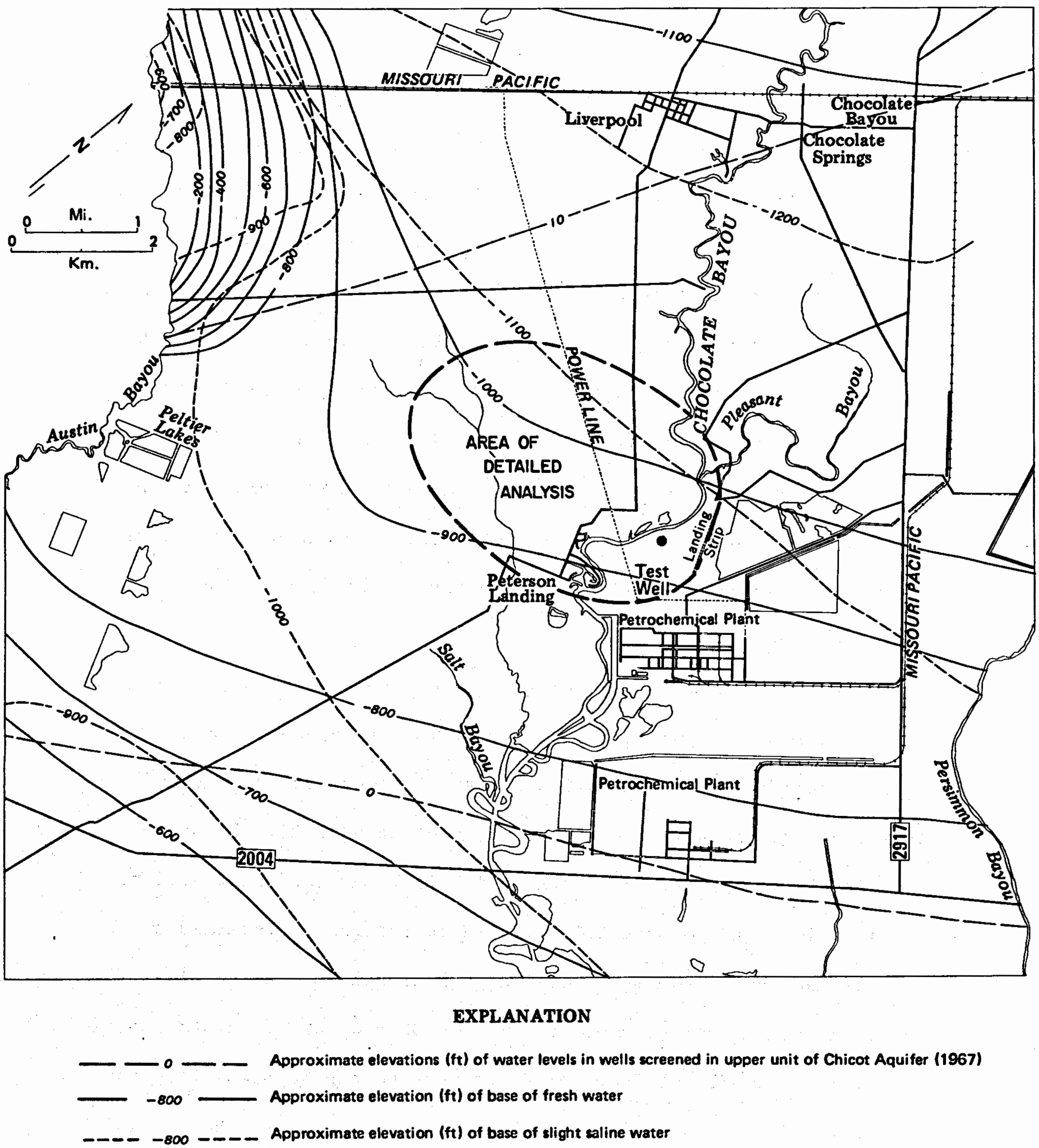
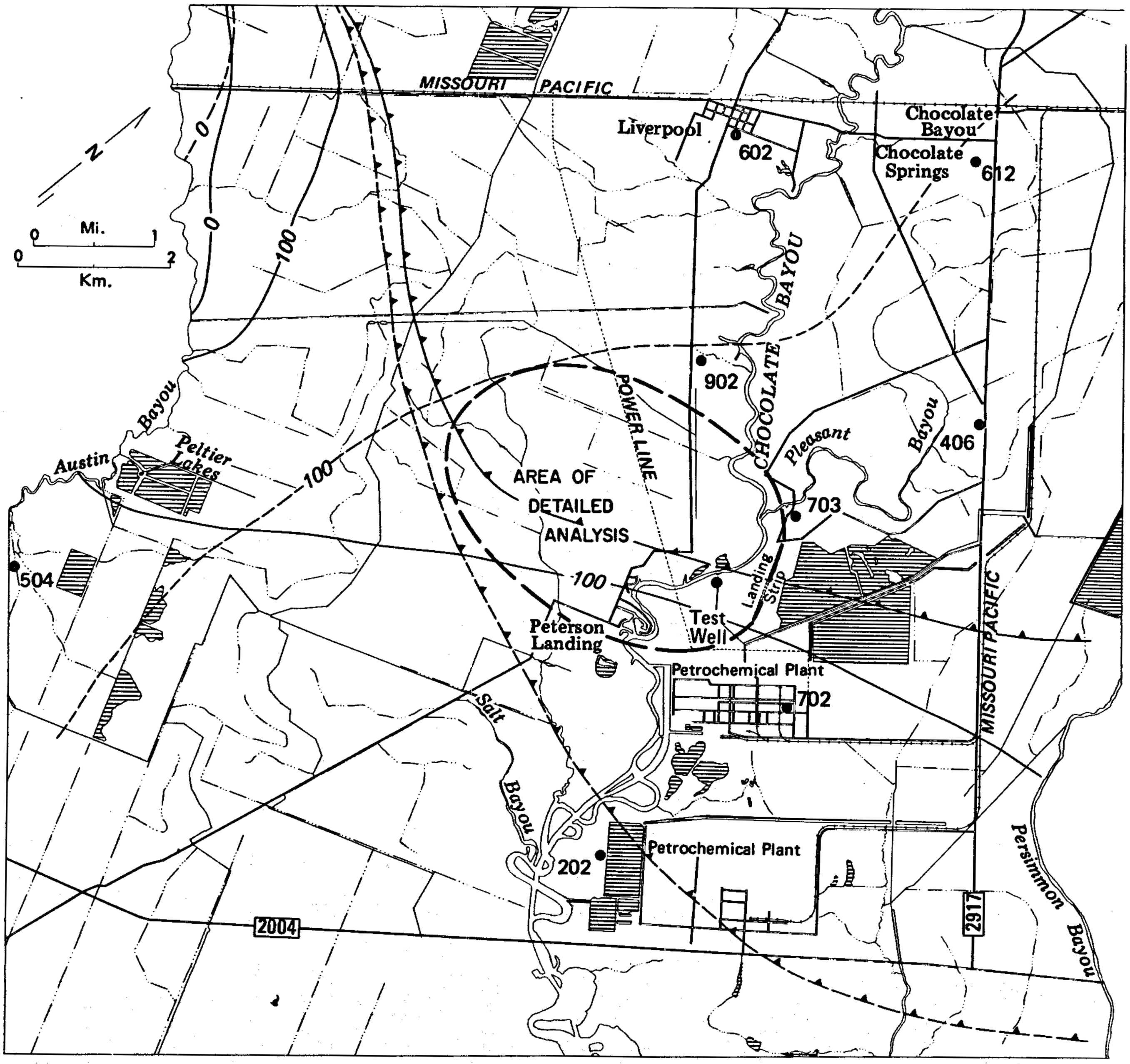


Figure 12. Ground-water features in the Brazoria County prospect area. (Modified from Sandeen and Wesselman, 1973)

(1,000 to 3,000 mg/l of total dissolved solids) in the Brazoria County prospect area is shown in figures 12 and 13, in terms of the following approximate characteristics: (1) elevation of water levels in wells screened in the shallowest aquifer--the upper unit of the Chicot, (2) elevation of the base of fresh water and slightly saline water, (3) downdip limit of fresh and slightly saline water in the deepest aquifer--the Evangeline, and (4) thickness of sands containing fresh and slightly saline water in the Evangeline and lower unit of the Chicot. The presence of a salt dome (Danbury Dome) in the western corner of the map area is reflected by changes in the distribution of fresh and slightly saline water in the area of the dome (figs. 12 and 13).

Results of chemical analyses of water from wells located within the Brazoria County prospect area (fig. 13) are shown in table 10. As indicated by dissolved solids and specific conductance (total dissolved solids in mg/l can be roughly esimated using 50 to 60 percent of the specific conductance in micromhos per centimeter at 25°C), all but two of the wells listed in the table contained fresh water (less than 1,000 mg/l total dissolved solids) at the time of sampling and analysis; water from wells 702 and 703 contained approximately 2,000 mg/l total dissolved solids and can be classified as slightly saline. As noted in table 9, concentrations of boron (which are often high in water from the geopressured zone) were not analyzed in the water wells listed, however, of 21 analyses of water in other



EXPLANATION

GROUND WATER

Evangeline Aquifer

Approximate downdip limit of fresh water

Approximate downdip limit of slightly saline water

Evangeline and Lower Unit of Chicot Aquifers

—100— Approximate thickness (ft) of sand containing fresh water

---100--- Approximate thickness (ft) of sand containing slightly saline water

Approximate location of water wells for which water quality data are reported

SURFACE WATER

Reservoirs and ponds

Natural and man-made waterways

permanent

intermittent

Figure 13. Ground-water and surface-water features in the Brazoria County prospect area. (Ground water data from Sandeen and Wesselman, 1973, and Neftel and others, 1976; surface-water features modified from U. S. Geological Survey topographic maps)

TABLE 10. CHEMICAL ANALYSES OF WATER FROM WELLS IN THE BRAZORIA COUNTY PROSPECT AREA

(Compiled from Sandeen and Wesselman, 1973, and Naftel and others, 1976)
(Analyses in milligrams/liter except where otherwise noted)

WELL	202	406	504	602	612	702	703	902
WATER BEARING UNIT	C	CU	CU	CU	CL	CL	CU	C
DEPTH OR PRODUCING INTERVAL (FT)	750-838	65	140	145	220	924	30	400
DATE OF COLLECTION	3-6-69	5-17-39	5-18-39	5-25-67	8-28-46	5-25-67	5-17-39	5-24-67
TEMPERATURE (°C)	—	—	—	—	—	—	—	—
SILICA (SiO_2)	14	—	—	—	—	—	—	—
IRON (Fe)	0.30	—	—	—	—	—	—	0.01
CALCIUM (Ca)	10	—	—	—	—	—	—	—
MAGNESIUM (Mg)	3.0	—	—	—	—	—	—	—
SODIUM (Na)	210	87	184	—	—	—	394	—
BICARBONATE (HCO_3)	415	494	412	428	578	406	508	624
CARBONATE (CO_3)	0	—	—	0	—	0	—	0
SULFATE (SO_4)	.0	10	8	14	40	1.6	122	17
CHLORIDE (Cl)	260	100	320	175	130	890	945	142
FLUORIDE (F)	1.1	—	—	—	—	—	—	—
NITRATE (NO_3)	.02	1.5	—	—	—	—	—	—
BORON (B)	—	—	—	—	—	—	—	—
DISSOLVED SOLIDS	693	588	867	—	—	—	2,106	—
HARDNESS AS $CaCO_3$	38	368	398	308	141	150	1,020	160
RESIDUAL SODIUM CARBONATE (RSC)	6.03	—	—	0.85	—	3.65	—	7.03
SODIUM ABSORPTION RATIO (SAR)	15	—	—	—	—	—	—	—
SPECIFIC CONDUCTANCE (MICROHOS AT 25°C)	1,440	—	—	1,190	—	3,330	—	1,370
pH	8.0	—	—	7.6	—	7.9	—	7.7

C = Chicot aquifer
CL = Chicot aquifer, lower unit
CU = Chicot aquifer, upper unit

wells located in Brazoria County, boron exceeded a concentration of 1 mg/l in only one, where the concentration was 1.9 mg/l (Sandeen and Wesselman, 1973).

In 1967, ground-water pumpage in Brazoria County was about 43 million gallons per day, of which approximately 52 percent was used for irrigation, 30 percent for industrial purposes, and 18 percent for public and domestic supplies. Almost all drinking water came from ground water in 1967. Most of the heavy use of ground water, as indicated by cones of depression in 1967, was in the southern part of Brazoria County near Brazosport and Freeport which are southwest of the prospect area. The magnitude of land-surface subsidence that has accompanied ground-water withdrawal in the Freeport area is more than 0.5 m (1.5 ft). A small cone of depression in the upper unit of Chicot was present in the Danbury area near the western corner of the Brazoria County prospect area in 1967, indicating ground-water usage in that area. Heavy ground-water pumpage from the artesian aquifers in Harris and Galveston Counties to the northeast and east of Brazoria County have resulted in movement of ground water from Brazoria County toward cones of depression in those two counties. Estimates indicate that about 5 million gallons of fresh water a day in the Chicot aquifer are moving across the northeastern part of Brazoria County into Harris and Galveston Counties. Maps prepared by Gabrysch and Bonnet (1975) depicting land-surface subsidence associated with ground-water withdrawal for several counties in the Houston-Galveston area, show about 1.5 to 0.3 m (0.5 to 1.0 ft) of subsidence may have occurred in the Brazoria County prospect area between 1943 and 1973.

Surface-Water Resources

Surface water has been the major source of fresh water in Brazoria County as indicated by usage in 1967 when consumption of surface water was 1.58 million kl (417 million gallons) per day as compared to 0.16 million kl (43 million gallons) per day of ground water (Sandeen and Wesselman, 1973). Numerous surface-water features are present in the Brazoria County geopressured-geothermal prospect area including several bayous, a complex network of irrigation ditches and canals, and man-made reservoirs (fig. 13). The primary source of fresh water is apparently the Brazos River which crosses Brazoria County southwest of the prospect area. Water is transported from the Brazos via two major canals, one of which supplies water to areas west of Chocolate Bayou (South Texas Water Company Canal), and the other (Briscoe Canal) supplies areas east of the bayou.

To determine the quality of surface water in the area of geopressured-geothermal fluid production, water quality information on Chocolate Bayou was collected because of the location of the bayou with respect to the area of detailed analysis. Locations along and gulfward of Chocolate Bayou for which there are existing water quality data are shown in figure 14. Of these locations, only two (location #3) are within the Brazoria County prospect area, but by considering water quality information upstream and downstream, proba-

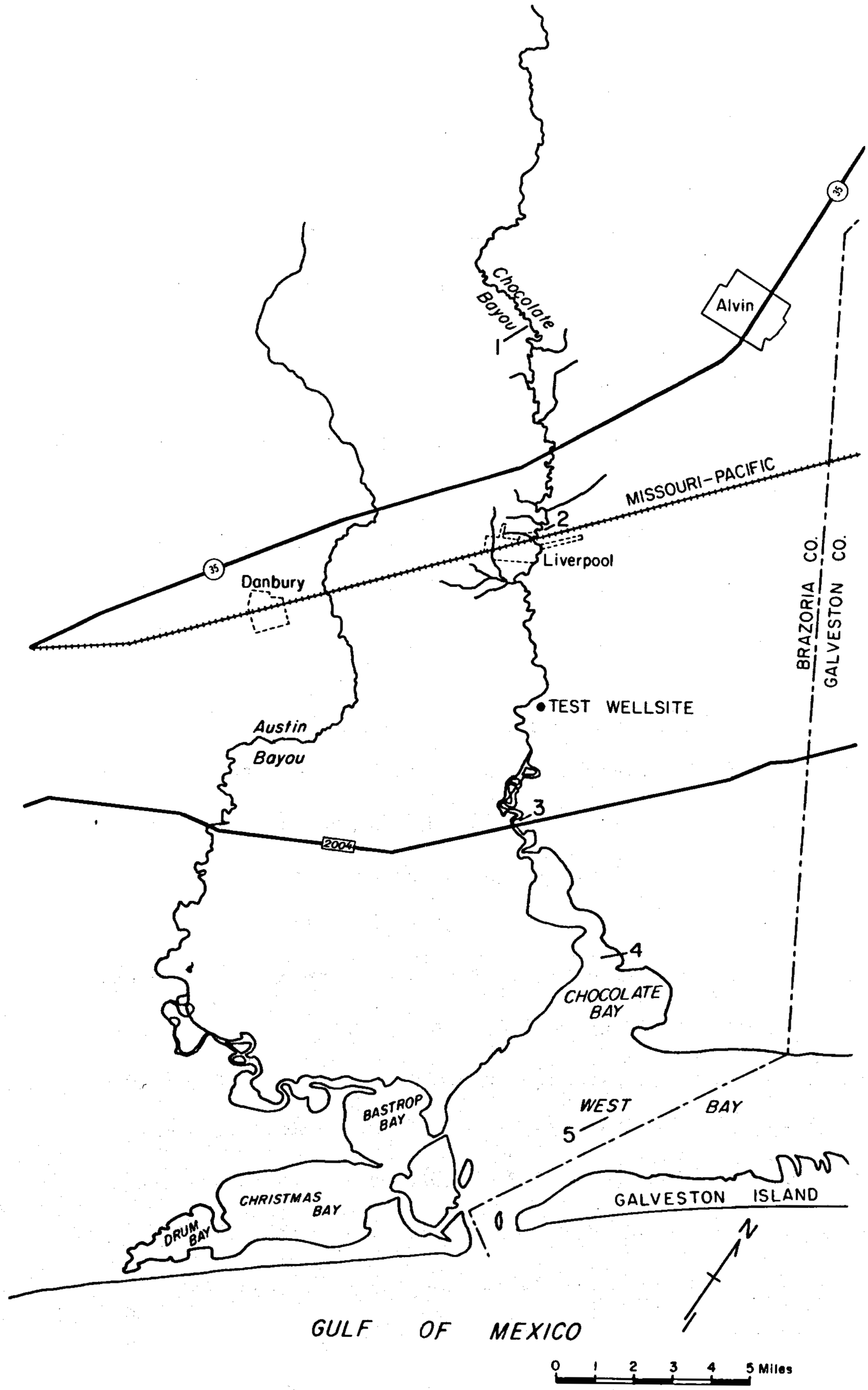


Figure 14. Location of water quality sampling stations along Chocolate Bayou, Chocolate Bay and West Bay, reported in table 11.

ble ranges of values for some water quality parameters can be estimated for area of detailed analysis. The area of detailed analysis lies between sampling stations 2 and 3 (fig. 14, table 11). The two petrochemical plants southeast of the area of detailed analysis and north of station 3 (fig. 14) have permits from the Texas Water Quality Board (Texas Department of Water Resources) to discharge up to a maximum of 19.5 million gallons per day of industrial process water, storm water, and domestic sewage into Chocolate Bayou. These discharges may have an effect on water samples from station 3.

Selection of Test Well Site on the Basis of Water Resources

In the area of detailed analysis, usable ground water (fresh and slightly saline water) occurs from near the surface as indicated by water levels in wells completed in the upper unit of the Chicot aquifer, to depths of about 335 m (1,100 ft) as indicated by the base of slightly saline water (fig. 12). The base of fresh water occurs between 275 m (900 ft) to 305 m (1,000 ft).

Because of plans to dispose of waste water by injection into saline aquifers at depths between 610 m (2,000 ft) and 2,135 m (7,000 ft) (Bebout and others, 1978), the quality of ground-water resources should not be adversely affected. The shallowest depth of injection will be approximately 275 m (900 ft) below the base of sands containing slightly saline water in the area of detailed analysis (fig. 12). Injection wells are presently used by the Monsanto Chemical Company just southeast of the test well site. At one well,

TABLE 11. COMPARISON OF CHEMICAL ANALYSES OF WATER FROM THE GEOPRESSURED ZONE WITH WATER FROM CHOCOLATE BAYOU, CHOCOLATE BAY AND WEST BAY

SAMPLING STATIONS★

Values are in milligrams per liter unless otherwise noted	Gardiner #1 Chocolate Bayou oil and gas field (geopressured zone)	Chocolate Bayou Ranges of values for analyses in 1975-1976				Chocolate Bay 1976-1977	West Bay 1971
		1	2	3		4	5
				Surface	Depth 9-12 ft		
TDS	68,500	272-666	300-1,000*	1,400-15,500*	10,500-17,500*	13,000-20,500*	25,500-36,600**
NA	24,000	38-160				7,200	
K	300	2.4-6.8					
NH_3	26	0.01-0.14	0.01-0.48	0.01-1.0		0.03-0.08	
Mg	235	10-30					
Ca	2,000	43-84					
Mn	2.7	0-0.01					
Cl	40,500	49-260	30-266	725-9,300			
HCO_3	520	138-341					
SO_4	0.6	23-89	22-53	117-1,250			
SiO_2	87	3.9-32					
B	30	0.11-0.4					
pH (units)	6.3	6.4-8.0	7.0-8.1	7.70-8.30	7.60-8.60	8.0-8.4	7.2-8.2
Temp (°C)	129	15-29	15.6-28.3	18.5-30.0	19.0-29.5	9.5-15.5	16-30.6
Conductivity (micromhos)		502-1,400	600-2,000	2,800-31,000	21,000-35,000	26,000-41,000	

★ See figure 14 for location of sampling stations

• Calculated as 50% of conductivity

** Salinity in parts per million

Data sources: Gardiner #1, Kharaka and others, 1977; sampling station 1, U. S. Geological Survey, 1976; sampling stations 2 and 3, Texas Water Quality Board (now part of Texas Department of Water Resources) unpublished water sampling data inventory; sampling station 4, U. S. Geological Survey unpublished data; sampling station 5, Martinez, 1971.

fluids are injected at depths between 610 m (2000 ft) and 1950 m (6400 ft), at rates approximating 20,000 barrels per day and at injection pressures of near 750 psi (open file report, Texas Department of Water Resources). Bebout and others (1978) estimate that there are between 455 m (1500 ft) and 550 m (1800 ft) of sandstone suitable for injection of geothermal waters between the depths of 610 m (2000 ft) and 2135 m (7000 ft) in the area of detailed analysis.

Surface casing in the geopressured-geothermal test well will be set to a depth of 335 m (1100 ft) (Draper and others, 1977) which is generally below the base of the sands containing slightly saline water in the area of detailed analysis. Four to six 10,000 barrel holding tanks will initially be used for temporary surface storage and cooling of produced geothermal fluids, although a cooling tower may eventually be required (Draper and others, 1977).

In light of the proposed methods of producing, storing, and cooling geothermal fluids, it is unlikely that they will come into contact with surface- or ground-water resources regardless of the location of the test well and support facilities within the area of detailed analysis. In the event of accidental surface discharges, however, the specific location of the test well could have a bearing on the degree to which water resources are affected. For example, location of the test well in areas of permeable sand (which may serve as ground-water recharge areas) would allow discharged geothermal fluids to percolate downward into shallow ground-water aquifers (upper unit of the Chicot). As indicated in the discussion of substrate lithology and figure 10, permeable recharge areas may coincide with relict distributary and fluvial channel sands that occur in the east half of the area of detailed analysis along both sides of Chocolate Bayou. Low permeability soils (fig. 11, table 8) covering much of this area, however, should help retard movement of fluids into ground-water aquifers. Locating the test well in the western extremes of the area of detailed analysis would place it in an area mapped as Pleistocene interdistributary and flood-basin muds on the environmental geology map (fig. 10) and in an area mapped as Lake Charles Clay on the soils map (fig. 11). These are areas of low permeability and would offer some protection to underlying ground-water aquifers. A possible problem with location of the test well on the west side, however, is that if inadvertently discharged fluids did reach deeper ground-water aquifers, water quality in public wells to the east at Peterson Landing could be adversely affected. As noted previously, ground-water movement in the deeper aquifers is toward the east and northeast because of heavy pumpage in adjacent Harris and Galveston Counties.

The major surface-water feature in the area of detailed analysis that might be affected by inadvertently discharged geothermal waters is Chocolate Bayou. Surface-water salinity reported by Moffett (1975) for water samples taken between the mouth of Pleasant Bayou, which discharges into Chocolate Bayou just upstream from Peterson

Landing, and a point near Farm to Market Road 2004 ranged (approximately) between 1,500 to 18,000 parts per million in 1969-1971; salinities for bottom waters were substantially higher. These salinity ranges agree with those expected for the area of detailed analysis as shown by table 11. These data suggest that the salinity of Chocolate Bayou in the area of the test well is generally unsuitable for many human uses, but the fact that important biological assemblages (discussed in the following section) are adapted to the existing salinity conditions indicates the need to protect Chocolate Bayou from geothermal fluids. This could best be accomplished by locating the test well at sufficient distances from the bayou to allow containment of accidentally discharged fluids.

BIOLOGICAL ASSEMBLAGES

Flora

The prospect area displays the characteristics typical of the Gulf Prairies and Marsh Vegetation Area as described by Gould (1962). These are broad expanses of almost level grasslands traversed by wooded meandering rivers and bayous flowing into the Gulf. The climax vegetation of the Gulf Prairie is the "tall-grass" prairie which forms a dense cover of tall range species common to the eastern prairie regions of the United States (Thorp, 1952). In the study area, much of this assemblage has been replaced by rice and grain cultivation and grazing. In the southeastern part of the prospect area below Farm to Market Road 2004 a transition occurs from the typical grassland assemblage to one dominated by sedges and rushes. Fresh water ponds dot the prospect area--a region of poor drainage. Natural drainage is modified by irrigation and drainage ditches, which support water tolerant shrubs and trees.

The Chocolate Bayou prospect area is divided into five vegetation assemblages based on species composition and physiognomy. Vegetation map units were interpreted from 1:120,000 winter (February) 1975 color IR photographs, supported by field reconnaissance, and from published information. Table 12 lists the common plant species found in each of these assemblages. A description of each vegetation assemblage as shown in figure 15 follows:

(1) Fluvial Woodlands: The Fluvial Woodlands assemblage comprises the timbered areas along the floodplains of the Austin, Chocolate, and Pleasant Bayous and a portion of New Bayou. The assemblage is characterized by several species of Oak, Green Ash, American and Cedar Elm, Hackberry, and Pecan. Understory shrubs are dense to sparse depending on the tree canopy and predominantly consist of Yaupon, Pepper-vine, and to a lesser extent, Indigo-Bush Amorpha. Grape vines are abundant while Greenbriar, Trumpet-Creeper and Japanese Honeysuckle are common. Spanish Moss drapes some tree branches along the bayous' edge.

For each of the bayous, some special characteristics are also notable. For example, Austin Bayou is characterized by more river

TABLE 12. PLANT SPECIES FOUND IN THE CHOCOLATE BAYOU PROSPECT AREA GROUPED BY VEGETATION ASSEMBLAGE

(Plant species identification was aided by Correll and Johnston, 1970, Hitchcock, 1950, and Vines, 1960. Nomenclature after Correll and Johnston, 1970)

1. Fluvial Woodlands			
Swamp Red Oak	*Quercus falcata* var. pagodifolia	Pecan	*Carya illinoinensis*
Water Oak	*Quercus nigra*	Water Hickory	*Carya aquatica*
Post Oak	*Quercus stellata*	Mulberry	*Morus rubra*
Virginia Live Oak	*Quercus virginiana*	Chinese Tallow Tree	*Sapium sebiferum*
Overcup Oak	*Quercus lyrata*	Yaupon	*Ilex vomitoria*
Willow Oak	*Quercus phellos*	Possum-haw	*Ilex decidua*
Green Ash	*Fraxinus pensylvanica*	Dewberry	*Rubus* sp.
Eastern Red Cedar	*Juniperus virginiana*	Bastard Indigo	*Amorpha fruticosa*
American Elm	*Ulmus americana*	Wax Myrtle	*Myrica cerifera*
Cedar Elm	*Ulmus crassifolia*	Grape	*Vitis* sp.
Loblolly Pine	*Pinus taeda*	Trumpet-creeper	*Campsis radicans*
Black Willow	*Salix nigra*	Japanese Honeysuckle	*Lonicera japonica*
Hackberry	*Celtis laevigata*	Greenbriar	*Smilax* sp.
Water Elm	*Planera aquatica*	Rattan-vine	*Berchemia scandens*
Dwarf Palmetto	*Sabal minor*	Pepper-vine	*Ampelopsis arborea*
	Poison Ivy	*Rhus toxicodendron*	
2. Frequently Flooded Fluvial Areas			
Eastern Baccharis	*Baccharis halimifolia*	Chinese Tallow Tree	*Sapium sebiferum*
Black Willow	*Salix nigra*	Japanese Honeysuckle	*Lonicera japonica*
Hackberry	*Celtis laevigata*	Grape	*Vitis* sp.
3. Fresh Water Pond			
Bulrush	*Scirpus* sp.	Coon-tail	*Ceratophyllum* sp.
Cattail	*Typha latifolia*	Water Milfoil	*Myriophyllum* sp.
Water Smartweed	*Persicaria punctata*	Musk Grass	(Algae)
Pondweed	*Potamogeton* sp.	Bladderwort	*Utricularia* sp.
	Duckweed	*Lemna* sp.	
4. Marsh			
Smooth Cordgrass	*Spartina alterniflora*	Heliotrope	*Heliotropium curassavicum*
Sea Ox-eye Daisy	*Borrichia frutescens*	Sea Blite	*Suaeda* sp.
Salt Meadow Cordgrass	*Spartina patens*	Swertia	*Swertia* sp.
Glasswort	*Salicornia* sp.	Bulrush	*Scirpus* sp.
Salt Cedar	*Tamarisk* sp.	Cattail	*Typha latifolia*
	Rush	*Juncus* sp.	
5. Tallgrass Prairie			
Indian Grass	*Sorghastrum avenaceum*	Crinkle-awn	*Trachypogon secundus*
Little Bluestem	*Schizachyrium scoparium*	Dropseed	*Sporobolus* sp.
Big Bluestem	*Andropogon Gerardi*	Panic Grass	*Panicum* sp.
Switch Grass	*Panicum virgatum*	Dallis Grass	*Paspalum dilatatum*
Florida Paspalum	*Paspalum floridanum*	Bermuda Grass	*Cynodon dactylon*
	Carpet Grass	*Axonopus compressus*	
Eastern Baccharis	*Baccharis halimifolia*	Tickle-tongue	*Zanthoxylum Clava-Herculis*
	Macartney Rose	*Rosa bracteata*	

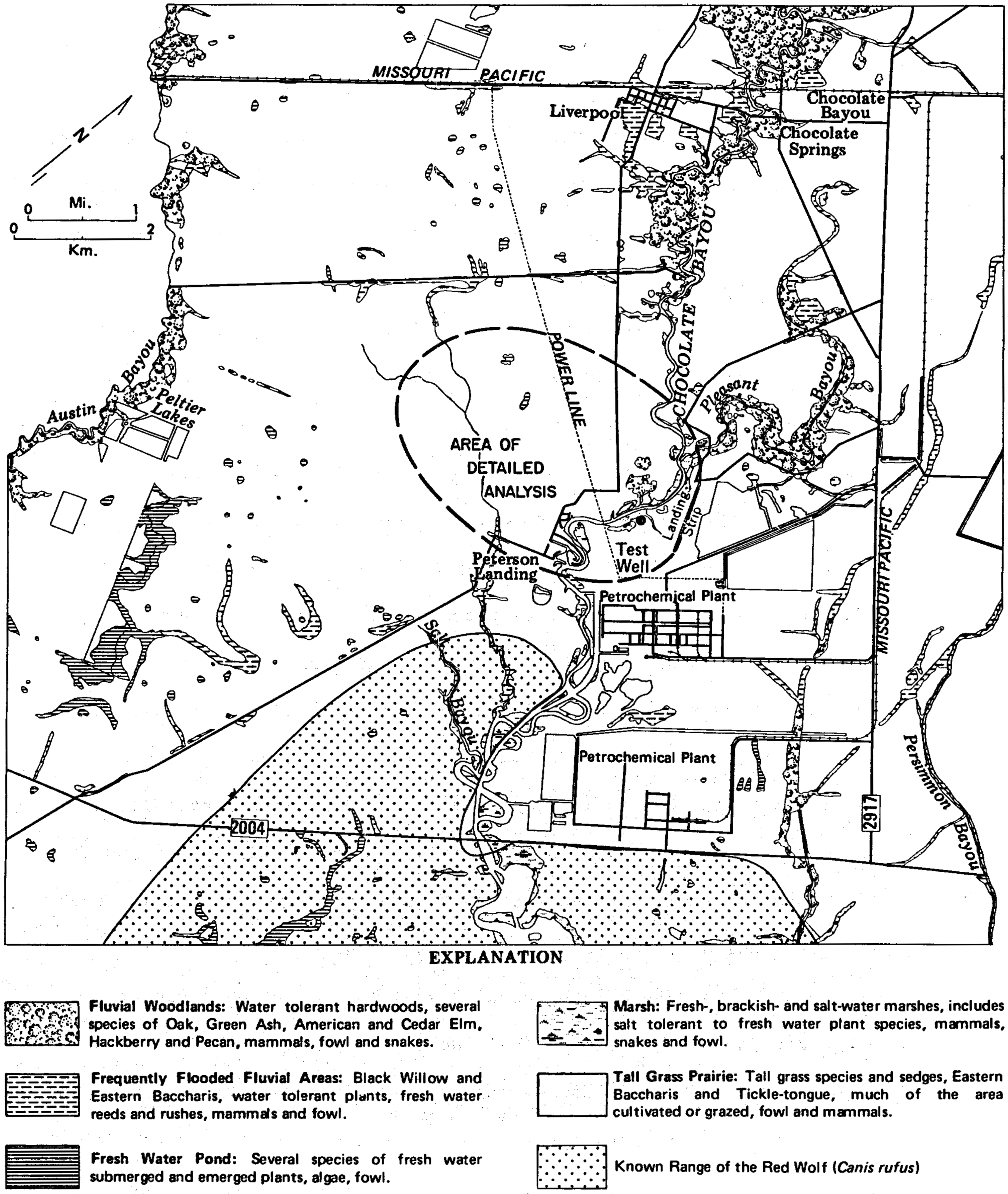


Figure 15. Vegetation assemblages identified in the Chocolate Bayou prospect area; range of the Red Wolf. (Surface water features can be identified by referring to figure 13.)

bottom species including Dwarf Palmetto, Water Elm, and Water Hickory. Chocolate and Pleasant Bayous display inner zones where Oak is more predominant, and the higher and drier outer zone is dominated by tall (approximately 20 m) Loblolly Pine.

(2) Frequently Flooded Fluvial Areas: This assemblage is characteristic of small streams and irrigation and drainage ways, and some such areas are products of man's alteration of the environment. Characteristic species are Black Willow and Eastern Baccharis. Hackberry, Chinese Tallow, and Japanese Honeysuckle are also common. Cattail and fresh water reeds and rushes are also present.

(3) Fresh Water Pond: Numerous ponds dot the study area, especially near rice fields where water is abundant and drainage is controlled. They are characterized by variable water levels and impermeable substrate. Notable species of this assemblage are Cattails, Bulrushes, Water Smartweed, Coontail, Water Milfoil, and Bladder Wort (Wilson, personal communication). This assemblage also provides cover and food for waterfowl. At least three species present that provide food for waterfowl are Pondweed, Duckweed, and Musk Grass.

(4) Marsh: This assemblage occupies lowlands along the banks of Chocolate Bayou where storm tidal inundation intermixed with fresh water floods and runoff causes variable salinities. The flora ranges from salt tolerant species near the bay to fresh marsh species along the bayou in the vicinity of the test well site. A. W. Moffett (1975) collected marsh plants along Chocolate Bay in 1969 and found

Smooth Cordgrass (Spartina alterniflora) to be the dominant emergent plant. Additional species have been collected near the intersection of Chocolate Bayou and Farm to Market Road 2004. These are Sea Ox-eye Daisy, Salt Meadow Cordgrass, Glasswort, Salt Cedar, Heliotrope, Sea Blite, and Swertia. In the area of detailed analysis on the north bank of Chocolate Bayou, Bulrush and Cattail were noted. These species conform to an orderly transition of plant assemblages from salt- to fresh-water marsh described by Fisher and others (1972) and also are those predicted by salinity data in this report for Chocolate Bayou.

(5) Tall Grass Prairie: The Tall Grass Prairie assemblage occupies the broad level plains in the prospect map area. In its climax state, this assemblage is characterized by a dense cover of tall grass range species and sedges (Thorpe, 1952). Much of the region has been converted to rice and grain cultivation and cattle grazing. Areas under cultivation lack most native species; grazed areas display some form of modified assemblage because of grazing pressures. The native range was characterized by several woody shrubs, some remnants of which now occupy fallow ground along roadsides and in open fields. Notable species are Eastern Baccharis, Tickle-tongue, and Macartney Rose. The Tall Grass Prairie assemblage has been compiled from grass species identified by the Brazoria County Soil Survey (in press) for soil associations in the area. It is characterized by species of Big and Little Bluestem, Indian Grass, Switch-

grass, Florida Paspalum, Crinkleawn, and Dropseed, as well as Bermuda Grass and Carpet Grass, which are not true tall-grass species. It should be noted that the Bluestems and Indian Grass are good forage species which are susceptible to decline under heavy grazing (Gould, 1962). The introduced species, Bermuda and Carpet Grass, are also good forage species, but they more readily withstand the pressures of trampling and grazing. In heavily grazed pastures, these latter species are most often dominant.

Endangered Plant Species

A table has been prepared from Rare Plant Study Center and Texas Parks and Wildlife Department data (Blevens and Novak, 1975). Table 13 lists plant species that are rare and/or are most directly threatened with extinction in Brazoria County and its environs. Information on frequency and distribution is also given. Further field study is needed to determine whether any of these species occur in the area of detailed analysis and what measures must be taken to protect them.

Discussion of Vegetation Assemblages with Reference to the Test Well Site

To determine the best sites for the test well, not only must the attributes of a single assemblage be examined, but also the role of the assemblage as part of the entire biological community. Natural factors which influence the existence of a particular community are critical. For example, the roles of water availability and drainage

TABLE 13. RARE AND ENDANGERED PLANT SPECIES THAT HAVE BEEN IDENTIFIED IN BRAZORIA COUNTY AND ITS ENVIRONS

(From Blevins and Novak, 1975)

GENERA/SPECIES	COMMON NAME	RARENESS	DISTRIBUTION
Bothriochloa exaristata (Grass Family)	Awnless Bluestem	5-H(B)	Information needed
Carex gigantea (Sedge Family)	Giant Sedge	6-E(B)	Harris County; also in Polk County, East Texas
Chloris texensis (Grass Family)	Texas Windmill Grass	6-E	Information needed; also in Rio Grande Plains
Hymenoxys texana (Sunflower Family)	Texas Bitterweed	7-I	Houston area—not collected since 1900
Ilex Cassine (Holly Family)	Dahoon Holly	6-I(B)	Brazoria County only
Ilex myrtifolia (Holly Family)	Myrtle Holly	7-I(B)	Brazoria County?—no precise information
Leitneria floridana (Corkwood Family)	Corkwood	5-I?(B)	Brazoria County—near Angleton and Lake Jackson
Lithospermum tuberosum (Borage Family)	Bulb Gromwell	7-I(B)	Brazoria County—1914; also in Polk County—1914
Machaeranthera aurea (Sunflower Family)	Houston Machaeranthera	6/7-I	Near Houston, Harris County
Oenothera sessilis (Evening Primrose Family)	Coastal Evening Primrose	7-I(B)	Last collected c. 1858
Ophioglossum vulgatum (Adder's-tongue Family)	Common Adder's-tongue	5-E(A)	Coastal Prairie; also in East Texas
Rhododon ciliatus (Mint Family)	Prairie Bobwort	5-E	Coastal Prairie; also in East Texas
Sabal minor, trunked form (Palm Family)	Louisiana Palm	5-E(B)	Coastal Prairie
Scirpus cubensis (Sedge Family)	Cuban Bulrush	6/7-I(B)	Brazoria County—known only from Eagle Nest Lake, collected once in 1958
Scleria Baldwinii (Sedge Family)	Baldwin Stone-rush	6/7-I(B)	Harris County
Scleria minor (Sedge Family)	Minor Nut-rush	6-E(B)	Matagorda County; also in Newton County, E. Texas
Wolffiella gladiata (Duckweed Family)	Sword Bog-mat	6-I(B)	Brazoria National Wildlife Refuge only

Rareness and distribution are indicated by the following scale:

Rareness

5 Scarce, endangered in Texas
6 Very rare, acutely endangered in Texas
7 Presumed extinct, with no records since 1930 from Texas

Distribution

*A Distributed widely on the continent or in the world
*B Distributed broadly but regionally in North America and extending into Texas
E Distributed in two of the broad vegetational areas of Texas
H Distribution limited to 1 to 3 counties in one broad vegetational area of Texas
I Known only from one or a few populations

* If A or B are not given, then it is implied that the species is endemic to Texas.

and salinity are prime natural features determining community composition and distribution (Blevins and Novak, 1975). Other factors such as existing man-made changes and the impacting activities of constructing and operating the test well must be considered.

The boundary between prairie and forest is indirectly related to water through the effect of soil moisture which prevents prairie fires from burning into lowland forests (Harcombe, 1974). Urban and agricultural activities also play major roles in reducing the areal extent of forestland. A major consideration for not locating the test well site in the Fluvial Woodlands is the amount of time it takes for native forest to become reestablished--on the order of tens or hundreds of years. This assemblage also has an important role in controlling runoff, and it provides food and cover for a variety of mammals including squirrels, Coyotes, and waterfowl. In addition, the forest in the prospect area has an important aesthetic value in adding variation and relief to relatively flat, monotonous topography. This is especially important to home-owners in the area.

The fresh to brackish marsh environment found in the area of detailed analysis is a vital component in maintaining the nutrient balance of the bay-marsh ecosystem. Runoff from heavy rains and related stream flooding are probably the most effective agents of transporting nutrients from these marshes to the estuary (Blevins and Novak, 1975). It is also one of the most fragile environments.

Marshes are extremely susceptible to changes in water availability (i.e. drainage from uplands and inundation caused by subsidence). Salinity regimes which vary in the area of detailed analysis also determine marsh species composition. Because they occupy the land-water margin, these areas are easily eroded when cleared; this may induce a permanent loss of the plant assemblage. Ultimately, changes in this plant assemblage will affect the finned and shell fish fishing industries downstream, as well as destroy food sources and habitats for a variety of wildlife.

Frequently Flooded Fluvial Areas reflect nature's response to man's alteration of the environment. Species characteristic of this assemblage are those that return quickly to a disturbed area. Many of these areas are early seral assemblages which, if not disturbed over a long period of time, would eventually become climax communities of fluvial woodland or fresh-water marsh via processes of ecological succession. An important feature of this assemblage is its role in influencing drainage rates and erosion by stabilizing stream banks and man-made levees. They are also a source of nutrients for the bay-marsh region and provide cover for mammals and habitat for fowl.

The Tall Grass Prairie occupies the highest ground in the area of detailed analysis. When cleared, grass assemblages rather quickly become reestablished, provided that soil characteristcs are not changed. In these areas the most important effect on the construction of the test well site will be on surface water quality and the flow of nutrients into the marshes and bay.

Some of the effects of land alteration on the hydrologic regime associated with the construction of the test well site can be anticipated: clearing, compacting, and paving will decrease surface permeability and increase runoff; construction of platforms or potential subsidence from geopressured-geothermal water extraction may result in changed water levels and drainage patterns. Fresh water runoff from the prairies directly affects salinity and turbidity of marsh and bay waters. Increases in turbidity may upset nutrient balance and impair photosynthetic processes of lower trophic levels (Rowe and Williams, 1974). Over much of the area, natural drainage patterns are already modified by agriculture and irrigation practices.

Fauna

The following is a description of the more important faunal species living in or utilizing the Brazoria County prospect area.

Waterfowl. The prospect area is located in the southern terminus of the Central Flyway (Blevins and Novak, 1975). Because of the abundance and quality of habitat, hundreds and thousands of ducks and geese winter in the region. Species of waterfowl are diverse and consequently utilize every available kind of aquatic habitat, in addition to the rice and grain fields. To some extent they utilize every environment in the prospect area, but aquatic habitats are the most important. Appendix B includes several species of water fowl whose geographic range includes the Brazoria Prospect Area and which have some sort of state or federal protection. The Texas Parks and Wildlife Department has designated Chocolate Bay and Chocolate Bayou and its perimeter as excellent bird watching areas.

Squirrels. Two native species of squirrels, the Eastern Fox Squirrel (*Sciurus niger*) and the Eastern Gray Squirrel (*Sciurus carolinensis*), are present in the region (Blevins and Novak, 1975). Squirrels are primarly woodland species and are affected by modification or destruction of the forest. The habitat of the Fox Squirrel consists of open mixed hardwood forest with patches of clearing, but the Gray Squirrel requires a continuous forest of mature hardwood with dense understory. Consequently strip-clearing can improve Fox Squirrel habitat only, and complete clearing destroys habitat for both squirrel species. Both species require mast-producing hardwoods for food and prefer hollow trees for dens. The Texas Parks and Wildlife Department has designated the Fluvial Woodlands along Chocolate, Austin, and Pleasant Bayous in the prospect area as a good Fox Squirrel habitat.

Southern Bald Eagle. The Southern Bald Eagle (*Haliaeetus leucocephalus*), an endangered species, (Appendix B) has also been reported to nest in Brazoria County. The Southern Bald Eagle requires tall trees near rivers or lakes for perching and nesting--requirements which are fulfilled by the Fluvial Woodlands.

Aquatic fauna. The Chocolate Bayou estuarine system is a major nursery habitat and game fish habitat on the Gulf Coast. Moffett, (1975)* determined seasonal abundances of macro-biota in the Chocolate Bayou estuary and reports that major nursery areas for commercial shrimps (Penaeus aztecus, P. setiferus), Blue Crabs (Callinectes sapidus), estuarine game fishes, and other marine forms are present. Bay Anchovy (Anchoa mitchelli), Atlantic Croaker (Micropogon undulatus), and Gulf Menhaden (Brevoortia patronus) were the dominant fish species collected. Principal game fish are Red Drum (Sciaenops ocellata), Spotted Sea Trout (Synoscion nebulosus), and Southern Flounder (Paralichthys lethostigma). The Eastern Oyster (Crassostrea virginica) is also plentiful in Chocolate Bay but cannot be harvested from the waters which contain high coliform bacteria counts (Moffett, 1975). Fresh-water Catfish (Ictaluridae) and Sunfish (Centrarchidae) are caught in the upper bayous.

Peripheral salt marshes and bayous offer protection and nutrients to estuarine and non-estuarine fauna during juvenile development and for breeding. Brackish water, fresh water, and salt water marshes benefit the nursery system by removal of undesirable or excessive nutrients that contribute to pollution and adverse phytoplankton blooms (Blevins and Novak, 1975).

Important undersirable effects from the test well site may be increased turbidity due to runoff from construction and clearing, and chemical and thermal pollution from accidental spill of geothermal fluids, drilling fluids, fuel, or sewage. Turbidity levels can have effects on

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* See Moffett, 1975, . . . for additional aquatic species data.

photosensitive flora and fauna by restricting available light. Table 11 provides data on salinity ranges in the bayou versus salinity concentrations of geothermal brines. It is obvious from these data that while many estuarine organisms can survive changes in salinity, the concentrations present in geothermal fluids will radically deviate from the normal ionic composition and salinity range. In addition, trace elements such as boron may exist in harmful quantities. A consequence of thermal pollution can be illustrated by the following data:

In a report by the Texas Water Quality Board on fish kills in major channels, ports, and waterways of Texas (Espey, Huston & Assoc., Inc., 1976), three out of five fish kills in Chocolate Bayou resulted as a consequence of oxygen depletion. Moffett (1975) has shown that mean bottom water dissolved oxygen and temperature values for Chocolate Bayou and Chocolate Bay are inversely related: as water temperatures are increased, dissolved oxygen levels decrease. Although temperature has not been proven to be responsible for oxygen depletion in these specific cases, thermal discharges coupled with other variables could possibly produce this effect.

Alligator. Brazoria County has one of the largest alligator populations of the state (Blevins and Novak, 1975). The American Alligator (*Alligator mississippiensis*) is classified as threatened in this region* (Appendix B) and the principal reason for its historic decline

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* The American Alligator (*Alligator mississippiensis*) has been redesignated by the U. S. Fish and Wildlife Department as 'threatened' along certain parts of the coastal zone (including Brazoria County) and 'endangered' further inland. See U. S. Department of the Interior (1978).

was overhunting. Its numbers are presently increasing. Alligator habitats are primarily coastal marshes and inland habitats along stream corridors. A good to excellent habitat occurs along Austin Bayou in Brazoria County. The upper reaches of Chocolate Bayou, upstream from the area of detailed analysis are also considered prime alligator territory.

Red Wolf. The endangered status (Appendix B) of the Red Wolf (*Canis rufus*) has resulted from a combination of factors including habitat reduction, hybridization, parasites, a high natural mortality rate, and shooting by man (Blevins and Novak, 1975). The Red Wolf is an open country animal, travelling in a "circuit-type" pattern over a range of 25-30 square miles. Present habitats or range areas are in the lower Coastal Prairie and marsh areas. In Brazoria County, these have dwindled to 91,000 acres and continue to be reduced by urban and industrial development. The known range of the Red Wolf has been delineated by the Texas Parks and Wildlife Department and the portion of it near the prospect area is shown in figure 15 in a modified version excluding the area occupied by the petrochemical plant. Encroachment upon Red Wolf territory needs to be considered not only in reference to the location of the test well site, but also to future development associated with utilization of the energy resource.

Additional endangered and threatened faunal species whose vital requirements should be considered are listed in Appendix B.

Selection of Test Well Site on the Basis of Biological Assemblages

The preceding data show that the region in which the area of detailed analysis is located is characterized by rich and diversified biological communities. Several basic ecosystem relationships are apparent. Floral species present are dependent on the highly variable hydrologic and salinity regime. Aquatic and terrestrial wildlife depend on the diversity of vegetation assemblages to satisfy different habitat and feeding requirements. Modification of any one of these interdependent components can have an effect on the ecosystem.

In terms of conservation of biologic resources, the preferred locations for the test site in the area of detailed analysis will be on higher elevations occupied by the Tall Grass Prairie assemblage either east or west of Chocolate Bayou. The characteristics of the assemblage that support this choice are: (1) the Tall Grass Prairie assemblage generally shows a high resiliency, (2) it occupies the largest land area, (3) it is the least specialized type of habitat for wildlife, and (4) in its modified state it probably supports the least diversified fauna. It is preferred that the test site be located on the east side near the petrochemical plant where land modification by industrial activity already exist. The Tall Grass Prairie is an important link in the hydrologic regime of the area. Modifications or interruptions of natural drainage patterns should be avoided. The greatest direct hazard would be leakage or spillage of geothermal brines. The location of the test well as shown in figure 15 is along the edge of a marsh that fringes Chocolate Bayou. Because of the salinity and temperature of geothermal fluids, severe impacts on flora and the bay-marsh ecosystem may result if accidental releases occur.

METEOROLOGICAL CHARACTERISTICS

Climatological Data

Normal annual temperature at Angleton, Texas, approximately 19 km (12 mi) southwest of Liverpool is 69.1°F (20.6°C). The highest temperature occurs most frequently during July and August and ranges around 97°F (36.1°C) and the lowest usually occurs in January and ranges around 20°F (-6.7°C) (fig. 16). Normal annual precipitation is 52.17 in (132.5 cm), although variations have occurred during the past 16 years from a low of about 34 in (86 cm) in 1963 to a high of near 100 in (254 cm) in 1973 (fig. 16). As indicated by comparing normal monthly precipitation and monthly precipitation during 1976, there can be a large variation between monthly precipitation levels during any one year and "normal" monthly precipitation levels based on several years (fig. 17).

Two major wind systems predominate along the Texas Coastal Zone: (1) southeasterly winds from March through November, and (2) strong (although of short duration) northerly winds from December through February (Fisher and others, 1972). Wind direction and speed recorded at Clute, Texas, in conjunction with the Texas Air Control Board's continuous air quality monitoring station, is shown below for the years noted.

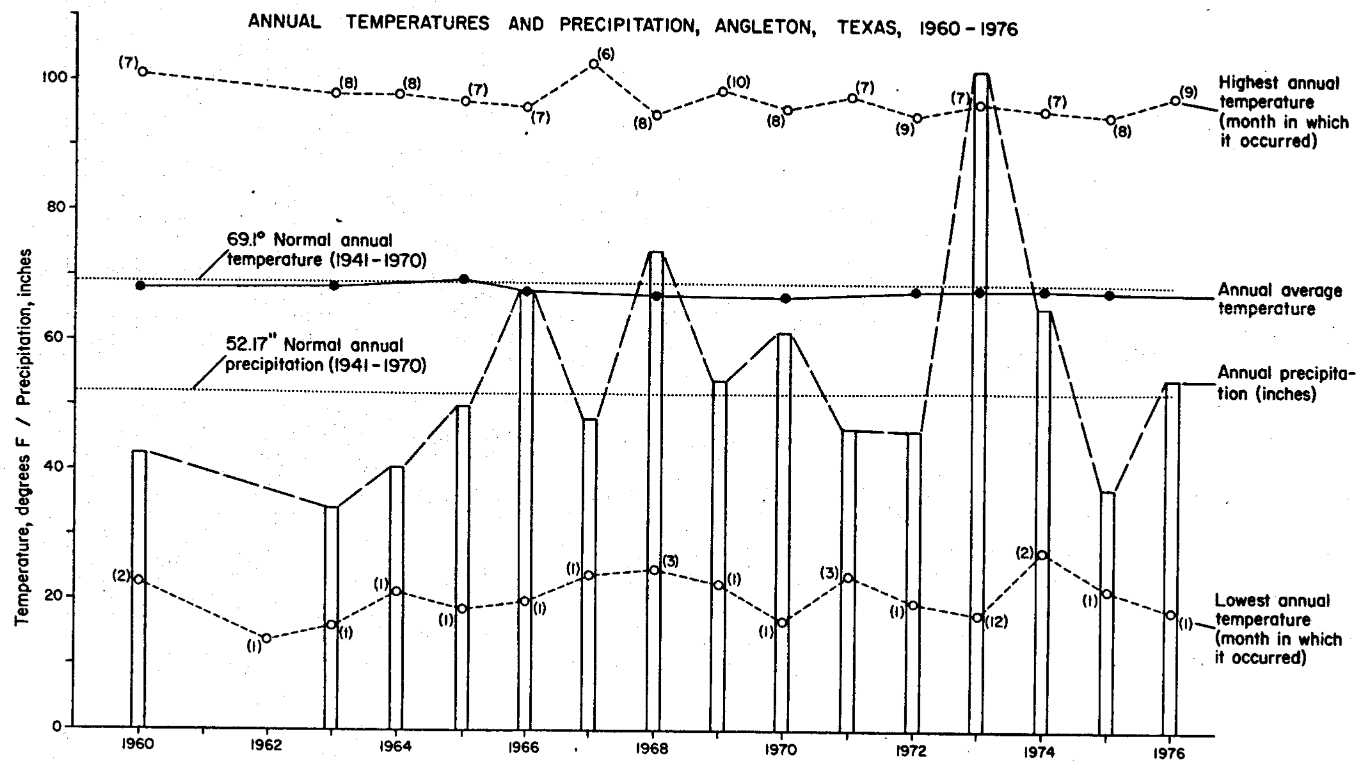


Figure 16. Temperature and precipitation for Angleton, Texas. (Compiled from records of the U. S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service)

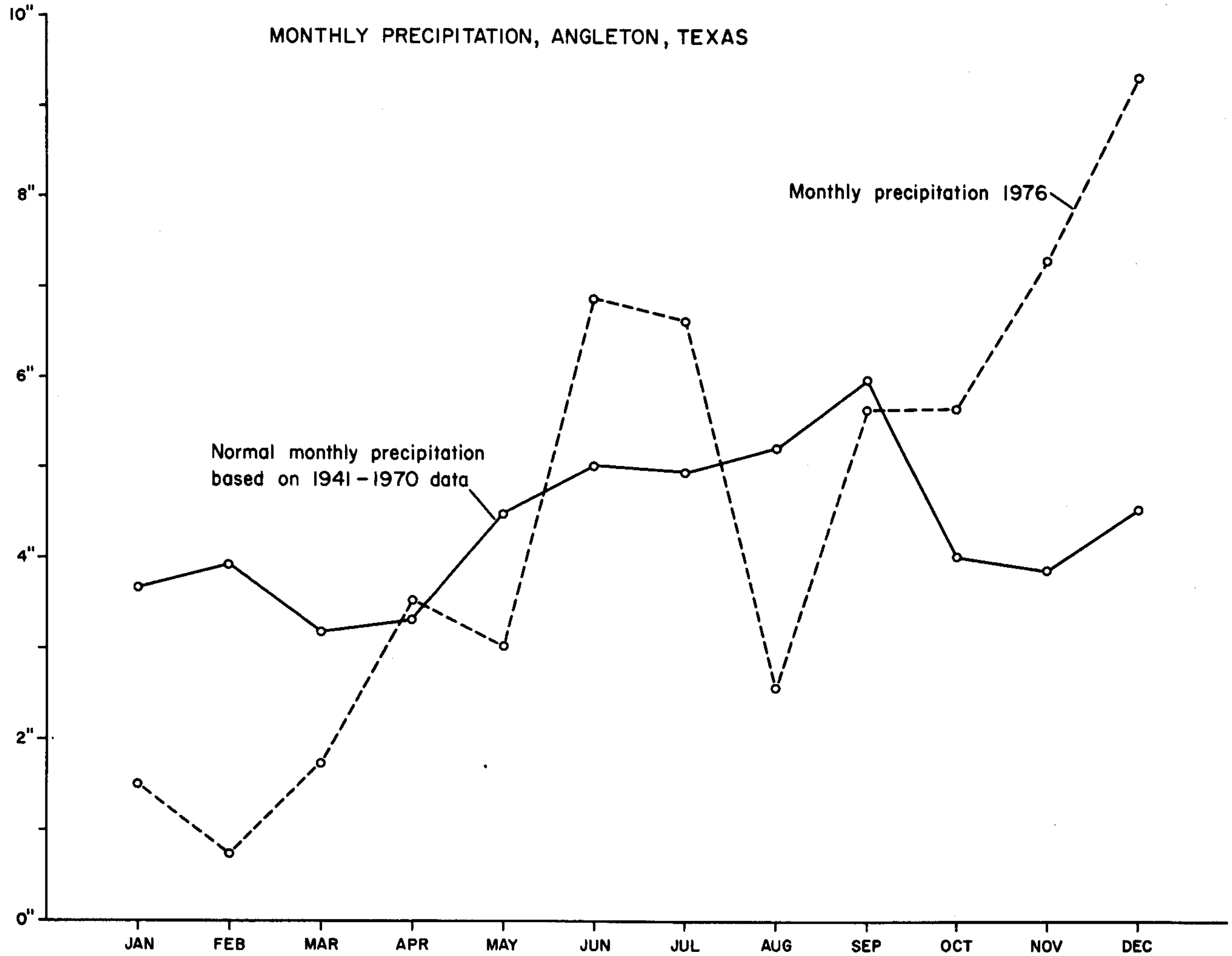


Figure 17. A comparison between monthly precipitation levels during 1976 with normal monthly precipitation levels based on the period 1941-1970, Angleton, Texas. (Compiled from records of the U. S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service)

	1974	1975	1976
Resultant wind direction overall	121°	155°	142°
Wind speed, mi (km) per hr			
High one-hr average	21.4(34.2)	25.2(40.3)	28.8(46.0)
Low one-hr average	0.4 (0.6)	0.4 (0.6)	0.3 (0.5)
Arithmetic mean of one-hr averages	8.0(12.8)	7.9(12.6)	8.2(13.1)
Resultant wind speed overall	2.0 (3.2)	3.0 (4.8)	2.0 (3.2)

As indicated above, resultant wind direction overall is southeasterly. Although not as persistent as southeasterly winds, north winds accompanying a severe polar front may blow at an average wind speed of 64 kilometers (40 mi) per hour during a 24-hour period (Fisher and others, 1972). Precipitation often accompanies these sudden 24- to 36-hour storms.

Ambient Air Quality

Air quality information was assembled from reports by the Texas Air Control Board for continuous and non-continuous air quality monitoring stations located in Brazoria, Galveston, and Harris Counties. Air quality data from continuous air monitoring stations in region 7 (which includes Brazoria County) indicate that ozone and nonmethane hydrocarbons are commonly at levels that exceed the maximum allowable as defined by national ambient air standards (table 14). Total suspended particulates (TSP) recorded by noncontinuous air monitoring stations have occasionally exceeded national standards

TABLE 14. COMPARISON SUMMARY OF CONTINUOUS AIR MONITORING STATION DATA WITH AMBIENT STANDARDS

(Data compiled from Texas Air Control Board Continuous Air Monitoring Network Data Summaries, 1974-1977)

Year	Station Location (Region 7)	Ozone - High One Hour Average	Ozone - Second Highest Hour	Ozone - Percent of Time > 0.08 ppm	Carbon Monoxide 2nd Highest Hour	Carbon Monoxide 2nd Highest 8 Hours	Nonmethane Hydrocarbons 6-9 AM High	Sulfur Dioxide 2nd Highest 24 Hours	Sulfur Dioxide Annual Mean	Sulfur Dioxide 2nd Highest 3 Hours	Nitrogen Dioxide Annual Mean	Methane - High One Hour Average	Methane - Percent of Time > 5.0 ppm
	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	no standards	%
1974	Houston, East	0.219	0.205	3.0	33.9	15.9	7.2	0.02	0.00	0.14	0.02	11.2	1.5
	Harris County (Aldine)	0.204	0.165	3.4	3.4	2.4	2.2	0.00	0.00	0.00	0.02	7.3	0.4
	Texas City	0.277	0.234	4.2	6.0	4.2	2.3	0.02	0.00	0.00	–––	10.5	2.8
	Clute	0.116	0.110	1.3	8.9	3.4	3.8	0.00	0.00	0.01	0.00	4.7	0.0
1975	Houston, East	0.288	0.223	3.7	9.0	4.7	3.9	0.02	0.00	0.13	0.03★	8.0	1.8
	Harris County (Aldine)	0.321	0.300	4.2	6.7	4.4	2.1	0.00	0.00★	0.08	0.02★	5.6	0.1
	Texas City	0.222	0.193	4.6	3.4	1.9	5.4	0.01	0.00★	0.12	0.01★	9.0	1.0
	Clute	0.160	0.155	2.8	7.4	3.0	3.1	0.01	0.00★	0.01	0.01	4.4	0.0
1976	Houston, East	0.297	0.267	4.2	8.6	6.7	3.4	0.01	0.00	0.07	0.02	8.3	2.0
	Harris County (Aldine)	0.272	0.255	7.7	7.9	6.2	3.9	0.00	0.00	0.00	0.02	5.1	0.0
	Texas City	0.225	0.203	5.1	5.5	2.6	3.8	0.01	0.00	0.21	0.01	6.6	0.4
	Clute	0.186	0.186	4.0	5.2	2.3	4.5	0.00	0.00	0.03	0.01	4.0	0.0
1977 (1st quarter)	Houston, East	0.121	0.106	0.7	12.5	6.4	2.8	0.01	0.00*	0.06	0.03*	8.6	3.3
	Harris County (Aldine)	0.098	0.106	0.4	3.1	2.2	3.3	0.00	0.00*	0.00	0.02*	6.2	0.6
	Texas City	0.085	0.073	0.1	0.9	0.3	0.7	0.00	0.00*	0.02	0.02*	1.7	0.0
	Clute	0.105	0.104	1.8	5.2	2.7	3.6	0.00	0.00*	0.01	0.01*	3.6	0.0

★Set of data does not meet E. P. A. criteria for calculating an annual mean

*Quarterly mean

during the last five years at Clute and Alvin although standards were not exceeded in 1976 (fig. 18). Selected gaseous concentrations measured in Clute and Alvin are shown in figure 19 for comparison purposes. Sulfur dioxide and nitrogen dioxide apparently have not exceeded national standards at either location during the years for which data are presented; national standards have not been set for ammonia. The graphs showing total oxidants (fig. 19) are useful for making relative comparisons between Clute and Alvin, but because of the air sampling method used for determining these values, a direct comparison with national standards cannot be made (Texas Air Control Board, 1975).

Selection of Test Well Site on the Basis of Meteorological Characteristics

Perhaps the most important climatological factor with regard to selecting suitable well sites within the area of detailed analysis is the resultant southeasterly wind direction. Location of the test well at certain points on the east side of Chocolate Bayou will place it in an upwind position with respect to residential-commercial development near Peterson Landing. Although air pollutants associated with geopressured-geothermal fluid production have not yet been adequately identified, volatile carbon compounds, ammonia and hydrogen sulfide are potential pollutants. Texas ambient air quality standards (set by the Texas Air Control Board), which are supplementary to national standards, specify that the net ground level

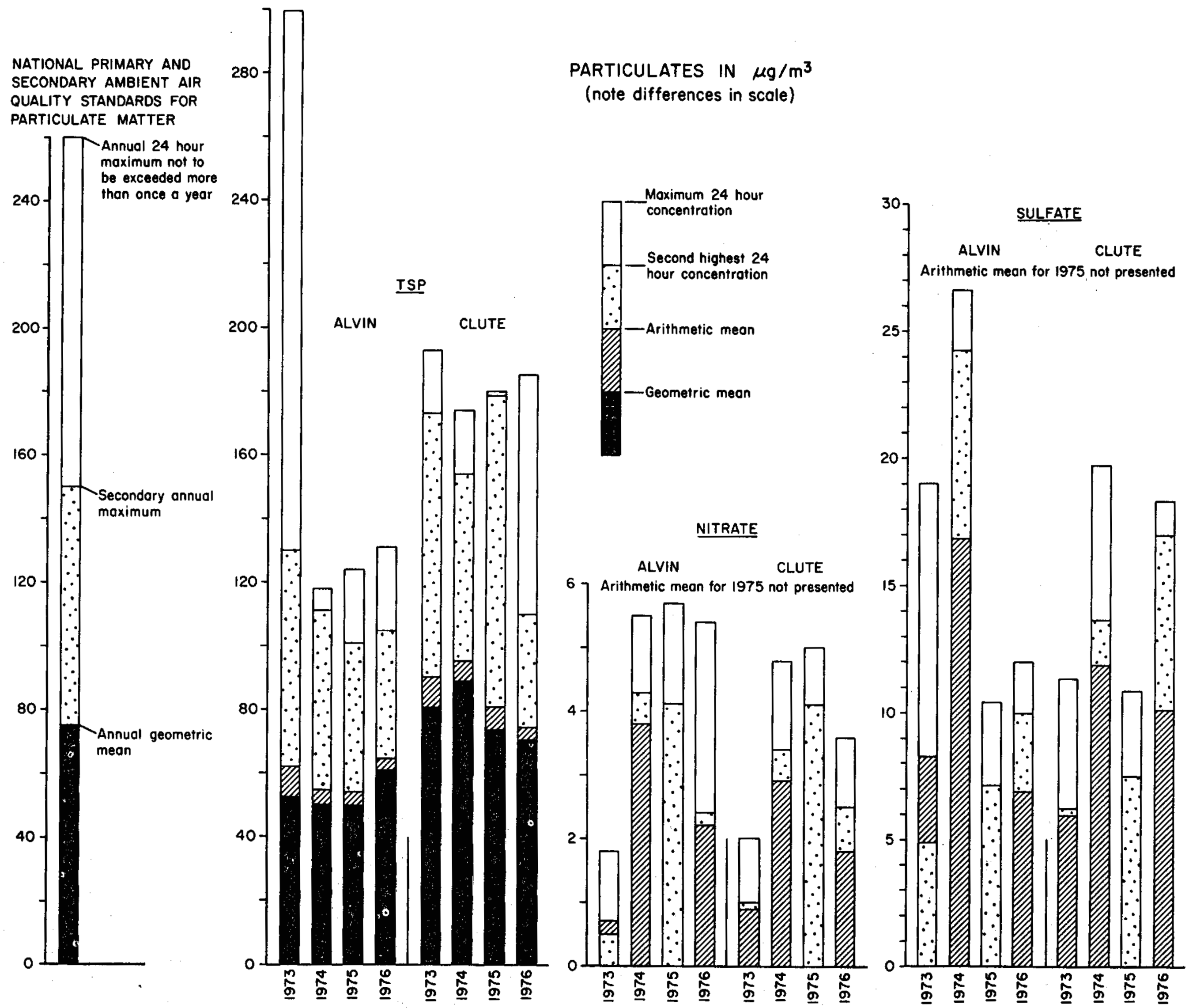


Figure 18. Concentration of particulates including total suspended particulates (TSP), nitrate, and sulfate at Alvin and Clute, Texas. (Compiled from Texas Air Control Board annual data summaries, 1973–1976)

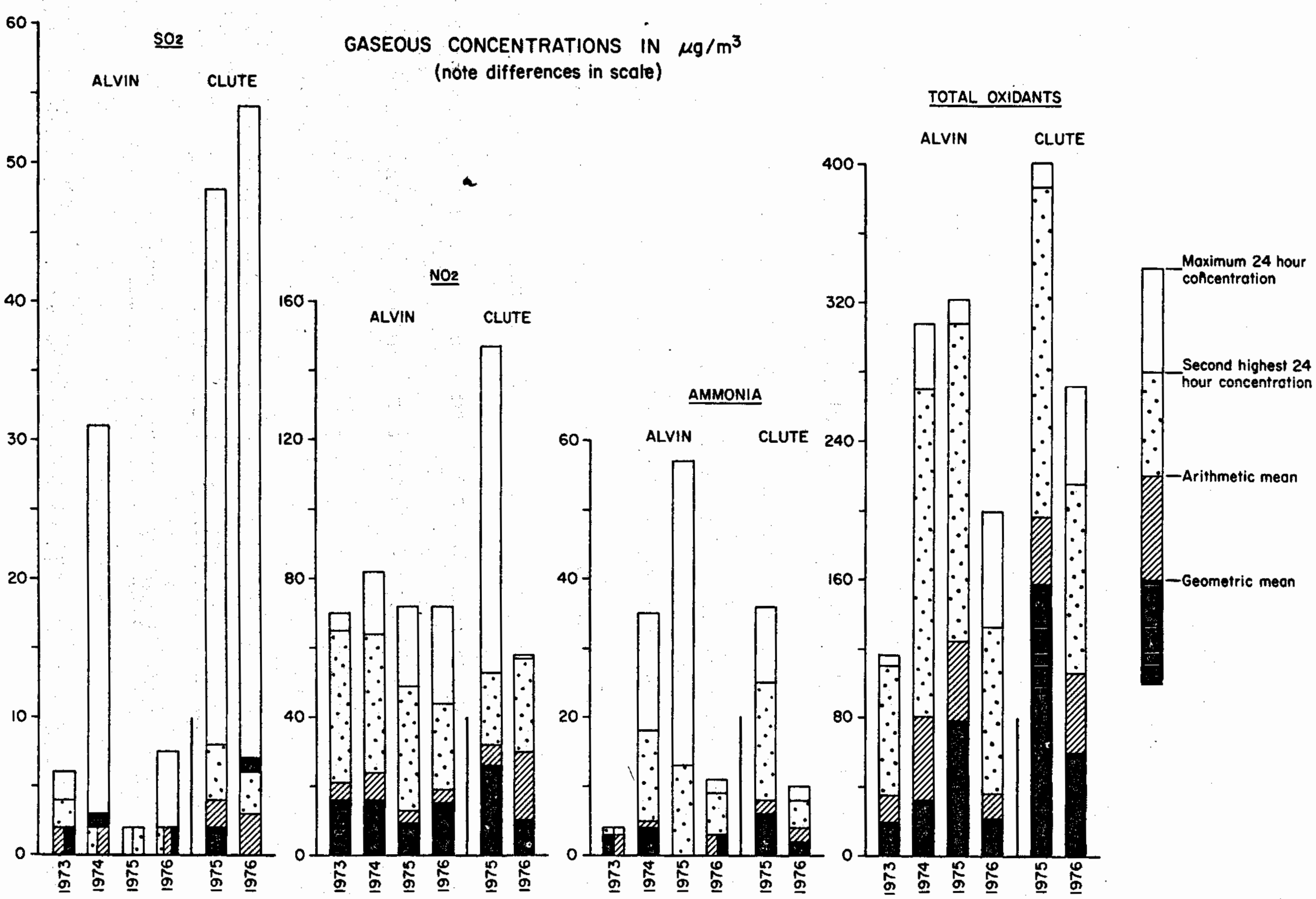


Figure 19. Concentration of sulfur dioxide, nitrogen dioxide, ammonia and total oxidants at Alvin and Clute, Texas. (Compiled from Texas Air Control Board annual data summaries, 1973–1976)

concentration of hydrogen sulfide cannot exceed 0.08 parts per million for a 30-minute average in areas used for residential, business or commercial purposes. The net downwind concentration of hydrogen sulfide in other areas (vacant land, rangeland, industrial property, etc.) cannot exceed 0.12 ppm for a 30-minute average. The net downwind concentration is equivalent to the downwind concentration minus the upwind concentration.

The Texas Air Control Board has established rules with regard to storing and handling volatile carbon compounds in Brazoria and other counties. Compliance with set rules should leave few air quality problems that could be alleviated by varying the location of the test well within the area of detailed analysis. In terms of meteorological characteristics, then, suitable sites for geopressured-geothermal wells are present on both the east and west side of Chocolate Bayou within the area of detailed analysis. The persistent southeasterly winds should be considered, however, in placing the well on the east side of Chocolate Bayou across from residential-commercial development at Peterson Landing.

SELECTION OF TEST WELL SITE ON THE BASIS OF ALL ENVIRONMENTAL CHARACTERISTICS

Decision criteria guidelines and a site selection methodology were established to aid in the overall analysis and evaluation of environmental characteristics. The criteria and methodology are explained in detail in Appendix A, but basically they involve using: (1) matrices to assist in making relative suitability comparisons between various environmental characteristics, and (2) transparent-translucent overlay maps to help identify the most suitable areas for well development. A composite map of the Brazoria County prospect area (fig. 20) was prepared following the decision criteria guidelines and site selection methodology described in Appendix A. The composite map (fig. 20) depicts areas of varying suitability (with those areas appearing the lightest in tone or most transparent being the most suitable) for test well development, by combining current land use, flood potential, shallow substrate lithology, water resources, and biological assemblages. Environmental factors, such as potential for subsidence, ground water conditions, and meteorological characteristics, which could not be meaningfully depicted on the transparencies, were also considered in the final evaluation of test well locations. The overall analysis indicates that the most suitable location for test well development within the area of detailed analysis is in the western extremes where:

(1) range-pasture/grasslands or croplands are present and distances between the test well and residential-commercial development and known archeological-historical resources will be at a maximum,

(2) distances between the well and residential-commercial development and industrial facilities will provide a "buffer zone" to

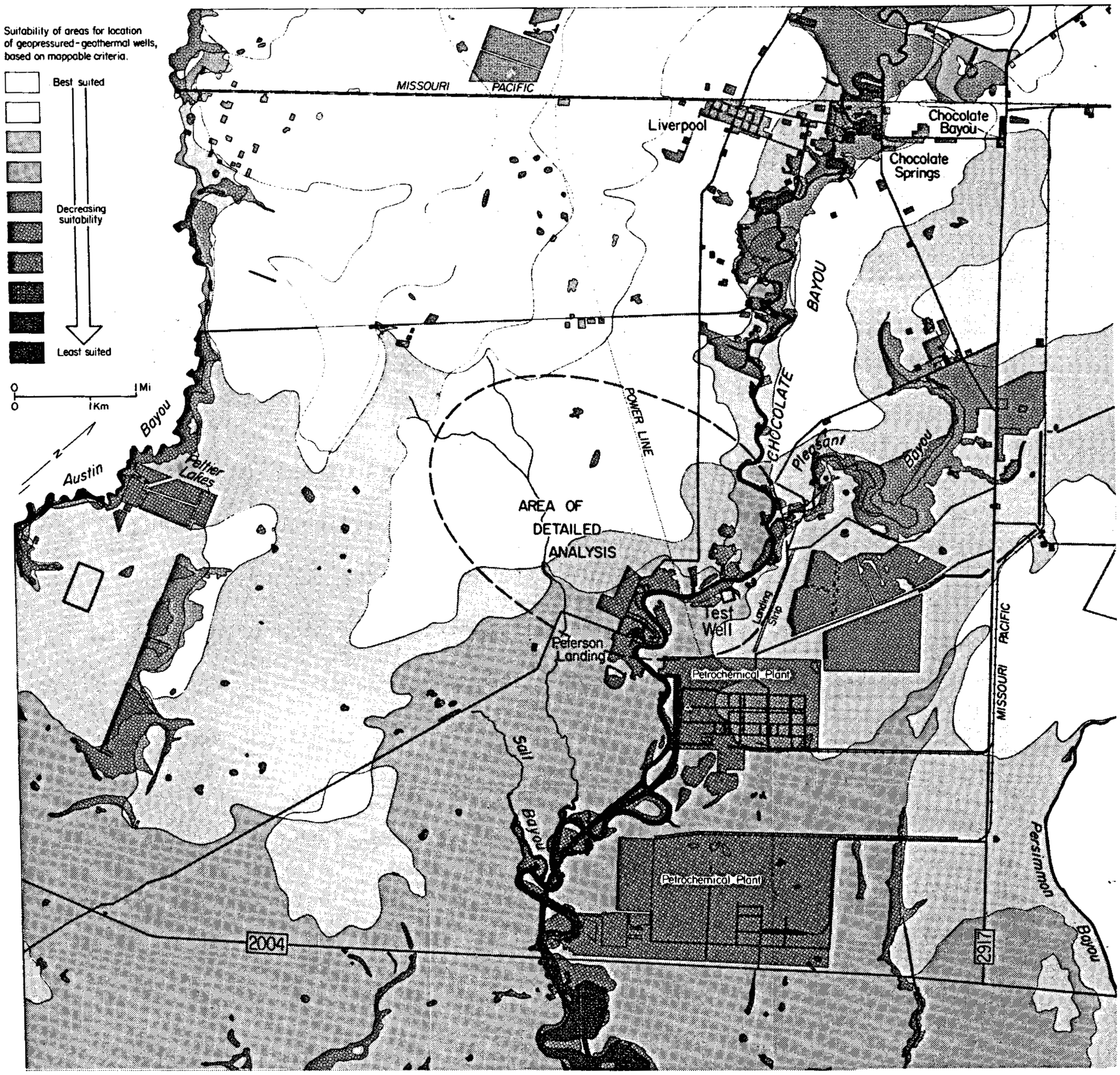


Figure 20. Areas of varying suitability for location of test well. Compiled in accordance with Appendix A.

minimize damage to surface facilities in the event that fault activation and subsidence are significant problems,

(3) naturally high elevations will provide a measure of natural flood protection,

(4) low permeability clay substrates will inhibit ground water recharge by inadvertently discharged fluids,

(5) major surface water features (such as Chocolate Bayou) will be less likely affected,

(6) significant biological assemblages such as those in and along Chocolate Bayou will be far removed from inadvertently discharged fluids,

(7) test well development activities will most frequently be downwind from recreational-commercial development and therefore unlikely to contribute to undesirable air quality conditions in residential-commercial areas.

Selection of the western extremes of the area of detailed analysis as the most suitable area for location of a test well is based on the combined analyses and evaluations of all environmental factors, but only environmental factors. It should be noted that suitable sites are also present east of the bayou if precautionary measures are taken to offset possible undesirable interactions between the test well and specific environments such as those environments that are in close proximity to archeological-historical resources and residential-commercial development, or those environments that are susceptible to natural hazards such as flooding. Perhaps the most imposing problem with respect to the location of the test well as shown on the maps in this report is the close proximity of the well to Chocolate Bayou. In the unlikely event of a blowout, discharged brines will be difficult to contain and will almost certainly flow into the bayou and bay where they will place a severe stress on the marshes-estuary system and its associated flora and fauna which include commercially valuable fish, crustaceans, and mollusks. In addition, the close proximity to the Bayou places the well and surface support facilities at very low elevations (between 1.8 and 3.4 m--6 and 11 ft--according to U. S. G. S. topographic maps) where flood depths at the well site could be as great as 2.4 and 4 m (8 to 12 ft) during a "100-year flood." The probability of occurrence of either of these events (blowout or "100-year flood") is very low, which is a positive factor that helps to mitigate the importance of these potential impacts.

PART II: PRELIMINARY ENVIRONMENTAL ANALYSIS OF A GEOPRESSURED-GEOTHERMAL TEST WELL IN KENEDY COUNTY, TEXAS

INTRODUCTION

In terms of known and suspected reservoir characteristics--porosity, permeability, mineralogy, and temperature--the Kenedy County geopressured-geothermal fairway is not as promising as the Brazoria County prospect (Bebout and others, 1978). Nevertheless, the Kenedy County fairway may have some potential and may eventually be selected as a site for testing geopressured-geothermal energy resources.

The area of potential geopressured-geothermal energy development, as reflected by subsurface reservoir conditions (Bebout and others, 1978), is slightly larger than the surface area mapped and analyzed in this environmental study (figs. 1 and 21). Favorable reservoir conditions extend slightly beyond the northern boundary of the area selected for evaluation, but environmental characteristics to the north are similar to those in the mapped area.

GENERAL SETTING--KENEDY COUNTY PROSPECT AREA

The area for which environmental data were collected and analyzed in Kenedy County, encompasses approximately 180 km^2 (70 mi^2) of land situated in a region dominated by agriculture (ranching). The prospect area is located in west central Kenedy County, and is centered approximately 45 km (28 mi) west of the Gulf shoreline of Padre Island, 70 km (44 mi) south of Kingsville, and 45 km (28 mi) north of Raymondville (fig. 21). The small rural community of Armstrong with a 1976 population of 20 (Dallas Morning News) is located within the prospect area which is subequally divided by U. S. Highway 77.

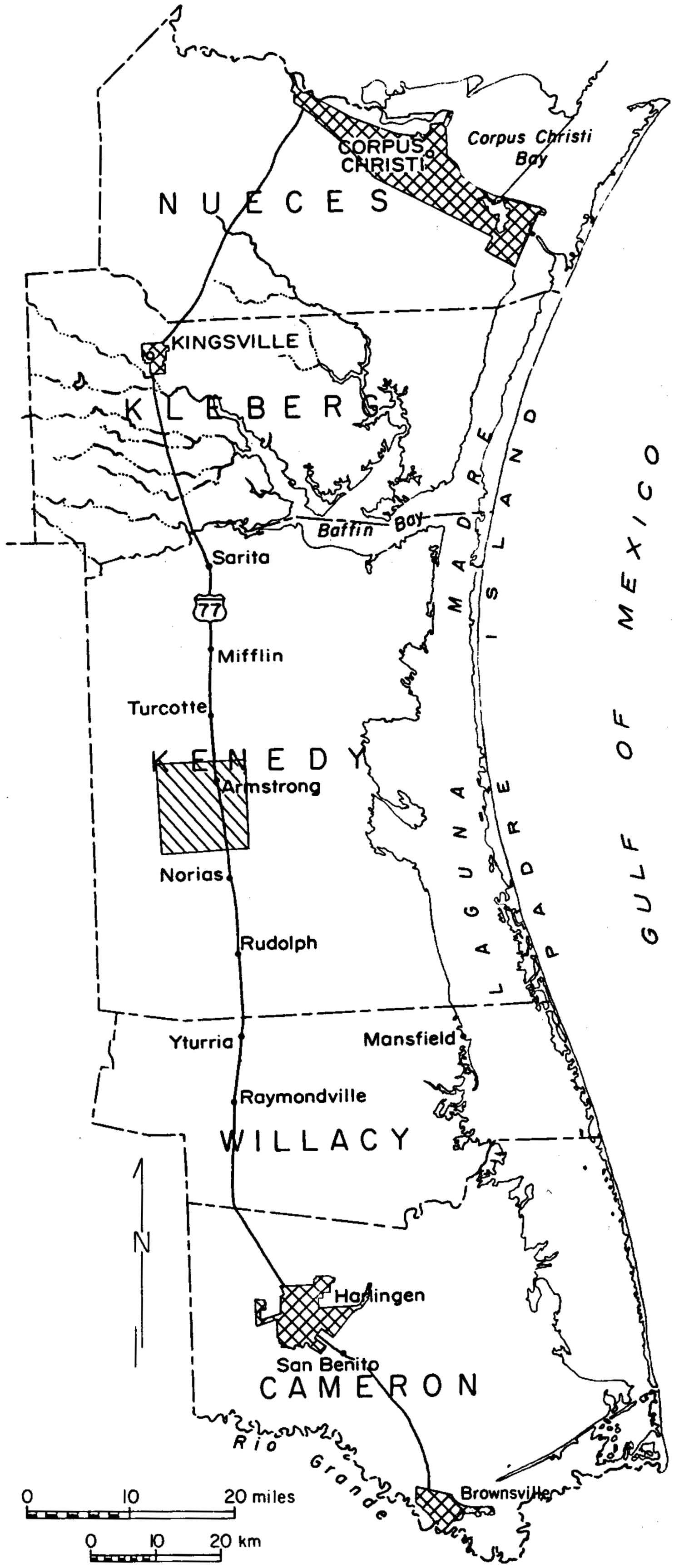


Figure 21. Location of Kenedy County geopressured-geothermal prospect area. Various environmental characteristics were mapped in area shown by line pattern in Kenedy County.

ENVIRONMENTAL CHARACTERISTICS

Environmental characteristics that were mapped, analyzed, and evaluated are similar to those discussed in Part I for Brazoria County and include: current land use, potential for subsidence and fault activation, flood potential, environmental geology and physical processes, water resources, biological assemblages, and meteorological characteristics.

CURRENT LAND USE

Current land use patterns were mapped using 1972 color aerial photographs (scale 1:121,000), U. S. Geological Survey topographic maps, and the land use map from the Environmental Geologic Atlas of the Texas Coastal Zone (Brown and others, 1977).

Land use in the Kenedy County prospect area is dominated by range-pasture/grasslands which are used for beef cattle grazing. The importance of cattle ranching in this area is reflected in agricultural statistics for Kenedy County which show that there were 103,000 cattle reported in the county as of January 1, 1977 (Texas Crop and Livestock Reporting Service, 1976). Although comprising only a small percentage of land area, other types of land use include residential-commercial, petroleum production facilities, roads, quarries (caliche pits), railroad and transmission line. The residential-commercial development is limited to the small rural community of Armstrong, located along U. S. Highway 77, and Armstrong Ranch Headquarters, located in the northeast corner of the map area (fig. 22). The Missouri Pacific Railroad and an electrical transmission line parallel U. S. Highway 77. The prospect area includes part of the King Ranch which is listed in the National Register of Historic Places (fig. 22). An archeological cultural resource (historical site) is located just west of U. S. Highway 77 and approximately 4.8 km (3 mi) south of Armstrong. Private roads extend from the highway across much of the prospect area and apparently were constructed for oil and gas exploration and production, and for ranch operations.

Selection of Test Well Site on the Basis of Current Land Use

Current land use patterns should present few limitations in the location of geopressured wells. Vast areas of range-pasture/grasslands provide suitable locations far removed from the community of Armstrong, Armstrong Ranch Headquarters, King Ranch, archeological cultural resources, and from U. S. Highway 77. Several wells have been drilled in developing the Candelaria oil field west of U. S. Highway 77 and Armstrong. Existing roads provide access to this area which is the heart of the geopressured-geothermal prospect fairway (Armstrong fairway) as identified and defined on the basis of reservoir characteristics by Bebout and others (1978). Location of the production wells on the west side of U. S. Highway 77 would be in agreement with the proposed location of a water-dominated geothermal energy system as noted by Muehlberg and Shepard (1975).

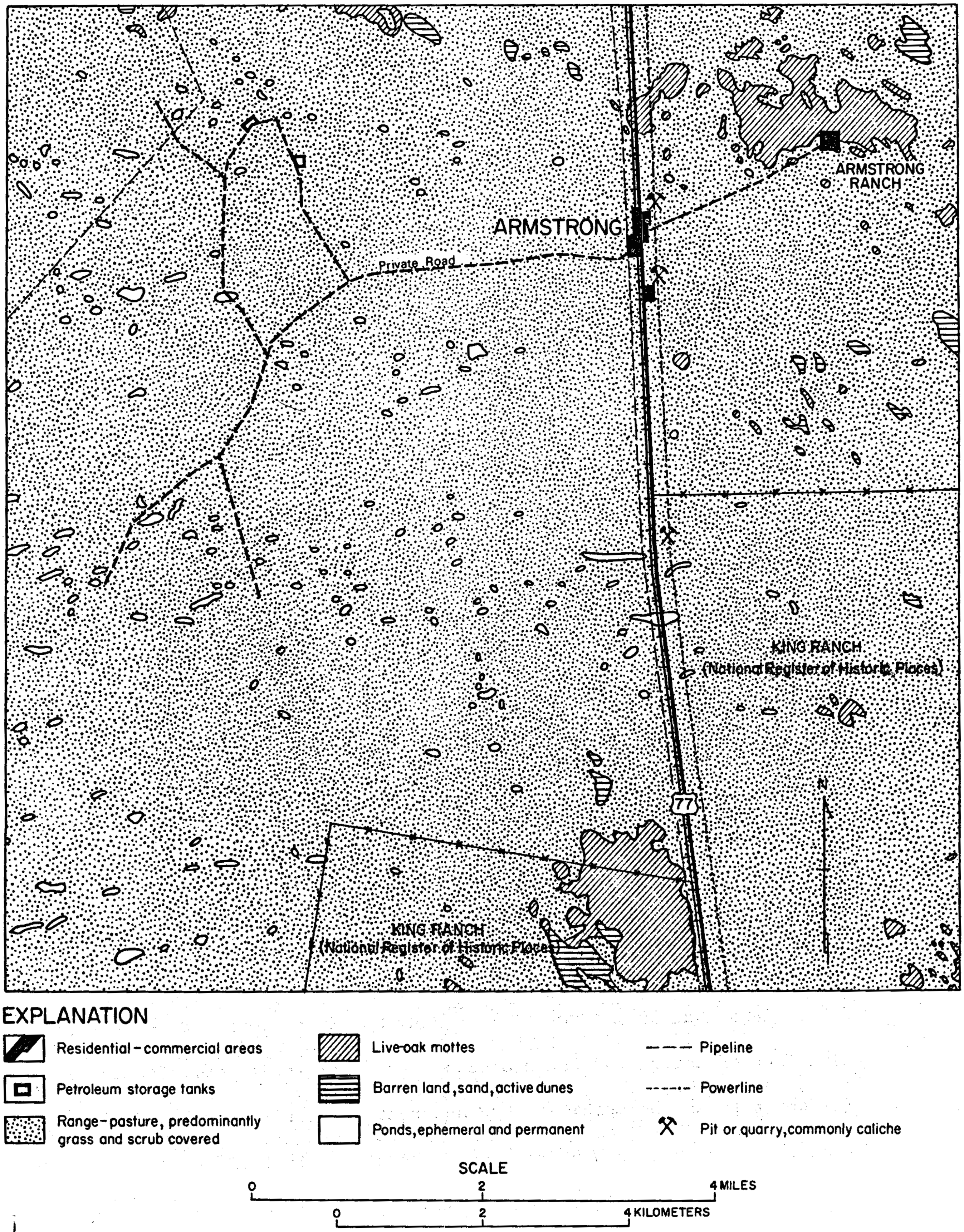


Figure 22. Current land use in the Kenedy County prospect area. (Modified from Brown and others, 1977; pipeline information in part derived from Dewitt and Company, Inc., Houston, Texas)

POTENTIAL FOR SUBSIDENCE AND FAULT ACTIVATION

Much of the discussion in Part I concerning potential for subsidence and fault activiation in the Brazoria County prospect area applies to the Kenedy County prospect area; as in the Brazoria County prospect, reservoir compaction and subsidence may accompany geopressured-geothermal fluid production. The two prospect areas have certain inherent similarities: (1) proposed production zones are composed of geopressured sandstones and interbedded shales which are part of the Frio Formation (although the upper Vicksbury is included in the Kenedy County fairway), and (2) growth faults are present in both prospect areas (Bebout and others, 1978). In Kenedy County faults bound the geopressured zone on the east and west. Differences in the two prospect areas can also be noted (from Debout and others, 1978): (1) proposed production depths in the Kenedy County prospect area are from approximately -3,350 m (11,000 ft) to -3,960 m (13,000 ft) as compared to -4,300 m (14,100 ft) and -5,030 m (16,500 ft) in Brazoria County, (2) net sandstone thickness ranges from a maximum of near 215 m (700 ft) to less than 90 m (300 ft) in Kenedy County as compared to an estimated net sandstone thickness of 255 m (840 ft) in Brazoria County, and (3) porosity and permeability are apparently lower in the Kenedy County prospect area than in Brazoria County as a result of differences in mineralogy which has increased the amount of cementation and reduced the amount of secondary leached porosity.

Low permeability and low fluid temperatures are factors that limit the geopressured-geothermal energy capabilities of the Kenedy County prospect area (Bebout and others, 1978). Although low permeabilities and porosities are undesirable factors with respect to fluid production, they indicate that reservoir sandstones are well cemented which should help to mitigate the amount of reservoir compaction and subsidence that can occur.

The magnitude of subsidence that may accompany reservoir sandstone compaction can be roughly estimated by using equation 1 presented in Part I, and by assuming that the two prospect areas are similar except for average production depth (D) and net sand thickness (H), which are approximately 3,655 m (12,000 ft) and 150 m (500 ft) respectively, in Kenedy County. Assuming the reservoir radius (r) (well drainage radius) will be the same as in the Brazoria County prospect, the difference in production depth (depth of burial, D) will affect factor "A" (which is determined using tables presented by Geertsma, 1973) by increasing it to 0.27 as compared to 0.17 for Brazoria County. This increase in "A" effectively increases the potential amount of subsidence that may occur in the Kenedy County prospect area, but the lower net sand thickness--150 m (500 ft) as compared to 255 m (840 ft) in Brazoria County--effectively decreases the amount of compaction that may occur, so that the resulting magnitude of subsidence that may accompany fluid withdrawal in the Kenedy County prospect area is very close to the values calculated for the

Brazoria County prospect for the same amounts of reservoir pressure declines (Δp). The amount of subsidence accompanying sandstone compaction for the Kenedy County prospect indicated by equation 1 is 11.2 cm (4.4 in) and 13.7 cm (5.4 in), for pressure declines of 275 psi and 340 psi, respectively.

Gustavson and Kreitler (1976) estimate that subsidence accompanying mudstone compaction in the Kenedy County prospect area could be as much as 2.7 to 12.6 m with pressure declines of 1000 psi and a net clay thickness of 146 m.

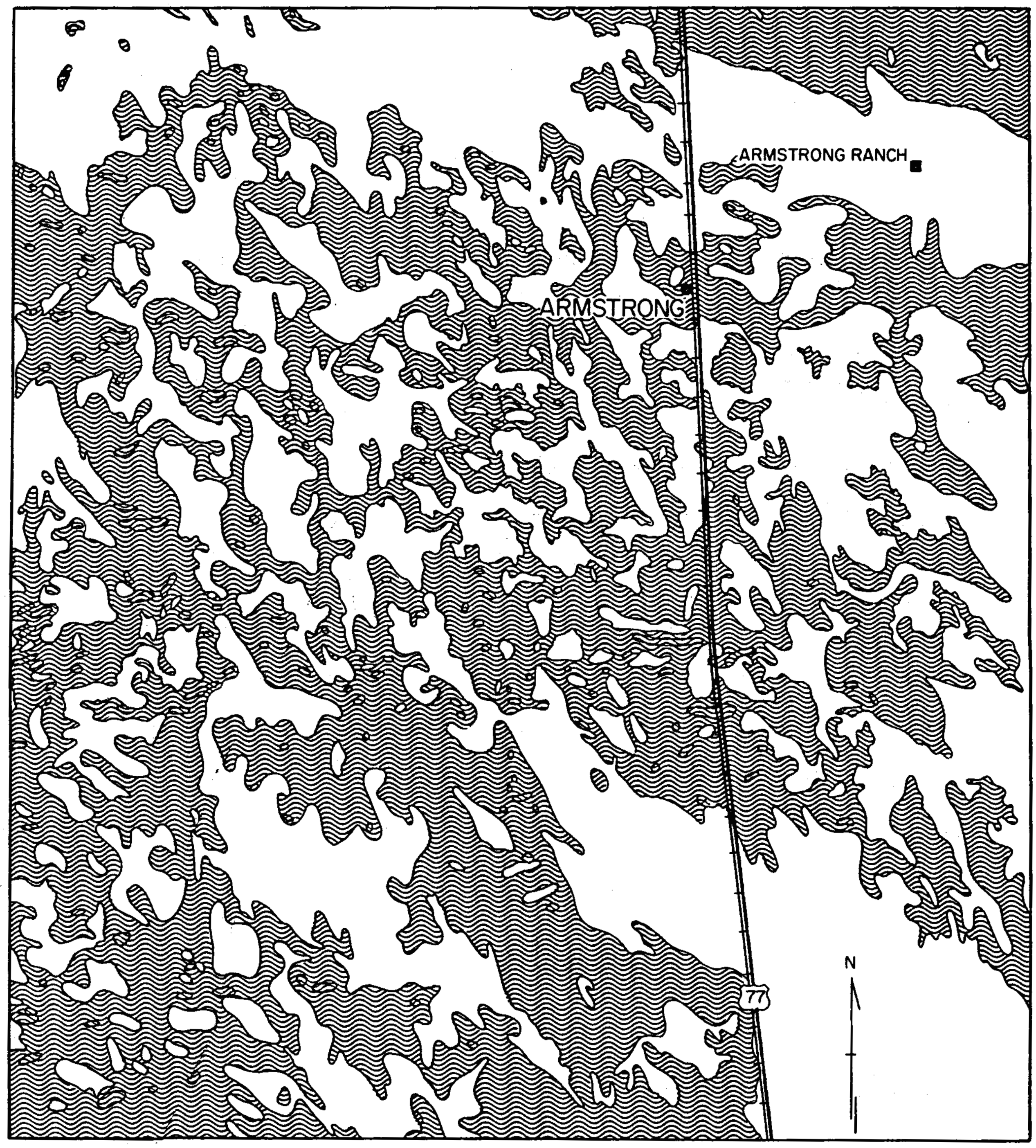
Selection of Test Well Site on the Basis of Potential Subsidence and Fault Activation

A major difference between the Brazoria County and Kenedy County prospect areas is the kinds of surface features that will be affected should significant subsidence and fault movement occur. Impact to surface facilities will be much less significant in the Kenedy County prospect area because few man-made structures are present. This flat, poorly drained area is susceptible to flooding by torrential rainfall, however, and subsidence will increase this susceptibility. In addition, subsurface faults projected to the surface intercept U. S. Highway 77 at two locations within the prospect area; one fault projected upward at 60° intersects the surface near Armstrong. Nevertheless, adverse impacts from subsidence and fault activation will be much less significant in this area dominated by rangeland than in areas where urban and industrial facilities have been established.

FLOOD POTENTIAL

Streams are absent in the Kenedy County prospect area primarily because of: (1) semi-arid climatic conditions, (2) sandy soils which allow relatively rapid infiltration of water, and (3) eolian activity which has modified surface conditions through deflation, leaving numerous depressions that pond water. Thus, in contrast to the Brazoria County prospect area, fresh-water flooding along streams is not a problem but the relatively flat, wind-modified and poorly drained surface that characterizes this south Texas region enhances its potential for rather extensive local flooding by heavy rains especially during aftermath storms accompanying passage of hurricanes.

The approximate area flooded by torrential rains accompanying Hurricane Beulah, which made landfall just south of Brownsville (approximately 112 km (70 mi) south of Armstrong) in 1967, is shown in figure 23. Debris or drift line elevations left by the flood near U. S. Highway 77, were 6.2 m (20.4 ft) and 6.6 m (21.5 ft) at locations approximately 3.7 km (2.3 mi) and 9.6 km (6 mi) south of Armstrong, respectively (U. S. Army Corps of Engineers, 1968). U. S. Highway 77 was not passable at several locations because of inundation by ponded water (Grozier and others, 1968). At the end of October, 1967, according to Grozier and others (1968), boats were a



EXPLANATION

Approximate area inundated by rainfall or runoff accompanying Hurricane Beulah and aftermath storms

SCALE

0 2 4 MILES

0 2 4 KILOMETERS

Figure 23. Areas susceptible to flooding in the Kenedy County prospect area. Areas were delineated using aerial photo mozaics and U. S. Geological Survey topographic maps with references to areas flooded by Hurricane Beulah as shown by U. S. Corps of Engineers, 1968, and Brown and others, 1977.

common means of transportation at the Norias Division of the King Ranch which is just south of the prospect area; all ranch roads were closed. Attempts to drain the standing water into the Gulf of Mexico were unsuccessful because water that was removed was replaced by ground water inflow from the underlying and adjacent sands (Grozier and others, 1968).

Selection of Test Well Site on the Basis of Flood Potential

As shown in figure 23 a large percentage of the prospect area is susceptible to flooding. Because of poor surface drainage in this area, ponded water can present problems for many days following heavy rains. The threat of having to shut down geopressured-geothermal operations because of inaccessibility to the site during floods emphasizes the need to select sites that will be above flood levels, but also sites that will not become isolated by ponded flood waters. With reference to elevations shown on topographic maps and levels of flooding during Hurricane Beulah, sites that are less likely to be flooded can be appropriately selected; the map of flood-prone areas shown in figure 23, was developed in this fashion. Acceptable sites are present on both the east and west side of U. S. Highway 77 (fig. 23).

ENVIRONMENTAL GEOLOGY AND PHYSICAL PROCESSES

Environmental geology and physical properties maps of the Kingsville area by Brown and others (1977), were used to determine the environmental geologic characteristics of the prospect area and the processes that are operative there. Processes are dominated by eolian activity as reflected by the numerous eolian related features which include active and stabilized sand dunes, sand and loess (silt) sheets, deflation areas, and accretionary clay-sand dunes (fig. 24). Sand dunes that have migrated into or across the prospect area are controlled and directed primarily by the predominant southeasterly winds; the net direction of sand migration is toward the northwest. Some sand dunes have become well stabilized by live oaks while others are moderately stabilized by grasses and scrubs. Active dunes occur only in a few isolated areas.

Numerous depressions have been formed in deflation and blowout areas producing a surface characterized by many ponds and playas. During dry periods the playas dry up exposing clay substrates. As the clay desiccates and cracks, it becomes the source of clay pellets that are transported by the southeasterly winds to the leeward side of the playa where the pellets accumulate forming accretionary ridges composed of clay and sandy clay (Huffman and Price, 1949). Thus, the main lithologic types in the prospect area are the sands and silts associated with sand dunes and eolian sheet sands and the clay and sandy clay that has accumulated along the leeward margin of playas

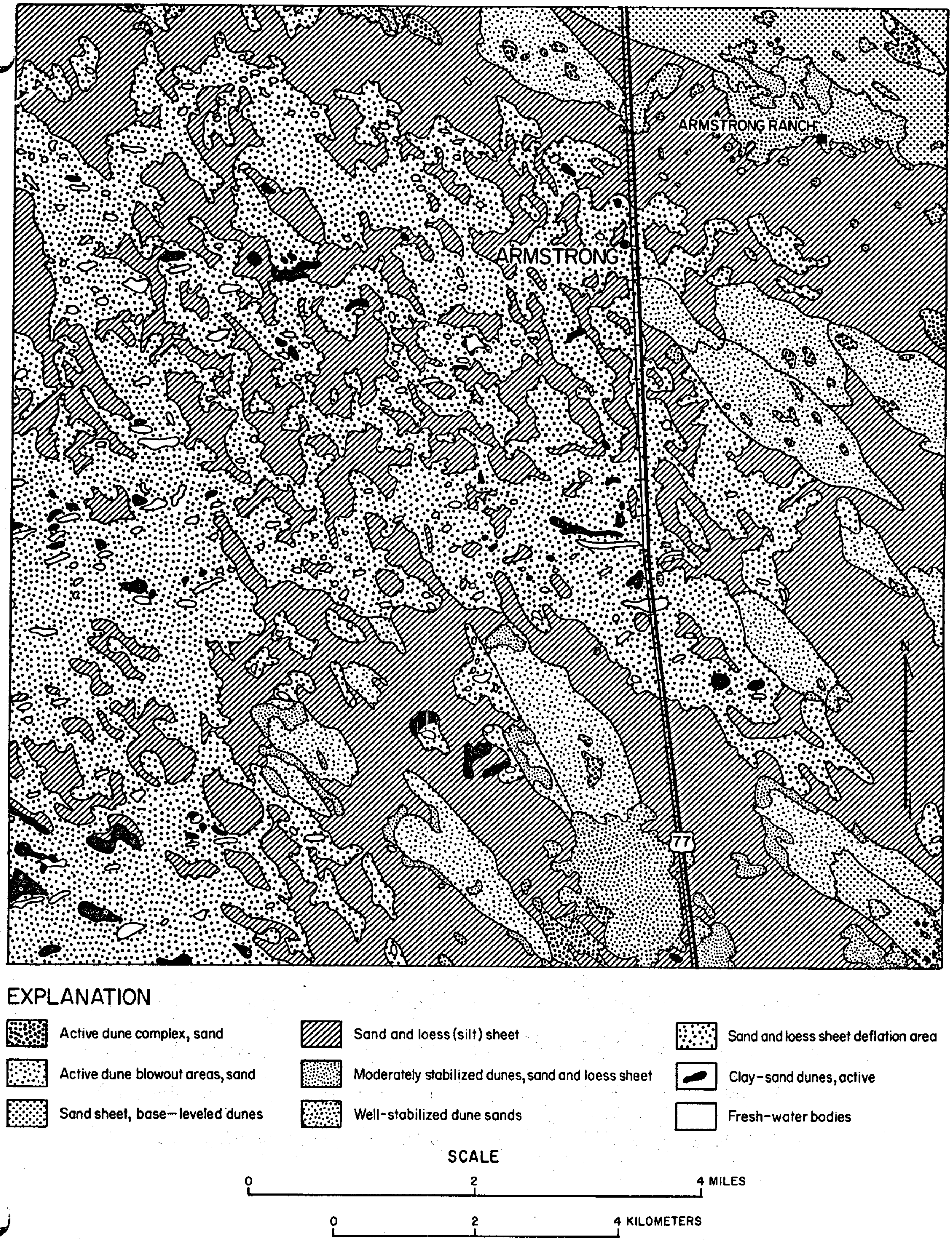


Figure 24. Environmental geology of the Kenedy County prospect area. (Modified from Brown and others, 1977)

(fig. 25). These areas of sand and sandy clay are of high and low to moderate permeability, respectively (Brown and others, 1977). The clay content in the sandy clay areas (clay-sand dunes) produces a moderate shrink-swell potential relative to areas of sand where the shrink-swell potential is negligible.

Soils in the prospect area are characterized by the Sarita-Falfurrias-Nueces Association (U. S. Department of Agriculture Soil Conservation Service, 1972). Deep sands that are highly susceptible to wind erosion when not protected, typify this soil association.

Selection of Test Well Site on the Basis of Environmental Geology and Physical Processes

Areas that should be avoided in locating the production well and surface support facilities are sand dunes both active and stabilized, clay-sand dunes, and deflation areas. The dune areas should be avoided because of problems that may arise from blowing sand and silt. If stabilized dune areas are stripped of their vegetation, blowout areas may result and active sand dunes may form. Deflation areas are topographically low areas that generally have high water tables and pond meteoric water. Suitable sites for the production well and support facilities are present in areas mapped as sand and loess (silt) sheets.

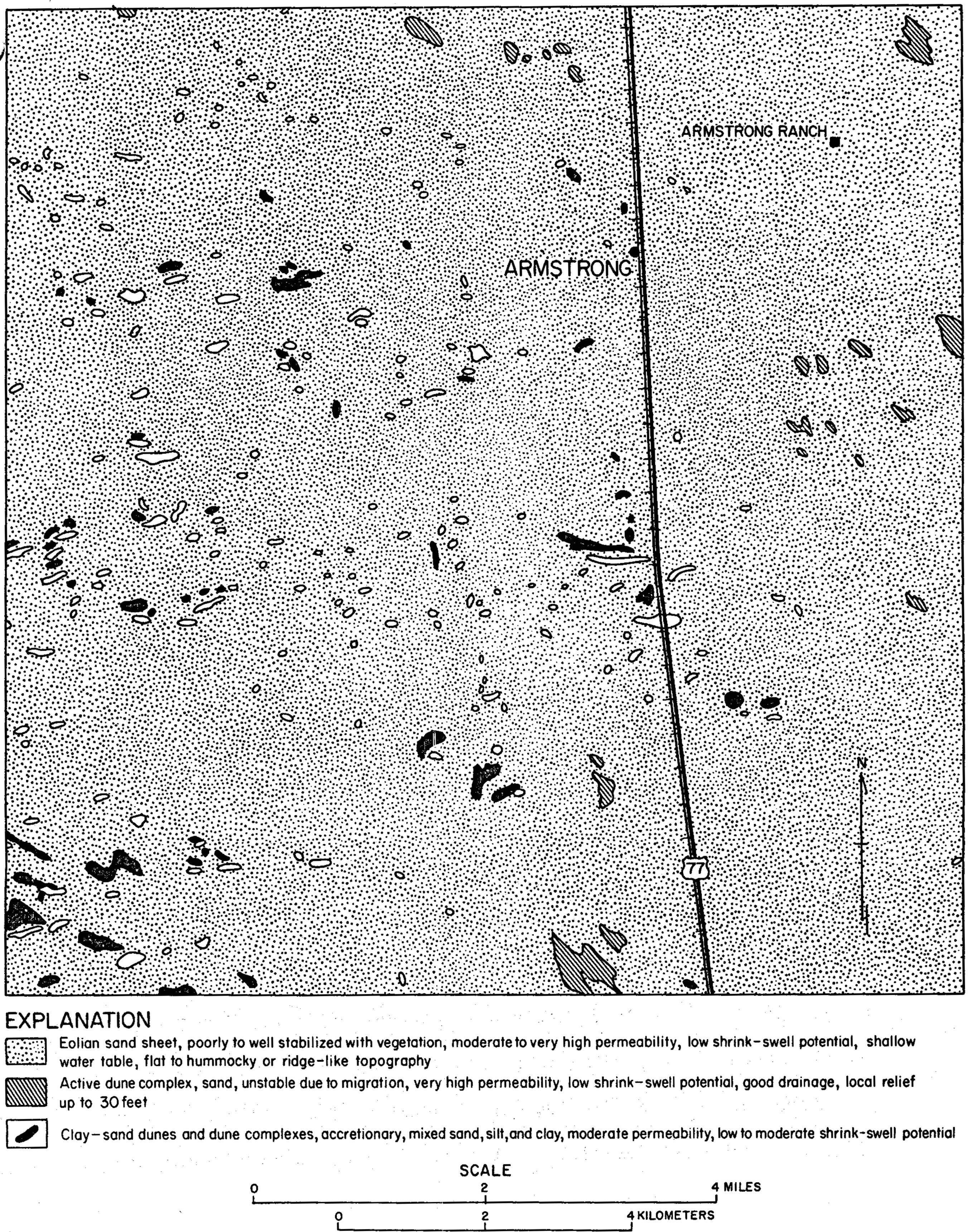


Figure 25. Distribution of eolian sand sheet, active dunes, and clay-sand dunes, Kenedy County prospect area. (Modified from Brown and others, 1977)

WATER RESOURCES

Chemical analyses indicate geopressured-geothermal fluids are brines with various constituents such as boron at concentrations substantially higher than in sea water or in hypersaline lagoons such as Laguna Madre which is Gulfward of the Kenedy County prospect area. Inadvertent discharges of the fluids at the surface or leakage from production or disposal wells could have a serious adverse affect on water resources, and vegetation.

Ground-Water Resources

The following discussion of ground water in the Kenedy County prospect area is primarily from Shafer and Baker (1973).

The importance of ground water in the Kenedy County prospect area is underscored by the fact that over 30 water wells, many of them artesian, have been drilled in the area. Ground water is used primarily for rural-domestic and livestock purposes. The primary aquifer is the Goliad Sand from which approximately 14 million gallons per day (mgd) are available in Kenedy County; only 2.8 mgd were used in 1968. The Goliad Sand crops out west of Kenedy County where recharge occurs. According to Shafer and Baker (1973), "the area most favorable for the development of additional ground-water supplies from the Goliad Sand is west-central Kenedy County, where the sands are thickest and where the present rate of development is relatively small." This area of favorability for ground water development includes most of the Kenedy County geopressured-geothermal prospect area. The approximate downdip limit of fresh water (less than 1000 mg/l TDS) in the Goliad Sand almost coincides with U. S. Highway 77 (fig. 26). Ground water in the eastern half of Kenedy County (east of U. S. Highway 77 in the prospect area) is slightly (1,000 to 3,000 mg/l TDS), moderately (3,000 to 10,000 mg/l TDS), or very saline (10,000 to 35,000 mg/l TDS). The fresh water lens in the Goliad Sand is apparently overlain and underlain by slightly saline water which is in turn enveloped in moderately to very saline water (fig. 27).

The eolian sand sheet (eolian plain deposits) that occurs at the surface and at relatively shallow depths in the prospect area contains ground water under water table conditions, but the water is generally slightly to very saline. Observation wells drilled from 5.8 m (19 ft) to 7.3 m (24 ft) near Armstrong show the eolian deposits in that area contain water with chloride concentrations as high as 28,000 mg/l. Chemical analyses of ground water from 22 wells completed at various depths in the Goliad Sand and in the eolian plain are presented in table 15; the approximate locations of the wells are shown in figure 26. As indicated by concentrations of dissolved solids in table 15, water from the Goliad Sand is much less saline than water from shallow eolian plain sands.

The high salinities in shallow aquifers may in part reflect past methods of disposing of salt water. Until 1969, a common method used

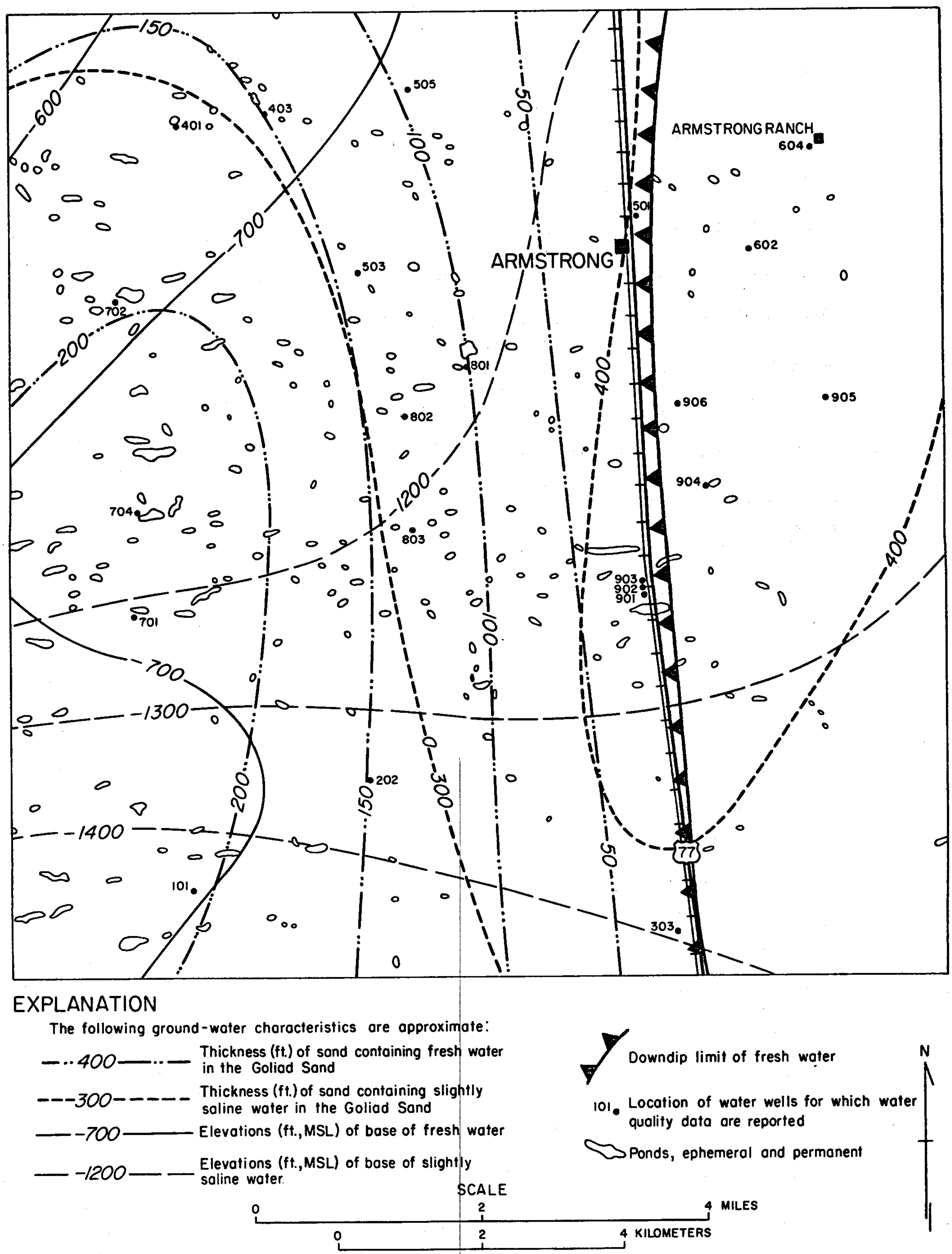


Figure 26. Ground-water characteristics in the Kenedy County prospect area. (Modified from Shafer and Baker, 1973)

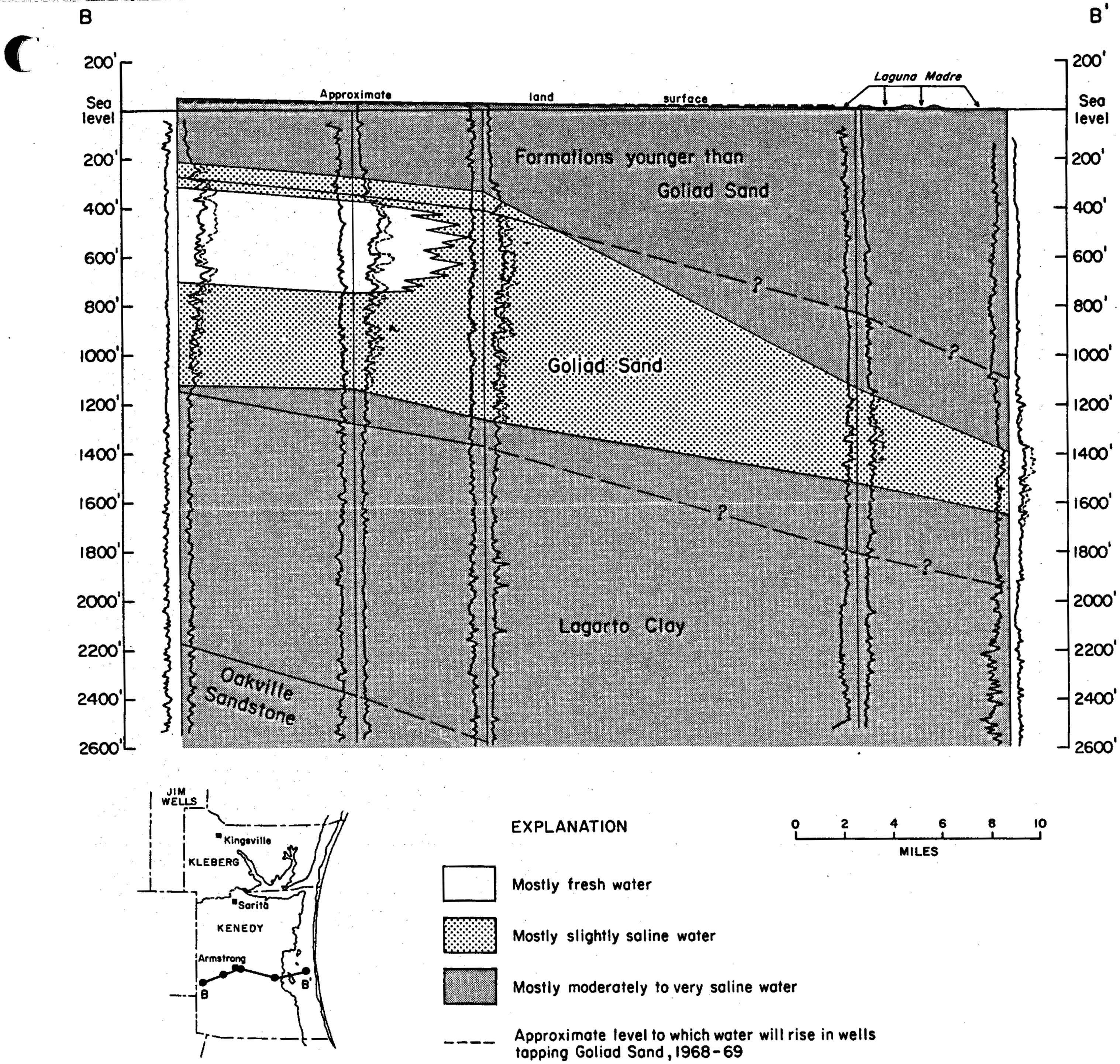


Figure 27. Approximate distribution of fresh, slightly saline, and moderately to very saline water along line B-B', Kenedy County. (Modified from Shafer and Baker, 1973)

TABLE 15. CHEMICAL ANALYSES OF WATER FROM WELLS IN THE KENEDY COUNTY PROSPECT AREA

(Compiled from Shafer and Baker, 1973)

Well	Depth or producing interval (feet)	Date of collection	Water-bearing unit	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium Na	K	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dis-solved solids	Hardness as $CaCO_3$	Percent sodium	Sodium Adsorption Ratio (SAR)	Residual Sodium Carbonate (RSC)	Specific conductance (micromhos at 25°C)	pH	Water temperature °C	°F
101	864	June 11, 1969	Tg	16	0.13	10	2.2	471		262	364	322	3.3	1.7	1,320	34	97	35	3.61	2,120	8.2	30	86
202	828	May 7, 1969	Tg	10	0.11	8.2	3.6	476		208	422	322	1.8	2.5	1,350	36	97	35	2.71	2,220	8.5	25	77
303	40	February 21 1969	Qcp	--	--	123	83	--		316	--	1,410	--	--	--	648	--	--	0.00	5,010	7.6	23	73
401	--	May 14, 1969	Tg	16	0.80	30	5.9	546		102	664	360	0.9	1.6	1,670	100	92	24	0.00	2,650	7.8	26	79
403	1,099	do.	Tg	17	0.05	18	4.1	427		168	380	322	0.9	2.3	1,250	62	94	24	1.51	2,060	7.9	--	--
501	900±	April 18, 1933	Tg	30	0.26	12	4.4	373	12	244	279	275	--	0.25	1,110	48	--	--	--	--	8.0	--	--
		May 14, 1969		18	0.58	12	2.8	390		252	280	275	1.3	1.1	1,100	42	95	26	3.30	1,820	--		
503	490	May 14, 1969	Tg	18	1.7	46	19	614		216	688	445	2.3	2.4	1,940	193	87	19	--	3,030	7.7	--	--
505	--	June 11, 1969	Tg	17	0.04	44	8.8	711		128	1,020	368	1.7	1.0	2,230	146	91	26	--	3,250	7.1	--	--
602	925	June 12, 1969	Tg	17	0.11	60	1.3	389		292	232	270	1.8	0.9	1,060	20	98	38	4.38	1,750	8.6	30	86
604	910	June 17, 1969	Tg	17	--	7.2	1.4	430		300	278	295	2.4	1.4	1,180	24	97	38	4.44	1,910	8.4	--	--
701	--	May 8, 1969	Tg	17	0.41	8.5	1.3	451		230	346	320	1.9	1.6	1,260	26	97	38	3.24	2,130	8.3	--	--
702	900	March 3, 1913	Tg	--	--	--	--	430		183	344	300	--	--	1,200	76	--	--	--	--	--	29	84
		May 14, 1969		17	0.79	18	4.0	414		200	356	300	1.5	1.1	1,210	62	94	23	2.05	2,000	7.8		
704	857	March 3, 1913	Tg	--	--	--	--	470		212	362	312	--	--	1,300	50	--	--	--	--	--	27	81
		May 8, 1969		17	0.35	9.5	1.5	448		228	358	315	1.8	1.7	1,260	30	97	36	3.01	2,060	8.2		
801	900	March 3, 1913	Tg	--	--	--	--	430		232	328	272	--	--	1,200	54	--	--	--	--	--	--	--
802	1,002	May 7, 1969	Tg	17	0.16	13	3.1	432		216	380	290	1.3	0.8	1,240	46	95	28	2.63	2,030	8.2	26	79
803	567	March 3, 1913	Tg	--	1.4	--	--	240		106	810	376	--	--	1,900	990	--	--	--	--	--	26	79
		May 7, 1969		12	0.52	19	4.5	426		214	388	290	1.4	1.6	1,250	66	93	23	2.19	2,020	8.3		
901	19	April 6, 1968	Qep	62	--	875	1,490	15,600	142	462	6,340	25,200	--	0.0[a]	49,900	8,310	80	--	0.00	75,600	7.4	--	--
		May 15, 1968		--	--	975	1,110	--		42	--	21,500	--	0.0[b]	--	7,000	--	--	--	65,300	5.8	24	75
		June 18, 1969		--	--	810	1,750	--		452	7,930	27,500	--	--	--	9,220	--	--	0.00	75,500	7.1	24	75
902	24	April 7, 1968	Qep	30	--	950	1,230	12,600	113	266	7,010	20,000	--	--	42,100	7,430	78	--	0.00	62,500	7.1	27	81
		May 15, 1968		--	--	875	1,140	--		0.011	--	19,200	--	--	--	6,870	--	--	0.00	61,100	3.3	--	--
		June 18, 1969		--	--	880	1,960	--		344	9,560	26,000	--	--	--	10,300	--	--	0.00	71,900	6.9	24	75
903	20	April 7, 1968	Qep	--	--	475	660	--		284	--	11,600	--	12	--	3,900	--	--	--	37,100	7.3	26	79
		May 15, 1968		26	--	925	1,140	12,200	100	174	4,720	20,800	--	--[c]	40,000	7,000	79	--	0.00	64,300	6.1	26	79
		June 18, 1969		--	--	765	1,280	--		310	6,410	20,400	--	--	--	7,170	--	--	0.00	59,000	7.3	24	75
904	--	June 17, 1969	Tg	17	0.99	16	2.9	566		148	653	338	1.6	1.1	1,670	52	96	34	1.39	2,560	7.7	--	--
905	800±	March 3, 1913	Tg	--	--	--	--	560		280	431	340	--	--	1,500	40	--	--	--	--	--	--	--
906	912	June 17, 1969	Tg	17	0.05	14	3.7	434		250	363	288	1.9	1.5	1,250	50	95	27	3.10	2,010	8.1	30	86

*includes any carbonate present Tg = Tertiary Goliad Sand Qep = Quaternary, eolian plain [a]includes 0.07 mg/l ammonia as NH_4^+ [b]sample contains 1.6 mg/l ammonia as NH_4^+ [c]includes 2.6 mg/l ammonia as NH_4^+

to dispose of salt water which was produced with oil in Kenedy and adjacent south Texas Counties was to place the water in unlined surface pits. In 1967, 36,500 barrels of salt water produced in the Candelaria oil field, which is in the geopressured-geothermal prospect area in Kenedy County, was disposed of in unlined surface pits (Shafer and Baker, 1973). This method of disposal was discontinued on January 1, 1969 when a no-pit order applying to all of Texas was issued by the Texas Railroad Commission. Shafer and Baker (1973) state that during their investigation of ground-water resources in Kenedy County, they found no conclusive evidence of contamination of the water from wells sampled, although they note that it may be occurring.

Surface-Water Resources

Surface-water resources in the Kenedy County prospect area are composed primarily of numerous small ephemeral and some permanent water bodies that have been formed principally by water ponded in deflation depressions. Water sampled in 1968 and 1969 from one of the more permanent ponds located along U. S. Highway 77 approximately 5.3 km (3.3 mi) south of Armstrong, was slightly to moderately saline as indicated by a dissolved solids content ranging from 1,500 to 9,220 mg/l (table 16). These relatively high salinities apparently reflect the influence of the shallow ground water which is brine in this area. Studies of the relationship of ground water and the ponded water in 1968 and 1969 indicated the pond is maintained by

TABLE 16. CHEMICAL ANALYSES OF PONDED WATER,

KENEDY COUNTY PROSPECT AREA

(Compiled from Baker, 1971)

Chemical Constituents (*mg/l*)	*Date of Collection* April 6, 1968	July 16, 1968	September 17, 1968	December 10, 1968	March 26, 1969	June 18, 1969	September 18, 1969
Silica (SiO_2)	30	––	3.2	––	––	––	2.9
Calcium (Ca)	77	91	139	207	348	178	545
Magnesium (Mg)	45	34	43	66	119	68	182
Sodium (Na)	399	576	886	––	2,050*	91*	2,460
Potassium (K)	9.1	9.8	12	––	––	––	36
Bicarbonate (HCO_3)	240	40	32	28**	54	50	72
Sulfate (SO_4)	224	––	601	––	1,340	704	2,060
Chloride (Cl)	592	900	1,380	1,950	3,100	1,360	3,900
Flouride (F)	0.1	––	0.6	––	––	––	––
Nitrate (NO_3)	3.0	1.1	0.1	––	––	––	––
Boron (B)	––	––	––	––	––	––	1.4
Dissolved Solids	1,500	––	3,080	––	6,980	2,430	9,220
Hardness as $CaCO_3$	377	367	524	788	1,360	724	2,000
Percent Sodium	69	77	78	––	––	––	71
Sodium Adsorption Ratio (SAR)	8.9	13	17	––	––	––	––
Residual Sodium Carbonate (RSC) (*me/l*)	0.00	0.00	0.00	0.00	––	0.00	0.00
Specific Conductance (Micromhos at 25°C)	2,630	3,440	5,470	7,160	11,200	5,410	14,000
pH	7.2	7.0	7.2	8.6	7.1	7.3	7.1
Temperature °C	22	––	––	17	19	29	30
°F	72	––	––	63	66	84	86

* Sodium and potassium calculated as sodium
** Includes the equivalent of 9 mg/l carbonate

ground water seepage inflow (Baker, 1971). If this pond is representative of the surface water quality in the prospect area, the high salinities limit the suitability of the surface water for many human uses.

Selection of Test Well Site on the Basis of Water Resources

The most valuable water resource in the prospect area is ground water in the Goliad Sand which occurs at depths between approximately 90 m (300 ft) and 365 m (1200 ft), and is an artesian aquifer. Both fresh and slightly saline water occur in the aquifer, however, the fresh water lens extends only a short distance east of U. S. Highway 77 (fig. 26). Although Texas Railroad Commission regulations require surface casing to be set in production and disposal wells to protect ground water, if leakage or discharge of geothermal fluids should occur, the impact on ground-water resources would be less severe in the eastern one-third of prospect area where fresh ground water is not present. Thus, in terms of affording maximum protection to water resources, the most suitable location for the test well is east of U. S. Highway 77.

BIOLOGICAL ASSEMBLAGES

Plants

The South Texas eolian plains can be described as an area of gently undulating topography broken only by clumps of scrubby live oak trees (*Quercus virginiana* and *Q. oleoides quaterna*) and large sand dunes; the rest of the prairie is covered with expanses of coarse bunch grasses and scattered Mesquite and brush. The dynamic nature of the environment is clearly represented by the activity of the mobile sand dunes. During dry and windy periods sand and loess are swept across the plains and build up against thickets and larger vegetation; roots are exposed to the seering salty winds in blow-outs, and other vegetation is buried in accreting sand and killed (Johnston, 1955). When moisture is more abundant and/or winds are arrested, a seral plant community becomes established in dunes and depressions which again stabilizes the sand. During rainy periods water accumulates in depressions and lowland areas and very little drainage is evident.

Aside from the seral vegetation on the mobile dunes, distinct vegetational communities occupy the uplands; and lowland communities are characterized by a strict topographic plant zonation. Upland vegetation includes Live Oak mottes and scrub, brushland, and prairie. The environmental factors which govern when each upland vegetational assemblage occurs will be discussed along with that particular unit. The sequence of lowland communities includes, in order of decreasing relative elevation, *Spartina spartinae* community, *Borrichia-Batis-Monanthochloe* community and *Batis-Salicornia-Sueda* community. These assemblages also are influenced by increases in air-borne and ground-water salinity. In the Kenedy Prospect area, only the *Spartina* spartinae community is present probably because of the decreased salinity of ground water inland from the coast.

Mapping of vegetation assemblages is taken from the Environmental Atlas of the Texas Coastal Zone, biological assemblages map, Kingsville sheet (Brown and others, 1977) (fig. 28). Mapped units are based on Johnston's work and use 1:24,000 black-and-white aerial photographs taken in 1959. Six vegetation units occupy the study area and will be described in the following paragraphs. The unit descriptions are based mainly on M. Johnston's Ph. D. thesis (1955). Other sources will be acknowledged in the text.

Live Oak Mottes

Live Oak mottes and groves form the most distinctive vegetation unit in the prospect area. The community is dominated by Live Oak (*Quercus virginiana* and *Q. oleoides quaterna*) growing to heights of 25 feet but generally about 15 feet tall. The shading by the trees normally discourages other prairie species to invade or intermix, however several shade tolerant grasses, epiphytes, vines, herbs, and brush species are characteristic (table 17). Live Oak mottes only occupy the highest upland areas on loose sandy soil and are never replaced by any other community. It is the edaphic climax of the area.

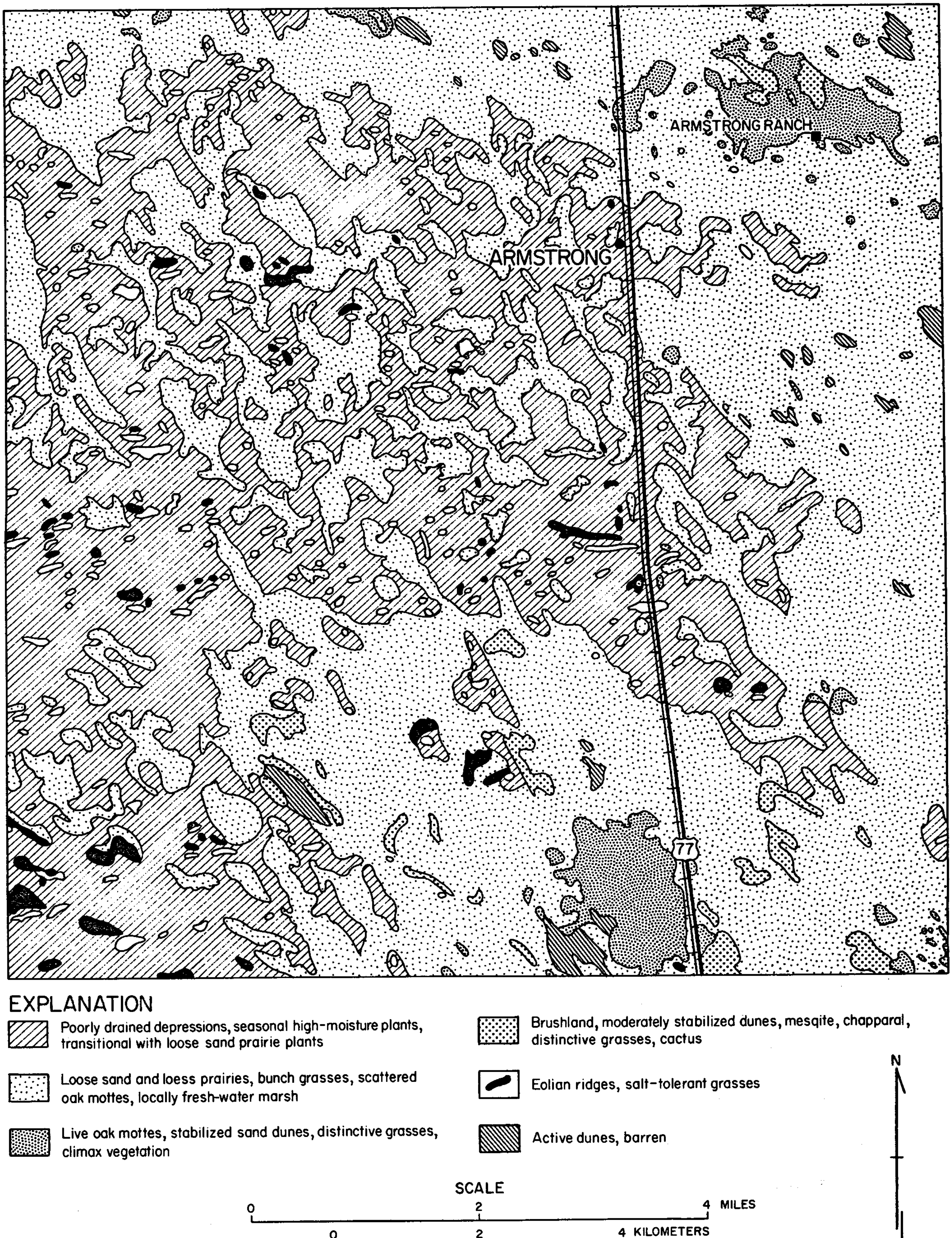


Figure 28. Environments and biological assemblages in the Kenedy County prospect area. (Modified from Brown and others, 1977)

TABLE 17. PLANT SPECIES IN LIVE OAK MOTTE COMMUNITY

(Modified from Johnston, 1955)

	Trees	
Quercus virginiana		*Quercus oleoides quaterna*
	Motte-grasses (shade tolerant)	
Vaseyochloa multinervosa	*Paspalum ciliatifolium*	*Trichoreura elegans*
Sporobolus purpurascens	*Digitaria texana*	*Cenchrus pauciflorus*
	Epiphytes	
Tillandsia Baileyi	*Tillandsia recurvata*	*Tillandsia usneoides*
	Vines	
Metastelma barbigerum		*Vitis mustangensis*
	Herbs and forbs	
Malvaviscus Drummondii	*Mentzelia texana*	*Solanum verbascifolium*
Wissadula amplissima	*Tradescantia hirsutiflora*	*Sclerocarpus uniserialis*
Pterocaulon virgatum	*Hybanthus verticillatus*	*Cnidoscolus texanus*
Schrankia latidens		
	Shrubs	
Yucca Treculeana	*Bumelia lanuginosa*	*Sapindus Drummondii*

Brushland

Brushland exists predominantly in the eastern portion of the study area, although much scattered brush exists throughout the area. It is characterized by xerophytic shrubs and short trees dominated by Mesquite (*Prosopis glandulosa*). It thrives on upland areas not occupied by Live Oak mottes and in general is not soil-type dependent and is therefore considered to be the climatic climax vegetation of the region (Johnston, 1955). In overgrazed areas, brushland vegetation tends to invade, and Johnston (1955) has noted a succession of invading woody species. In general, arboreal Mesquite pioneers as scattered plants. Then the brush thickens as mottes and clumps appear, made up of Mesquite, Prickly Pear (*Opuntia Lindheimeri*, *O. leptocaulis*), Hackberry (*Celtis pallida*), and Yucca (*Yucca Treculeana*). Eventually many other brush associated species appear while vegetation becomes more dense (table 18). In the meantime, many prairie species decline probably because of competition for light and water.

Loose Sand and Loess Prairies

This vegetation assemblage (table 19) is characteristic of loose sand uplands not dominated by brush or Live Oak scrub Seacoast Bluestem (*Schizachyrium scoparium* var. *littoralis* (Nash) Gould) is the most abundant grass species in this community in its undisturbed state, but principally because of grazing, the compo-

TABLE 18. PLANT SPECIES FOUND IN BRUSHLAND COMMUNITY

(Modified from Johnston, 1955)

	Trees and shrubs	
Prosopis juliflora, arboreal mesquite	*Porlieria angustifolia*	*Croton humilis*
Celtis pallida	*Salvia ballotaeflora*	*Isocoma Palmeri*
Yucca Treculeana	*Isocoma Drummondii*	*Randia mitis*
Zizyphus obtusifolia	*Baccharis texana*	*Amyris texana*
Xanthoxylum Fagara	*Colubrina texensis*	*Viguiera stenoloba*
Opuntia Lindheimeri	*Pithecellobium pallens*	*Maytenus phyllanthoides*
Opuntia leptocaulis	*Pithecellobium flexicaule*	*Chiococca alba*
Bumelia angustifolia	*Schaefferia cuneifolia*	*Acacia rigidula*
Lantana horrida	*Castela texana*	*Ephedra antisyphilitica*
Condalia obovata	*Capsicum baccatum*	*Berberis trifoliolata*
Mozinna spathulata	*Citharexylum barchyanthum glabrum*	*Cercidium macrum*
Lantana macropoda	*Phaulothamnus spinescens*	*Eysenhardtia texana*
Aloysia lycioides	*Malpighia glabra*	*Sophora secundiflora*
Lycium Berlandieri	*Prosopis juliflora,* running mesquite	*Bernardia myricaefolia*
Karwinskia Humboldtiana	*Leucophyllum frutescens*	*Lantana citrosa*
Forestiera angustifolia	*Citharexylum Berlandieri*	*Cordia Biossieri*
Brayodendron texanum	*Phoradendron flavescens* (parasitic herb)	*Hibiscus cardiophyllus*
	Tillandsia recurvata (epiphytic herb)	
	Perennial herbs	
Siphonoglossa dipteracantha	*Commelina erecta angustifolia*	*Parthenium lyratum*
Ayenia pusilla	*Celosia nitida*	*Manfreda variegata*
Verbesina microptera	*Dyschoriste linearis*	*Zexmenia hispida*
Calyptocarpus vialis	*Solanum triquetrum*	*Menodora heterophylla*
Encelia calva	*Acleisanthes Berlandieri*	*Dyschoriste crenulata*
Abutilon Berlandieri	*Gayoides crispum*	*Carlowrightia glabrata*
Monoxalis dichondraefolia	*Elytraria bromoides*	*Dichondra repens carolinensis*
Talinum aurantiacum	*Gymnosperma glutinosa*	*Tradescantia micrantha*
Boerhaavia decumbens	*Sedum texanum*	*Manfreda maculosa*
Salvia coccinea	*Perezia runcinata*	*Gomphrena Nealleyi*
Trixis radialis	*Bastardia viscosa*	*Reullia Corzoi*
Abutilon incanum	*Sida paniculata*	*Ruellia Runyonii*
	Stenandrium dulce	

TABLE 18. (Continued)

	Perennial grasses	
Trichloris pluriflora	*Tridens eragrostoides*	*Andropogon perforatus*
Trichachne insularis	*Panicum filipes*	*Bouteloua trifida*
Setaria macrostachya	*Panicum Hallii*	*Tridens texanus*
Setaria gibbosa	*Aristida Roemeriana*	*Eragrostis spicata*
Sporobolus Wrightii	*Trichachne patens*	*Pappophorum bicolor*
Bromus texensis	*Sporbolus Buckleyi*	
	Small cacti	
Hamatocactus setispinus	*Echinocereus Berlandieri*	*Echinocereus pentalophus*
Ferocactus hamatocanthus	*Neomammillaria hemisphaerica*	
	Vines and scandent herbs	
Metastelma barbigerum	*Cardiospermum Halicacabum*	*Clematis Drummondii*
Eupatorium incarnatum	*Commicarpus scandens*	*Eupatorium odoratum*
Cocculus diversifolius	*Cissus incisa*	*Anredera vesicaria*
Serjania brachycarpa		*Tragia glanduligera*
	Annual herbs	
Polypteris rosea	*Verbena bipinnatifida*	*Nama jamaicense*
Dyssodia tenuiloba	*Scutellaria Drummondii*	*Verbena delticola*
Portulaca retusa	*Florestina tripteris*	*Margaranthus solanaceus*
	Sanvitalia ocymoides	

TABLE 19. PRAIRIE SPECIES FOUND ON LOOSE SAND AND SANDY LOAM

(Modified from Johnston, 1955)

	Perennial grasses	
Andropogon littoralis	*Elyonurus tripsacoides*	*Vaseyochloa multinervosa*
Cenchrus pauciflorus	*Panicum virgatum*	*Sporobolus purpurascens*
Chloris cuculiata	*Bouteloua hirsuta*	*Panicum nodatum*
Brachiaria oiliatissima	*Digitaria texana*	*Paspalum plicatulum*
Eragrostis oxylepis	*Aristida Roemeriana*	*Heteropogon contortus*
Sporobolus cryptandrus	*Eragrostis sessilispica*	*Aristida purpurascens*
Panicum firmulum	*Aristida Wrightii*	*Eragrostis Swellenii*
Paspalum ciliatifolium	*Paspalum monostachyum*	*Paspalum debile*
Aristida purpurea		
	Annual grasses	
Trichoneura elegans		*Triplasis purpurea*
	Perennial forbs	
Lotoxalis Berlandieri	*Sida cordifolia*	*Aeschynomene viscidula*
Polygala alba	*Convolvulus incanus*	*Yucca constricta*
Thelesperma filifolium	*Meriolix serrulata*	*Sphaeralcea Lindheimeri*
Opuntia Allairei	*Matelea parviflora*	*Petalostemon obovatum*
Cassia aristellata	*Sida Lindheimeri*	*Prunus texana*
Euphorbia innocua	*Rhynchosia americana*	*Liatris elegans*
Galactia canescens	*Croptilon divaricatum*	*Tephrosia Lindheimeri*
Monarda fruticulosa	*Cnidoscolus texanus*	*Croton argyranthemus*
Oxybaphus albidus	*Eupatorium compositifolium*	*Indigofera miniata*
Tetragonotheca ludoviciana repanda	*Gaillardia lanceolata*	*Schrankia latidens*
Stylosanthes viscosa	*Senecio Hiddellii Parksii*	*Zornia bracteata*
Ditaxis pilosissima	*Stillingia sylvatica*	*Evolvulus alsinoides*
Zornia diphylla	*Dalea aurea*	*Acalypha radians*
Centrosema virginianum	*Hichardia brasiliensis*	*Commelina erecta angustifolia*
Hymenopappus artemisiaefolius (biennial)		
	Winter annual forbs	
	Verbena ciliata	

TABLE 19. (Continued)

	Spring annual forbs	
Phlox Drummondii glabriflora	*Pyrrhopappus multicaulis*	*Linum rigidum*
Aphanostephus skirrhobasis thalassius	*Sabbatia campestris*	*Plantago Hookeriana inflexa*
Coreopsis nuecensis	*Brazoria arenaria*	*Lobelia Berlandieri*
Sisyrinchium spp.	*Psoralea rhombifolia*	*Senecio ampullaceus*
Petalostemon emarginatum	*Eurytaenia texana*	*Vicia Leavenworthii occidentalis*
Polypremum procumbens		
	Summer annual forbs	
Gaillardia pulchella	*Paronychia Drummondii*	*Heliotropium convolvulaceum*
Chamaesyce missurica	*Houstonia subviscosa*	*Richardia scabra*
Dyssodia tenuiloba	*Diodia teres*	*Rudbeckia serotina*
Cristatella erosa	*Chamaesyce cordifolia*	*Scutellaria muriculata*
Chamaesyce ammennioides	*Sclerocarpus uniserialis*	*Polypteris rosea*
Phyllanthus abnormis	*Heliotropium texanum*	
	Summer and fall annual forbs	
Cassia fasciculata	*Croton Engelmannii*	*Croton* (sp. undetermined)
Helianthus debilis cucumerifolius	*Croton Parksii*	*Croton glandulosus*
	Fall annual forbs	
Polypteris Hookeriana	*Froelichia Drummondii*	*Eriogogonum multiflorum*

sition of the prairie changes to the exclusion of _S. littoralis_ and the promotion of a larger variety of grasses and forbs. In addition, grass composition is altered by the sowing of domestic grass seeds which, in this area includes predominantly Kleberg Bluestem and King Ranch Bluestem. At lower elevations where the topography of the prairie approximates the ground water table, more water tolerant species are present in addition to prairie species. Many botanists have conjectured on the decline of desert grasslands in the Southwest and the encroachment of brushland (c.f. Bogusch, 1952; Humphrey, 1958; Johnston, 1968; etc.). Major contributing factors have been identified as over-grazing, decrease in number of prairie fires, sowing of brush seeds by animal migration, and near the coast, the influence of salt spray. All these conditions exist in the prospect area and may be contributing to decreasing grassland coverage, possibly with the exception of salt spray influence this far inland.

Poorly-drained Depressions

In the Armstrong prospect area, the loose sand and loess prairie grades at its lower limit into _Spartina spartinae_ community principally owing to the availability of ground water in these lower lying areas. An impermeable soil caliche layer is principally responsible for ponded water during flash flooding and hurricanes (Johnston, 1955). In its undisturbed state the community is generally entirely dominated by Coastal Sacahuiste (_Spartina spartinae_) but again grazing pressures allow a variety of other grasses to invade, including Bushy Beardgrass (*Andropogon glomeratus*), Flaveria (*Flaveria oppositifolia*), Wooly Stemodia (*Stemodia tomentosa*), Fleabane (*Erigeron myrionactis*), and Single-spike Paspalum (*Paspalum monostachyum*). Species found in poorly-drained depressions are listed in table 20.

Eolian Ridges

This unit is characterized by a salt tolerant grass community seral to brush. According to Johnston (1955), it is unique to the windward edges of actively building eolian ridges. Coppice mounds are formed in the accreta. By recurrent accretion over nearby brush, the brush is finally killed by burial in the saline wind-blown material. This new accreta is then invaded by Leafless Cressa (*Cressa nudicaulis*), Espanta Vaqueros (*Tidestromia lanuginosa*), Glasswort (*Salicornia perennis*), and Cenicilla (*Sesuvium Portulacastrium*). Saltbush (*Atriplex acanthocarpa*) and Quelite Cenizo (*A. matamorensis*) will also become established accompanying increased stabilization of the accreta, followed by Isocoma (*Isocoma Drummondii*), Dropseed (*Sporabolus pyramidatus*), Tornillo (*Prosopis reptans ceneroscens*), and Sacaton (*Sporobolus Wrightii*).

Active Dunes

High persistent winds, a loose sandy substrate, and a semi-arid climate are the factors responsible for the existence of mobile sand

TABLE 20. PLANT SPECIES IN POORLY-DRAINED DEPRESSIONS

(Modified from Johnston, 1955)

Species in poorly-drained depressions		
Spartina spartinae	*Juncus polycephalus*	*Lippia incisa*
Cynanchum palustre	*Juncus marginaus setosus*	*Verbena Halei*
Chloris petraea	*Nemastylis purpurea*	*Gerardia strictiflora*
Panicum sphaerocarpon	*Rorippa Walteri*	*Stemodia tomentosa*
Cyperus aristatus	*Mimosa strigillosa*	*Pluchea purpurascens*
Dichromena colorata	*Linum rigidum Berlandieri*	*Cirsium horridulum*
Fimbristylis castanea	*Limnosciadium pumilum*	*Conoclinium bentonicum*
Scirpus americanus	*Eustoma Russellianum*	*Erigeron myrionactis*
Coreopsis cardaminaefolia		*Flaveria oppositifolia*

dunes in this area. Vegetation cannot easily become established on this unstable substrate, and early seral invasion can be cut short by the resumption of blowing sand. Table 21 lists early, established seral species found on dunes. As stabilization continues, the dune sere leads to the development of loose sand prairie and may eventually be followed by brush and Live Oak scrub.

Discussion of Vegetation Assemblages with Reference to the Kenedy Prospect Area

Some of the most important environmental factors that might be affected by industrial development at the Kenedy Prospect and that affect the growth of flora in this region are availability of ground water, the salinity of ground water, and blowing sand. This, combined with infrequent and highly variable precipitation, poor drainage, and the time it takes to reestablish a disturbed community, must govern well site selection. The main concerns are to avoid removing plant communities which take a great deal of time and specific conditions to reestablish themselves, and those which play an important role in the balance of the entire ecosystem. The first concern may be a little easier to define than the second. As we have noted, the eolian prairie is a dynamic system, where natural factors such as wind erosion, burial in accreting sand, seering salty winds during droughts, and flooding accompanying hurricanes continually alter plant communities. Communities seral to grassland and brushland can

TABLE 21. EARLY SERAL PLANT SPECIES ON DUNES

(Modified from Johnston, 1955)

	Annuals	
Heliotropium convolvulaceum	*Amaronthus arenicola*	*Helianthus debilis cacumerifolius*
	Polypteris Hookeriana	
	Perennials	
Salix nigra	*Aristida Roemeriana*	*Galactia conescens*
Erogrostis oxylepis	*Cenchrus pauciflorus*	*Xanthoxylum Clava-Herculis*
	Oenothera Drummondii	*Lantana horrida*

reestablish rather quickly under the right conditions, leading to eventual stabilization by prairie and brush. Also, all vegetative cover plays an important role in stabilizing the loose substrate and therefore construction should proceed with provisions made for retaining as much ground cover as possible to avoid enhancement of blowouts and dunes. The Live Oak motte community takes the longest to reestablish and removal of this community should be avoided.

Endangered Plant Species

A listing of plant species known to be endangered in South Texas is provided from Rare Plant Study Center and Texas Parks and Wildlife Department data (Blevens and Novak, 1975) (table 22). Field reconnaissance is required to determine whether any of these species occur in the Kenedy Prospect Area or in areas that will be affected by geopressured-geothermal development.

Discussion of the Use of the Kenedy Prospect Area and the Vicinity By Wildlife

The most important effect to consider concerning wildlife in this area is that the area is relatively undisturbed by human interference and a wide variety of wildlife can utilize and inhabit this area. When alterations of the environment occur which upset the ecological balance, at first the most sensitive species will be eliminated and modifications to the habitats of more tolerant species will occur. For instance, if construction in a particular area

TABLE 22. RARE AND ENDANGERED PLANT SPECIES THAT HAVE BEEN IDENTIFIED IN KENEDY COUNTY AND ITS ENVIRONS

(From Blevins and Novak, 1975)

GENERA/SPECIES	COMMON NAME	RARENESS	DISTRIBUTION
Amoreuxia wrightii (Cochlospermum Family)	Yellowshow	6-H(B)	
Amyris madrensis (Citrus Family)	Mountain Torchwood	5-H(B)	
Carlowrightia parviflora (Acanthus Family)	Small Wrightwort	6-I(B)	
Chloris texensis (Grass Family)	Texas Windmill Grass	6-E Information needed	Also in Coastal Prairie
Cienfuegosia drummondii (Mallow Family)	Yellow Fugosia	5-H(B)	
Clappia suaedaefolia (Sunflower Family)	Fleshy Clap Daisy	6-H(B)	
Grindelia oolepis (Sunflower Family)	Plains Gumweed	5-H	
Matelea radiata (Milkweed Family)	Falfurrias Milkvine	7-I	Brooks County, 1909
Nephropetalum pringlei (Cacao Family)	Pringle Kidneypetal	7-I	Hidalgo County, 1888
Notholaena schaffneri (True Fern Family)	Schaffner Cloakfern	5-D(B)	Also in Edwards Plateau and Trans-Pecos
Polianthes runyonii (Amaryllis Family)	Runyon Huaco	5/6-H(B)	
Prunus minutiflora (Rose Family)	Texas Almond or Small-flower Peach-brush	5-D	Also in Edwards Plateau and North-Central Texas
Sedum texanum (Orpine Family)	Texas Stonecrop	5-H?(B)	Coastal counties
Sidà tragiaefolia (Mallow Family)	Ear-leaf Sida	6-E(B)	Also in Trans-Pecos
Willkommia texana (Grass Family)	Willkommia	5/6-H	Coastal Bend counties
Wissadula amplissima (Mallow Family)	Big Yellow Wissadula	5-I(B)	Cameron and Kenedy Counties
Xylosma flexuosa (Flacourtia Family)	Brush-holly or Coronilla	6/7-H(B)	

Rareness and distribution are indicated by the following scale:

Rareness

- 5 Scarce, endangered in Texas
- 6 Very rare, acutely endangered in Texas
- 7 Presumed extinct, with no records since 1930 from Texas

Distribution

- *A Distributed widely on the continent or in the world
- *B Distributed broadly but regionally in North America and extending into Texas
- E Distributed in two of the broad vegetational areas of Texas
- H Distribution limited to 1 to 3 counties in one broad vegetational area of Texas
- I Known only from one or a few populations

* If A or B are not given, then it is implied that the species is endemic to Texas.

required the clearing of brush and trees, while food for deer, birds, and other wildlife may still be abundant, the lack of cover may limit the use of this area by these animals. Increased noise and activity may also scare some animals away and interfere with bird songs and other forms of animal communication. In addition, food chains will be modified and wildlife that need large ranges may be cut off from their home range and may be forced into competition with others for a smaller and smaller area of undisturbed land. Some animals may not be able to adjust to these modifications and will be eliminated.

Appendix B is a compilation of wildlife species designated as endangered, threatened, or protected nongame by the Texas Organization for Endangered Species (TOES), Texas Parks and Wildlife Department (TPWD) or U. S. Fish and Wildlife Service (F&WS); the latter two enforce rules and regulations to protect these animals. The species listed followed by a K under "Prospect Areas" are those that may occupy, feed and/or roam the Kenedy Prospect Area and its surroundings and which could be affected by modifications of the environment by the development of the well site. Data are given on the protected animal's range in Texas, preferred habitat and reason for its status. For most species, reason for their protected status has been induced by some type of human interference with their environment. Thorough preliminary assessment and careful planning is needed to avoid degradation of wildlife and vegetation. In addition to the protected species, deer, antelope, javalina, armadillos, possum, bobcat, coyote, raccoons, squirrels, mourning and whitewing dove, quail, rodents, reptiles, nongame birds, etc. are native to this area, while domestic cattle, sheep, and goats graze the region.

METEOROLOGICAL CHARACTERISTICS

Climatological Data

Although some climatological data are available for Armstrong (the small rural community located in the prospect area, fig. 29), more complete and reliable records on climatic conditions have been maintained at Raymondville (fig. 30), which is approximately 48 km (30 mi) south of Armstrong. Normal annual temperature at Raymondville is 23.2°C (73.7°F). The highest temperature recorded each year is generally over 37.8°C (100°F) and occurs most frequently during August, while the lowest yearly temperature averages around -3.3°C (26°F), and occurs most frequently in January (fig. 30). Normal annual precipitation is 65.5 cm (25.80 in), although variations have occurred during the past 17 years, from a low of 34.3 cm (13.50 in) in 1962 to a high of 106.6 cm (41.97 in) in 1973 (fig. 30). Monthly precipitation is generally the highest during September and May and lowest during March and December (fig. 31). Variations to the monthly normals (based on 1941-1970 records) may occur during any year (fig. 31).

Two major wind components predominate along the South Texas Gulf Coast--prevailing southeasterlies that are dominant during most of the year, and strong north winds that accompany polar frontal passage

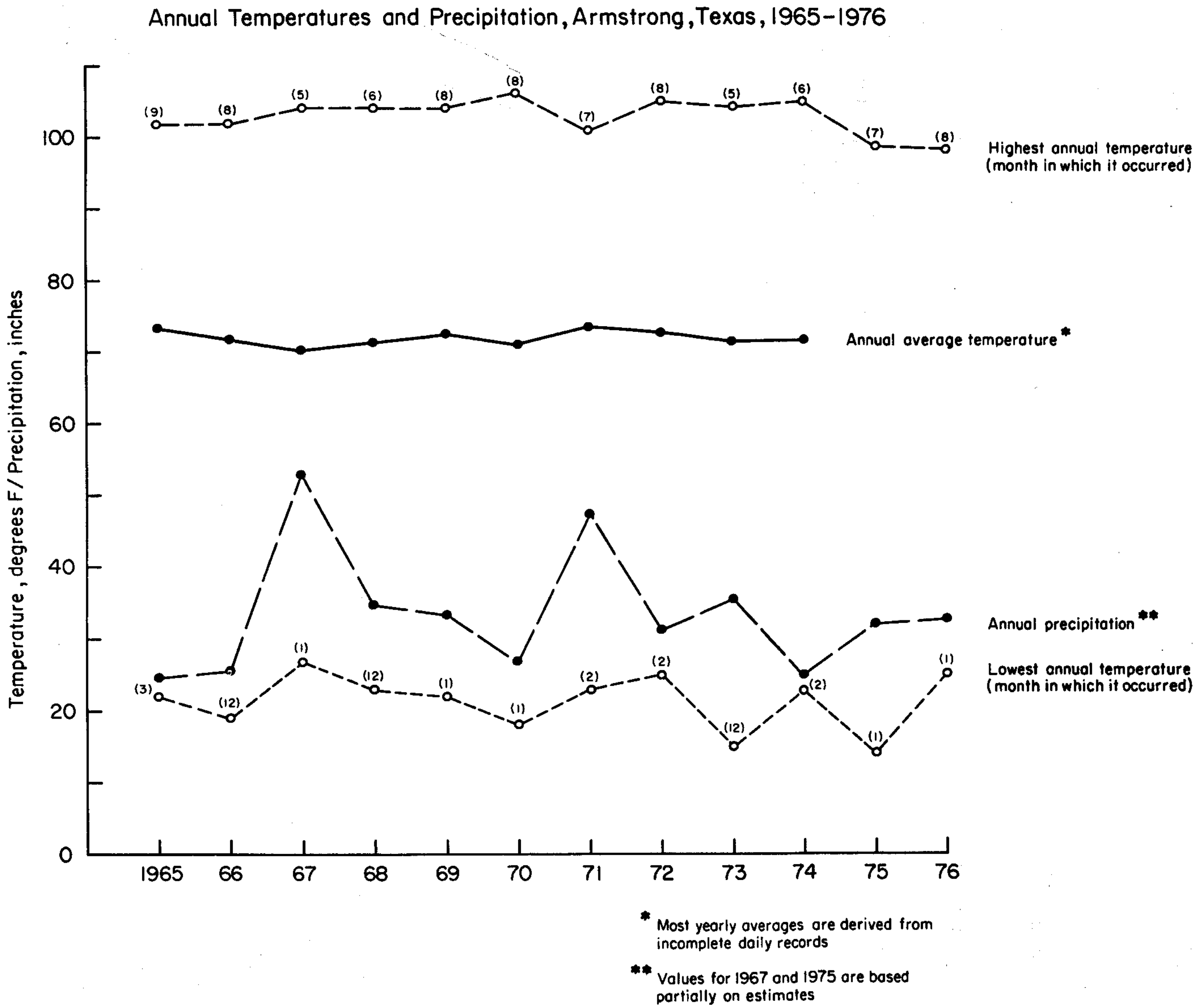


Figure 29. Temperature and precipitation, Armstrong, Texas. (Compiled from records of the U. S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service)

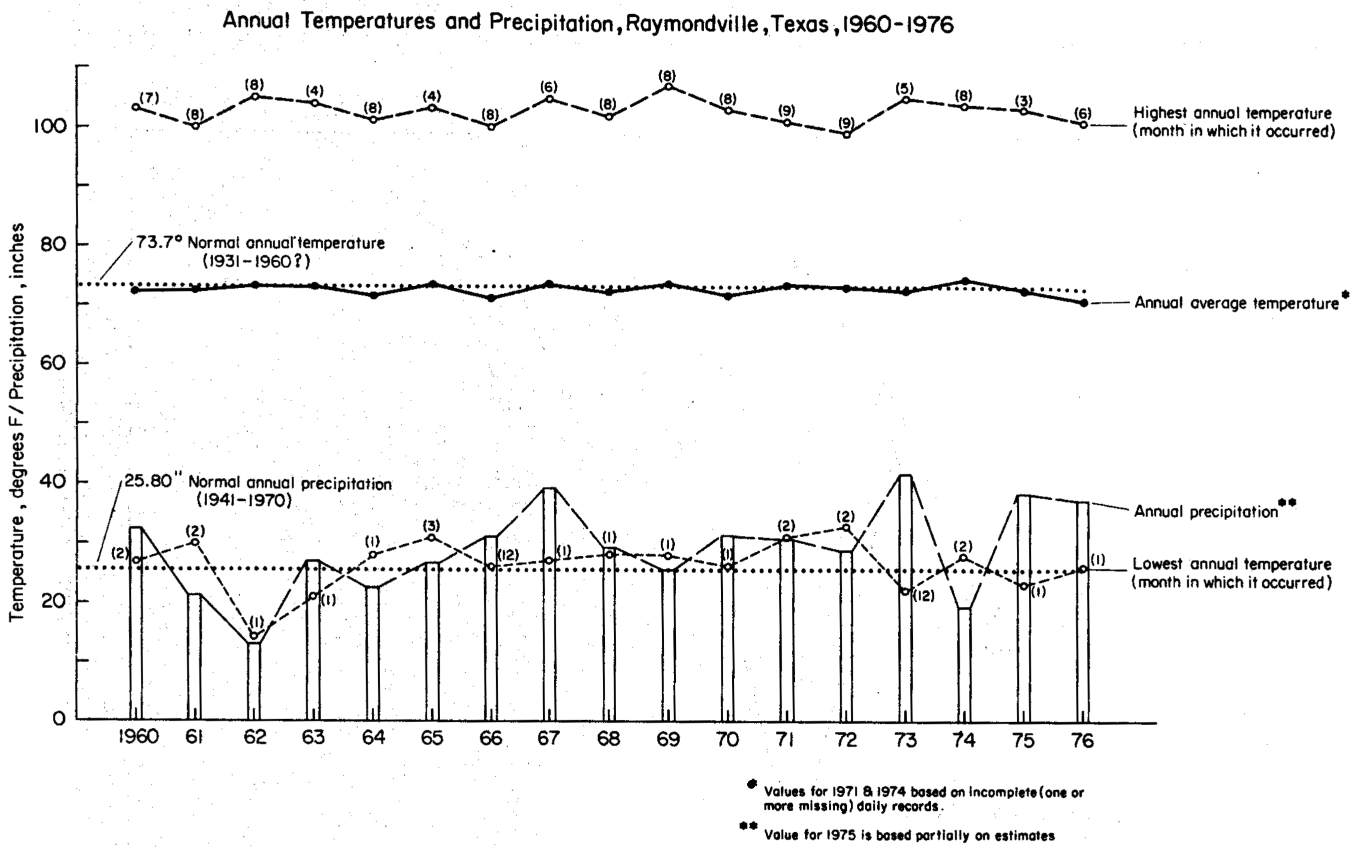


Figure 30. Temperature and precipitation, Raymondville, Texas. (Compiled from records of the U. S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service)

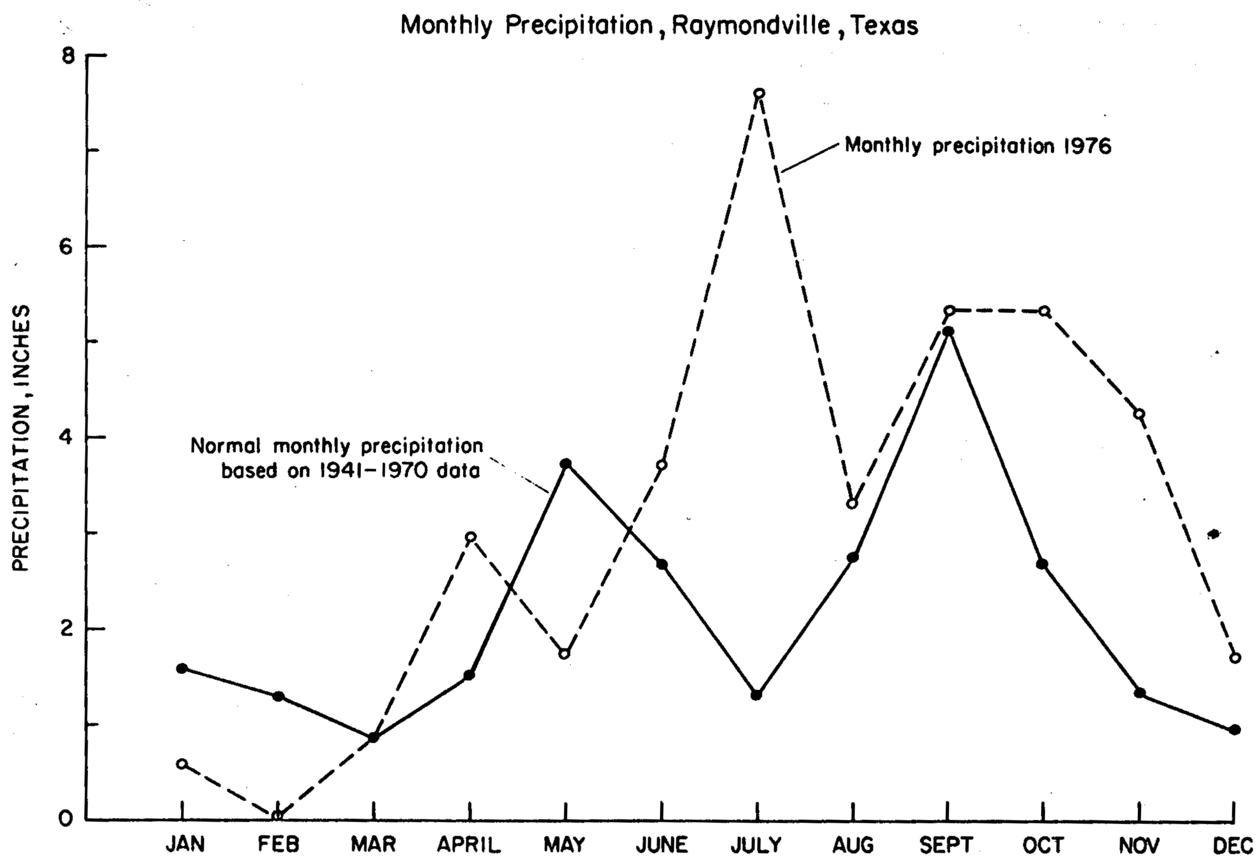


Figure 31. A comparison between monthly precipitation levels during 1976 with normal precipitation levels based on the period 1941-1970, Raymondville, Texas. (Compiled from records of the U. S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service)

during winter months (fig. 32). The physical effect that the southeasterly winds have on this semi-arid region is manifested in the northwest-southeast alignment of many eolian features and northwestward migration of active sand dunes.

Ambient Air Quality

The nearest air quality monitoring stations are located in Corpus Christi which is about 105 km (65 mi) north of Armstrong (fig. 21). Because of the remoteness of the Kenedy County prospect from industrial and urban activity, ambient air quality should be relatively good, and most potential air pollutants should be below the maximum values allowable by national standards. It should be noted, however, that Kenedy County is in Air Control Region Number 5, which is monitored primarily at Corpus Christi. From 1974 through 1976, ozone and nonmethane hydrocarbons monitored at Corpus Christi exceeded the maximum allowable levels set by national ambient air standards (table 23).

Selection of Test Well Site on the Basis of Meteorological Characteristics

As in the Brazoria County prospect, the prevailing southeasterly winds should be a consideration when selecting test well locations. Air pollutants associated with geopressured-geothermal fluid production may include volatile carbon compounds, ammonia, and hydrogen

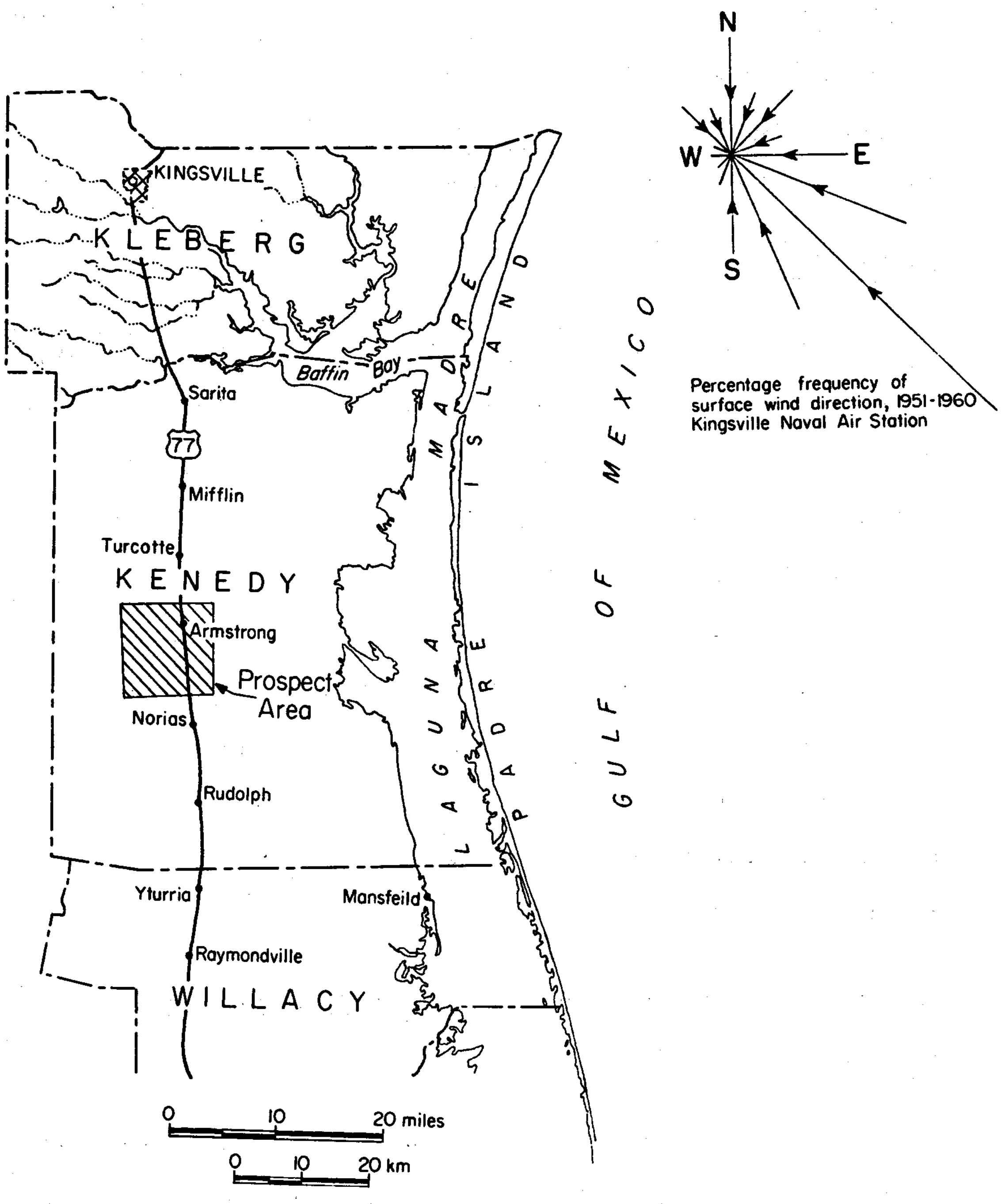


Figure 32. Vector diagram indicating surface wind directions at Kingsville, Texas. (Modified from Brown and others, 1977)

TABLE 23. COMPARISON SUMMARY OF CONTINUOUS AIR MONITORING STATION DATA WITH AMBIENT STANDARDS, CORPUS CHRISTI, TEXAS

(Data compiled from Texas Air Control Board Continuous Air Monitoring Network Data Summaries, 1974-1977)

	Maximum allowable by ambient air standards (parts per million or percent)	Corpus Christi Station Location (Region 5) 1974	1975	1976	1977 (first quarter)
Ozone *High one-hour average*		0.126	0.124	0.143	0.079
Ozone *Second highest hour*	0.080	0.123	0.123	0.139	0.075
Ozone *Percent of time>0.08 ppm*	0.0	1.1	1.0	2.8	0.0
Carbon Monoxide *Second highest hour*	35	11.2	11.7	8.8	4.6
Carbon Monoxide *Second highest 8 hours*	9	6.6	4.2	5.1	2.2
Nonmethane Hydrocarbons *6-9 AM high*	0.24	5.5	3.6	3.1	4.1
Sulfur Dioxide *Second highest 24 hours*	0.14	0.00	0.00	0.02	0.02
Sulfur Dioxide *Annual mean*	0.03	0.00	0.00[1]	0.00[1]	0.00[2]
Sulfur Dioxide *Second highest 3 hours*	0.50	0.07	0.05	0.12	0.12
Nitrogen Dioxide *Annual mean*	0.05	0.01	0.01[1]	0.01[1]	0.01[2]
Methane *High one-hour average*	no standards	1.54	8.5	8.3	7.6
Methane *Percent of time>5.0 ppm*	no standards	1.3	0.9	0.6	1.4

[1] Set of data does not meet EPA criteria for calculating an annual mean

[2] Quarterly mean

sulfide. To mitigate possible undesirable effects of pollutants on the community of Armstrong, Armstrong Ranch Headquarters, and travelers on U. S. Highway 77, downwind locations should be chosen for the prospect well. As shown in figure 22, the wind seldom blows from the west. This factor indicates that in terms of meteorological characteristics, the most suitable sites for well development are west of U. S. Highway 77 and Armstrong.

SELECTION OF TEST WELL ON THE BASIS OF ALL ENVIRONMENTAL CHARACTERISTICS

As in the Brazoria County prospect area, decision criteria guidelines and site selection methodology explained in Appendix A were used: (1) to assist in making relative suitability comparisons between various environmental characteristics, and (2) to help identify the most suitable areas for well development. A composite map of the Kenedy County prospect area (fig. 33) was prepared following the decision criteria guidelines and site selection methodology described in Appendix A. The composite map (fig. 33) depicts areas of varying suitability (with those areas appearing the lightest in tone or most transparent, being the most suitable) for test well development, by combining current land use, flood potential, shallow substrate lithology, water resources, and biological assemblages. Environmental factors, such as potential for subsidence, and meteorological characteristics, which could not be meaningfully depicted on the transparencies, were also

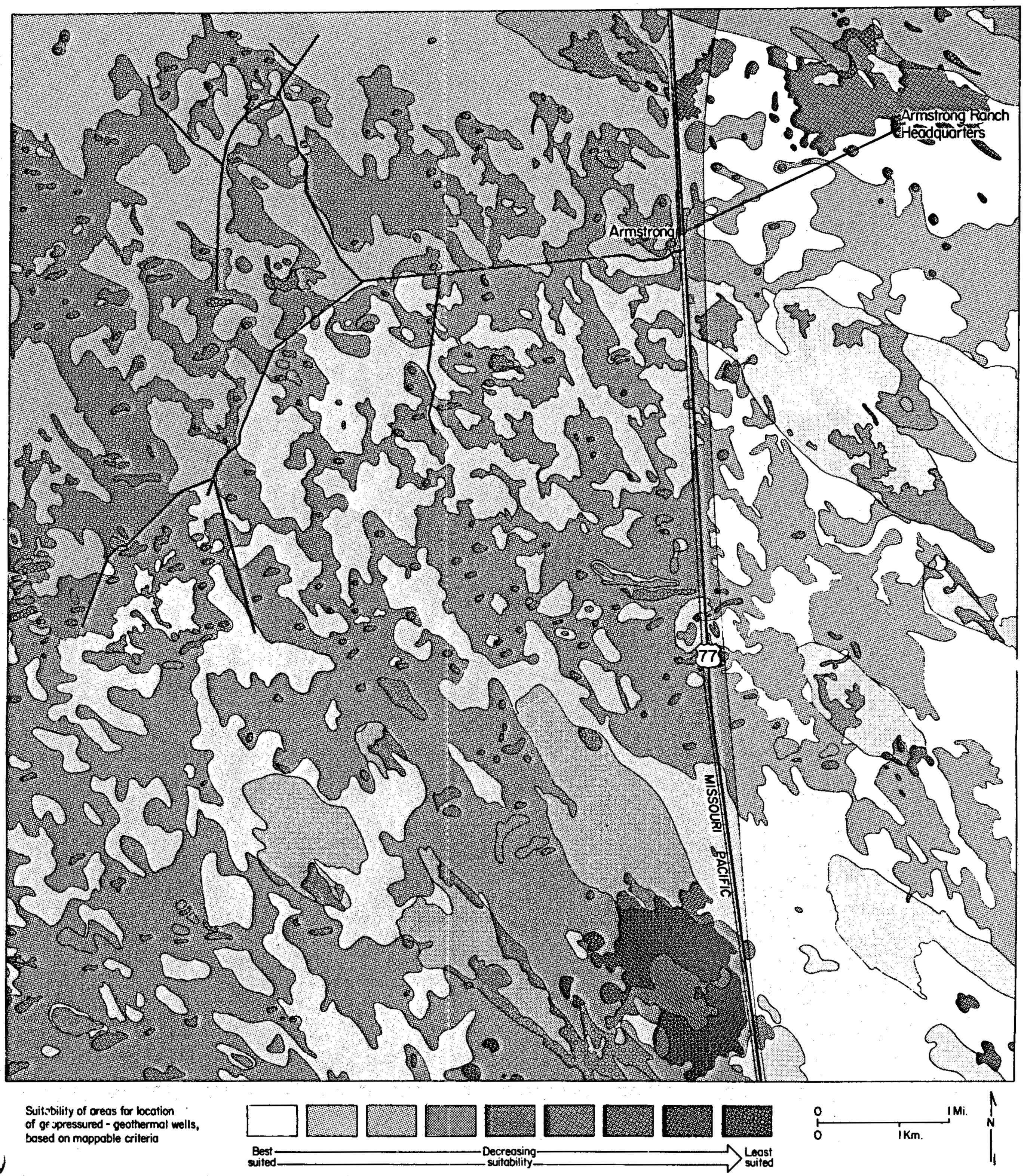


Figure 33. Areas of varying suitability for location of test well in Kenedy County. Compiled in accordance with Appendix A.

considered in the final evaluation of test well locations. It was noted previously in the section on ground-water resources that the area west of U. S. Highway 77 is underlain at depth by fresh ground water in the Goliad sand. But this aquifer is apparently: (1) capped by impermeable strata since it is under artesian conditions, (2) recharged in areas west of the prospect area, and (3) sandwiched between ground water of moderate to high salinities. These conditions will undoubtedly provide a measure of protection to the usable ground-water resources in the Goliad sand should geothermal fluids be inadvertently discharged at the surface. Therefore, in terms of protecting ground-water resources, there seems to be little advantage in locating the test well in areas east of U. S. Highway 77 where the fresh water lens in the Goliad sand grades into slightly saline water.

The overall analysis indicates that the most suitable locations for test well development within the Kenedy County prospect area are in areas where:

(1) range-pasture lands are present and there are adequate distances (over 1 mi; 1.6 km) between production wells and the rural community of Armstrong, Armstrong Ranch Headquarters and U. S. Highway 77;

(2) the archeological site 3 mi. (4.8 km) south of Armstrong and just west of U. S. Highway 77, and those lands belonging to the King Ranch which are listed in the National Register of Historical Places, will remain unaffected;

(3) naturally high elevations will provide a measure of natural flood protection;

(4) active dunes, blowouts, moderately and well-stabilized, and active clay-sand dunes can be avoided;

(5) significant biological assemblages--live oak mottes--do not occur; and

(6) test well and development activities will most frequently be downwind from Armstrong, Armstrong Ranch Headquarters and U. S. Highway 77 to avoid undesirable air quality conditions in these areas.

Although there are acceptable sites east of U. S. Highway 77 and north of the King Ranch, all of the factors listed above can be satisfied by locating wells in the northwest quarter of the Kenedy County prospect area, almost due west of Armstrong. In this area there are existing roads, and oil and gas wells have previously been drilled during development of the Candelaria Oil and Gas Field. Location of geopressured-geothermal wells on the west side of U. S. Highway 77 is in agreement with the recommended location of a water-dominated geothermal energy system by Muehlberg and Shepard (1975).

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APPENDIX A

DECISION CRITERIA GUIDELINES AND SITE SELECTION METHODOLOGY

To help establish the relative suitability of the surface and near-surface environments for geopressured-geothermal energy development, and to identify the most suitable sites or areas for location of production wells, decision criteria guidelines and a site selection methodology were formulated. Map units, parameters, or other components comprising major environmental characteristics were evaluated by employing the decision criteria guidelines. The most suitable areas for test well locations were then determined using the site selection methodology. Environmental characteristics that were selected for analysis and discussed in the report include current land use, potential subsidence and fault activation, flood potential, shallow substrate lithology and soils, water resources, biological assemblages, and meteorological characteristics.

DECISION CRITERIA GUIDELINES

Numerous methodologies have been formulated for the purpose of describing, evaluating, and ranking natural environments, generally for the purpose of making environmentally sound choices with regard to man's planned modifications to the environment (Brown and others, 1971; Dee and others, 1973; Gehlbac, 1975; Leopold and others, 1971; McHarg, 1969; Warner and Preston, 1974; and Zieman and others, 1971). In many methodologies, numerical values generally representing importance and/or significance are assigned to various characteristics or parameters. In all methodologies reviewed, although some are more quantitative than others, qualitative judgments are made at some point in the process of priority ranking the environments or parameters.

Decision criteria guidelines used in this study employ two matrices for the purpose of: (1) identifying and ranking the relative suitability of each unit/parameter within each major environmental characteristic and (2) comparing and ranking the relative suitability of problem areas for all the major environmental characteristics.

In the first matrix, each of the units/parameters that comprise the various environmental characteristics is analysed in terms of its relative suitability as host for the test well, and assigned a numerical value using the following scale:

INCREASING SUITABILITY FOR LOCATION OF TEST WELL →

4 3 2 1

← INCREASING PROBABILITY OF UNDESIRABLE INTERACTION

The numerical values are used to show only the relative order of suitability. In other words, an area noted 1 is better suited for test well development than an area rated 2, but the magnitude of how much better (1X, 2X, 10X, etc.) is not expressed by the numbers.

Those units/parameters considered the least suitable for well development--those assigned numerical ratings of 3 or 4--are then combined in a second matrix and classified with respect to each other into one of the following orders of unsuitability:

D = unsuitability--first order (least suited for location of test well)

M = unsuitability--second order

L = unsuitability--third order (better suited for location of test well than areas classified D or M)

The matrices are shown in tables 24 and 25. The areas best suited for test well development, of course, are those rated 1 and 2 in matrix A; these areas are not shown in matrix B.

The decision criteria used to classify the expected interactions between the planned activities and the environmental characteristics are based on informed, although qualitative, judgments. Interactions are evaluated by considering both the potential effect of the test well and associated activities on the environment and the potential effect of the environment on the test well and associated activities. Stated another way, activities are evaluated in terms of (1) their probable effects on environmental quality and natural processes, and (2)

TABLE 24. SUITABILITY/UNSUITABILITY OF MAPPED ENVIRONMENTS AS HOSTS FOR GEOPRESSURED-GEOTHERMAL TEST WELL, BRAZORIA COUNTY PROSPECT AREA

ENVIRONMENTAL CHARACTERISTICS	SUITABILITY/ UNSUITABILITY Matrix A	Matrix B
Current Land Use		
Cropland	2	
Range-pasture/grasslands	1	
Residential-commercial areas	4	D
Industrial complexes	4	D
Archeological-cultural resources	4	D
Woodlands	2	
Orchards and experimental tree farms	3	M
Experimental cropland	3	D
Scrubland	2	
Flood Potential		
Area of storm-surge tidal flooding as indicated by Hurricane Carla	3-4	M
Area of "100-year" flood excluding land flooded by Hurricane Carla	2-3	L
Area unaffected by "100-year" flood and Hurricane Carla	1	
Shallow Substrate Lithology *as indicated by Environmental Geology Map*		
Mud/clay—low permeability	1-2	
Sand/silt—moderate to high permeability (ground-water recharge areas)	3	L
Water Resources		
Ground-water recharge areas *(see* Sand/silt *above)*		
Surface-water features	4	D
Biological Assemblages		
Fluvial woodlands	3	M
Frequently flooded fluvial areas	2	
Fresh water ponds	3	M
Marsh	4	D
Tall grass prairie	1	
Chocolate Bayou and Chocolate Bay	4	D

Matrix A

increasing suitability for location of test well

4 3 2 1

increasing probability of undesirable interaction condition

Matrix B

Order of *unsuitability* for units assigned value 3 or 4 in matrix A:

D = *Unsuitability*—first order (least suited for well)

M = *Unsuitability*—second order

L = *Unsuitability*—third order (better suited for well)

TABLE 25. SUITABILITY/UNSUITABILITY OF MAPPED ENVIRONMENTS AS HOSTS FOR GEOPRESSURED-GEOTHERMAL TEST WELL, KENEDY COUNTY PROSPECT AREA

ENVIRONMENTAL CHARACTERISTICS	*SUITABILITY/ UNSUITABILITY Matrix A	Matrix B
CURRENT LAND USE		
Residential--commercial areas	4	D
Petroleum storage tanks	4	D
King Ranch (National Register of Historic Places)	2	
Range--pasture	1	
Live-oak mottes	2	
Barren land, sand, active dunes	2	
Ponds, ephemeral and permanent	3	M
FLOOD POTENTIAL		
Approximate area susceptible to flooding by intensive rainfall and runoff as indicated by Hurricane Beulah aftermath storms	3	M
ENVIRONMENTAL GEOLOGY		
Active dune complex, sand	3	L
Active dune blowout areas, sand	2-3	L
Sandsheet, base-leveled dunes	1-2	
Sand and loess (silt) sheet	1-2	
Moderately stabilized dunes, sand and loess sheet	2-3	L
Well-stabilized dune sands	3-4	M
Sand and loess sheet deflation area	1-2	
Clay sand dunes, active	2-3	M
WATER RESOURCES		
Approximate area underlain by fresh ground water	2-3	L
Approximate area underlain by slightly saline ground water only	1-2	
ENVIRONMENTS AND BIOLOGICAL ASSEMBLAGES		
Poorly drained depressions, seasonal high-moisture plants	1-2	
Loose sand and loess prairies, bunch grasses, scattered oak mottes	1-2	
Live-oak mottes, stabilized sand dunes, climax vegetation	2-3	D
Brushland, moderately stabilized dunes	2	
Eolian ridges, salt-tolerant grasses	2	
Active dunes barren	1	

*See table 24 for explanation.

their capability for effective utilization of the environments with minimal loss or damage from natural processes and events.

Following are some general guidelines used in the evaluation process. Interactions between well development activities and environmental units are considered undesirable if they are likely to:

1. create conditions that tend to increase the frequency, rate, and extent of flooding and erosion.

2. create conditions whereby planned activities are susceptible to unnecessary damage, loss of property or maintenance costs as a result of natural events and processes.

3. produce or increase the extent and rate of formation of undesirable conditions such as contamination of water and atmospheric resources or of undesirable features such as blowouts and active dunes.

4. interfere substantially with natural processes, thereby decreasing the capability of the natural system to adjust or to recover following alterations either by man or by natural events such as hurricanes.

5. destroy or significantly disturb areas that are important biologically such as faunal nesting, breeding, or feeding grounds.

6. destroy or significantly disturb areas that are habitats for endangered or rare species.

7. destroy or disturb significant archeological or historical resources.

In determining whether an interaction will lead to "substantial" or "significant" effects, judgments of importance and magnitude for the particular interaction are made. Where possible, quantitative data are an integral part of the judgment. For example, the amount of cropland affected by development compared to the total existing cropland in the area would enter into a judgment. In some cases, interaction may not only be detrimental but prohibited because existing land use preempts such interaction at given location. These interactions would be classified as unsuitability--first order.

SITE SELECTION METHODOLOGY

The site selection methodology involves the preparation and use of transparent-translucent overlay maps in a fashion similar to that described by McHarg (1969). Each mappable environmental characteristic either is shaded a specified density of gray, or it remains transparent depending on its classification as shown in matrix B of the decision criteria guidelines (tables 23 and 24). Mappable environmental units in which unsuitability--first order (D) interactions (as denoted in matrix B of the decision criteria) occur are represented as dark gray areas on large-scale (1:24,000) transparent-translucent overlay maps; units in which interactions are classified as unsuitability--second order (M) are represented by medium gray; and units with unsuitability--third order interactions (L) are light gray. Areas representing interactions that appear in matrix A but not in matrix B remain transparent.

By superimposing the overlay maps on a base map of the prospect area, the most suitable areas (as determined by mappable characteristics) for the geothermal test well are defined by those areas remaining the most transparent or translucent. For this report the various overlay maps were combined and reduced in scale to form a single "page-size" composite map for each prospect area (figures 20 and 33). Using the composite map, the most suitable location or locations within areas of equally good suitability can be identified by considering other characteristics including those interactions that were classified 1 or 2 in the first matrix as well as interactions involving environmental units that could not be adequately mapped, such as air quality parameters and subsidence potential.

JUSTIFICATION FOR THE METHODOLOGIES

Matricies in which activities are plotted against environmental characteristics (Brown and others, 1971; Leopold and others, 1971; the decision criteria methodology used in this report), serve as checklists in which the interactions between the activities and natural environment may be identified for the purpose of analysis and evaluation. Completed matricies which contain the results of the analysis and evaluations provide a quick-reference visual summary of the possible significant interactions that are evaluated and discussed in more detail in the text. Although the second matrix was designed for the purpose of ordering the relative significance of interactions involving dissimilar environmental characteristics, geological vs. biological, for example, it also provides a means of double checking or cross-examining significant interactions identified in the first matrix.

The decision to use overlay maps in the site selection methodology is supported by the following:

1. The approved proposal for this environmental research effort calls for the use of maps to describe and define the environmental characteristics in the prospect areas. The use of transparent-translucent overlay sheets is a natural extension of the maps.

2. In a review of environmental impact assessment methodologies, Warner and Preston (1974) state that the McHarg approach, which is "a system employing transparencies of environmental characteristics overlaid on a regional base map," is a valuable method of screening alternative project sites.

3. The high degree of cartographic skill and training plus the sophisticated cartographic equipment and procedures needed to prepare accurate and detailed overlay maps at a scale of 1:24,000 are available in the cartographic section of the Bureau of Economic Geology.

APPENDIX B

ENDANGERED, THREATENED, AND PROTECTED ANIMAL SPECIES NATIVE TO THE BRAZORIA AND KENEDY PROSPECT AREAS AND SURROUNDING REGIONS

(Modified and updated from Blevins and Novak, 1975)

The species listed in the following table are those which may inhabit, feed in, or roam the Kenedy and Brazoria prospect areas. The status of these taxa, which has been designated by the Texas Organization for Endangered Species (TOES), the Texas Parks and Wildlife Department (TPWD), and the U. S. Fish and Wildlife Service (F&WS), is defined as follows:

E	Endangered--in danger of extinction in all or most parts of its geographic range in the United States, particularly in Texas.
T	Threatened--depleted or affected by man; likely to become endangered in the near future.
P	Peripheral--endangered or threatened in the United States, especially in Texas, although not in its range as a whole.
PR	Protected--designated Protected Nongame Species in Texas.
H	Protected by hunting regulations.
NC	Not considered endangered or threatened at this time.
SU	Status undetermined.
?	Data not available.

Designations of "Endangered" or "Threatened" proposed by the U. S. Fish and Wildlife Service and "Endangered" or "Protected" proposed by the Texas Parks and Wildlife Department have the force of law. Waterfowl species protected by hunting restrictions are those with closed seasons or very low bag limits at this time, and these restrictions are enforced by the TPWD. Contact the U. S. Fish and Wildlife Service or the Texas Parks and Wildlife Department for information concerning specific regulations about individual species.

The table below also provides information concerning the species' range in Texas, preferred habitat, and reasons for its current status. The prospect area is identified by K for the Kenedy Prospect area and B for the Brazoria Prospect area.

NAME	TOES	TPWD	F&WS	RANGE IN TEXAS	PREFERRED HABITAT	REASON FOR STATUS	PROSPECT AREA
MAMMALS							
Southern yellow bat (Lasiurus ega)	P	PR	NC	Lower Rio Grande Valley	Roost in palm grove near Brownsville	Habitat destruction	K
Gray wolf (Canis lupus monstrabilis)	?	E	E	Statewide	Broken, open country in which suitable "hideouts" and denning sites are available	Habitat destruction; predator control; disease	K
Red wolf (Canis rufus)	E	E	E	Galveston-Chambers-Brazoria County area	Coastal and prairie marshes	Habitat destruction; predator control; disease	B
Mexican wolf (Canis lupus baileyi)	?	E	E	Trans-Pecos area and Rio Grande Plain		Rare in Texas	K
Mountain lion (Felis concolor)	E	NC	NC	Statewide but scattered	Areas of low human population density	Predator control; hunting	K
Ocelot (Felis pardalis)	P	E	E	South Texas	Subtropical woodland	Habitat destruction; predator control	K
Jaguarundi (Felis yagouaroundi)	P	E	E	Lower Rio Grande Valley and lower coast	Subtropical woodland	Habitat destruction; predator control; hunting	K
Margay (Felis wiedii)	?	E	E	Lower Rio Grande Valley	Subtropical woodland	Rare in Texas; northern edge of distribution; not recorded since 1850's	K
Jaguar (Felis onca)	?	E	E	Lower Rio Grande Valley	Chaparral; open forests	Small population; hunting	K
River otter (Lutra canadensis)	T	NC	NC	Trinity River and eastward	Marshes, river or stream habitat	Trapping pressure	B

NAME	TOES	TPWD	F&WS	RANGE IN TEXAS	PREFERRED HABITAT	REASON FOR STATUS	PROSPECT AREA
BIRDS							
Brown pelican (Pelecanus occidentalis)	E	E	E	Lower and central coastal areas	Coastal islands and bays	Pesticides; human disturbance	K + B
Olivaceous cormorant (Phalacrocorax olivaceus)	P	NC	NC	Coastal zone; less frequently inland	Coastal islands, bays and marshes	Pollution; marsh drainage	K + B
Reddish egret (Dichromanassa rufescens)	E	PR	P	Coastal zone	Coastal islands and brackish marshes	Restricted distribution; pollution, pesticides	K + B
White-faced ibis (Plegadis chihi)	T	PR	SU	Coastal zone; less frequently inland	Coastal islands and marshes	Cultivation of habitat	K + B
Roseate spoonbill (Ajaia ajaja)	P	NC	P	Coastal zone; less frequently inland	Coastal islands and marshes	Human disturbance (recovering)	K + B
Ross' goose (Chen rossii)	T	H	NC	Coastal zone; less frequently inland	Coastal prairies	Small population	K + B
Fulvous tree duck (Dendrocygna bicolor)	E	H	NC	Coastal zone; less frequently inland	Fresh-water marshes and prairies	Pesticides; cultivation of habitat	K + B
Masked duck (Oxyura dominica)	P	H	P	Coastal zone	Coastal marshes and resacas, ponds and depressions	Small population; marsh drainage	K + B
White-tailed kite (Elanus leucurus)	P	NC	P	Lower Rio Grande Valley coast and east-central area	Prairies and farm country with clumps of trees	Indiscriminate shooting	K
Swallow-tailed kite (Elanoides forficatus)	T	NC	NC	Eastern half of state	Open woodlands	Indiscriminate shooting; lumbering	K + B
Zone-tailed hawk (Buteo albonotatus)	P	PR	P	Mexican border region	Steep canyons and river woodlands	Indiscriminate shooting	K

NAME	TOES	TPWD	F&WS	RANGE IN TEXAS	PREFERRED HABITAT	REASON FOR STATUS	PROSPECT AREA
BIRDS (Continued)							
Canvas-back (Aythya valisineria)	?	H	NC	Coastal zone	Coastal bays and marshes	Declining population	B
Redhead (Aythya americana)	?	H	NC	Coastal zone	Lakes and bays	Declining population	B
Black-bellied whistling duck (Dendrocygna autumnalis)	?	H	NC	Coastal zone	Coastal marshes, ponds and lakes, prairies, swamps	Declining population	K + B
Gray hawk (Buteo nitidus)	P	PR	P	Lower Rio Grande Valley; less often coast and Trans-Pecos	Subtropical woodlands	Clearing of woodlands	K
White-tailed hawk (Buteo albicaudatus)	P	PR	P	Coastal zone; less frequently inland	Coastal prairies and marshes	Indiscriminate shooting	K + B
Black hawk (Buteogallus anthracinus)	P	PR	P	Along Rio Grande and in Davis Mountains	River woodlands	Clearing of woods; indiscriminate shooting	K
Bald eagle (Haliaeetus leucocephalus)	E	E	E	Statewide	Lakes, reservoirs, and large rivers	Pesticides; indiscriminate shooting	K + B
Golden eagle (Aquila chrysaetos)	T	NC	NC	Statewide	Mountains, hilly country	Indiscriminate shooting	K + B
Osprey (Pandion haliaetus)	E	PR	SU	Statewide	Coastal zone; lakes and reservoirs	Pesticides; indiscriminate shooting	K + B
Peregrine (Falco peregrinus)	E	E	E	Statewide	Coastal zone; lakes and mountains	Pesticides; nest robbing by falconers	K + B
Prairie falcon (Falco mexicanus)	T	NC	T	Statewide, except extreme east	Open country of arid areas	Pesticides; nest robbing by falconers	K

NAME	TOES	TPWD	F&WS	RANGE IN TEXAS	PREFERRED HABITAT	REASON FOR STATUS	PROSPECT AREA
BIRDS (Continued)							
Arctic peregrine falcon (Falco peregrinus tundrius)	?	E	E	Migrates through Texas; found along coast during spring and fall	Open country	Pesticides	K + B
Aplomado falcon (Falco femoralis septentrionalis)	?	PR	NC	South Texas and the Trans-Pecos area	Arid brushy prairie	Change in habitat due to brush encroachment and habitat modification	K
Merlin (Falco columbarius)	T	NC	SU	Statewide	Open country	Pesticides	K + B
American oystercatcher (Haematopus palliatus)	P	NC	NC	Coasts	Coastal islands, beaches and mudflats	Small population	B
Eskimo curlew (Numenius borealis)	E	E	E	Coastal zone	Coastal prairies	Small population	K + B
Whooping crane (Grus americana)	E	E	E	Coastal zone	Coastal marshes and bays	Small population size; restricted winter range	B
Ferruginous owl (Glaucidium brasilianum)	P	PR	P	Lower Rio Grande Valley	Subtropical woodland	Clearing of woodland	K
Ringed kingfisher (Megaceryle torquata)	P	NC	NC	Lower Rio Grande Valley	Rio Grande	Small population	K
Beardless flycatcher (Camptostoma imberbe)	P	NC	P	Lower Rio Grande Valley	Subtropical woodland	Clearing of woodlands	K
Rose-throated becard (Platypsaris aglaiae)	P	NC	P	Lower Rio Grande Valley	Subtropical woodland	Clearing of woodlands	K
Wood stork (Mycteria americana)	NC	PR	NC	Coastal zone; less frequently inland	Swamps, marshes, and ponds	Habitat destruction; pesticides; drainage of marshlands	K + B

NAME	TOES	TPWD	F&WS	RANGE IN TEXAS	PREFERRED HABITAT	REASON FOR STATUS	PROSPECT AREA
BIRDS (Continued)							
Sooty tern (*Sterna fuscata*)	P	NC	NC	Coastal zone	Coastal islands	Disturbance during nesting	B
Least tern (*Sterna albifrons antillarum*)	?	PR	NC	Coastal zone	Common along sandy beaches; inland	Incomplete information	K + B
Yellow-green vireo (*Vireo flavoviridis*)	P	NC	NC	Lower Rio Grande Valley and coast	Subtropical woodland	Clearing of woodlands	K
Tropical parula (*Parula pitiayumi*)	P	NC	P	Lower Rio Grande Valley	Subtropical woodland	Clearing of woodlands	K
White-collared seedeater (*Sporophila torqueola*)	P	NC	P	Lower Rio Grande Valley	Pastures and weedy fields	Restricted distribution; small population size	K
Botteri's sparrow (*Aimophila botterii*)	P	NC	P	Lower Gulf Coast	Coastal prairies	Restricted distribution; small population size	K
Attwater's prairie chicken (*Tympanuchus cupido*)	E	E	E	Coastal zone	Coastal prairies	Overgrazing; agriculture	B
REPTILES							
American alligator (*Alligator mississipiensis*)	E	E	E	East Texas and coastal areas	Marshes, rivers, canals, ponds, and lakes	Indiscriminate killing; commercial hunting	K + B
Diamond-backed terrapin (*Malachemys terrapin*)	T	E	NC	Coastal zones	Salt marsh	Destruction of habitat; over-hunting for food	K + B
Black-striped snake (*Coniophanes imperialis*)	P	PR	NC	Cameron and Hidalgo Counties	Subtropical woodland	Woodland clearing	K

NAME	TOES	TPWD	F&WS	RANGE IN TEXAS	PREFERRED HABITAT	REASON FOR STATUS	PROSPECT AREA
REPTILES (Continued)							
Mexican milk snake (Lampropeltis triangulum annulata)	?	PR	NC	South and central Texas	Variable, ranging from sand dunes to cultivated fields	Habitat loss; commercial exploitation	K
Texas indigo snake (Drymarchon corais erebennus)	?	PR	NC	South Texas		Commercial exploitation	K
Speckled racer (Drymobious margaritiferus)	P	E	NC	Cameron County	Subtropical woodlands; riparian areas	Woodland clearing; marsh drainage	K
Northern cat-eyed snake (Leptodeira septentrionalis)	P	PR	NC	Cameron, Hidalgo, Kenedy, and Willacy Counties	Subtropical woodlands; riparian areas	Woodland clearing; drainage	K
Smooth green snake (Opheodrys vernalis)	T	NC	NC	North central coastal zone	Coastal prairies	Cultivation	B
Texas tortoise (Gopherus berlandieri)	?	PR	NC	South Texas	Sandy soils in arid regions	Brush clearing; automobile traffic; urbanization; pesticide usage	K
Texas horned lizard (Phrynosoma cornutum)	?	PR	NC	Statewide	Dry, flat, open terrain with sparse plant cover; sandy, rocky, or loamy soil	Commercial exploitation; pesticide usage	K
AMPHIBIANS							
Giant toad (Bufo marinus)	P	PR	NC	Hidalgo, Starr, and Zapata Counties	Riparian areas; resacas	Drainage; clearing; and collection	K
Mexican burrowing toad (Rhinophrynus dorsalis)	?	PR	NC	South Texas; Starr and Zapata Counties		Over-collecting	K

NAME	TOES	TPWD	F&WS	RANGE IN TEXAS	PREFERRED HABITAT	REASON FOR STATUS	PROSPECT AREA
AMPHIBIANS (Continued)							
Mexican white-lipped frog (Leptodactylus labialis)	P	PR	NC	Cameron, Starr, and Hidalgo Counties	Subtropical woodlands; riparian areas	Clearing; drainage	K
Mexican tree frog (Smilisca baudini)	P	PR	NC	Cameron and Hidalgo Counties	Subtropical woodlands; resacas	Clearing of woodlands; habitat modified by development; pesticide usage; collection	K
Rio Grande frog (Syrrhophys cystignathoides)	?	PR	NC	Cameron, Hidalgo, and Starr Counties	Palm groves, thickets, ditches, and resacas; also thrives in residential areas	Brush clearing; pesticide usage; collection	K
Rio Grande siren (Siren intermedia texana)	?	PR	NC	Lower Rio Grande Valley	Ponds and shallow water habitats	Habitat disturbance such as pesticide runoff, oil spills, or over-utilization of fresh water; over-collecting	K
Black-spotted newt (Notophthalmus meridionalis)	?	PR	NC	Gulf Coast of South Texas	Ponds, lagoons, and swampy areas in arid regions	Habitat destruction; pesticides; over-collecting	K
FISH							
Blue sucker (Cycleptus elongatus)	?	PR	NC	Gulf Coast and inland	Large streams and artificial impoundments	Reservoir construction prohibiting reproduction in flowing streams	K

Appendix C

FEDERAL AND STATE RULES AND REGULATIONS AFFECTING DEVELOPMENT OF GEOPRESSURED-GEOTHERMAL ENERGY ALONG THE GULF COAST WITH PARTICULAR EMPHASIS ON THE BRAZORIA AND KENEDY PROSPECT AREAS

Appendix C is a compilation of rules and regulations that directly affect the development and construction of the geothermal test well site and the drilling and operation of the geothermal test well. Special emphasis is given to agencies with regulations requiring permits to be obtained by the operator.

SITE DEVELOPMENT AND DRILLING A GEOTHERMAL WELL

Table 26 lists agencies which have regulatory control and which issue permits for activities associated with geopressured-geothermal energy site development. Application of certain rules and regulations dealing with site preparation depends on the specific design of the site which in turn depends on special features of the location. The rules listed for this category deal basically with locating permanent structures and physical alteration of surface conditions. Activities such as these are not new and many general construction-type rules apply. Normally, specifications for particular types of construction are assessed by regulatory agencies on an individual basis. Guidelines for construction activities can be obtained by consulting the individual agencies.

The Texas Railroad Commission (TRRC) is the principal authority and regulatory agency for drilling for oil, gas and geothermal resource waters and for the production of these resources in the State of Texas. Rules and regulations pertaining to drilling activities are stated in the "Conservation Rules and Regulations for Oil, Gas, and Geothermal Resources of the Texas Railraod Commission" (Rules 051.02.02.000-080).

The Texas Parks and Wildlife Department (TPWD) has the responsibility of managing and maintaining the State's fish and wildlife resources and should be consulted before disturbance of natural wildlife habitats. They also issue permits for dredging activities.

Under the Endangered Species Act of 1973, all federal agencies must ensure that their activities and programs do not jeopardize the continued existence of a listed endangered or threatened species and do not result in the destruction or adverse modification of critical habitats (Title 50, Chap. 402.01). Operators should consult U.S. Fish and Wildlife Service (U.S.F.W.S.) and the National Marine Fisheries Service (NMFS) for lists of species of threatened and endangered fish, wildlife and plants that are found in the area, and how development activities might affect them.

Rules and regulations proposed under the authority of the Antiquities Committee (A.C.) are to protect state archeological landmarks and cultural resources (includes such cultural resources as historical sites, structures and artifacts; shipwrecks; aboriginal campsites; etc.). The Antiquities Committee is the enforcement arm of several state agencies involved in historical preservation including the Texas Historical Commission.

Table 2[illegible]

LOCATION AND PREPARATION OF WELL SITE

Agency	Authority and Regulations
Texas Air Control Board (TACB)	Operating under the authority of the Texas Clean Air Act (TEX.REV.CIV. STAT.ANN. art. 4477-5 Sect. 105 and 107b pts. 1 and 2 as amended (Supp. 1977) the TACB may designate air quality control regions; and it issues permits for construction of new facilities, modification of existing structures, and one for starting operation of facilities-all of which may emit air contaminants into the atmosphere. (TACB General Rules 131.08.00.001-.009)[1]
Antiquities Committee	<u>State Archeological Landmarks</u> A person cannot take, alter, damage, salvage, or excavate state archeological landmarks without a contract or permit from the A.C. (TEX.REV.CIV.STAT.ANN. art. 6145-9(1970) as amended (Supp. 1975)[1] redefined Texas Natural Resource Code, Title 9, Section 191.093)
Texas Water Commission (TWC) (Texas Department of Water Resources)	<u>Water Diversion and Storage Activities</u> Issues permits for water diversion and storage activities of the State's surface waters. A person may not take, divert, or appropriate state surface waters or begin construction of a work designed for the storage, taking or diversion of state surface waters without a permit. (Rule 129.02.01.001)[1]
General Land Office of Texas (GLO)	<u>Rights of Way Over Public Lands</u> The commissioner of the General Land Office may execute grants for easements for rights-of-way across public lands (other than University lands) for improvements such as telephone, telegraph, electric transmission, and power lines; oil, gas, sulfur, electric and other pipelines; and irrigation canals, laterals, and water pipelines granted by the state. Easements may

Agency	Authority and Regulations
	also be granted for electric substations, tanks, farms, loading racks and pumping stations. (Rules 126.18.02.001-006; TEX.REV. CIV.STAT.ANN. art. 6020a (1962), as amended (Supp. 1975).[1]
Texas Department of Water Resources (TDWR) (formerly Texas Water Development Board)	No person, corporation, or levee improvement district may construct, cause to be constructed, maintain, or cause to be maintained, any levee or other such improvement on, along, or near any stream of Texas that is subject to floods, freshets, or overflows so as to control, regulate, or otherwise change the floodwater of the stream, without first obtaining approval of the plans by the Texas Department of Water Resources (Rule 128.04.04.401.405, Authority: Sec. 11.025 chap. 11 of Texas Water Code)[1]
Texas Railroad Commission	<u>Drilling, Deepening, and Plugging Back Wells</u> A permit is required to drill, deepen, or plug back exploratory, fluid injection, injection water source, oil, gas, and geothermal resources wells. The statewide spacing rule prohibits the drilling of oil, gas, and geothermal resource wells: 1) nearer than 1,200 ft. to a completed well in, or to the same horizon on, the same tract or farm. 2) nearer than 467 ft. to any property, lease, or subdivision lines. (no more than 1 well per 40 acre tract) (Rules 051.02.02.005 and 051.02.02.037 General Conservation Rules and Regulations)
Texas Parks and Wildlife Department	A person may not disturb marl, sand, gravel, shell or mudshell under the management and protection of the Parks and Wildlife Commission or operate in

Agency	Authority and Regulations
	or disturb an oyster bed or fishing water for a reason other than that necessary or incidental to navigation or dredging under federal or state authority. (Tex. Parks and Wildlife Code Ann. Sec. 86.002(a) (1976).[1]
U. S. Fish and Wildlife Service	Interagency Cooperation - Endangered Species Act of 1973 Requires that a federal agency ensures that its activities or programs do not result in destruction or adverse modification of critical habitat, or jeopardize the continued existence of a listed endangered or threatened species. If activities may affect a listed species, formal consultation must be intiated with a U. S. F. W. S. Regional Director. (Title 50, CFR, Chap. IV, Part 402)

[1]General Land Office of Texas, 1976a.

TRANSPORTATION

The transportation of volatile or dangerous liquids is regulated at several levels of government. The main function of these regulations is to ensure fair trade practices and the protection of the environment and the community. At three stages in the production cycle will transportation of volatile liquids occur: (1) hot geothermal resource liquids will be transported to the energy conversion site, (2) extracted methane will be transported to the fuel power plant, (3) spent geothermal brines will be transported to the disposal site. Although several modes of transportation are available (truck, tanker, pipeline, etc.), because of the quantities of liquids produced, and the locations of the test well sites, at present the most likely transportation method will be by pipeline at all stages. There is a possibility that methane could be transported by tankers from the Brazoria site. Table 27 lists agencies with regulatory responsibilities for transportation of volatile liquids.

Table 27

TRANSPORTATION

Agency	Authority and Regulations
General Land Office	Rights-of-Way Over Public Lands Commissioner of GLO may execute grants for easements for rights of way across public lands for improvements such as ... gas, sulfur, electric and other pipelines; and irrigation canals, laterals, and water pipelines granted by the State. (Rules 126.18.02.001-006;TEX.REV. CIV.STAT.ANN. art. 6020a (1962), as amended, (Supp. 1975)[1]
Texas Department of Highways and Public Transportation	Utility Accommodation Policy Prescribes and approves accommodation, location and methods for the installation, adjustment, relocation and maintenance of utilities (including pipelines) on highway rights-of-way or other state-owned rights-of-way. (Rules 101.15.03.030.034)[1]
U.S. Department of Transportation (Office of Pipeline Safety)	Has the overall authority and responsibility for prescribing the requirements and specifications governing pipeline construction in the U.S. Pipeline developers must meet its specifications. (Title 49, CFR, Part 192, Transportation of Natural and Other Gas by Pipeline: Minimum Federal Safety Standards and Amendments; Title 49, CFR, Part 195, Transportation of liquids by pipelines and amendments)[2]
Texas Railroad Commission	Responsible for implementing the Department of Transportation's program. (TEX.REV.CIV.STAT., Title 102, arts. 6004-6049g and 6066a,b,c.)[2] A pipeline or gathering system, regardless of whether it is a common carrier, cannot be used to transport oil, gas, or geothermal resources from a tract of land within the state without a permit issued by the TRRC. The permit is issued when the TRRC is satisfied that pipelines are laid,

Agency	Authority and Regulations
	equipped, and managed in a manner designed to reduce the possibility of waste and to operate in compliance with state conservation laws and Railroad Commission rules. (Rule 051.02.02.070 General Conservation Rules and Regulations)
	No transmission of gas or liquid with a concentration of H_2S > beyond fixed limits of field when produced except by approval of the TRRC. (Rule 051.02.02.036(7) General Conservation Rules and Regulations)
	Also prescribes some specifications for transmission by pipelines. (Rule 051.02.02.008(D)(2)(f) and Rule 051.02.02.013(E)(8) General Conservation Rules and Regulations)
Federal Power Commission	Issues certificates authorizing natural gas pipelines to construct, extend, acquire, or to operate transportation and storage facilities for the movement of natural gas in interstate commerce. (15 U.S.C.S. sec. 717 et seq. (1976))[3]
U.S. Army Corps of Engineers	Structure Permit Prior to construction, reconstruction, or major renovation of a structure in, on, or under a navigable water, a permit must be obtained from the Corps of Engineers. Structures requiring permits include those under navigable waters including pipes, and submerged structures in navigable waters such as intake and outfall pipes. (33 U.S.C.S. sec. 403 (1960))[1]

[1] General Land Office of Texas, 1976a

[2] Haynes, 1975

[3] General Land Office of Texas, 1976b

STORAGE

At some stage in the production of geothermal energy, large quantities of resource liquids may have to be stored. Storage may be used for containment of separated methane or for spent geothermal fluids especially in the event of injection well shut-down. Regulations are provided to protect from safety hazards such as spillage and escape of volatile compounds and liquid contaminants, and pollution of surface and shallow ground water and the atmosphere. The main regulatory agencies are listed in Table 28.

Table 28

STORAGE

Agency	Authority and Regulations
Texas Air Control Board	Rule 5 Control of air pollution from compounds (applies only to certain counties including Brazoria County) Storage of volatile compounds. Storage tanks with greater than 25,000 gallon capacities must be pressure tanks capable of maintaining working pressures sufficient at all times to prevent vapor or gas loss to the atmosphere or must be designed and equipped with one of the specified vapor loss control devices. (TACB General Rule 131.07.02.001)[1] No person shall place, store, or hold any new stationary storage vessel of more than 1000 gallons capacity, any volatile carbon compound unless such vessel is equipped with a permanent submerged fill pipe or is a pressure tank (as above) or is filled with a vapor recovery system. (TACB General Rule 131.07.02.002)[1]
Texas Railroad Commission	Prohibits the use of salt water disposal pits for storage of evaporation of geothermal resource waters. (Rule 051.02.02.008(c) General Conservation Rules and Regulations) (Impervious collecting pits may be approved for use in conjunction with approved salt water disposal operations. (Rule 051.02.02.008(c)(1)(b) General Conservation Rules and Regulations) Salt water disposal pits shall be back-filled and compacted when usage ceases. (Rule 051.02.02.008(c)(4) General Conservation Rules and Regulations)
Environmental Protection Agency	Spill prevention control and countermeasure plan Requires a plan to be submitted whenever more than 1,320 gallons of oil or oil products are to be stored

Agency	Authority and Regulations
	above-ground, or more than 42,000 gallons are in buried storage. Rules and regulations give guidelines for the preparation and implementation of a plan. (Title 40, CFR, Chap. I, Part 112)

[1] General Land Office of Texas 1976a

SURFACE DISPOSAL OF GEOTHERMAL BRINES

The Texas Department of Water Resources*, as the principal authority in the state on matters relating to the quality of water in the state, has established Texas Water Quality Standards (TWQB, 1975). These include numerical criteria for segments of water quality regions and cover temperature, chloride, sulfate, total dissolved pH solids, dissolved oxygen content, and coliform bacteria. Geothermal brines disposed of via surface methods will have to come within these established criteria in order to maintain the quality of surface waters in the state. The Texas Department of Water Resources regulates the disposal of these types of fluid wastes by issuing Waste Disposal Orders and recommending treatment procedures and disposal methods for surface disposal from point sources.

In addition to these major constituents, other elements contained in geothermal brines may produce hazardous effects on surface waters.

The Texas Department of Water Resources has published regulations for 'hazardous metals' (TWQB Order No. 75-1125-5), and specific effluent standards for many 'toxic pollutants' and 'hazardous substances' will be developed in the future under the requirements set up in the Federal Water Pollution Control Act Amendment of 1972 (FWPCAA) (Rogers and Oberbeck, 1978).

It has not yet been established whether the TDWR or the TRRC will have jurisdiction over the disposal of geothermal brines**. Since

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* Formerly the Texas Water Quality Board (TWQB)

** The reader is encouraged to see Rogers and Oberbeck (1978) for further discussion of this ambiguity in Texas Law.

substantial quantities of methane will be produced along with geothermal fluids, disposal may come under the authority of the TRRC. Furthermore, the TRRC has rewritten the General Conservation Rules and Regulations establishing standards for oil and gas production and transportation operations to include geothermal resources (Rules 051.02.02.000-.080) (Texas Railroad Commission, 1975).

The Water Protection Rule 8

For brines produced in conjunction with the production of oil, gas and geothermal resources, the Texas Railroad Commission proposes the following regulations for protection of surface waters:

Water Protection (Rule 051.02.02.008)

(A) Fresh water, whether above or below the surface, shall be protected from pollution.....

(B) ...(The operation of) geothermal well or wells drilled for exploratory purposes.... shall be carried on so that no pollution of any stream or watercourse of this State, or any subsurface waters, will occur as the result of the escape or release of injection of geothermal resource or other mineralized waters from any well.

It has been found that "the disposal of salt water into open-surface pits is the most hazardous method with respect to contamination of shallow fresh water" (TWQB, 1973). Rule 8 continues in part (C)(1) which prohibits the use of salt water disposal pits for storage and evaporation of oil field brines, geothermal resource waters or other mineralized waters. However, provision (b) under this same part states:

(C)(1)(b) Impervious collecting pits may be approved for use in conjunction with approved salt-water disposal operations....

Discharge of oil field brines, geothermal resource waters or other mineralized water into a surface drainage water course, whether it be a dry creek, a flowing creek or a river, except where permitted by the Commission, is not an acceptable disposal operation and is also prohibited by provision (C)(1)(c).

For protection of the Texas offshore and adjacent estuarine zones, Pollution Prevention rules are promulgated in part D. These rules provide for protection from oil or hydrocarbon, solid and liquid wastes, drilling mud containing oil and other contaminants related to well drilling and producing operations. Provisions of these rules are also required and enforced for operations conducted on the inland and fresh waters of the state of Texas, such as lakes, rivers, and streams (D)(4).

(D) Pollution Prevention

(Reference Order No. 20-59,200, effective 5-1-69)

(1) The operator shall not pollute the waters of the Texas offshore and adjacent estuarine zones (salt-water bearing bays, inlets, and estuaries) or damage the aquatic life therein.

(2) All oil, gas, and geothermal resource well drilling and producing operations shall be conducted in such a manner to preclude the pollution of the waters of the Texas offshore and adjacent estuarine zones. Particularly, the following procedures shall be utilized to prevent pollution.

(a) The disposal of liquid waste material into the Texas offshore and adjacent estuarine zones shall be limited to salt water and other materials which have been treated, when necessary, for the removal of constituents which may be harmful to aquatic life or injurious to life or property.

(b) No oil or other hydrocarbons in any form or combination with other materials or constituent shall be disposed of into the Texas offshore and adjacent estuarine zones.

Note that rule (2)(a) does permit salt water disposal offshore provided the water is properly treated beforehand.

Table 29 lists permitting agencies involved in surface disposal. Based on the decision of who has jurisdiction over geothermal brine disposal, either a TDWR or a TRRC permit will have to be obtained. Note the dual permitting system of the Texas Department of Water Resources whereby the TDWR issues its own permit plus the National Pollutant Discharge Elimination System (NPDES) permit which is issued by the EPA through the Department of Water Resources. This is because the TDWR does not yet satisfy all the requirements set up in the FWPCAA to handle permitting of surface disposal independently. In addition, a person applying for a waste disposal permit from the TRRC will have to obtain an NPDES permit (Rogers and Oberbeck, 1978). In either case, both agencies are responsible for the maintenance of surface water quality set up in the Texas Water Quality Standards.

When there is a possiblity of surface disposal activities presenting a health hazard, the Texas Department of Health Resources should be consulted to avoid this situation.

Table 29

SURFACE DISPOSAL

Agency	Authority and Regulations
Texas Department of Water Resources (formerly Texas Water Quality Board)	Regular Waste Control Order A regular waste control order must be obtained to discharge any of a variety of wastes into the waters of Texas, or adjacent to the waters of the state when such a procedure could cause pollution of the ground or surface water. (Rule 130.01.30.002) (An industrial regular waste control order is required when any public or private entity seeks to discharge an effluent that is more than 50 percent industrial sewage)[1]
Environmental Protection Agency (EPA)	National Pollutant Discharge Elimination System Under the Federal Water Pollution Control Act, the EPA issues National Pollutant Discharge Elimination System permits to regulate the discharge of pollutants into the navigable waters of the United States. (33 U.S.C.S. sec. 1342(a) (Supp. 1977))
Texas Department of Water Resources (U.S. Environmental Protection Agency)	Certification from the State An applicant for an NPDES permit must obtain certification (from the TDWR) that the proposed discharge will comply with provisions of sections 1311, 1312, 1316, and 1317 of Title 33 U.S.C. (FWPCA) before the EPA issues the permit. (33 U.S.C.S. sec. 1341(a) (Supp. 1977))
Texas Railroad Commission	Surface Disposal Permits Discharge of geothermal waters into a surface drainage water course is prohibited except where permitted by the Commission. (051.02.02.008(C)(1)(c) General Conservation Rules and Regulations)

Agency	Authority and Regulations
U.S. Fish and Wildlife Service	Reviews all federal water use projects and those water use projects requiring federal permits to determine their effects on fish and wildlife. (16 U.S.C.S. sec. 662 (1959)[2]
Texas Department Water Resources	Thermal Discharges Has adopted temperature limitations for discharges into Texas waters as published in the Texas Water Quality Standards (Texas Water Code chap. 21).

[1] General Land Office of Texas 1976a

[2] General Land Office of Texas 1976b

THERMAL POLLUTION

Thermal discharges present another important form of surface water pollution. Section 1313(D) (1970) of the FWPCAA requires that each state set up total maximum daily thermal loads for the state's waters to assure protection and propagation of shellfish, fish, and wildlife. Section 1326 of the same further requires that the EPA (or, if appropriate, the State) set up effluent limitations for the control of the thermal component of any discharge from a point source. The following limitations concerning thermal discharges are written into the Texas Water Quality Standards (TWQB, 1975) (also see Gustavson and Kreitler, 1976).

> "The temperature limitations are intended to be applied with judgment and are applicable to the waters specifically identified...(in the published standards).... Temperature standards are composed of two parts, a maximum temperature and a maximum temperature differential attributable to heated effluents.
> Natural high temperatures, in excess of 96°F, occur regularly in Texas waters during the summer months... It is consequently concluded that the 90°F maximum temperature suggested by the National Technical Advisory Committee is not applicable to Texas conditions.
>
> Fresh Water Streams:
>
> | | |
> |---|---|
> | Maximum Temperature | See Table for Specific Waters |
> | Maximum Temp. Diff. | 5°F rise over ambient |
>
> Fresh Water Impoundments:
>
> | | |
> |---|---|
> | Maximum Temperature | See Table for Specific Waters |
> | Maximum Temp. Diff. | 3°F rise over ambient |
>
> Tidal River Reaches, Bay and Gulf Waters:
>
> | | Fall, Winter, Spring | Summer |
> |---|---|---|
> | Maximum Temp. Diff. | 4° F | 1.5° F |
> | Maximum Temperature | 95° F | 95° F |
>
> The temperature requirements shall not apply to off-stream or privately owned reservoirs, constructed principally for industrial cooling purposes and financed in whole or in part by the entity or successor entity using, or proposing to use, the lake for cooling purposes."

SUBSURFACE DISPOSAL OF GEOTHERMAL BRINES

The main concern in subsurface injection programs in the protection of freshwater strata as well as mineral producing formations. This is expressed as the primary purpose of the State Disposal Well Act and the Federal Safe Drinking Water Act, both of which are the controlling legislation in regard to subsurface disposal. Under the Disposal Well Act (D.W.A.) the Texas Department of Water Resources is charged with the permitting of injecting industrial and municipal wastes while the Texas Railroad Commission is placed in charge of permitting injection of oil and gas waste. Both agencies must specify casing requirements to protect freshwater zones from pollution for individual applicants. (Sec. 22.055 and 22.056 of the D.W.A.) The Disposal Well Act has not been amended to include geothermal resource wastes specifically.

The Texas Railroad Commission calls for the protection of freshwater from pollution by disposal methods under Rule 8 and regulates the injection of saline and mineralized water under Rule 9 (Rules 051.02.02.008 and 051.02.02.009 of the General Conservation Rules and Regulations) (see Table 30).

Table 31 summarizes the major state and federal agencies responsible for regulating the various activities described.

Table 30

SUBSURFACE DISPOSAL

Agency	Authority and Regulations
Environmental Protection Agency	Safe Drinking Water Act Part C calls for protection of underground sources of drinking water by the establishment of State underground injection control programs. (Public Law 93-523, Title xv, Part C, 1974)
Texas Department of Water Resources	Disposal Well Act (Texas Water Code Sec. 22.001 et seq) No person may begin drilling a disposal well or converting an existing well to dispose of industrial or municipal waste without a permit from the TDWR (B-Sec. 22.011). (57th Legis., Ch. 82, Sec. 3, Subsec. (a), sen. 1 as amended) (Additional rules and regulations regarding disposal of municipal, industrial and oil and gas waste are still pending. The TDWR should be contacted later in regard to the enactment of these rules.)
Texas Railroad Commission	No person may begin drilling a disposal well or converting an existing well to dispose of oil and gas waste without a permit from the TRRC. (Sec. 22.031) (57th Legis., Ch. 82, Sec. 4, Subsec. (a), sen. 1, as amended) Salt Water Disposal Well Applications The Commission grants permits to dispose of salt water or other water containing minerals, unfit for domestic, stock, irrigation, or other geothermal uses, by injection. It also gives requirements to be met so that injection methods will not contaminate oil, gas, geothermal resources and fresh water reservoirs. (Rule 051.02.02.009, General Conservation Rules and Regulations)

Agency	Authority and Regulations
TRRC	Fresh Water to be Protected Fresh water, whether above or below the surface shall be protected from pollution whether in drilling, plugging, producing, or disposing of salt water already produced. (Rule 051.02.02.008(a), General Conservation Rules and Regulations) Application to Drill, Deepen or PlugBack Operations for drilling, deepening or plugging back any exploratory well, fluid injection well, or injection water source well cannot commence until a permit is granted by the Commission. (Rule 051.02.02.005(c) General Conservation Rules and Regulations)

Table 31

SUMMARY OF AGENCIES RESPONSIBLE FOR REGULATING ACTIVITIES ASSOCIATED WITH PRODUCTION OF GEOPRESSURED-GEOTHERMAL ACTIVITIES

Site Preparation and Drilling of Geothermal Wells	Antiquities Committee General Land Office Texas Railroad Commission Texas Air Control Board Texas Water Commission Texas Department of Water Resources Texas Parks and Wildlife Department U.S. Fish and Wildlife Service
Transportation	General Land Office Texas Department of Highways and Public Transportation Texas Railroad Commission U.S. Department of Transportation (Office of Pipeline Safety) Federal Power Commission U.S. Army Corps of Engineers
Storage	Texas Air Control Board Texas Railroad Commission Environmental Protection Agency
Surface Disposal of Geothermal Fluids	Texas Department of Water Resources Texas Railroad Commission Environmental Protection Agency U.S. Fish and Wildlife Service Texas Department of Health Resources
Subsurface Disposal of Geothermal Fluids	Texas Department of Water Resources Texas Railroad Commission Environmental Protection Agency

APPENDIX C
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