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ENVIRONMENTAL ANALYSIS OF GEOPRESSURED-GEOTHERMAL PROSPECT AREAS, DE WITT AND COLORADO COUNTIES, TEXAS

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By

Thomas C. Gustavson
Florette S. Reeder
Elizabeth A. Badger

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Bureau of Economic Geology
W. L. Fisher, Director
The University of Texas at Austin
University Station, P. O. Box X
Austin, Texas 78712

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DISCLAIMER

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INTRODUCTION[1]

This report comprises information collected and analyzed for a preliminary environmental analysis of geopressured geothermal prospect areas in Colorado and DeWitt Counties, Texas (figs. 1 and 26). The report identifies and discusses specific environmental concerns for each geopressured geothermal prospect area but is not nor was it intended to be an environmental impact assessment. Approximately 218 km^2 (85 mi^2) were studied in the vicinity of each prospect area to: (1) conduct an environmental analysis to identify more and less suited areas for geopressured test wells; and (2) provide an environmental data base for future development of geopressured geothermal energy resources.

The report contains a series of maps and tables to illustrate environmental characteristics including: geology, water resources, soils, current land use, vegetation, wildlife, and meteorological characteristics, and additional relevant information on cultural resources, power- and pipelines, and regulatory agencies. The maps depicted in the report were produced at a scale of 1:24,000, and further reduced for purposes of presentation. A series of transparent overlays at the scale of the original mapping has also been produced for the purposes of identifying and ranking areas of potential conflict between geopressured geothermal development and environmental characteristics. The methodology for ranking suitability of areas within the two prospect areas is fully discussed in the appendix and follows the form of White and others (1978).

Environmental Characteristics

Inclusion in this report of the environmental characteristics that are described below required that each characteristic meet two criteria: (1) data were available or could be generated within the time frame required by this report, and (2) the environmental characteristic was specifically relevant to development of geopressured geothermal energy in DeWitt County.

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[1]This report follows closely the format established for the "Environmental Analysis of Geopressured Geothermal Prospects Areas, Brazoria and Kenedy Counties, Texas" (White and others, 1978).

Each of the following sections describes environmental characteristics of the region surrounding the Cuero and Eagle Lake prospect areas. Environmental data and tables are provided for the entire study area, but the smaller prospect areas are emphasized in discussing relative suitability of environmental units for location of a test well.

Possible impacts were evaluated by considering both the impacts of the test well and associated facilities and activities on the environment and the potential effects of the environment on the test well site. For example, the test well will affect the environment by occupying a portion of the land surface, and by withdrawing large volumes of fluids during test phase operations, surface subsidence might be induced. On the other hand, natural processes could affect the operation of the test well; examples include stream flooding and foundation problems resulting from construction on expansive clay soils.

Construction and Maintenance Activities

The program for setting up geopressured geothermal testing facilities has been discussed in detail in several previous publications (Coastal Environments Inc., 1977; Gustavson and others, 1978; Newchurch and others, 1978; and U.S. Department of Energy, 1979); therefore, only a brief outline of construction and maintenance activities will be given with emphasis on potential environmental problems.

Drilling of the test well will involve construction of access roads (if necessary), clearing, leveling, and compaction of the drill site, and construction of a mud pit and retaining levees. The operational phase of the project will require pipelines, separators, possibly a cooling tower, storage tanks to hold the brine, several disposal wells, and support and testing facilities. Flaring and/or scrubbing of gases which come out of solution may be required. Four to six acres of land will be needed for the entire facility. The testing phase of the project may last several years, after which the well will be shut in and the area restored, as near as possible, to its original condition, or a commercial facility will be constructed. This would require more land; impacts would vary depending on the type of facility and would of course necessitate further analysis.

Possible Environmental Effects

Since exploitation of geopressured geothermal fluids is a new area, very little is known about the actual impacts of such operations. There has been much speculation, however, and valuable discussions can be found in the following publications:

1. Gustavson and Kreitler, 1976
2. Coastal Environments, 1977
3. Gustavson and others, 1978
4. U.S. Department of Energy, 1978
5. Newchurch and others, 1978.

A summary of the information available is presented in Table 1.

Table 1. Test well activities and environmental effects.

	Test well activities	Likelihood of event/ activity	Effect on environment	Likelihood of effect if event occurs	Temporal	Type of effect: Areal extent	Type of effect: Severity
Construction	Road construction and/or access	certain	Habitat destruction	certain	mid*	small	severe
			Erosion	likely	mid	small	slight/mod.
			Drainage alteration	possible	mid	small	slight
	Site preparation: including clearing, leveling, compacting	certain	Habitat destruction	certain	mid/long	small	severe
			Erosion	likely	mid	small	slight/mod.
			Drainage alteration	possible	mid	small	slight
			Increased sediment load	possible			
	Ponds, dikes, and levees	certain	Habitat destruction	certain	mid	small	severe
			Erosion	likely	mid	small/med.	slight/mod.
			Drainage alteration	possible	mid	small	moderate
	Drilling of well	certain	Noise	certain	short	small/med.	moderate
			Air pollution—dust, hydrocarbon exhaust	certain	short	small/med.	slight/mod.
	Pipelines	certain	Habitat alteration	certain	long	small	slight
Surface facilities on prepared site	Well pumping	certain	Noise	certain	mid	small	slight
	Sanitary facilities	possible	Possible groundwater contamination	unlikely	mid	small	slight/mod.
	Separators	certain	Gaseous impurities if flared—air pollution	likely	mid	small/med.	slight/mod.
	Cooling towers	likely	Minimal (few additional effects)	likely	—	—	—
	Storage tanks	certain	Minimal	likely	—	—	—
	Liquid disposal pump	certain	Noise	certain	mid	small/med.	slight/mod.
Normal operations	Geothermal-geopressured fluid removal at depth	certain	Subsidence	likely	long	med/large	slight/severe
			Fault activation by subsidence	possible	long	med/large	slight/severe
	Reinjection of fluids	certain	Groundwater contamination	unlikely	long	med/large	slight/severe
			Cementation of aquifer due to incompatible fluids	unlikely	long	small/med.	slight/severe
			Fault activation	unlikely	long	small/med.	slight/severe
Accidents	Well blowout: hot brine	unlikely	Destruction of fauna and flora	certain	short/long	medium	severe
			Injury to fauna and flora	certain	short	med/large	moderate
			Soil contamination	certain	mid	med/large	mod./severe
			Groundwater contamination	possible	long	med/large	mod./severe
			Surface water contamination	likely	short	medium	moderate
			Air pollution	certain	short	medium	moderate
	Spill from well, pipeline, or cooling ponds	unlikely	Destruction of fauna and flora	likely	short	medium	severe
			Injury to fauna and flora	likely	short	medium	moderate
			Soil contamination	certain	mid	small/med.	mod./severe
			Groundwater contamination	possible	long	small/med.	mod./severe
			Surface water contamination	possible	short	small/med.	moderate
	Break or overflow of retaining dikes—geothermal brines plus toxic drilling fluids	possible	Destruction of vegetation	likely	short	small/med.	severe
			Soil contamination	certain	mid	small/med.	mod./severe
			Groundwater contamination	unlikely	long	small/med.	mod./severe
			Surface water contamination	possible	short	small	severe

*mid = for life of test well, approximately 3 years

PRELIMINARY ENVIRONMENTAL ANALYSIS OF A GEOPRESSURED GEOTHERMAL PROSPECT AREA IN DEWITT COUNTY, TEXAS

The DeWitt County prospect area is the most favorable site for testing geopressured geothermal resources in the Wilcox Formation of the Texas Coastal Plain and thus received emphasis in this environmental report. Evaluation of the DeWitt County prospect area and other Wilcox Group areas in terms of reservoir volume, porosity, permeability, sand distribution, reservoir thermal properties and associated structures, and potential as a geopressured geothermal energy resource are reported by Bebout and others (1978). The DeWitt County reservoir consists of 197 m (645 ft) of sandstone in the interval between 3,299 m (10,815 ft) and 3,642 m (11,940 ft). Whole core analyses from the reservoir section show a range in porosity from 6 to 25 percent and a range in permeability from 0.01 to 242 millidarcies. The maximum corrected bottom hole temperature was 156°C (313°F). Formation fluid salinity was calculated from log analyses and is expected to range from 30,000 to 100,000 ppm TDS (Bebout and others, 1978).

The site of the test well within the Cuero study area will be determined by comparing areas that are most suitable geologically with areas that have few environmental constraints to identify a site or sites that are acceptable both geologically and environmentally.

GENERAL SETTING--DEWITT COUNTY PROSPECT AREA

The DeWitt County study area encompasses approximately 85 mi^2 (218 km^2). It is located near the center of DeWitt County and is transversed by the Guadalupe River which runs from northwest to southeast through the study area (fig. 1). Included within the study area are the city of Cuero with a population of approximately 7,000, Arneckeville, an unincorporated community, and several crossroads communities (fig. 2). Physiographic divisions within the study area include the gently rolling uplands and the Guadalupe River bottomlands. Elevations in the bottomlands range from 120 ft (36 m) to 180 ft (54.8 m); the uplands range up to 360 ft (118 m) but are generally less than 300 ft (31.4 m) (fig. 3).

The test well prospect area, centered within the study area, covers approximately 12 mi (31 km^2) and represents the surface projection of the geopressured geothermal reservoir. It is located mostly in the rolling uplands of the study area, although a smaller section includes part of the Guadalupe River Valley.

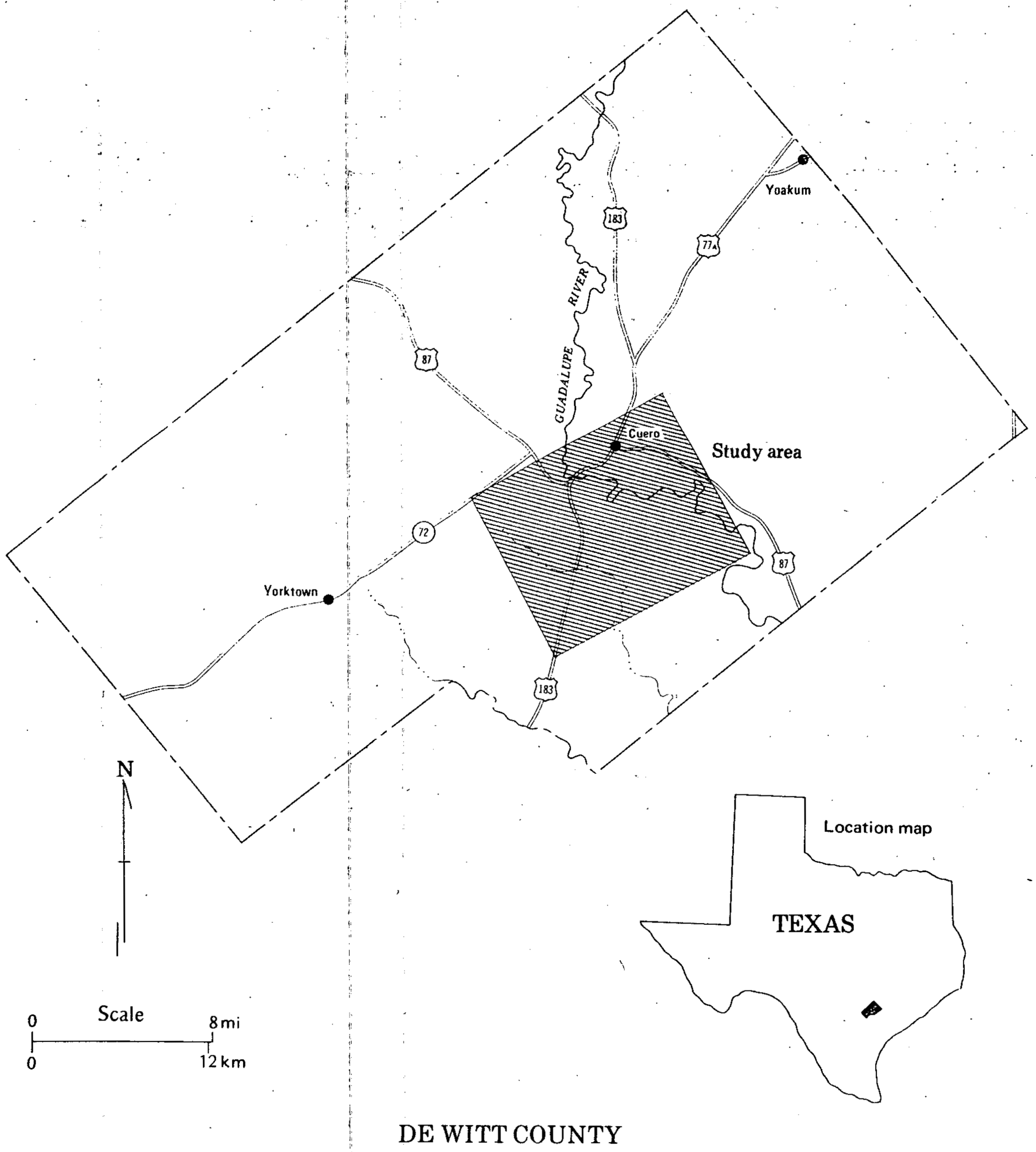

Figure 1. Location of the Cuero Study Area.

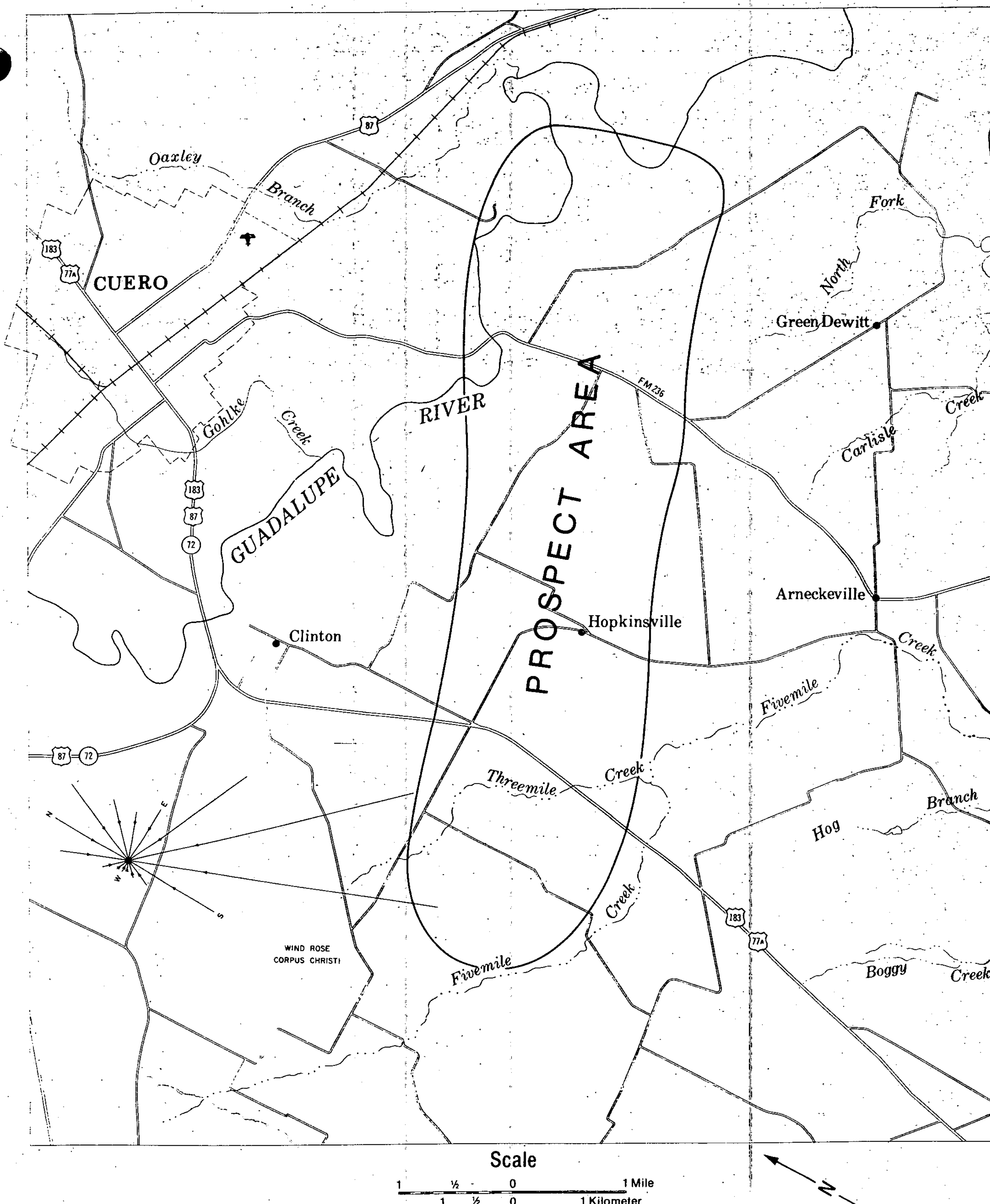

Figure 2. General Setting of Cuero Study Area, Location of Prospect Area, and Wind Rose. (Sources: Texas Air Control Board Continuous Air Monitoring Data Summaries, 1978; U.S. Geological Survey Topographic Maps; Texas Highway Department County Maps.)

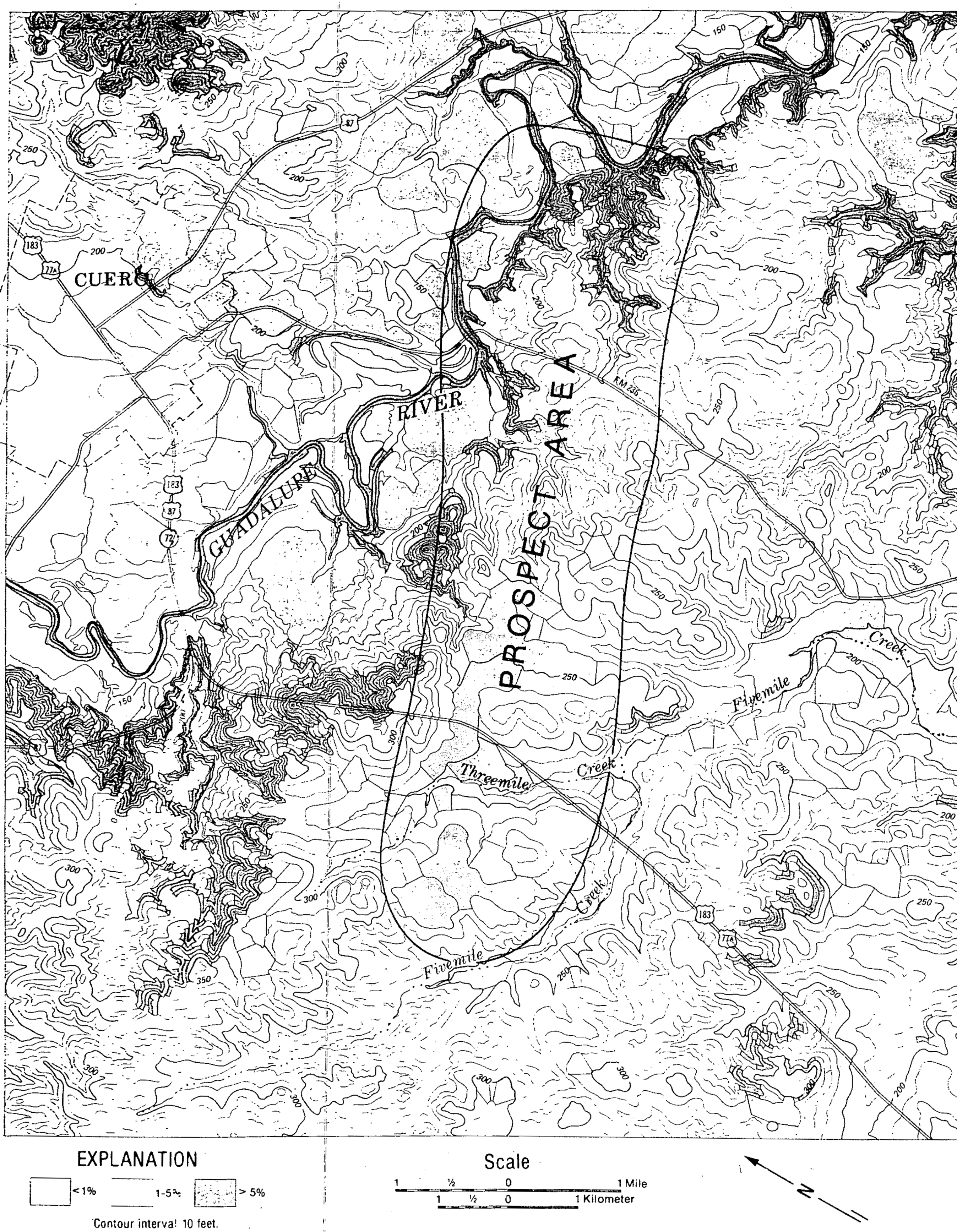

Figure 3. Relief and Slope, Cuero Study Area. (Source: U.S. Geological Survey Topographic Maps.)

SUMMARY

Review of Environmental Concerns for the Cuero Prospect Area

The Cuero area does not appear to pose many serious problems to the location of a test well. The more significant concerns are summarized below.

Archaeology. Several archaeological sites are known to occur in the prospect area. The proximity of the Cuero 1 Archaeological District which contains a high density of sites suggests that a study conducted in the prospect area would similarly reveal many more sites of interest. A survey of the proposed well site should be conducted to ensure that the well is not located on an area of archaeological interest.

Subsidence and Fault Activation. A potential for subsidence exists, especially if production continues for a number of years. Effects could include structural damage and drainage alteration. If accompanied by fault activation, damage along the fault lines could be more severe. The surface projection of one of the deep faults in the study area runs through the city of Cuero. If this fault were activated many structures could be damaged.

Groundwater Contamination. Groundwater contamination may result from accidental brine releases. This is especially true in areas of coarse grained sediments that have a high infiltration rate.

Flooding. Elevation in relation to the river should be considered if the well is to be located in the Guadalupe River floodplain. The 100 year flood represents about a 12 m (40 ft) rise in the level of the water, but the entire flood plain is covered at least once every ten years.

Soils. Properties: Some of the soils in the prospect area may pose problems for construction activities due to their clay content. These soils are corrosive or have high shrink swell properties.

Prime Soils: Some of the major soils of the prospect area are classified as Prime Agricultural soils. While this does not pose a problem for locating a test well from the standpoint of acreage removed from agriculture it should be a consideration if full scale production is implemented. Another concern is the potential long-term damage to the soil from a brine spill as constituents toxic to plants could become adsorbed by clay particles reducing the soil's suitability for agriculture.

Erosion. Although slopes in the Cuero area are not steep enough to cause engineering problems for construction, they are steep enough to rapidly develop gullies if vegetation cover is removed.

Vegetation. Valuable Habitat: Pecan forest occurs on the frequently flooded bottomlands of the Guadalupe River. This habitat is scarce in the area and particularly valuable because of the many years that would be required for the forest to recover from damage or destruction.

Rare Plants: It is possible that the rare plant Calliandra biflora may occur in the prospect area. It is possible that other rare or endangered species may also occur there as the vegetation of DeWitt County has not been thoroughly studied. A survey of the proposed well site should be conducted to ascertain the presence or absence of rare species.

Wildlife. The only abundant population of the protected river dater (Hadropterus shumardi) in Texas occurs in the Guadalupe River in the vicinity of Cuero. Should the test well be located so that activities may affect the Guadalupe River a further study should be conducted on the river darter's habits and habitat to determine any possible effects on the species.

LOCATION OF A TEST WELL ON THE BASIS OF ENVIRONMENTAL CHARACTERISTICS

An analysis of the studied environmental characteristics of the test well prospect area suggests that the uplands of the prospect area do not pose many problems to test well location and are thus relatively suitable for a test well site. The most suited areas are those of Orelia soils (sandy loams) as they have no characteristics significantly unsuited to test well development. The bottomlands of the Guadalupe River pose many problems to test well development due both to construction costs and environmental considerations and are therefore relatively unsuited for the location of a test well.

METEOROLOGICAL CHARACTERISTICS

Climate

Climate in the Cuero area is humid subtropical with hot summers (National Oceanic and Atmospheric Administration Climatological Summary, 1972). Climate is continental, characterized by a considerable range in annual temperature extremes; however, air masses of continental origin play a minor role in determining the weather in the Cuero area. The prevailing winds are southeasterly throughout the spring, summer, and fall months (Wind Rose, fig. 2). Tropical maritime air masses from the Gulf of Mexico predominate throughout the above seasons. Polar air masses, greatly modified by a long trajectory across southern latitudes, in combination with the warm water surface of the Gulf of Mexico, are responsible for mild winter temperatures. Rainfall, most often in the form of thundershowers, may vary considerably from month to month, and from year to year. Rainfall averages 33.17 inches annually (fig. 4) with peak monthly totals in May and September (fig. 5). In most years, March is the driest month.

Cuero receives about 62 percent of the total possible annual sunshine. Sunshine varies from about 49 percent in winter to 74 percent in summer. The mean relative humidity, at noon, C.S.T., is estimated at 63 percent in January, 62 percent in April, 53 percent in July, and 54 percent in October.

Winter climate alternates mild, sunny, less humid days with cool, cloudy, drizzly weather. Temperature drops to 32° or below on about 25 days each year. Summer climate is hot and humid with little change in the day-to-day weather, especially during mid-season. Spring and fall temperatures are moderate, and the weather has greater variety than in summer (fig. 6). Considerable morning cloudiness is present in early spring. Tropical storms that occasionally visit the Texas coast during late summer and early fall may bring heavy rains to the Cuero area, but this is an infrequent occurrence.

The tornado density in DeWitt County, based on the years 1951-1971, is about .8 tornados per 1,000 sq mi per year (National Weather Service, 1951). For the 85 mi^2 study area 1 tornado every 15 years could be expected.

The mean date of the last spring frost is March 3 and the mean date for the first fall frost is November 29. This gives Cuero an average frost free period of 270 days.

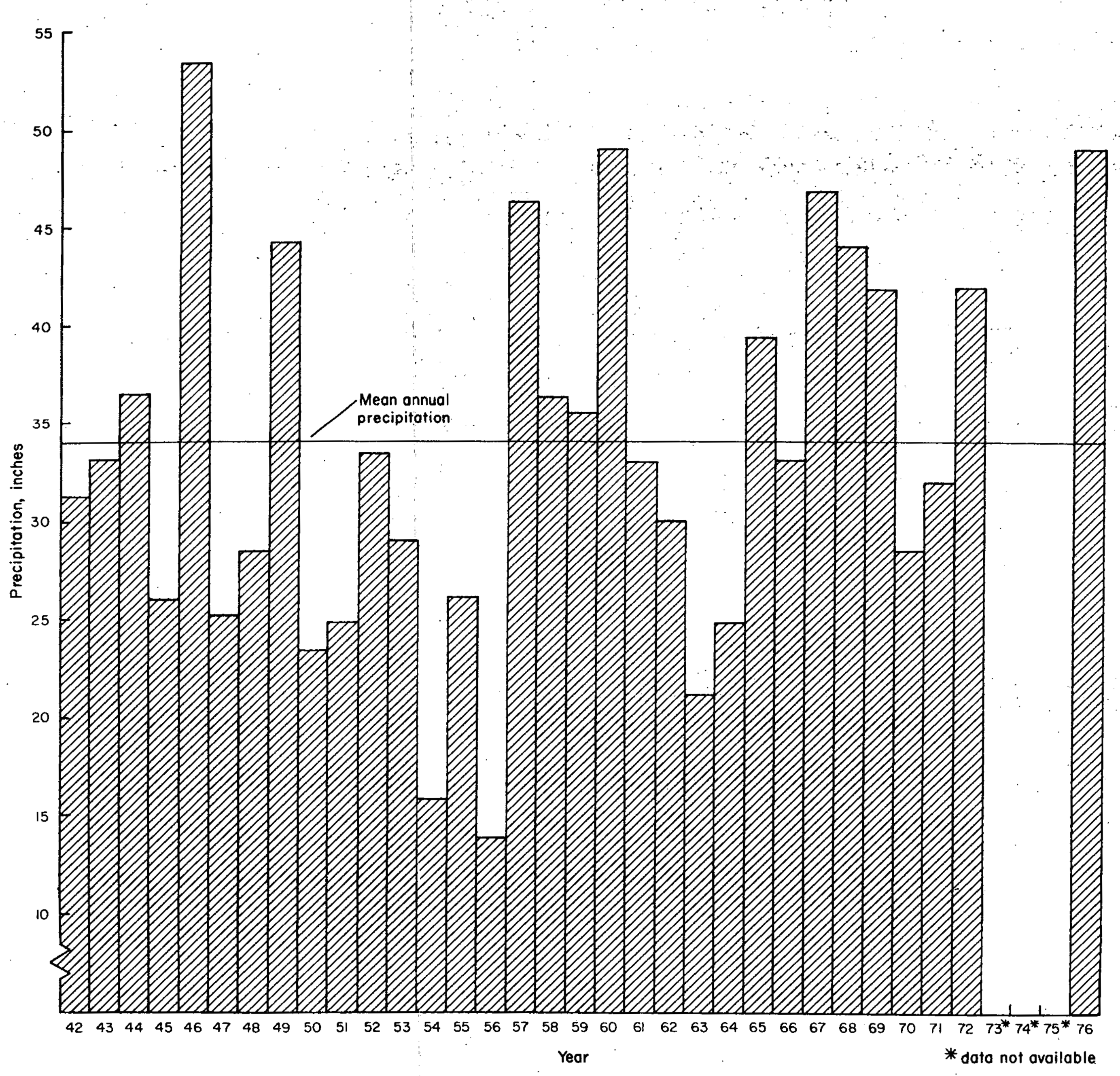

Figure 4. Annual Precipitation, Cuero, 1942-1976. (Source: National Weather Service.)

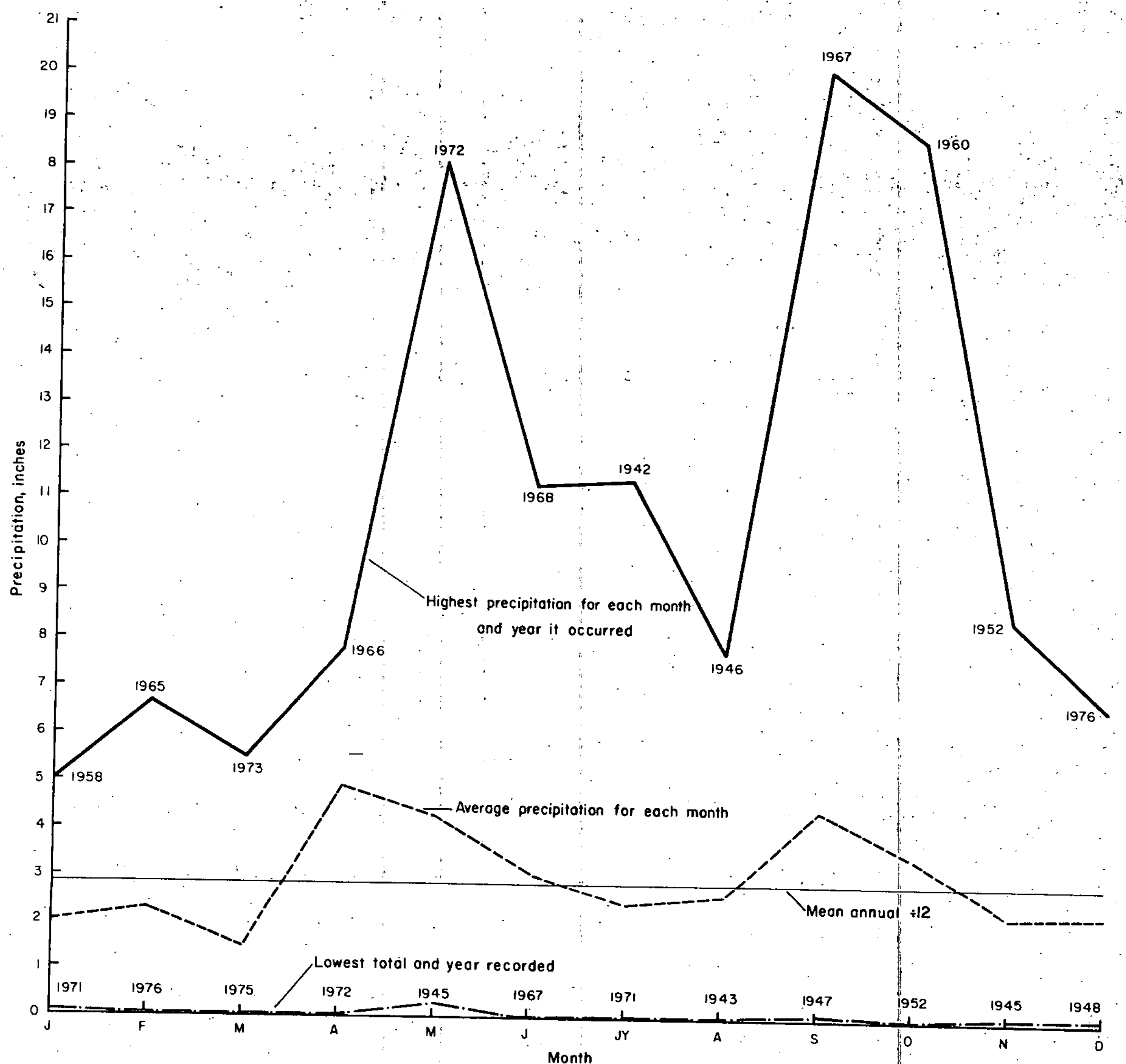

Figure 5. Monthly Precipitation, Cuero, 1942-1976.

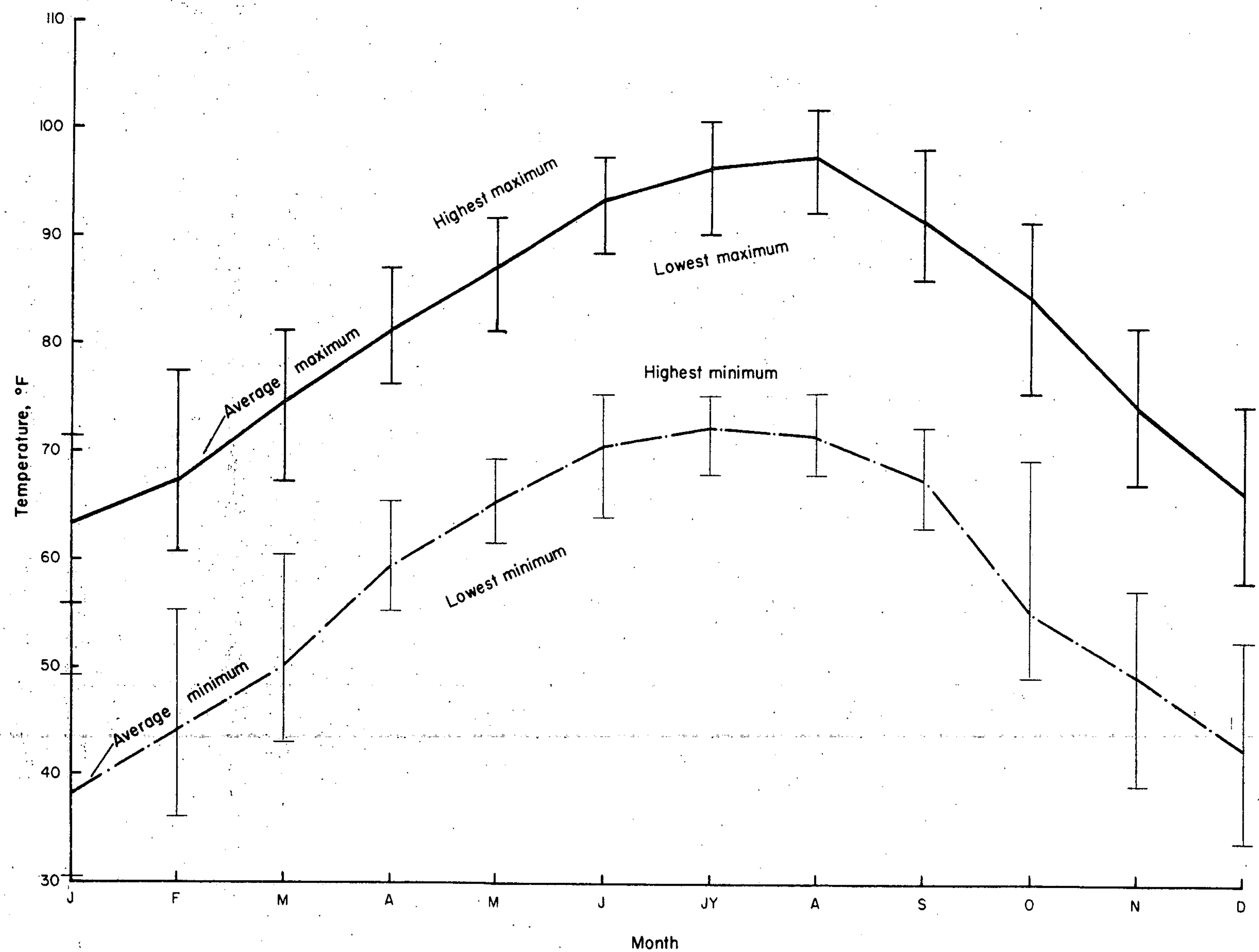

Figure 6. Monthly Temperature, Cuero, 1942-1976.

Mean annual lake (free water) evaporation is 55 inches, and in an average year, evaporation exceeds precipitation by 24 inches.

Air Quality

DeWitt County is in Region 5 of the Texas air monitoring network. Although there are no monitoring stations within the county, the air quality is presumed to meet national ambient air quality standards (Texas Air Control Board, personal communication). The nearest large metropolitan area, San Antonio, is upwind of prevailing winds and thus exerts little influence over air quality in the county; however, as it has the closest continuous monitoring stations; data from San Antonio are included on table 2. Victoria is the nearest metropolitan area downwind of DeWitt County, and measured air quality characterisics from the noncontinuous monitoring stations there are well within national standards (table 2).

Potential for Air Pollution from Test Well Activity

The test well will temporarily affect air quality through an increase in hydrocarbons and particulates during the drilling phase of the well operation. This will be caused by site preparation activities, increased vehicular movement and exhaust, and emissions from gasoline- or diesel-powered generators. During normal operations non-methane gases occurring in the geothermal brines may need to be flared-off. Although air pollutants associated with geopressured geothermal fluid production have yet to be adequately identified potential pollutants include hydrogen sulfide, ammonia and volatile carbon compounds; in the event of a blowout saline water would also be present in the air. Texas ambient air quality standards (set by the Texas Air Control Board), which are supplementary to national standards, specify that the net ground level 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. 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 (White and others, 1978; personal communication, Ralph Driscoll, 1979). The net downwind concentration is equivalent to the downwind concentration minus the upwind concentration. No standards exist for ammonia. As permits are required for the majority of emitting operations, a permit may be required should volatile carbon compounds be released. As geothermal test wells are not listed as exceptions to this requirement, when it is known

Table 2. Air quality data; Victoria and San Antonio stations, 1978.

Noncontinuous monitoring network

Selected stations in Region 5	Type of sample	Sampling interval (months)	Start date	End date	No. of samples	Concentrations in micrograms per cubic meter: Max 24 hour	Second high	Arith mean	Standard arith mean	Geo mean	Standard geo dev
Gaseous data											
Victoria	SO_2 [1]	12	1- 8-78	12-16-78	41	18	17	7	5	6	2.3
	NO_2 [2]	12	1-14-78	12-16-78	40	87	58	28	18	22	2.4
	Aldehyde [3]	12	1- 2-78	12-16-78	41	12	10	3	2	3	1.6
	Ammonia [3]	12	1- 2-78	12-16-78	41	24	23	6	6	4	2.4
Particulate data											
Victoria	Total suspended particulates	12	1- 2-78	12-16-78	40	129 (260)	108	63	24	57 (75)	1.6

Continuous monitoring network, 1978

Selected stations in Region 5	CAMS no.	Ozone—second highest hour	Ozone—% of time 0.12 ppm	Carbon monoxide—second highest hour	Carbon monoxide—second highest 8 hours (non-overlapping)	Nonmethane hydrocarbons 6-9 a.m.—second high	Sulfur dioxide—second highest 24 hours	Sulfur dioxide—annual mean	Sulfur dioxide—second highest 3 hours (non-overlapping)	Nitrogen dioxide—annual mean
Maximum allowable by ambient air standards (parts per million)		0.12	0.0	35	9	0.24	0.14	0.03	0.50	0.05
San Antonio, northwest	7	0.12	0.0	12.7	4.6	2.7	0.02	0.00	0.03	0.01
San Antonio, downtown	18	0.10	0.0	13.6	7.1	3.5	—	—	—	0.02

Standards:

[1] SO_2 Max 24-hour 365. Arith mean 80.

[2] NO_2 Arith mean 100.

Sources: Texas Air Control Board, 1978; "Annual data summary for noncontinuous monitoring," and "Continuous air monitoring network data summaries."

what is to be emitted by the test well, the Air Control Board should be contacted to determine the necessity of a permit.

Location of Test Well on the Basis of Meteorological Characteristics

Prevailing winds are southeasterly (fig. 2); thus, daily emissions from test well facilities would most consistently affect areas located northwest of the site. Location of the test well in the eastern third of the prospect area would therefore increase the effect on the city of Cuero, whereas location in the center may result in the communities of Hopkinsville and Clinton being affected. No communities appear to be located downwind of the western section of the prospect area. A blowout or other unexpected emission could however occur at anytime; the effect on specific locations would depend largely on the wind direction at the time of the accident. In addition to prevailing wind directions, proximity to vulnerable areas should be considered, the far western section of the prospect area again being the more suited location.

ECONOMY AND INDUSTRY

Agriculture

Agriculture is a major industry in DeWitt County. Total receipts from the sale of agricultural products were over $22 million in 1977, livestock and livestock products accounting for over 90 percent of this (Texas Crop and Livestock Reporting Service, 1978). The county is a leading producer of stocker and feeder calves; cattle are predominantly crossbred, with Brahma, Hereford, Angus, and Charolais breeding. Other livestock contributing to agricultural income include dairy cattle, turkeys, and swine (Cuero Chamber of Commerce, 1979). Much of the cultivated land is also devoted to cattle raising, producing fodder crops or improved pasture. Other crops include small grains and peanuts (table 3).

Mineral Resources

Much of the revenue of DeWitt County comes from mineral production--$29.5 million in 1975 (Zlatkovich and others, 1978). The most valuable resource to the county is natural gas, followed by oil and natural gas liquids (table 4). Several oil and gas fields occur in the Cuero area (fig. 7). The 1974 value of oil and gas produced in DeWitt County was $17.8 million (Bureau of Business Research, 1976). Additional revenue comes from sand and gravel production. The study area contains a number of gravel pits, the greatest concentration occurring to the northeast of Cuero. Although many of these are now exhausted, new mines are still coming into production especially in the area to the south of the Guadalupe River.

Industry and Commerce

Cuero is the county seat and commercial center of DeWitt County. Industry includes textiles, leather goods, woodwork, and the manufacture of internal furnishings for large buildings. It is also a shipping point for a wide variety of farm products including cottonseed oil and poultry.

Table 3. Agricultural statistics, DeWitt County.

		Acres
County land area		582,336
Proportion in farms (1974)		88%
Average farm size (1974)		352
Agricultural land use (1974)		
Total cropland		150,536
Harvested cropland		43,719
Cropland used for pasture		100,933
Woodland for grazing pasture		40,957
Improved pasture and range		40,136
Unimproved pasture and rangeland		224,790
Crops (1977)	Planted (Acres)	Harvested (Acres)
Sorghum-grain	13,000	9,600
Sorghum-hay		1,200
Corn	7,800	7,400
Oats	5,000	900
Wheat	4,400	1,800
Hay		9,800
Pecans		147,000 lbs.
Peanuts	700	690
Livestock (1977)	Numbers	
All Cattle	115,000	
Milk cows calved	2,300	
Beef cows calved	63,000	
Hogs	3,000	
Sheep	8,000	
Turkeys produced	194,000	
Hens and pullets laying eggs	50,000	

Sources:

1974 data: "1974 Census of Agriculture"; U.S. Bureau of the Census, 1977.

1977 data: "1977 Texas County Statistics," Texas Crop and Livestock Reporting Service, 1978.

Table 4. Industrial and economic statistics, DeWitt County.

Year				Source
1975	Value of minerals produced		$29,473,000	1,2
1974	Minerals in order of value			
	Natural gas		$ 9,832,966	4
	Petroleum (oil)		$ 7,969,289	4
	Natural gas liquids		n/a	
1976	Oil production 1976		941,464 barrels	1
	Total oil production to January 1, 1977		50,662,865 barrels	1
1977	Cash receipts from agricultural products		$22,218,000	3
	From crops	8%		
	From livestock	92%		
1975	Population: County	18,382		1
	Total annual income		$82,116,000	1
	Population Cuero	6,989		
1976	Employment	Total	7,796	1
		Civilian (1970)	6,828	5
		Mining	63	1
		Construction	107	1
		Manufacturing	1,058	1
		Transport, communication and public utilities	152	1
		Trade	1,163	1
		Financial, insurance and real estate	210	1
		Service	740	1
		State govt.	227	1
		Farm population (1970)	3,244	5

Sources:

1. "Texas Almanac 1978," Dallas Morning News.
2. "Texas Fact Book 1978." Zlatkovich and others, 1978.
3. "1977 Texas County Statistics," Texas Crop and Livestock Reporting Service, 1978.
4. "Atlas of Texas," Bureau of Business Research, 1976.
5. "County & City Data Book 1977," Bureau of the Census, 1978.

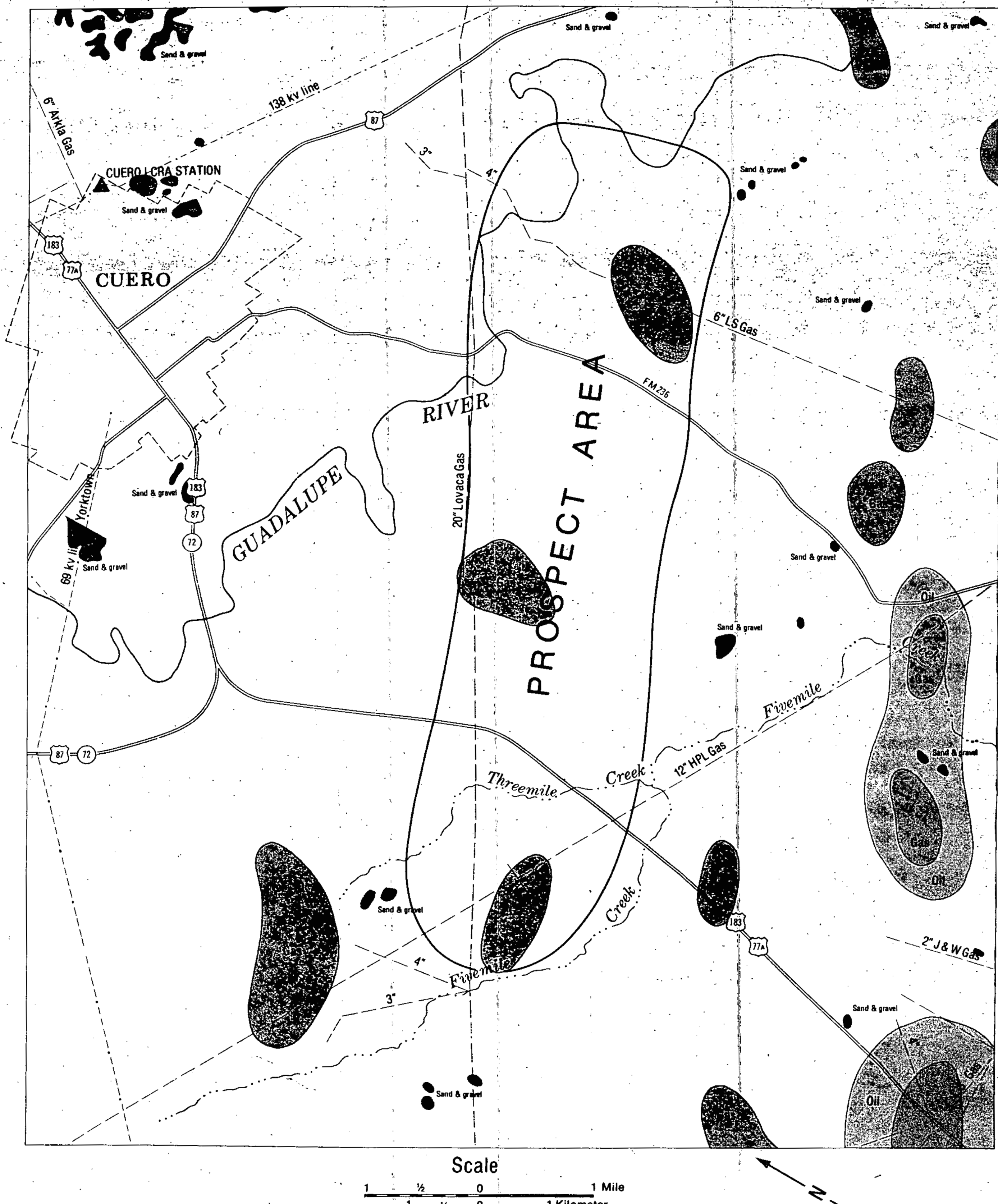

Figure 7. Mineral Resources and Transmission Lines, Cuero Study Area.

CULTURAL RESOURCES

Historical

The Texas Historical Commission has marked 28 places of historical interest in the study area. The majority of these sites are located within the city of Cuero (table 5).

Archaeological

Twelve archaeological sites (table 6), ranging in age from prehistoric to historic, have been found in the Cuero study area, 6 of these being located within the prospect area (fig. 8). While all those within the prospect area are prehistoric, two of those outside are historic cemeteries. Although only these have been identified so far, it is likely that if the area were to be studied many more would be found. An intensive archaeological survey conducted on the site of the proposed Cuero I reservoir (located in the Guadalupe River valley 4 miles north of Cuero, and therefore just north of the study area) revealed 245 prehistoric sites on the floodplains and terraces of a 45 mile stretch of the river. Preservation of nonlithic material such as pottery, bone, and shell was found to be generally excellent and significant data concerning man's adaptation to, and exploitation of, his natural surroundings over a period of some 7,000 years was obtained from the recovered artifacts. This area is now listed on the Federal Register as the Cuero I Archaeological District. Located only 4 miles south of this it is likely that the terraces and floodplain of the Guadalupe in the study area may similarly support many prehistoric sites.

Location of the Test Well on the Basis of Archaeological Resources

Archaeological sites that have already been identified should be avoided as sites for the test well. An archaeological survey should be made of the proposed location to ensure that it is not of archaeological significance.

Table 5. Historical Markers, Cuero Study Area

National Register	Location
DeWitt County Courthouse (1894)	Courthouse Square, Cuero

Official Texas Historical Markers	
Cuero (founded 1873)	Hwy 183 & 77A, N. side of Cuero
St Michael's Catholic Church	McLeod St., Cuero
The Edward Mugge House (1870's)	Terrell St., Cuero
Burial Place, James Norman Smith (1789-1875)	SH 183 & 77A, 2.6 mi S. Cuero
Robert Allert House (1893)	N. Indianola, Cuero
St. Mark's Lutheran Church	N. Esplanade, Cuero
The Breeden House (1883)	W. Broadway, Cuero
The Bates-Sheppard House (1886)	E. Broadway, Cuero
Leonard Roy Harmon (1917-1942)	Cuero Municipal Park, Cuero
Gohmert-Summers House (1895)	Terrell St., Cuero
Thomas M. Stell Grave Marker (1856-1939)	Hillside Cem. Cuero
Alexander Hamilton House (1883)	N. Esplanade, Cuero
Grace Episcopal Church (1889)	Esplanade and Live Oak Sts., Cuero
Judge Henry Clay Pleasants (1828-1899)	Hillside Cem., Cuero
Early Texas Bandstands	Municipal Park, Cuero
William Frobese Home (1875)	E. Newman, Cuero
Buchel Bank (1873)	E. Esplanade, Cuero
Cuero Land & Immigration Company (1871)	Cuero City Park, Cuero
Emil Reiffert Home	W. Prairie St., Cuero
Marker: Gen. August C. Buchel	Courthouse grounds, Cuero
English-German school	E. Newman, Cuero
DeWitt County Monument	E. of Clinton city limits on U.S. 77 & 87
John T. Wofford Home (1877)	W. Reuss Blvd., Cuero
Josiah Taylor Grave Marker	U.S. 87, 2.5 mi E. of Cuero, South 1.5 mi.
Morgan Steamship Line	
Old Chisholm Trail (1866 ff)	
Burns Station Cemetery	Hwy 87, 6 mi S.E. of Cuero
Clinton (County Seat 1848 & 1850-1876)	

Source: Texas Historical Commission

Table 6. Archaeological Sites, Cuero Study Area

NUMBER	DESCRIPTION
DW 1	Flint gouges, drills, arrow points
DW 6	Shell; fragments of chipped and burned stone
DW 78	Historic cemetery
DW 218	Flint and burned rock
DW 219	Flint and burned rock
DW 220	Many flint flakes, burned rock, shells, mussel and conc
DW 221	Scattered flint and burned rock
DW 223	Artifacts including Archaic shells and flint
DW 224	Abundant shells, Torrugas, Matamoros projectiles
DW 225	Tools, gouges, knife blades, baked clay. Possibly Archaic.
DW 226	Scrapers, broken projectiles of Refugio, Matamerros, Montell, early Archaic
DW 230	Historic cemetery
DW 231	Historic cemetery
DW 236	Archaic. 1 fragment, one 1849 $1 gold coin

Source: Texas Archaeological Research Laboratory

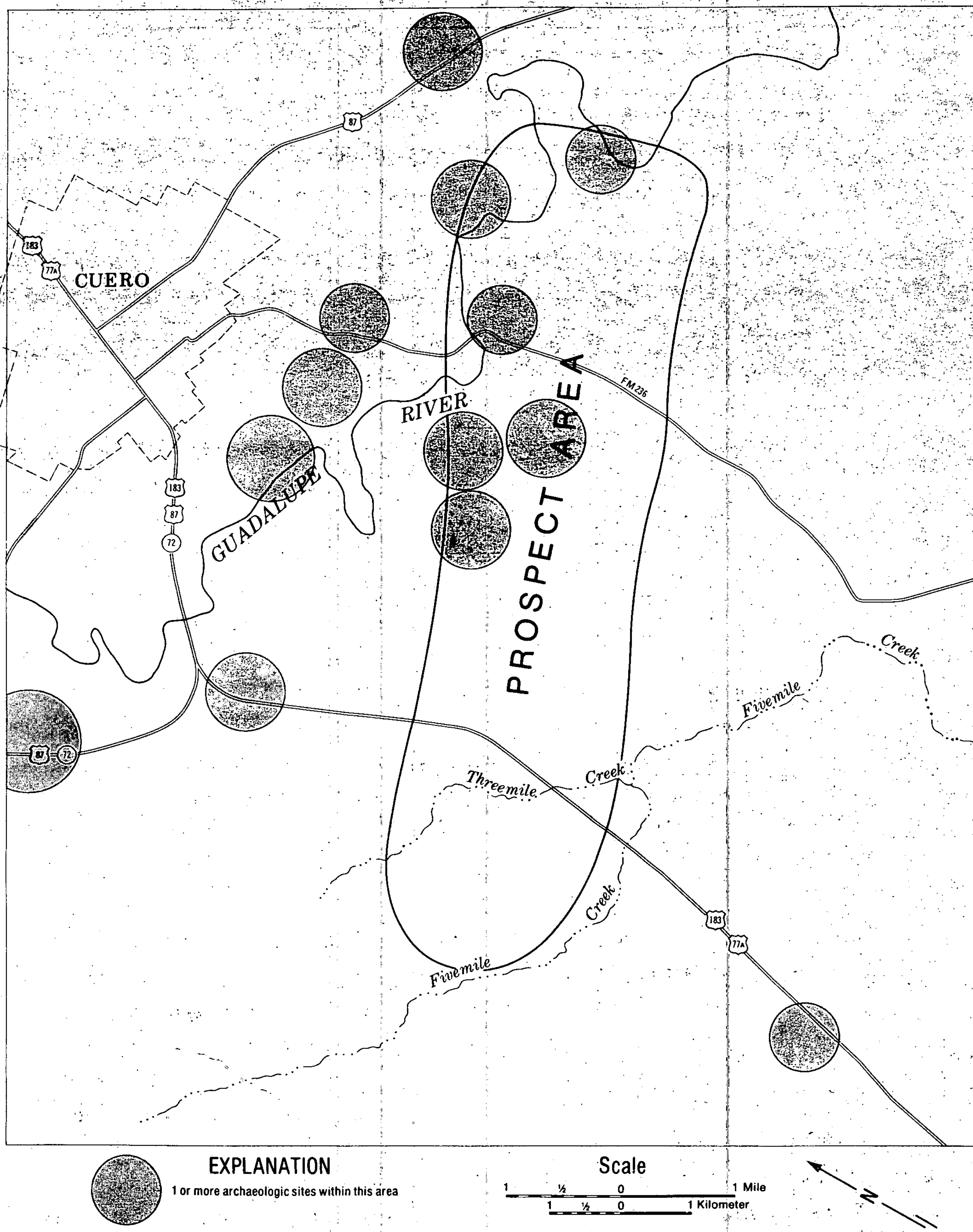

Figure 8. Known Archaeological Resources, Cuero Study Area. (Source: Texas Archeological Research Laboratory.)

GEOLOGY

The formations exposed in the Cuero study area consist of late Tertiary and Quaternary fluvial deposits (fig. 9). Uplift and erosion of older formations that occur to the northwest (on the Edwards Plateau and inner coastal plain) provided the source material for these deposits. Sediments range from coarse sand and gravel, deposited as stream channel fill and point bars, to fine muds of the ancient floodplains (fig. 10).

Fleming/Lagarto Formation

The oldest exposed sediments in the area are found along the outer edges of the Guadalupe River valley and comprise the Miocene Fleming Formation (referred to as the Lagarto Formation in The Geology of Texas (Sellards and others, 1932) and as Fleming Formation in the Geologic Atlas of Texas (Bureau of Economic Geology, 1978), and hereafter referred to as Fleming). These deposits consist largely of fine-grained sediments laid down in the latter part of the depositional cycle that formed the underlying Oakville Sandstone.

Rivers carrying loads of fine detritus spread broadly over a flat Miocene coastal plain building meander belt sequences, natural levees, and widespread thick floodplain muds. Locally, eolian processes sorted and modified these sediments. The composition of the Fleming Formation is largely clay and silt, with lesser amounts of sandstone. The clays are mostly montmorillonite and illite and are commonly calcareous. Sandstones are medium grained, calcareous, and locally thick bedded or crossbedded. Sand content increases south of the Guadalupe River valley.

Goliad Formation

Most of the Cuero study area is underlain by the late Pliocene Goliad Formation. These sands rest unconformably on the Fleming Formation indicating an intervening period of nondeposition. The Goliad Formation consists largely of sand and sandstone with lesser amounts of gravel, limestone, conglomerate, marl, caliche, and clay, the latter locally containing calcareous concretions. The more gravelly strata are channel deposits, whereas the finer-grained deposits indicate a broader spread of material over point bars, natural levees and floodplains. The sand and sandstone are medium to coarse grained, composed mostly of quartz with some black and red chert. Calichified sands and gravels are common. In the Cuero area this formation varies in surface

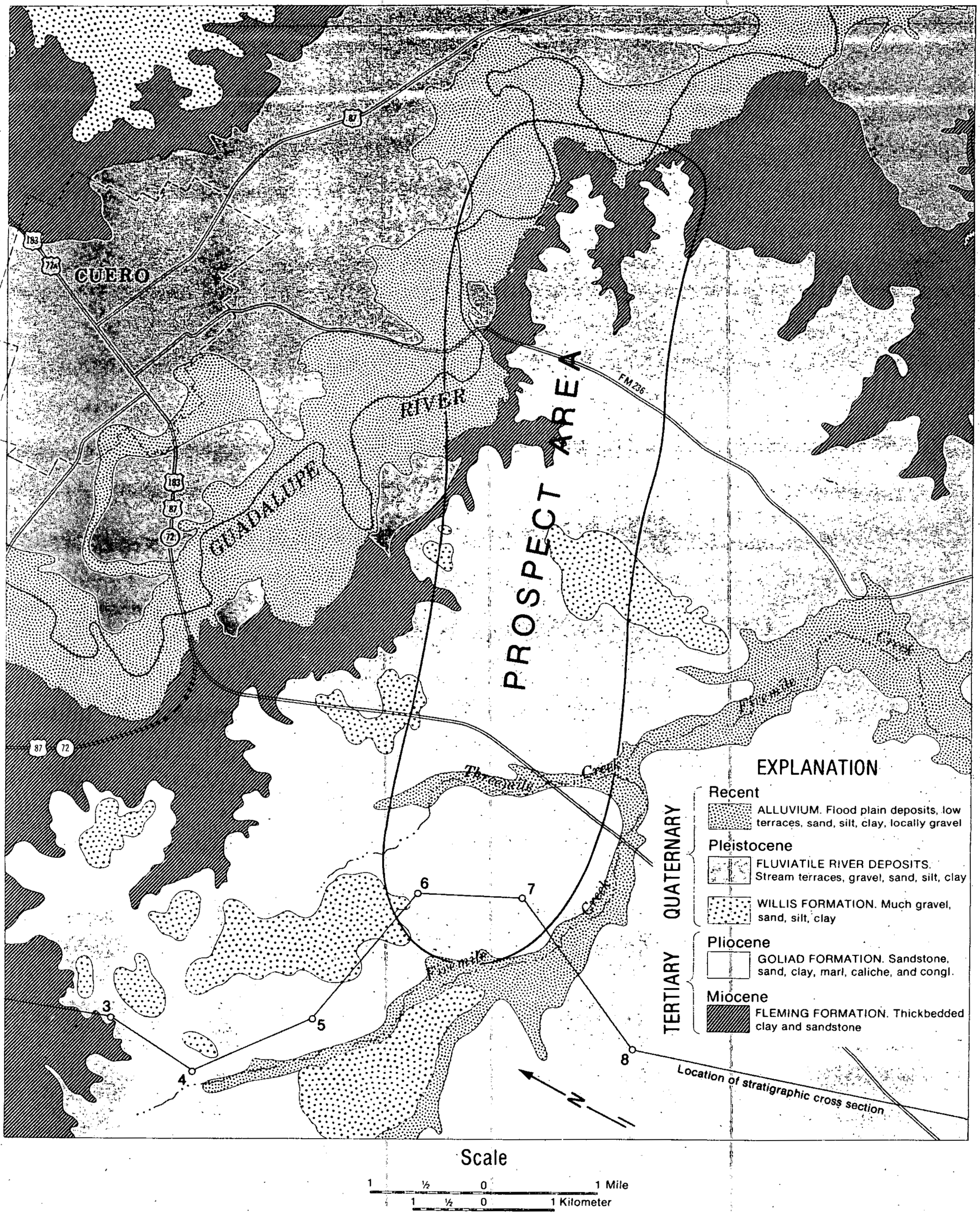

Figure 9. Geological formations, Cuero Study Area. (Modified from the Geologic Atlas of Texas, 1978.)

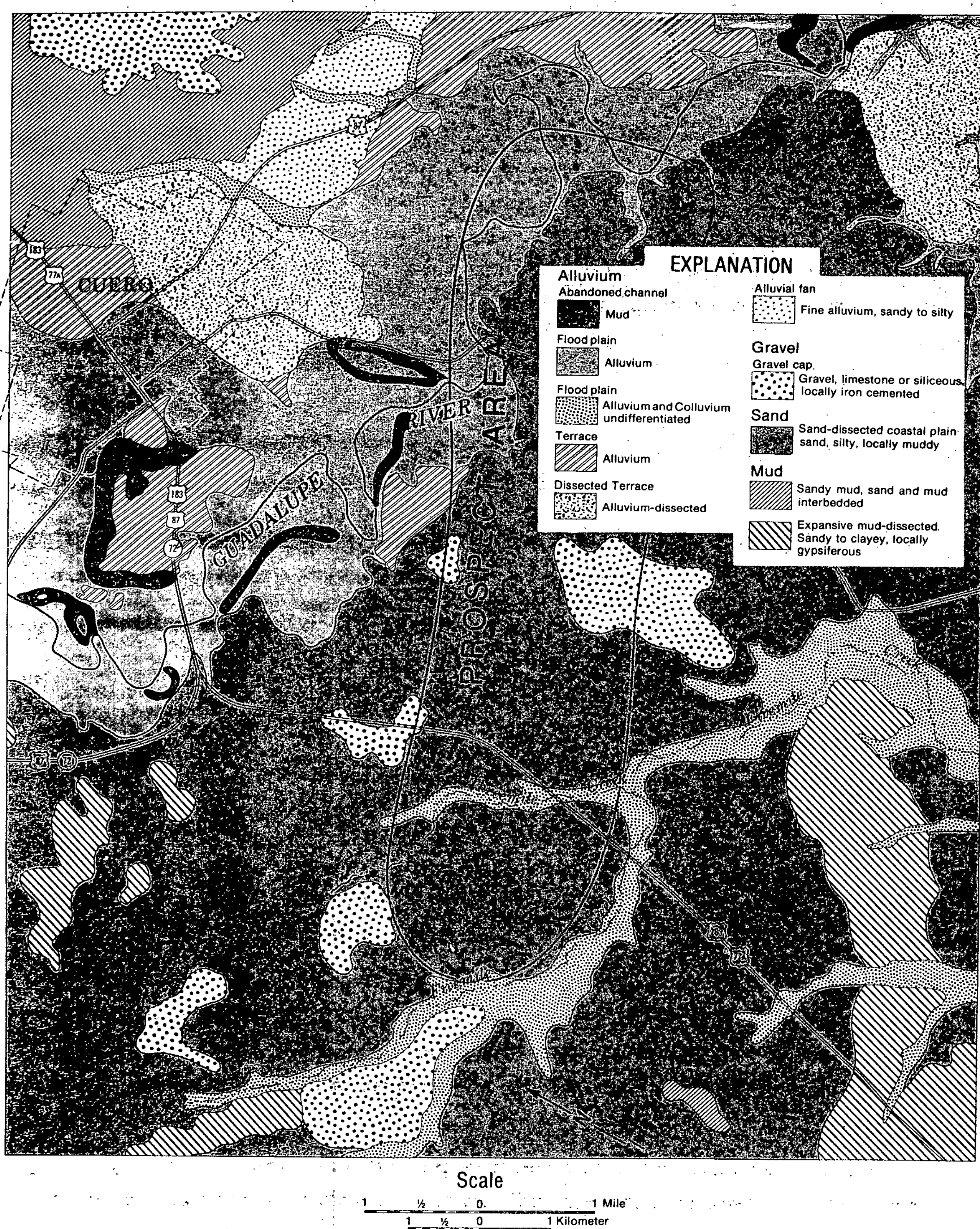

Figure 10. Environmental Geology, Cuero Study Area. (Source: Gustavson, 1979.)

expression to reflect the range of its components and history as well as more recent active processes. The majority of the surface consists of sandy material with local areas of expansive mud and patches with high gravel concentrations; these previous channel deposits now emerging as higher areas due to their resistance to erosion. The Goliad Formation is locally overlain by Willis or Willis-like deposits.

Willis Formation

The Pleistocene Willis Formation is composed of reddish sands and gravelly sands deposited unconformably on the Fleming and Goliad Formations. Deposition of this large volume of coarse sediments may have been by shallow braided streams with shifting channels. Following deposition of the Willis streams cut into this depositional plain, producing an irregular surface. Today the Willis outcrop is a hilly belt between the Lissie and Fleming Formations. In the study area, only remnants of the Willis are to be found capping the higher areas. Northeast of Cuero it rests unconformably on the Fleming Formation, while south of Cuero scattered remnants rest unconformably on the Goliad Formation.

Pleistocene Fluviatile Deposits

Terraces are found at elevations 10' to 50' above the present day Guadalupe River. They are remnants of ancient floodplains and are variable in composition, ranging from muds to gravels. Locally terrace gravels are exploited for sand and gravel.

Recent Alluvial Deposits

The youngest deposits in the study area are river alluvium found along the Guadalupe River and other streams, where they were deposited by floodwaters. These alluvial deposits contain clay, silt, sand, gravel, and organic matter, and are locally calcareous.

SUBSIDENCE AND FAULT ACTIVATION

The most serious possible effects of the production of large quantities of geopressured geothermal fluids include subsidence and fault activation (Gustavson and Kreitler, 1976; Kreitler, 1977). Subsidence may occur with or without fault activation. Subsidence with fault activation would produce a scarp at the surface in the vicinity of the fault, while subsidence alone would produce a relatively smooth, concave surface profile and affect a larger surface area with maximum subsidence being in the vicinity of the well.

SUBSIDENCE

Description

Two kinds of ground deformation may result from fluid withdrawal: vertical lowering of the ground surface and horizontal movements.

Vertical lowering of the surface is the major effect in subsidence areas. Compaction results from transfer of load from the pore fluid of a rock to its solid grain framework. As fluid is removed from a reservoir the internal fluid pore pressure decreases. The additional load transferred to the grains tends to rearrange, distort, and break them, causing the rock to reduce in volume. This effect may be highlighted in geopressured reservoirs where the fluid carries more of the total stress than in a normally pressured system (Atherton and others, 1976). Conversely, increasing fluid pressure by re-injecting fluid can cause the land surface to rebound although if this is done after subsidence has already occurred, the amount of rebound is generally small and temporary compared to prior subsidence.

The maximum vertical lowering experienced at a hydrocarbon field was 8.75 m at the Wilmington Field in California and at a geothermal field was 4.7 m at Wairakei, New Zealand. The area affected depends on the lateral extent of the reservoir. The vertical movements generally produce a depression centered over the area of fluid production.

Horizontal movements in subsiding areas result from the horizontal components of the motion associated with the deformation. They are also associated with the induced horizontal gradients in fluid pressure and associated seepage stresses. Movements are generally directed towards the center of the subsidence bowl. The greatest measured horizontal movement at a geothermal field was 0.8 m at Wairakei (Stilwell and others, 1975, in Atherton, 1976).

Factors Influencing Subsidence

The potential for land subsidence following fluid withdrawal depends on the characteristics of the reservoir itself and of the overburden. Table 7 gives a list of factors which influence subsidence. A comparison of those factors which contribute to subsidence and those which contribute to stability suggest that the chances for subsidence in the Cuero area are high, as 70 percent of the known factors that characterize the prospect area are similar to those which may contribute to subsidence. This percentage, however, represents only 53 percent of the total number of factors to be considered and it is not yet known if the remaining eight factors will contribute towards subsidence or stability. Of those factors considered to be major factors in subsidence or stability susceptibility, 55 percent of the known characteristics would contribute to subsidence. This would only represent 41 percent if the three unknown major factors were to contribute to stability. It has, however, been suggested by Allen and Mayuger (1969) that compactability (lack of cementation) and an inability to resist deformation in the reservoir rocks, plus a lack of internal support in the overburden, are prime requisites of subsidence. The Cuero reservoir therefore has three major positive characteristics contributing to stability: cementation of reservoir sands, and thickness (10,800 ft) and cementation of the overburden.

The history of deposition and subsequent events for the Wilcox Formation are very similar to those of the Frio Formation. Thus, descriptive models of subsidence due to geothermal fluid withdrawal from the Frio Formation can be applied to the Wilcox (see White and others, 1978; Bebout and others, 1978).

Cementation of Reservoir Sandstone

The degree of cementation has a significant influence over reservoir compaction and ultimately subsidence. According to Allen and Chilingarian (1975 in White and others, 1978) cementation is by far the single most important factor controlling (limiting) mechanical sandstone compaction.

The sandstones in the reservoir are expected to have undergone a rather complex history of cementation, leaching, and recementation at moderate to intermediate and

Table 7. Factors tending to influence geothermal subsidence (from Atherton and others, 1976) compared to factors that characterize the Cuero prospect area.

Factor type (● major; ○ minor)	Factors which may contribute to subsidence susceptibility	Factors which may contribute to surface stability	Factors characterizing prospect area (⊕ similar to characteristics listed in column 2)
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
○ Dissolved solids			High
○ Temperature			275–313°F
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	?
GEOHYDROLOGY			
Natural recharge[1]	Low rates	High rates	?
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	⊕ None
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)	Eocene
● Thickness (in communication)	Great vertical section	Small vertical section	Small
● Deformation properties[4]	Highly deformable	Slightly deformable	?
ASSOCIATED MATERIALS			
Type	Clays, siltstones, shales	Volcanic flows and shallow intrusions	⊕ 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)		
RESERVOIR GEOMETRY			
Width/thickness ratio[5]	Large	Small	⊕ Large (for several wells)
OVERBURDEN			
● Thickness	Small (<3000 ft)	Great	Great—10,800
● Competence	Incompetence, unconsolidated sediments	Competent, consolidated	Possibly competent
● Deformation properties[6]	Highly deformable	Slightly deformable	?
Density	High	Low	Low
SITE GEOLOGY, STRUCTURE			
Folding	Gentle, broad, synclinal	Sharp, anticlinal (arched)	⊕ None or gentle, broad
Flank dips	Less than 25°	Greater than 25°	⊕ Less than 25°
Faulting	Normal, graben blocks	Reserve or thrust	⊕ Normal
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 possibly respond more slowly than the reservoir materials below

geopressured depths (Bebout and others, 1978). Secondary porosity that may have occurred after the sandstones were under geopressured conditions may only be maintained while the abnormal pressures remain. Late stage cementation, if of the clay mineral kaolinite, could 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 compressiblity tests conducted, the question about cementation and compactional deformation cannot be adequately answered.

Compaction of Reservoir Shales

Without significant compaction in the sands in the prospect area, subsidence would be dependent on compaction of the mudstone (shale) associated with the producing sand reservoirs. The net thickness of shale within the proposed perforated interval of the test well is approximately 400 ft of the 1,045 ft production interval. The shales are mostly in thin layers interbedded with the standstones. The relatively small sequence of shale and the fact that they are interbedded may minimize their contribution to subsidence.

Overburden

Thickness. The depths, 3,338 to 3,658 m (10,950 to 12,000 ft) (Bebout and others, 1978), from which geopressured geothermal fluids will be produced in the prospect area, exceed the production depths of most areas that have subsided in response to fluid withdrawal (White and others, 1978). The importance of overburden thickness in resisting subsidence is noted by Atherton and others (1976):

> 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 compaction is likely to be transmitted to the surface.

Cementation of Overburden. In addition to the positive factor of having a thick overburden, the amount of cementation in overburden sandstones at moderate to intermediate depths may help prevent 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 sandstones at shallow to intermediate depths in the Frio, and if this high degree of cementation is also found in the Wilcox it 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 is the presence of growth faults which are planes of weakness in the prospect area.

Possible Magnitude of Subsidence Based on Expected Reservoir Characteristics

According to Geertsma (1973), "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. White and others (1978), estimating subsidence for the similar Brazoria County reservoir, used equations from Geertsma (1973) to predict 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 amounts of surface subsidence from sand compaction at the site of the test well are indicated by these calculations: 11.9 cm (4.7 in) after two years of fluid production and 14.7 cm (5.8 in) after a 5 year period of production. It should be emphasized that many assumptions were made with respect to both the equation and the values used in solving it. Although not considered in these calculations potential subsidence accompanying compaction of shales interbedded with reservoir sandstones could be more significant than that associated with reservoir sands.

Also, it was assumed that subsidence would occur without fault activation--if faulting should occur and compartmentalize subsidence, it would be expected that a greater depth of subsidence would occur over a smaller area (see Fault Activation, below). For a fuller discussion of the equations and methods used, see White and others, 1978, "Environmental analysis of geopressured geothermal prospect areas Brazoria & Kenedy Counties, Texas."

Effects of Subsidence

The effects of subsidence without faulting would depend on the amount of displacement that occurred, the time span over which it occurred, and the surface features of the land which subsided. A lowering of the land surface by a few inches over a number of years would have minimal effects, especially on sloping land surfaces.

On the other hand, subsidence in a flat area might alter drainage patterns and consequently affect vegetation types and farming, and increase the frequency or extent of flooding in low-lying areas. Pipelines could be ruptured if stretched by land movements, and buildings might suffer structural damage from settling.

FAULTS

Description

The Gulf Coast is a tectonically inactive area, and the growth faults that are present at depth are a result of the periodic slumping of sediments as deposition increased the load above them. Faults on the Gulf Coast are therefore only expected to become active as a result of differential subsidence on either side of the fault zone and not from induced tectonic activity.

Deep Faults

The Cuero reservoir is bounded by two north-east south-west trending faults in the Wilcox that dip towards the coast (fig. 10). Several other faults are found at similar depths 3,338 to 3,658 m (10,950 to 12,000 ft) in the Cuero study area (Geomap, 1979; Bebout, 1978). These faults are roughly parallel to each other and to the coast, and are simlar to others along the Texas Gulf Coast in being down-to-basin growth faults that dip steeply nearer the surface and flatten and converge to depth. Deep faults were mapped at 2,070 to 2,440 m. (6,800 to 8,000 ft) at the top of the Wilcox formation (from Geomap, 1979).

Near Surface Faults

Deep faults such as those in the reservoir area could extend to the land surface where they would be expressed through subtle geomorphic features such as lineations and rectilinear stream-drainage networks (Kreitler, 1976). Recent movement along near-surface faults in many areas of the Gulf Coast is greater than in the past and has been attributed to the extraction of oil, gas and ground water (Kreitler, 1976). The Tectonic Map of the United States (USGS, 1962) shows one of the faults of the Mirando-Provident City Fault Zone as occurring in the vicinity of the Cuero study area although the scale is too small to enable accurate location of the fault within the study area. Recent studies of cross sections in DeWitt and surrounding counties suggest the presence of several near surface faults (Solis, 1979). The Houston Area Test Site project (1973) mapped a number of surface lineations in the Cuero area. Most of these run parallel to the strike of growth faults that occur at depth. Rectilinear stream drainage is not apparent.

A cross sectional profile was constructed from electric logs of oil and gas wells in an attempt to identify near surface faults (fig. 11). This cross section shows a thickening of sediments between wells four and seven that would not be expected from the depositional slope of the beds alone, and thus suggests the presence of a fault. This evidence can be detected to within 1,000 ft of the surface (i.e., in the Oakville Formation). It was not possible to map the fault in the study area as there was a lack of near surface well data.

Fault Activation

Fault Activation from Fluid Withdrawal

Production of fluids accompanied by compaction of the reservoir can result in movement along fault zones. Kreitler (1977) analyzed a number of faults in the Houston-Galveston area which were activated primarily by ground-water production. He found that the faults act as partial hydrologic barriers to fluid migration from one side of a fault to the other side. When fluid removal occurs on only one side of a fault (as will occur with the test well), decline in pore pressure and compaction of sediments is greater on the production side of the fault. Thus the fault acts as a barrier to lateral transference of the effects of fluid production, and tends to compartmentalize subsidence. Since the reservoir is bounded by faults, subsidence might be limited to the zone between these faults. Effective compartmentalizaton of subsidence would be reduced if layers of sediments with similar porosity and permeability communicate with each other across the fault, or if a great deal of subsidence were to occur.

Fault Activation from Fluid Disposal

Disposal of the geothermal brines into reservoirs containing faults may lubricate these faults causing movement along them. Increased fluid pressure within disposal reservoirs may also increase stress along existing fault planes again resulting in movement across the faults.

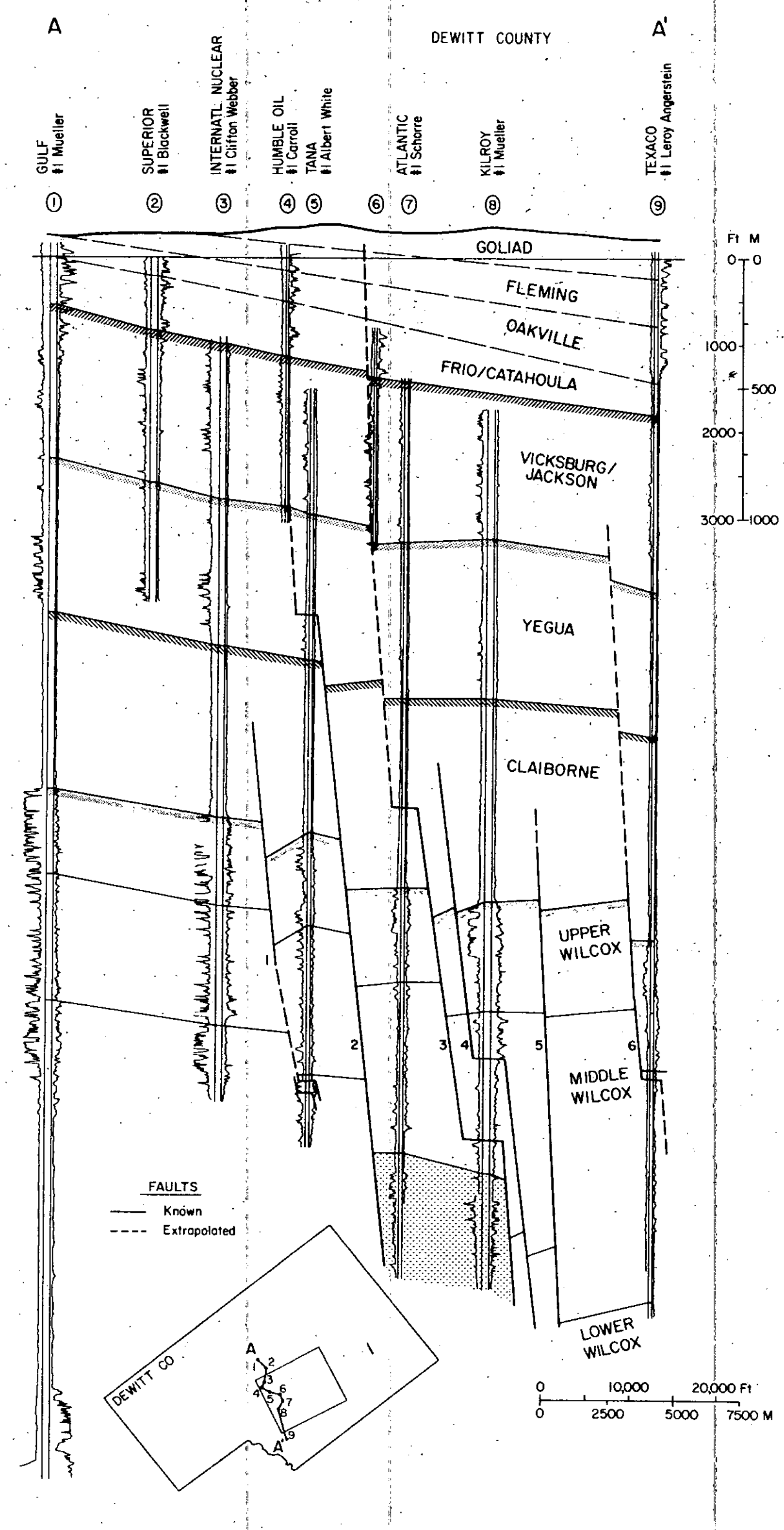

Figure 11. Geological Cross Section, Cuero Study Area.

Effects of Fault Activation

If fault activation resulted in propagation of the fault to the surface, its surface expression could therefore be a zone of differential subsidence. Such surface movement of faults could be damaging to man-made structures occurring along or across this zone. For this reason an attempt was made to show where the faults surrounding the reservoir might appear at the surface. Because the fault planes are curvilinear, with the angle of dip increasing towards the earth's surface, subsurface faults were projected upwards at angles of 45° and 60° in an effort to locate a zone within which any surface expression of the faults would be likely to occur. The range in angles of projection are in agreement with angles of faults reported by Quarles (1953) and Bruce (1973). Kreitler (1976; 1977) extrapolated faults at 45° and found good coincidence between extrapolated faults and surface faults and lineations. The zones of possible surface expression for these faults can be seen on figure 12. Surface facilities that could be affected by movement along the faults bounding the reservoir include paved roads, pipelines, the New Orleans Southern Railway, and the few buildings to the southeast of the Cuero city limit. Should, however, a significant amount of subsidence be transferred across this fault and result in differential settling along the next fault zone, it is possible that the city of Cuero could be affected, as the surface expression of this fault would run through the southwest side of the city (fig. 12).

Location of the Test Well on the Basis of Subsidence and Faulting Activation

The current state of knowledge about the potential for, and possible effects of, subsidence and faulting is such that there is no reliable way to reduce the potential for subsidence, although careful location of the well may help to minimize adverse effects on vulnerable areas. As in most cases, subsidence bowls produced by fluid withdrawal are centered around the area of maximum production (Atherton and others, 1976) an effort can be made to locate the well away from areas that would be most affected by subsidence. For example, locations near Cuero would increase the risk of damage to rigid structures in the city. Low-lying areas whose susceptibility to flooding would be increased by subsidence are less appropriate locations for a test well than are upland areas, and flat land less appropriate than sloping land.

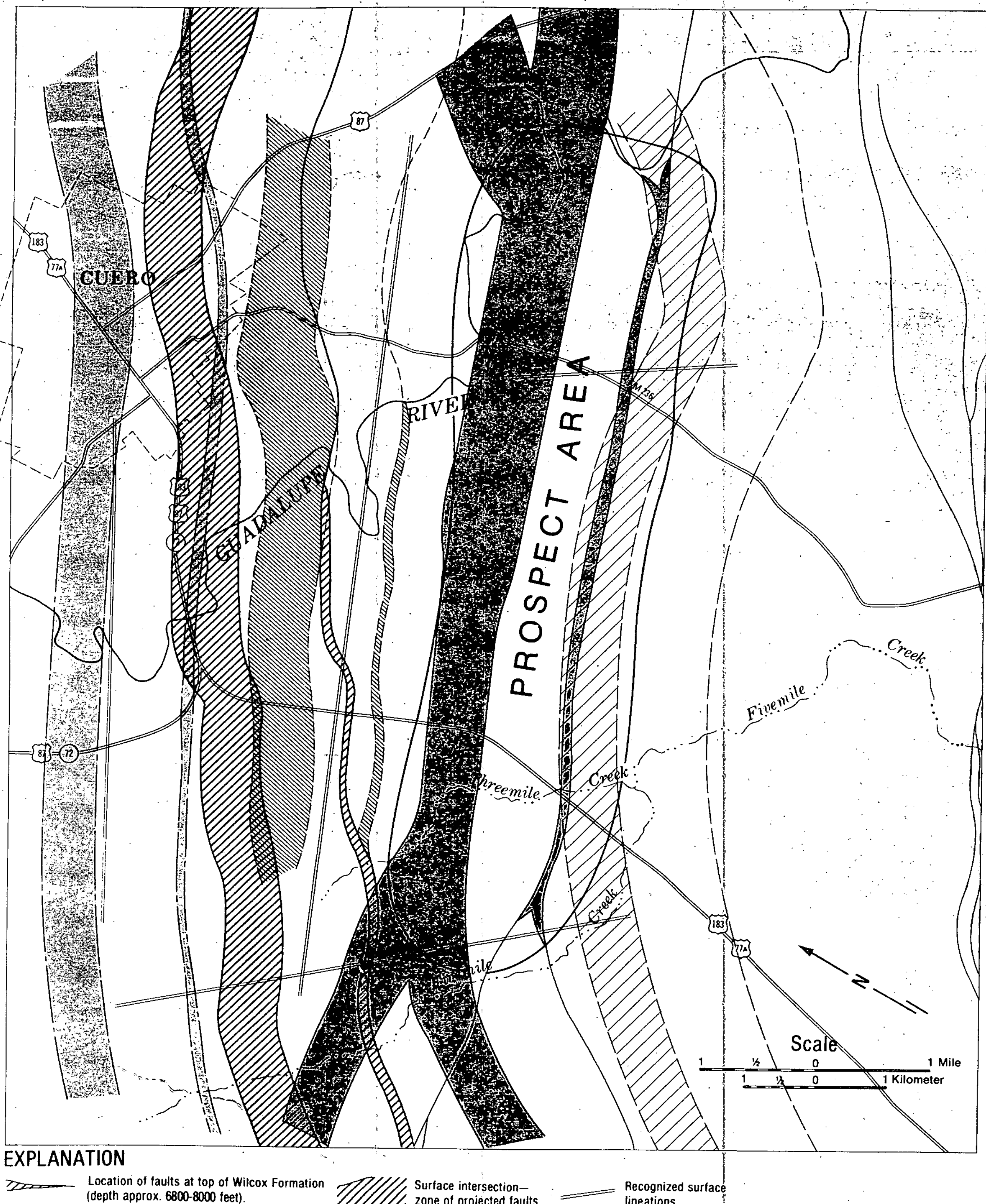

Figure 12. Location of Subsurface Faults and their Projected Zone of Surface Intersection, Cuero Study Area. (Sources: Geomap, 1979; Bureau of Economic Geology, 1973.)

HYDROLOGY

The necessity of producing and disposing of large quantities of hot saline water in geopressured geothermal energy development emphasizes the need for mapping and describing ground- and surface-water resources in order to evaluate how they may be affected should geothermal fluids come into contact with them.

Current plans with respect to the test well call for fluid production of up to 40,000 barrels a day. The water will be disposed of by reinjection via disposal wells, into salt-water bearing formations that do not contain gas, oil, or geothermal resources. This method of disposal is considered environmentally the most acceptable as surface and near surface waters are less likely to be affected.

GROUNDWATER[1]

Description

Aquifers

The geologic formations containing fresh to slightly saline (3,000 ppm) water in DeWitt County include the Catahoula Tuff, Oakville Sandstone, Fleming Formation and the Goliad Sand (fig. 13). These stratigraphic units are hydrologically interconnected and have been called collectively the Gulf Coast aquifer. More recent aquifer delineation identifies 5 units underlying DeWitt County, which, although corresponding approximately to geologic units in this area, are not restricted to time-stratigraphic boundaries but are lithologically or hydrologically defined (Baker, 1978). The geologic formations and the aquifers which approximately correspond to them are listed below:

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[1] The following discussion on the water resources of DeWitt County comes largely from a Texas Department of Water Resources report by Follett and Gabrysch (1965).

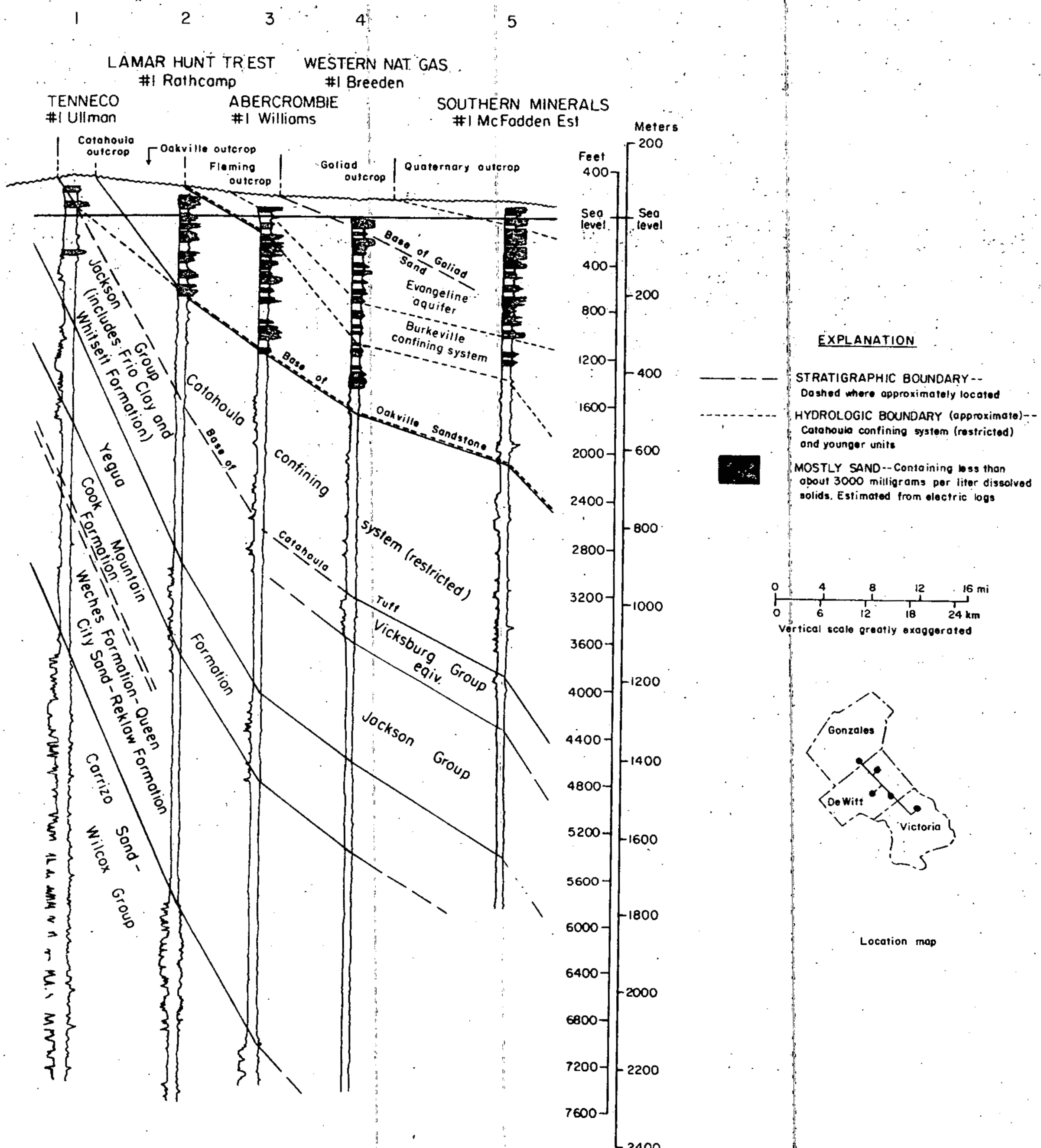


Figure 13. Geohydrologic Cross Section; De Witt County.

Hydrogeologic Unit	Approximate Stratigraphic Unit
Chicot Aquifer	Willis Sand
Evangeline Aquifer	Goliad Sand
Burkeville Confining System	Fleming Formation
Jasper	Oakville Sandstone
Catahoula Confining System	Catahoula

In keeping with modern definition and terminology, the aquifers will hereafter be referred to by their hydrologic rather than stratigraphic names.

The Catahoula confining system is not a significant aquifer in DeWitt County; although near the outcrop area in the northwest part of the county the base of fresh to slightly saline water approximates the base of the Catahoula, this zone thins rapidly and becomes moderately saline along a line that extends roughly northeastward from Yorktown to Cuero, extending somewhat further downdip northeast of Cuero. This aquifer is therefore not significant within the study area although it supplies variable quantities of water for domestic and stock purposes to wells in its outcrop area and a few miles downdip.

The Jasper is one of the principal aquifers in DeWitt County. Corresponding largely to the Oakville Sandstone, it has a maximum thickness of about 290 m (950 ft), and consists largely of crossbedded sands with lesser amounts of sandy clay and marls. It supplies up to 1,000 gallons per minute (gpm) of water to wells primarily for municipal and irrigation supply, although, in the study area, it is mainly used for domestic consumption. Fresh to slightly saline water extends to a depth of about 550 m (1,800 ft) in the eastern part of the county.

The Burkeville confining system corresponds approximately to the Fleming Formation which consists of clay and sandy clay and interbedded clay, sandstone, gravel, and conglomerate. The sand beds of this aquifer yield small to moderate supplies of water, but larger yields, as much as 800 gpm have been reported. Most of the municipal supplies of Yoakum and a small part of Cuero's are obtained from this aquifer.

The Evangeline aquifer coincides largely with the Goliad Sand which outcrops in the southern and southeastern parts of the county, and thus the Evangeline supplies many of the shallower water wells in the study area. This aquifer has a maximum thickness of about 152 m (500 ft) in the southeastern part of DeWitt County and consists primarily of sand and sandstone interbedded with clay and gravel. Many wells of small capacity obtain water from this aquifer for domestic and stock supplies. Shallow aquifers occur in the floodplain terraces of the Guadalupe River.

The groundwater in DeWitt County has a low velocity of movement. In 1962 the hydraulic gradient of the Gulf Coast aquifer in the county was 0.36 m/km (1.9 ft/mi) and transmitted about 7,500 acre-feet of water per year which was more than twice the 1962 (3,500 acre-feet) pumpage rate.

Altitude of Water Table

As there were no data on altitudes of the water table in DeWitt County this was mapped using information from 100 water wells located in the study area. The altitude of the water table in the study area ranges from less than 100 ft (above sea level) in parts of the Guadalupe River Valley to over 75 m (250 ft) in some of the higher areas (fig. 14). Some unreliability was inherent in this process, as measurements taken range from 1931 to 1978; the problem is further confused by some of the wells being under variable amounts of artesian pressure. The fact that the contours of the water table altitude correlate relatively well with the relief in the area suggests although the information may not be accurate in detail, that the general trend is probably reliable.

Depth of Fresh to Slightly Saline Water

The Gulf Coast Reservoir contains fresh to slightly saline water to depths ranging from 245 m (800 ft) 122 m (400 ft) below sea level in the northwest of the county to slightly more than 660 m (1,800 ft) 520 m (1,700 ft) (518 m) below sea level in the southeast, the range within the study area being approximately 365 to 460 m (1,200 to 1,500 ft) 275 to 430 m (900 to 1,400 ft) below sea level (fig. 15). The thickness of fresh to slightly saline water-bearing sands ranges from 61 m (200 ft) in the northwest of the county to 152 m (500 ft) in the south and east ranging from about 90 to 140 m (300 to 450 ft) in the study area.

Groundwater Quality

Chemical analysis of the groundwater used in DeWitt County shows that it is of good chemical quality, but with a tendency to hardness above a depth of 183 m (600 ft) (Table 8). Wells within the study area are generally used for domestic or stock purposes with a few used for irrigation, and four of those within Cuero for public supply. There are also many unused wells and wells for which these data are not available.

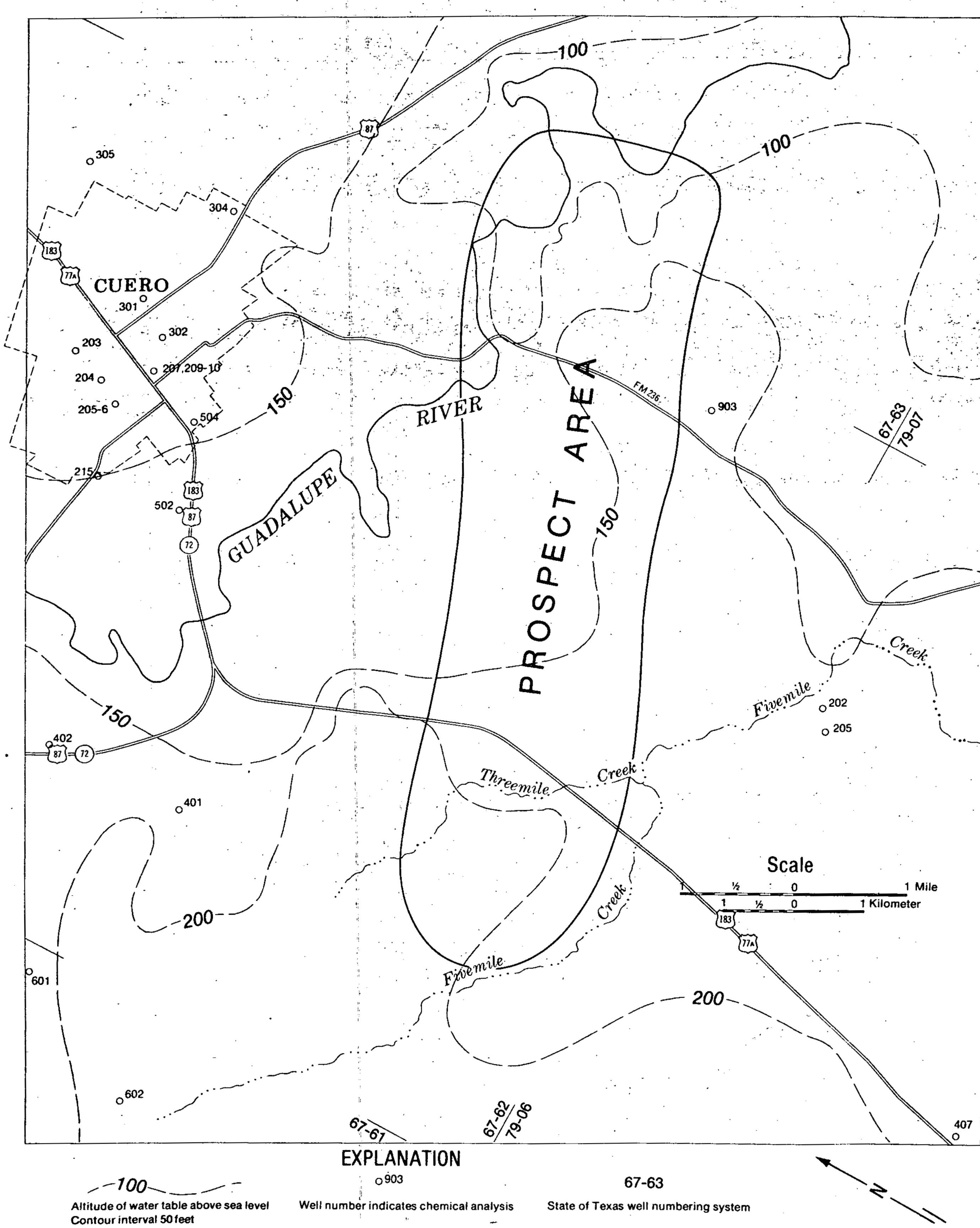
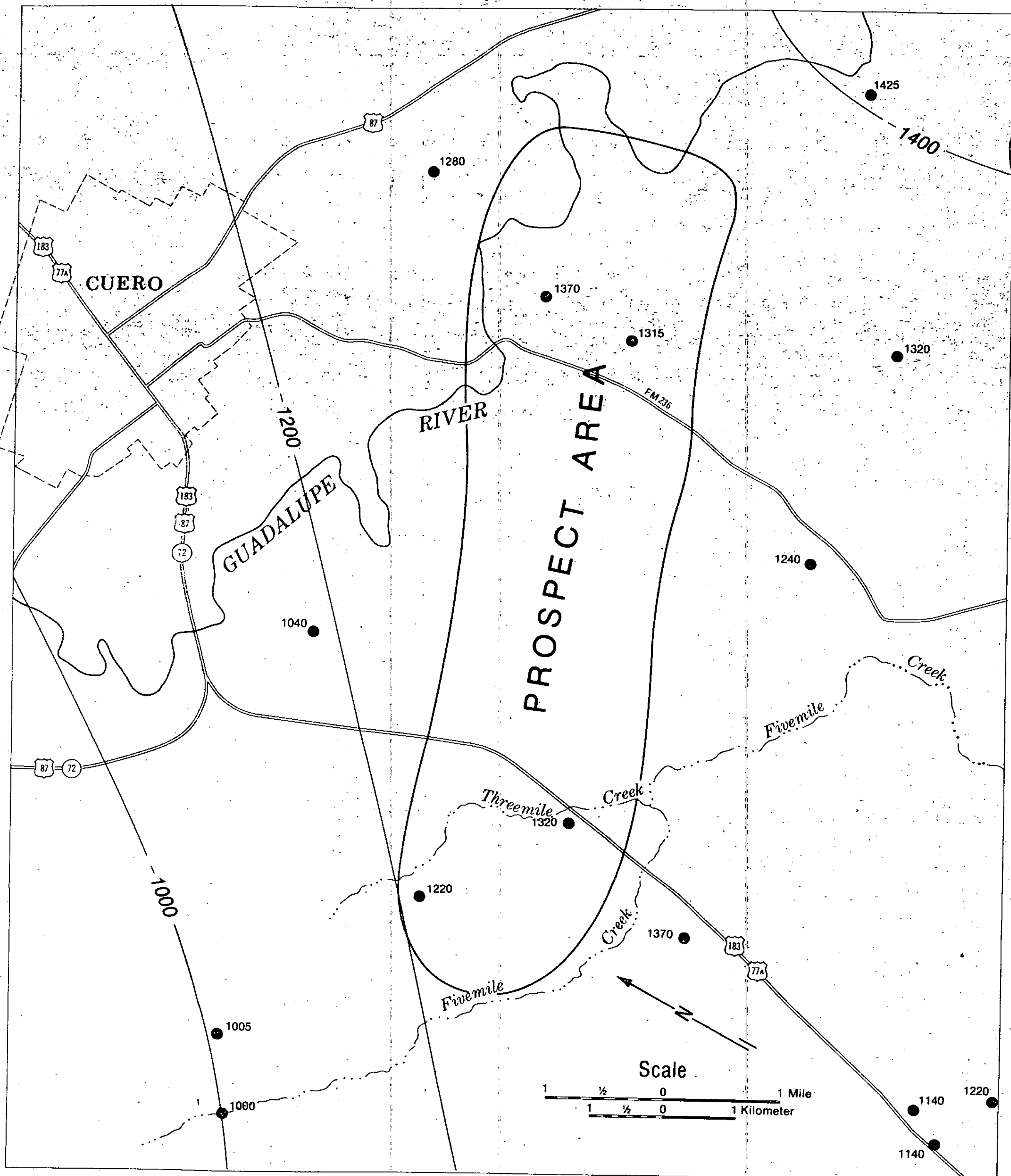


Figure 14. Altitude of Water Table and Location of Wells Sampling Chemical Quality of Groundwater, Cuero Study Area.



EXPLANATION

● 1280
Well used for control
Number indicates altitude below sea level of the base of fresh to slightly saline water-bearing sands

— 1200 —
Structure contour
Drawn at base of fresh to slightly saline water-bearing sands
Contour interval 200 feet; datum is mean sea level

Figure 15. Altitude of the Base of Fresh to Slightly Saline Water, Cuero Study Area. (Source: Follet and Gabrysch, 1965.)

Table 8. Chemical analyses of water from wells in the Cuero study area.[1]

Well	Depth of well (ft)	Date of collection	Water-bearing unit	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na+K)[2]	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids	Hardness as $CaCO_3$	% sodium	Sodium adsorption ratio (SAR)	Residual sodium carbonate (RSC)	Specific conductance (micromhos at 25°C)	pH	Use
67-61-601[3]	120	3-23-36	To	—	—	106	16	88	266	36	188	—	—	—	565	330	—	—	—	—	—	S
602[3]	100	do	Tl	—	—	93	6	24	305	[7]	44	—	—	—	317	259	—	—	—	—	—	S
67-62-104	86	1- 8-63	To	35	—	211	31	173	290	37	522	0.7	20	—	1,170	654	37	2.9	0.00	2,130	6.8	S
203[4]	874	9-16-48	Tl, To	17	0.18	18	2.2	234	390	128	128	0.9	0.4	—	633	53	—	—	—	—	8.1	P
204	296	6-11-59	Tl, To	20	—	30	8.5	169	379	50	81	0.5	0.0	—	545	110	77	7.0	4.01	915	7.6	N
205[3]	62	3-15-36	Tl	—	—	190	25	151	427	64	345	—	—	—	985	575	—	—	—	—	—	N
206[3]	26	4-15-36	Qa	—	—	228	25	280	464	119	550	—	—	—	1,430	670	—	—	—	—	—	N
207[3]	1,173	9-14-37	To	—	—	50	15	290	500	58	245	—	—	—	904	184	—	—	—	—	—	P
208[3]	1,165	do	To	—	—	2	1	346	500	26	232	—	—	—	853	11	—	—	—	—	—	N
67-62-209[3]	1,160	3-28-36	To	—	—	6	1	398	567	[7]	300	—	—	—	984	21	—	—	—	—	—	N
210	912	6-11-59	To	15	0.14	12	3.5	251	412	41	148	1.3	0.0	1.2	677	44	92	16	5.86	1,160	7.7	P
215	39	1- 9-63	Qa	28	—	184	14	163	304	46	368	0.2	68	—	1,020	516	41	3.1	0.00	1,800	7.0	D,S
216	30	do	Qa	46	—	328	51	439	328	188	1,070	—	12	—	2,300	1,030	48	5.9	0.00	2,930	6.9	D,S
301	1,207	12-22-44	To, Tct	25	0.26	8.8	1.4	418	565	1.1	334	0.4	0.2	—	1,070	28	95	34	8.70	1,890	7.8	P
302[5]	780	10- 1-58	To	—	0.1	10	1.2	246	346	32	132	—	—	—	566	30	—	—	—	—	7.8	Ind
304[4]	1,353	3-28-36	To, Tct	—	—	6	1	586	684	[7]	520	—	—	—	1,449	20	—	—	—	—	—	Irr
305	78	10-11-62	Tl	38	—	154	14	160	335	46	318	0.5	21	—	916	442	44	3.3	0.00	1,580	6.5	D,S
401[3]	171	3-23-36	Tl	—	—	63	15	40	293	[7]	48	—	—	—	310	219	—	—	—	—	—	S
402[3]	171	do	Tl	—	—	75	15	77	183	56	148	—	—	—	461	250	—	—	—	—	—	D,S
502[9]	38	4-10-63	Qa	34	—	120	3.9	29	238	30	56	0.2	90	—	480	316	17	0.7	0.00	777	7.2	D,S
903[3]	106	5- 5-37	Tl	—	—	76	10	47	146	26	60	—	120	—	411	225	—	—	—	—	—	D,S
63-401	55	10-23-62	Tl	54	—	136	11	59	358	33	100	0.4	54	—	678	384	25	1.3	0.00	1,000	6.9	D,S
502	307	do	Tl	25	0.01	56	5.3	35	218	11	33	0.4	1.0	0.1	274	162	31	1.2	0.34	457	7.2	Irr
79-06-101[6/9]	220-510	1-56	Tl	—	—	—	—	17	220	10	26	—	—	—	350	192	16	—	—	—	8.0	
	290-310	1-56	Tl	—	—	—	—	68	290	15	45	—	—	—	486	170	47	—	—	—	8.0	Irr
	400-440	1-56	Tl	—	—	—	—	86	329	11	48	—	—	—	538	160	54	—	—	—	7.9	
	500-585	1-56	Tl	—	—	—	—	95	278	7	73	—	—	—	506	132	61	—	—	—	8.0	
102[9]	72	9-27-62	Tl	26	—	115	6.8	28	276	9.6	71	—	50	—	442	315	16	0.7	0.00	766	6.7	D,S
202	283	6-11-59	Tg, Tl	33	—	58	9.8	50	221	18	66	0.3	1.5	0.06	349	184	37	1.6	0.00	594	7.1	Irr
205[3]	110	4-25-37	Tg	—	—	11	16	115	183	30	110	—	[8]	—	383	95	—	—	—	—	—	D,S
407	315	11-20-62	Tl	29	1.3	80	16	80	332	26	98	0.6	1.8	—	494	266	40	2.1	0.13	855	6.9	D,S

[1] Analyses given are in parts per million, except specific conductance, pH, percent sodium, sodium-adsorption ratio, and residual sodium carbonate.

[2] Sodium and potassium calculated as sodium (Na).

[3] Analyses by the WPA were done by methods not sufficiently accurate for results to be closely comparable to those of later analyses, but they may be used to estimate the generaly quality of the water.

[4] Analyses by Texas Department of Health.

[5] Analyses by Western Filter Co.

[6] Sample from indicated interval.

[7] Sulfate less than 10 ppm.

[8] Nitrate less than 20 ppm.

[9] Located just outside study area.

USE: S=Stock D=Domestic Ind=Industrial Irr=Irrigation P=Public supply N=None used. SOURCE: Follett and Gabrysch (1965).

Salinity

A general classification of water based on total dissolved solid (TDS) content (Swinson and Baldwin, 1965) is:

Description	Dissolved solids, parts per million (ppm)
Fresh	Less than 1,000
Slightly saline	1,000-3,000
Moderately saline	3,000-10,000
Very saline	10,000-35,000
Brine	35,000

The TDS of the 144 water well samples tested in DeWitt County (1965 report) range from 190 to 2,240 ppm, exceeding 1,000 ppm in only 16 samples (see table 9). Of the 28 wells within or on the periphery of the study area the salinity was over 1,000 in 6, all of these occurring in the northern corner of the area, north of Highway 87, and ranging in depth from 8 to 412 m (26 to 1,353 ft). The distribution of wells within the study area is, however, sparse, few monitoring wells occurring within the prospect area (fig. 14).

Chemical Composition

The precise chemical composition of wells within the study area can be found in table 8. With the possible exception of well number 216 that has high calcium and chloride values, the quality of the water in the study area tends to be within the recommended standards for its various uses. The levels of boron have often not been measured, but where they have, they fall well within recommended limits as they do throughout the county.

Aquifer Recharge

The principal source of recharge to aquifers is the infiltration of rainfall in their outcrop areas; much of the study area is therefore a recharge zone for the Evangeline. The Burkeville confining system outcrops less extensively as a narrow, relatively steeply sloping band along the valley of the Guadalupe River and therefore probably is not significantly recharged in this area. It is likely that the shallow floodplain and terrace aquifers are locally recharged.

Table 9. Discharge of the Guadalupe River at Cuero, Texas
U.S.G.S. Station 08175800

Year	High	Low	Daily Average
	cu. ft./sec.		
1964	3,670	138	622
1965	17,600	404	2,077
1966	3,270	551	1,243
1967	59,500	79	1,402
1968	39,900	670	2,545
1969	13,300	564	1,724
1970	9,050	621	1,572
1971	6,880	151	982
1972	56,800	719	2,105
1973	34,400	826	3,510
1974	10,300	648	2,090
1975	16,200	790	2,945
1976 (1-9)	13,700	714	

Source: U.S.G.S. Daily Streamflow Data

Although depth to the water table is an important factor in the problem of ground-water contamination, many other factors that influence infiltration and percolation rates could also be significant in determining vulnerability of a specific site to this problem.

The factors include:[1]

Factor	Characteristics of Greater Hazard	Characteristics of Lesser Hazard
*1. Soil		
a. Surface texture	Sandy	Clay (uncracked)
b. Subsurface texture	Sandy	Clay
2. Tillage	Not tilled	Tilled
3. Vegetation cover	Dense vegetation, grass trees with litter	Sparse vegetation, young crops, no litter
4. Season	Dormant	Growing
*5. Weather	Recently dry	Recently very wet
*6. Slope	Flat, gentle	Steeper
*7. Depth to water table	Shallow	Deep
8. Slope plus water table		Flat and very shallow W-T rapidly filled to capacity

*More important factors.

Based on soil infiltration rates the vulnerability to groundwater contamination of locations within the study area is indicated on figure 16. The degree of contamination would also depend on the nature and duration of the spill, a long lasting slow leak could be as, or more damaging than, a short blowout.

Effects of Groundwater Contamination

The significance of groundwater contamination would depend on the amount of saline water involved and the location of wells in the vicinity. Shallow wells located very near to, and downdip of the spill site would be the most affected, whereas dilution should increase with distance from the spill. Contamination could increase salinity of affected wells and cause an increase in some potentially hazardous substances such as

[1] From Meinzer (1942).

boron. The suggested allowable levels of these contaminants vary with the use of the water, domestic and drinking water having the highest standards. Figure 17 shows the range of values for constituents of several geothermal wells. Appendix B compares these values with recommended standards for various water uses.

Increasing the salinity of shallow ground water, especially in dry weather, could also affect vegetation depending on this for their water supply and would probably be especially important in the case of perched water tables where water for dilution is restricted. For a fuller discussion on the impact on vegetation see page 93.

Location of Test Well on the Basis of Groundwater Resources

Fluid Disposal and Subsurface Contamination

The plans to dispose of waste water by injection into deep saline aquifers well below the base of slightly saline water should, if recommendations are followed and the wells are properly cased and operated, ensure that groundwater is not contaminated. The Texas Department of Water Resources recommends that brines be injected into reservoirs with salinities greater than 10,000 ppm and that these reservoirs should be separated from the base of slightly saline water by at least 76 (250 ft) cumulative meters of shales and clays (Fink, TDWR, personal communication). Additionally, the Texas Railroad Commission limits injection pressure to 3.62 kg/m (1/2 lb per ft) of depth (Fink, TDWR, personal communication). This is to protect the formation rock from vertical fracturing and upward migration of the brine, which could pose problems of contamination and necessitate alternative disposal procedures. There is also the possibility of leakage of brines along fault planes or by breaching through abandoned wells in the area, contamination that would be difficult to detect (Newchurch and others, 1978). Due to the slow movement of groundwater in DeWitt County, dilution of induced brine would take a long time and water quality over a large area may not be affected for many years.

Spills and Surface Contamination

The possibility of a leak or spill from surface storage and cooling ponds or the occurrence of a blowout could result in contamination of shallow ground-water

Figure 16. Recharge and Groundwater Contamination Potential Based on Soil Characteristics, Cuero Study Area. (Source: Soil Conservation Service, 1978b.)

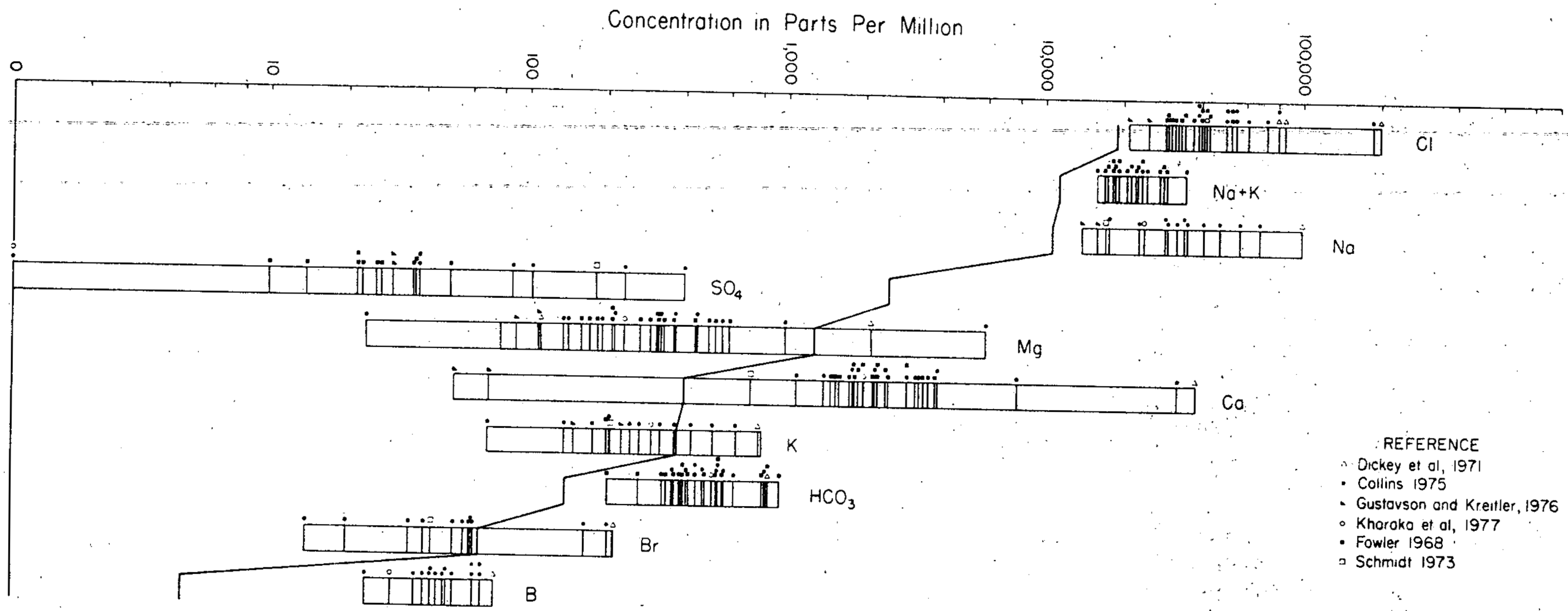


Figure 17. Range of Values for Constituents of Geothermal Wells in the Gulf Coast Area.

resources. An aquifer is recharged largely in its area of outcrop (although also from downward percolation from overlying aquifers). The large outcropping of the Evangeline aquifer in the study and reservoir area make the aquifer most vulnerable to contamination. Shallow, smaller aquifers such as those along the flood plain and terraces of the Guadalupe may also be affected by a brine spill. Areas where the water table is shallow may have more rapid and concentrated contamination, especially perched water tables where adequate dilution may not be possible. No precise data are available for the DeWitt water table; however, the Soil Survey of the county indicates that a seasonal high water table is not a problem and the water level in nonartesian wells is generally many feet below the surface.

SURFACE WATER

Description

Drainage Basins

The drainage of the Cuero area falls into two basins with the divide running approximately east-west through the study area (fig. 18). The northern basin drains northward and southward by way of many small streams into the Guadalupe River which runs from north-west to south-east in the area of study. The runoff from the southern basin drains eastward via Five-mile and Boggy creeks into Twelvemile Creek, the latter being located just outside of the study area. The water from Twelvemile Creek eventually drains into the Guadalupe River by way of Coleto Creek, the confluence being about 30 miles south of the study area.

The identification of drainage basins is important in considering the location of the test well as they provide an indication of the path that would be taken by saline water and the area that could be affected should a spill occur.

Discharge

Since its damming at Canyon Lake in 1964 the flow of the Guadalupe River has been monitored in the study area at the U.S.G.S. gaging station located on the U.S. 183 bridge southwest of Cuero. From 1964 to 1976, the highest daily flow recorded was 1,686 m^3/sec (59,500 ft^3/sec) on September 23, 1967, and the lowest 2.24 m^3/sec (79 ft^3/sec) recorded on August 13, 1967. The normal flow is generally between 14 to 85 m^3/sec (500 to 3,000 ft^3/sec), the distribution within this range varying with the year.

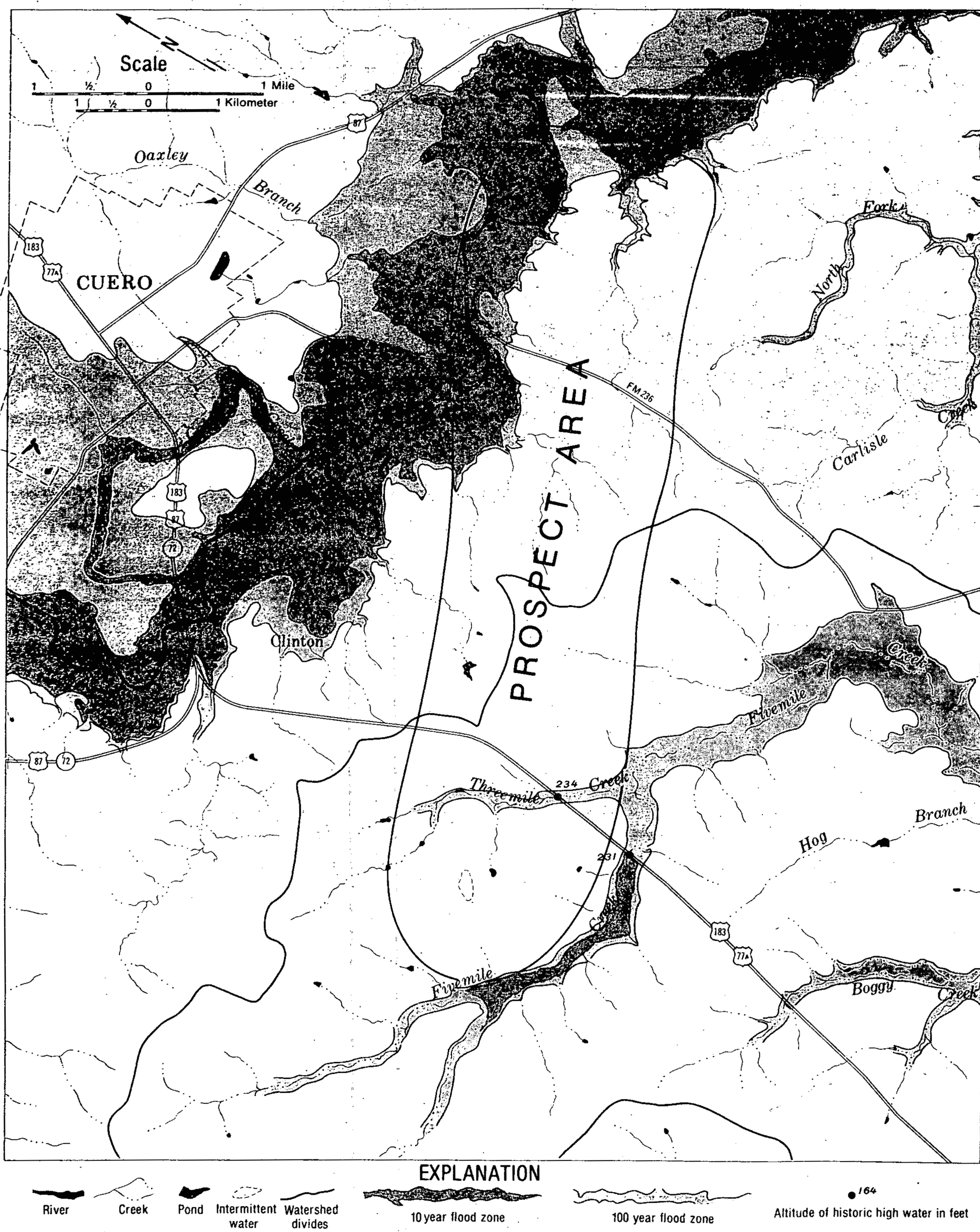


Figure 18. Surface Hydrology and Flood-Prone Areas, Cuero Study Area. (Sources: U.S. Geological Survey Topographic Maps; Federal Insurance Administration Flood Hazard Maps, 1977; Soil Conservation Service, 1978b.)

Although it is difficult to generalize, periods of low flow within a year tend to fall in winter, whereas spring and early summer frequently are the high flow times of the year (table 9).

There are no flow data available for other water courses within the study area. It is not possible to assume that the high and low flows in the smaller streams will occur at the same time as those in the Guadalupe as the latter, having a much larger drainage basin, will be affected by rainfall over a much wider area.

Flooding

Areas prone to inundation in the 100-year flood were mapped from the Federal Insurance Administration Flood Hazard maps, whereas information for more frequent flooding came from the soil survey of DeWitt County (fig. 18).

One hundred year floods are those with an average recurrence of once in every 100 years. It is possible for a 100-year flood to occur during any year, or even during successive years. The last 100-year flood to occur in the Cuero area of the Guadalupe River was in 1936.

Within the boundaries of the 100-year flood the land is subject to more frequent flooding, depending on its location and elevation. The more frequently flooded areas are indicated on the map, although these data may be incomplete.

A comparison of surface elevations with flood level elevations expected during 100-year floods suggests that the level of the Guadalupe River would have to rise approximately 12.2 m (40 ft) in order to reach this level. A rise of 6.1 m (20 ft) is needed to inundate the areas subject to yearly flooding.

Smaller streams in the area are also subject to varied frequencies and levels of flooding and the majority of the stream valleys would be affected by a 100-year flood, although to a much lesser extent and depth than the Guadalupe.

Historical high water levels, monitored by the Texas Highway Department at highway bridges (for locations see fig. 18) are recorded on table 10.

Water Quality

The only point source of discharge into the Guadalupe River in the study area is the Cuero sewage plant, one of only 3 sewage plants in its 20 county district to meet its discharge requirements (Bill Lockey, personal communication). Nonpoint sources that

Table 10. Historical high water levels recorded at highway bridges in the Cuero study area.

Location	Approximate Elevation of River	Elevation of High Water and Year	Approximate Elevation of 100 Year Flood
Hwy. 183 and Guadalupe River	145'	170-2 (1936)	170'
FM 236 and Guadalupe River	135'	164-0 (1936)	160'-170'
Hwy 183 and Three Mile Creek	225'	234-3 (1967)	230+'
Hwy 183 and Five Mile Creek	220'	231 (Before 1938)	230'-240'

Source: Reagan, Texas Highway Department, pers. comm.

may be affecting the river include chemicals and sediment in runoff from agricultural land, roads, oil and gas well sites, gravel pits, and areas of new construction. The quality of water in the Guadalupe River within the study area appears to be good, seldom exceeding the standards set for that section of the river in any of the measured constiuents. Most of the potential pollutants from geothermal brines are however not measured. Table 11 lists the available relevant water quality data as measured at the Department of Water Resources Stations 1803-0200 at the Old San Antonio road west of Cuero and at Station 1803-0200 at U.S. 183 bridge southwest of Cuero. The quality of water in the smaller streams of the area has not been monitored, but they are probably subject to similar nonpoint pollution sources as the Guadalupe.

Location of Test Well on the Basis of Surface Water Characteristics

Effect of Test Well on Drainage

The only effect of the test well development that could affect drainage is subsidence. It is possible that subsidence could slightly steepen or lower the profile of the streams, thus affecting their energy level and erosion rates. If subsidence were to be accompanied by faulting, it is remotely possible that, in time, streams could be diverted along the fault line or, depending on the downthrown side of the fault in relation to stream flow, ponding or a nick-point could develop in the stream profile. The presence of ponds, dikes, and other features associated with a test well may locally influence the flow of runoff.

Location of Test Well on the Basis of River Discharge

The well would be better located near a large, rather than a small, water course. In the first instance the impact of a spill or blowout would be greater on a small than a large river, the dilution factor being greater in a larger river. Similarly, during periods of high flow a river would be less affected by an influx of brine than during periods of low flow, due in part to the amount of water available to dilute the brine, and also to the increased turbulence and therefore more rapid mixing that would also occur during high flow.

Location of Test Well on the Basis of Flood Potential

The problems that flooding pose to the location of a test well depend both on the frequency and severity of the flooding. Elevation in relation to the river is probably the

Table 11. Water quality of the Guadalupe River at Cuero.

Station	*Factor*	*Measuring Unit*	*Range*	*Average*	*Number of Measurements*	*Segment Standards*
0200[1]	TDS[3]	mg/l	130-425	248	27	400 max.
0220[2]			148-354	281	34	
0200	Temperature	°C	9.2-30.5		31	33.8 max.
0200			10.6-29.4		44	
0200	Chloride	mg/l	11-59	37.7	20	100 max.
0220			13-69	37.5	33	
0200	Dissolved	mg/l	6-10	8.2	14	5 min.
0220	Oxygen		5-12.1	7.7	44	
0200	pH	Standard	7.2-8.2	7.9	28	6.5 min.
0220		Units	7.6-8.4	8.0	35	9.0 max.
0200	Ammonia	mg/l	.01-0.16	.06	8 valid	
0220		as N	.1		7	
0200	Alkalinity	mg/l	100-237	172.5	7	
0220		as $CaCo_3$	-----		0	
0200	Manganese	μg/l	20-50		2	
0220			-----		0	
0200	Boron	μg/l	.002		1	
0220			-----		0	

[1]Monitoring period 0200 10/22/71-05/23/78
[2]Monitoring period 0220 09/26/69-08/06/73
[3]Total dissolved solids calculated as 50% of specific conductivity
Source: Texas Department of Water Resources statewide monitoring network, Sampling Data Inventory.

key factor as this will determine both the depth of flooding and also often its frequency.

Flood protection measures including placement of surface facilities on land with naturally higher elevations, and the construction of protective dikes would be necessary if the test well were located on the flood plain. Location in low-lying, frequently flooded areas would require additional maintenance of dikes and roads and increase the risk of a high-level flood that could totally inundate and possibly damage test site facilities.

Location of the Test Well on the Basis of Surface Water Quality

On the basis of surface water quality, the test well would be best located at a great enough distance from water courses to avoid possible contamination. Site preparation for the test well, by clearing the ground and increasing erosion, could increase the sediment load, at least temporarily, in the nearby water courses. A spill, leak, or blowout could increase the salinity and concentration of various potentially harmful constituents of water downstream of the point of entry. The change in water quality would be related to the size of the stream and its discharge at that particular time, plus the amount of brine involved in the accident. A blowout involving a large volume of brine spilled over a short time would have a more serious, though shorter lasting, effect on water quality than a persistent leak. Although it is unlikely that the volumes of brine involved in a spill would be great enough to seriously change the quality of the water, the possibility exists that with the well in proximity to a river an uncontrolled blowout could temporarily render the water of the stream or river unfit for its current uses. A change in water quality could also affect the flora and fauna of the waterways; this topic is considered further under the section on Biological Resources.

As previously mentioned, the test well would be better located on the larger Guadalupe River than on a smaller stream due to the greater amounts of water available for dilution.

SOILS

Soil Forming Factors (Materials and Processes)

Five major interacting factors contribute to the formation of soils: (1) parent material, (2) climate, (3) topography, (4) living organisms, and (5) time (Brady, 1974). The differential interaction of these factors has led to the variety of soils to be found in the Cuero area.

1. Parent material affects many aspects of soils and their formation. The nature of parent material influences soil texture, largely controls the downward movement of water, and often determines the effectiveness of weathering forces by its chemical and mineralogical compositions.

Parent material has a marked influence on the type of clay minerals present in the soil profile, both by the minerals it contains and by influencing the nature of the clay which develops. For example, the formation of montmorillonite clay (which produces expansive soils if present in high enough concentrations) is favored by base-rich minerals high in calcium and magnesium.

In the Cuero area the texture of the soils in general reflects that of the parent material. For example, clay soils are found on clayey substrates (expansive Houston Black clays on calcareous clays and muds, and the Denhawken-Elmendorf complex on expansive clays) whereas sandy soils are formed of sandy parent material (Catilla soils form on sandy substrates, and the more gravelly sands of the Silvern-Ellen complex on ancient terraces of sand and gravel). Further examples can be seen on the table below:

Examples of soil relation to parent material:

Parent Material	Soil Texture	Soil Series
Clayey alluvial sediments	Clay	Branyon
Loamy alluvium	Clay loam	Degola
Loamy stratified floodplain sediments	Loam	Sinton
Loamy sediments with thin strata of calcareous sandstone	Fine sandy loam	Sarnosa
Thick sandy and loamy deposits	Fine sand	Catilla
Ancient terrace sands and gravel	Gravelly loam and sandy clay loam	Goldmire

2. Climate, particularly temperature and precipitation, is a major factor in soil formation through its influences on weathering and vegetation. The presence of water encourages chemical weathering and temperature affects the rate at which weathering occurs. Extremes in temperature and moisture cause breakup of soil material through expansion and contraction.

The Cuero area has dry summers and mild winters. Many of the soils fall into the 7th Approximation Suborder ustalfs, ustolls, and usterts (ust = Latin for burnt, meaning intermittently dry, usually hot in the summer).

Climate also affects soils through its influence on the type of vegetation it will support (see Living Organisms, below).

3. Topography of the land may hasten or delay the effect of climatic forces. In flat areas water tends to accumulate, slowing or even negating the influence of climate if saturated longer than typical for soils of a given climate. For example, Trinity floodplain soils display the characteristics of a soil formed under wet conditions rather than one formed under hot conditions as do most of the soils of the area.

Rolling topography encourages some natural erosion of the surface layers which, if extensive enough, may eliminate the possibility of a deep soil. For example, the Papalote soils have been formed on nearly level to gently sloping areas where little erosion took place. Consequently the absorption of rainfall into the soil profile allowed large amounts of material to be leached from the upper horizons and removed to the lower horizons resulting in deep soils with distinct soil horizons. Shiner soils, on the other hand, are formed in stronger sloping areas than the Papalote. Soil material is removed by erosion almost as fast as horizons form and therefore the Shiner soils are thinner and the horizons not as well defined.

4. As well as helping to break up the soil, living organisms are essential for the profile mixing, nutrient cycling, structural stability, and organic matter accumulation of the soil. The nature of soils is therefore influenced by vegetation and other organisms ranging from soil bacteria to burrowing animals. For example, Mollisols are generally formed under grassland vegetation, which accounts for the large amounts of organic matter that accumulate in the surface horizon. In the study area Runge soils formed under grassland and have a medium-high organic matter content. Alfisols generally do not accumulate as much organic matter because they are commonly formed under deciduous forests where breakdown and recycling of organic matter are more efficient due to the nature of the organic residues and their mode of decomposition.

In the Cuero area Ellen, Leming, Silvern, Straber, and Tremona soils formed under hardwoods (oak woodland or oak scrubland) and have lower contents of organic matter.

5. Soils are classified as mature or immature on the basis of their horizon differentiation. The length of time the soil has been exposed to soil-forming processes thus plays a significant role. Soils formed on alluvial deposits have not been in place long enough to develop mature horizons. Zalla, Degola, Meguin, Sinton, and Trinity soils are examples of alluvial soils with little leaching of upper horizons and no accumulation of clay or calcium in lower levels.

Upland soils have been in place much longer and are more mature. However, factors such as slope and soil drainage have affected the rate at which the soils developed, so that some upland soils are more mature than others. For example, Catilla, Crockett, and Goldmire soils have been leached of their carbonates and salts throughout the profile, while Papalote, Weesatche, and Runge soils have been leached of carbonates in the upper horizons only (Soil Conservation Service, 1978b). In general, the more mature soils are found in level to gently sloping upland areas and have good water drainage through the soil profile.

Soil Problems

There are a number of problems that may be encountered when considering the suitability of soils for test well development. These problems are related to inherent characteristics of the soils and to their positions in the landscape.

1. Expansive soils: A number of the soils exhibit high shrink-swell potential due to a high content of montmorillonite clay. Shrinking and cracking when dry and expanding when wet, they are generally unstable and present problems to construction and even to agriculture (Gustavson, 1975; Soil Conservation Service, 1978b).

2. Corrosivity: Many of the soils have a high corrosivity potential to steel or concrete. The rate of corrosion of uncoated steel is related to such soil properties as drainage, texture, total acidity, and electrical conductivity, whereas that for concrete is influenced mainly by the content of sodium or magnesium sulfate and to a lesser extent by soil texture and acidity. Installations of uncoated steel that intersect soil boundaries or soil horizons are more susceptible to corrosion than those entirely in one kind of soil or in one soil horizon (Soil Conservation Service, 1978b).

3. Drainage: The soils in the study area range from somewhat poorly drained to somewhat excessively drained, each having their advantages and disadvantages. The soils with better drainage, although better suited to construction, pose more problems for pond location; whereas the more poorly drained soils are better suited to pond location but are an inconvenience in construction. The better drained soils would also be more likely to allow ground-water contamination. On the other hand, poorly drained impermeable soils would increase the risk of river contamination if the well was placed on a slope adjacent to a stream.

4. Flooding: Several of the soils in the Cuero area are in low-lying positions that are subject to flooding. For a full discussion of flooding see the Cuero section on Hydrology and figure 18.

Drainage and flooding were not considered individually in the soil suitability analysis as, where relevant, these were taken into account in assigning suitability for various uses (table 12).

5. Slopes and Erosion: Slopes in the Cuero area are generally moderate, occasionally rising over 5 percent but not over 8 percent. Erosion is not a problem for soils on slopes under 1 percent, but where vegetation cover is removed almost all slopes over 1 percent may have a tendency to erode (Soil Conservation Service, 1978b). Miguel and Ferris soils, which occur at slopes over 3 percent, show evidence of erosion in some places. Generally erosion should not be a serious problem in the Cuero area especially if suitable precautions are taken during construction and if revegetation is undertaken.

6. Soils with High Adsorption Capacities: Due to the high adsorption capability of clay soils especially those with a high montmorilonite content (Brady, 1974) these areas may tend to retain contaminants from geothermal fluids longer than other soils and extend the period of residual effects. This effect is increased with pH over 6.0. A high content of humus may have a similar high adsorption and residual effect.

7. Synergic Effects: In acid soils, metallic ions may be dissolved in concentrations toxic to plants. The slightly acidic pH of geothermal fluids may make other components of the soil (copper, manganese, bicarbonate, cadmium, lead, hydrogen sulfide) more toxic because of such synergistic effects (Gustavson and others, 1978).

Prime Agricultural Lands

The U.S. Congress has mandated the U.S. Department of Agriculture (U.S.D.A.) to identify "prime agricultural land," that is, land with the best combination of physical and chemical characteristics for producing food, feed, forage, fiber, and oil seed crops (Federal Register, 1978). The Soil Conservation Service, using criteria developed by the U.S.D.A. and local agricultural extension services, has identified the prime agricultural soils in DeWitt County. Characteristics used include climatic factors of temperature and rainfall, topographic factors such as slope and susceptibility to flooding, and soil factors such as pH, permeability, texture, presence of stones or gravel, and soil depth (Appendix C, iv.). The criteria used are similar but not identical to those used to designate Agricultural Capability of soils (U.S.D.A., 1975; Miller, W., personal communication).

The soils table includes a list of prime soils in the study area. Of the more widespread soils, three are classified prime: Papalote, Weesatche, and the occasionally flooded areas of Meguin soils.

At present, there are no restrictions or regulations on the use of prime lands. Since only a few acres of land are involved on a test well siting the loss of this amount of prime land should not be very significant; however, since there is a possibility of future large-scale development, it would be preferable to locate the well away from large tracts of prime land (fig. 19). It is possible that brines escaping during a spill, leak, or blowout could so affect prime soils that, at least temporarily, their potential capabilities are reduced, and they may no longer belong in the category of prime. Prime lands were included in the final suitability analysis for locating the test well.

Soils Table

A table was constructed listing the soil series and a variety of characteristics to aid in description of the soils and to enable comparison (table 12). The information found in the table was taken from the Soil Survey of DeWitt County (Soil Conservation Service, 1978b). The table is in two sections:

1. The first part of the table consists of basic descriptive and interpretive characteristics of the soils. Included are soil order and great group, texture, slope, drainage, infiltration rate, hydrologic group, agricultural capability unit, and range site. A further description of the categories which are not self-explanatory can be found in the appropriate appendix.

2. Also included in the table is a matrix listing a number of land uses and activities and an indication of whether the characteristics of each soil lend themselves to each use.

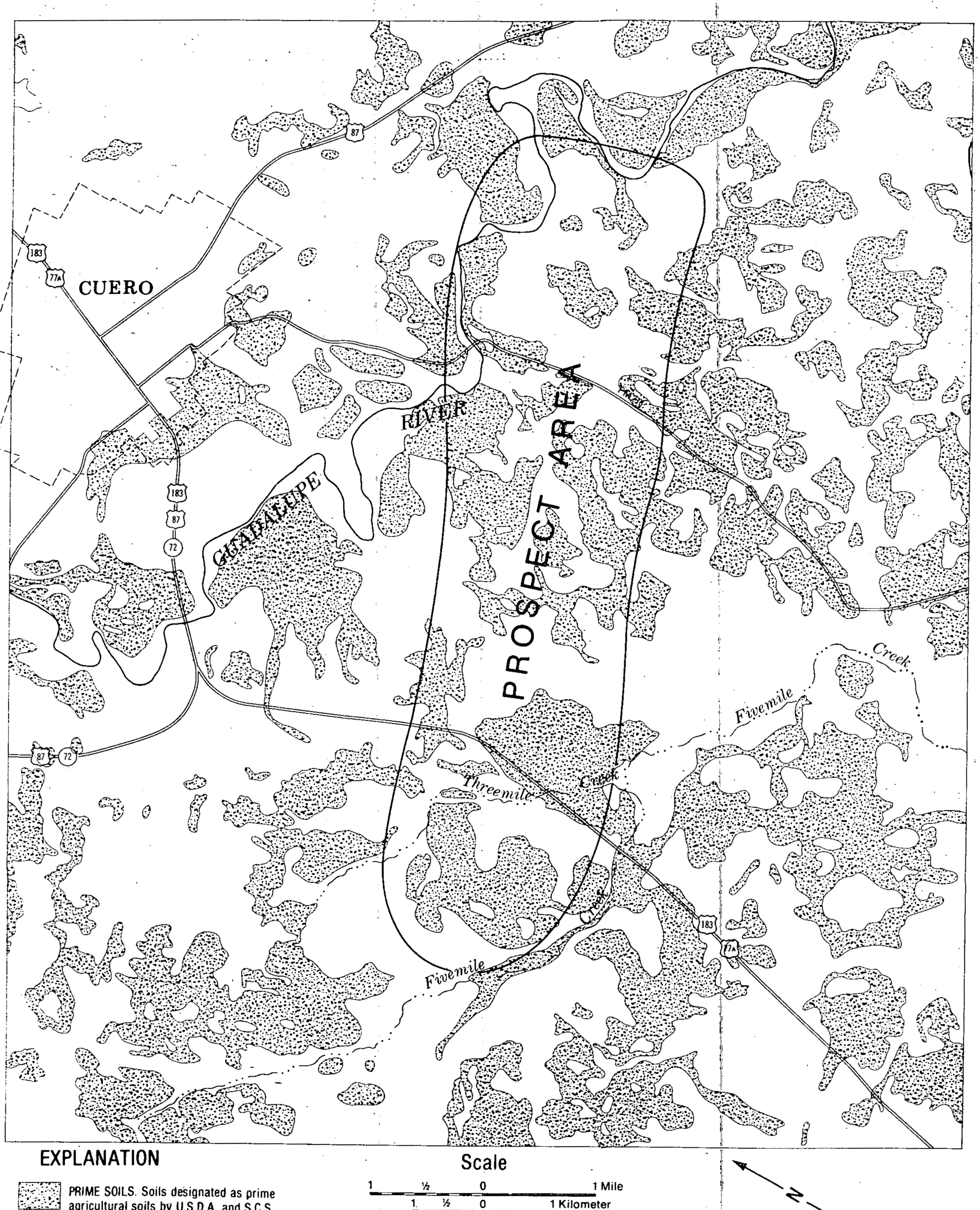


Figure 19. Distribution of Prime Soils, Cuero Study Area. (Source: Soil Conservation Service, 1979.)

Table 12. Soils table, Cuero

Soil order[8]	Great group[8]	Map symbol	Soils series name	Surface texture	Slope	Drainage	Infiltration rate	Agricultural capability unit[2/8]	Prime farmland[8]	Range-site[8]	Characteristics[10]: Drainage	Corrosivity: Steel	Corrosivity: Concrete	Shrink-swell potential	Suitability[9]: Shallow excavations	Pipelines[3]	Local roads	Road-fill	Pond reservoirs	Embankments, dikes, levees	Suitability for test well[7]: Construction[5]	Ponds, dikes[5]	Overall[6]	Septic tank	Dwelling without basements	Suitability for further development	Sewage lagoon	Sanitary landfill	Topsoil	Soil features affecting: Terraces and diversions	Waterways	Recreation	Wildlife: Open	Rangeland	Wetland
Mollisols	Argiustolls		Cuero	sandy clay loam	0-2%	well drained	moderate	II e-4	✓	Clay loam	++	±	++	++	++	+	±	±	±	±	A_5	B_4	1	++	±	A	±	++	±	++	++	±	++	±	−
		B	*Denhawken–Elmendorf complex* Denhawken[1] Elmendorf	clay loam	0-3%	well drained	very slow	III e-4	✓	Blackland	++	−−	++	−−	−−	−−	−−	−	++	±	C_{15}	A_2	2	−−	−−	C	++	−−	±	++	++	− ±	++	±	−−
		C	Runge	fine sandy loam	0-1% 1-3% 3-5%	well drained	moderate	II e-1 II e-3 III e-8	✓	Sandy loam	++	±	++	±	++	±	±	±	±	±	A_6	B_4	1	++	±	A	±	++	±	++	++	++	++	++	−−
		D	Weesatche	fine sandy loam	1-3% 3-5%	well drained	moderate	II e-3 III e-7	✓	Clay loam	++	—	++	±	++	−	±	±	±	±	B_7	B_4	2	±	±	B	±	++	±	++	++	±	+	±	−−
	Haplustolls	F_1	Degola, occasionally flooded Degola, frequently flooded	clay loam	0-1%	well drained	moderate	IIw-2 Vw-1	✓	Loamy bottomland	++	±	++	++	−−	+	−−	±	±	±	B_{11}	B_4	2	−−	−−	C	−−	−−	±	f	++	−	++	±	−−
		G_1 G_2	Meguin, occasionally flooded Meguin, frequently flooded	silty clay loam	0-1%	well drained	moderate	IIw-2 Vw-1	✓	Loamy bottomland	++	±	++	±	−−	±	−−	−	±	±	C_{13}	B_4	3	−−	−−	C	−−	−−	±	++ n	++	−	++	±	−−
		H	Sinton	loam	<1%	well drained	moderate	IIw-2	✓	Loamy bottomland	++	±	++	++	−−	+	−−	±	−−	±	B_{11}	C_6	3	−−	−−	C	−−	−−	±	++	++	−	++	++	−−
	Calciustolls	J	Lupe	gravelly sand clay loam	1-8%	well drained	moderate	VI s-2		Gravelly loam	++	±	++	++	±	+	++	++	−−	++	A_3	B_4	1	++	±	A	±	−−	−	s	++	±	−	±	−−
		K_1 K_2	Sarnosa Sarnosa, eroded	fine sandy loam	0-1% 1-3% 3-5% 5-8% 3-5%	well drained	moderate	II c-1 II e-3 III e-8 IV e-7 IV e-6		Gray sandy loam	++	±	++	++	++	+	++	++	−−	++	A_1	C_4	2	++	++	A	±	−−	±	s	s	++	++	++	−−
	Haplaquoll	L_1	Trinity, occasionally flooded Trinity, frequently flooded	clay	0-1%	somewhat poorly drained	very slow	IIw-1 Vw-1	✓	Clayey bottomland	−	−−	++	−−	−−	−−	−−	−	++	±	C_{15}	A_2	2	−−	−−	C	−−	−−	−	f; ps; w	f; ps; w	−−	±	++	−
	Albaqualf	M	Mabank	fine sandy loam	0-1% 1-3%	somewhat poorly drained	very slow	IIIw-1 III e-1		Claypan prairie (BL)	−	−−	±	−−	−−	−−	−−	−	++	±	C_{15}	A_2	2	−−	−−	C	++	−−	−	ps	ps	−	++	±	±
	Ochraqualf	N	Orelia	fine sandy loam	0-2%	somewhat poorly drained	very slow	IIIw-1		Claypan prairie (RG)	−	−−	++	±	±	−	±	−	++	±	B_{10}	A_2	1	−−	±	C	++	±	−	ps; w	d; ps	−	±	++	±
		O	Wilson	clay loam	0-1% 1-3%	somewhat poorly drained	very slow	IIIw-3 IIIe-10		Claypan prairie (BL)	−	−−	++	±	−−	−	−−	−	++	±	C_{14}	A_2	2	−−	−−	C	++	−−	±	ps	ps	−	++	++	−
			Catilla	fine sand	0-5%	moderately well drained	moderate	III e-9		Deep sand savannah	±	±	±	++	−−	+	++	++	−−	±	A_5	C_6	2	±	++	A	−−	−−	−	e; p; ts	d	±	±	±	−−
		R_1 R_2	Crockett Crockett, eroded	fine sandy loam	0-1% 1-3% 3-5% 2-5%	moderately well drained	very slow	III s-2 III e-1 IV e-1 IV e-5		Claypan prairie (BL)	±	−−	++	−−	−−	−−	−−	−	++	±	C_{15}	A_2	2	−−	−−	C	++ ±	−−	±	++	++	−	±	++	−−

Alfisols	Paleustalf	S	*Silvern-Ellen complex* Silvern Ellen	very gravelly loamy sand gravelly loamy sand	1-8%	well drained moderately well drained	high moderate	VI s-2		Gravelly	++ ±	++ ±	± --	++	--	++ +	++	++	-- ±	-- ±	A_4 A_5	C_8 B_4	2 1	++ --	++	A B	--	--	-	p; ss; ts	d; ss	±	-	- ±	--
		T	Goldmire	very gravelly	1-8%	moderately well drained	slow	VI s-2		Gravelly	±	±	--	++	--	+	±	++	++	++	B_7	A_0	1	--	++	B	--	--	-	ss	d; ss	--	-	±	-
		V	Leming	loamy fine sand	0-5%	moderately well drained	slow	III e-9		Loamy sand	±	--	++	±	±	-	±	±	++	±	B_9	A_2	1	--	++	B	±	±	-	ts	e	±	±	++	--
		W_1 W_2	Miguel, Miguel, eroded	fine sandy loam	3-5%	well drained	very slow	IV e-3		Tight sandy loam	++	--	++	±	--	-	--	-	++	++	C_{14}	A_2	2	--	±	C	±	--	±	ps	ps	+	±	++	--
		X	*Nueces-Sarita complex* Nueces Sarita	fine sand	0-5%	moderately well drained well drained	slow high	III e-5 IV e		Deep sand	± ++	± ++	++	± ++	± --	± ++	±	±	± --	± --	B_8	B_4 C_8	2 3	-- ++	++	B A	± --	++ --	-	e;p ts	e d	--	±	++ ±	- --
		Y	Papalote	fine sandy loam	0-1% 1-3%	moderately well drained	slow	II s-2 II e-2	✓	Tight sandy loam	±	--	++	±	++	-	±	±	±	++	B_7	A_2	1	--	±	C	++	++	±	++	++	+	++	++	-
		Z	Straber	loamy fine sand	0-1% 1-5%	moderately well drained	slow	III s-1 III e-1	✓	Sandy	±	--	--	--	±	--	±	±	++	±	B_{10}	A_2	1	--	±	C	++ ±	±	-	ps	++	+	++	++	-
		a_1 a_2	Tremona	loamy fine sand gravelly loamy sand	0-5% 1-5%	somewhat poorly drained	slow	III e-6 IV s-2		Sandy Gravelly	-	--	--	--	--	--	±	±	++	±	C_{12}	A_2	2	--	±	C	--	±	-	e; p; ts	d	±	++ -	++ ±	--
Vertisols	Pellustert		Branyon	clay	0-1%	moderately well drained	very slow	IIw-3	✓	Blackland	±	--	++	--	--	--	--	-	++	±	C_{15}	A_2	2	--	--	C	++	--	-	++	++	--	++	±	--
			Buchel	clay	0-1%	moderately well drained	very slow	IIw-3	✓	Clayey bottomland	±	--	++	--	--	--	--	-	++	±	C_{15}	A_2	2	--	--	C	--	--	-	++ n	++	--	±	-	-
		e	Houston black	clay	0-1% 1-3%	moderately well drained	very slow	IIw-3 II e-1	✓	Blackland	±	--	++	--	--	--	--	-	++	±	C_{15}	A_2	2	--	--	C	++	--	-	ps	ps	--	±	±	-
			Leemont	clay	3-5% 5-8%	moderately well drained	very slow	III e-3 IV e-2		Blackland	±	--	++	--	--	--	--	-	++	±	C_{15}	A_2	2	--	--	C	±	--	-	ps; s	ps; s	--	±	-	-
			Monteola	clay	0-1% 1-3%	moderately well drained	very slow	II s-1 III e-2	✓	Blackland	±	--	++	--	--	--	--	-	++	±	C_{15}	A_2	2	--	--	C	++	--	-	ps	ps	--	±	-	--
	Chromustert		Ferris	eroded	3-5%	well drained	very slow	IV e-2		Eroded blackland	++	--	++	--	--	--	--	-	++	±	C_{15}	A_2	2	--	--	C	±	--	-	ps	ps	--	±	-	--
Inceptisols	Ustochrept	r	Shiner	fine sandy loam	1-5% 5-8%	well drained	very slow	IV e-4 VI e-1		Chalky ridge	++	±	++	++	±	±	±	±	--	--	B_8	C_8	3	++	--	A	--	--	-	d; p	d; r	++	±	±	--
Entisols	Ustifluvent	t	Zalla	fine sand	0-1%	somewhat excessively drained	high	IVw-1		Loamy bottomland	++	++	++	++	--	++	±	++	--	--	A_6	C_8	2	--	--	C	--	--	-	e; ts	e	-	±	-	--

[1] Denhawken series is in Inceptisol soil order and Ustochrept great group

[2] Agricultural capabilities units range from I through VIII—limitations increase with number

[3] Suitability for pipelines was determined from soil characteristics of corrosivity to steel and shrink-swell potential

[4] Terraces and diversions—problems:
- ++ – favorable
- f – floods
- n – not needed
- s – slope
- ps – percolates slowly
- w – wet
- d – droughty
- e – erodes easily
- p – piping
- ts – too sandy
- ss – small stones
- dtr – depth to rock
- r – rooting depth

[5] A→B→C – decreasing suitability (see text)

[6] 1→2→3 – decreasing suitability (see text)

[7] See Text

[8] See Appendix

[9] Suitability:
++ – good ± – fair --- very poor

[10] Limitations:
++ – slight ± – moderate --- severe

In order to simplify the information found in the soil survey, a set of symbols was used to indicate relative suitability of soils and the severity of limitations: ++, +, ±, -, --. These symbols can be translated from the soil survey descriptions as follows:

Soil Survey Descriptions		Table Symbols	Text Interpretations	
Limitations	Suitability		Limitations	Suitability
Slight	Good/ Favorable	++	Slight	Most Suited
		+	Slight-Moderate	
Moderate	Fair	±	Moderate	
	Poor	-	Moderate-Severe	
Severe	Very Poor	--	Severe	Least Suited

In the event of soil characteristics changing with depth, the value of the horizon with the more restricting characteristics was entered in the table (for example: Tremona soils above 28 in have low corrosivity to steel, but below 28 in have high corrosivity and are therefore listed as high). Within the matrix is a suitability analysis that took into consideration factors relevant to various aspects of geothermal test well development.

Location of Test Well Based on Soil Characteristics

The overall suitability of soils for the test well depends both on the effect of the test well on the soils and the effect of the soils on the test well.

Effect of Test Well on Soils

The most likely effect of the test well on soils is to induce erosion by the clearing of vegetation in site preparation and road construction. Erosion potential varies with slope and with soil characteristics; areas vulnerable to erosion were mapped on figure 20. A less likely but potentially more damaging occurrence is an accidental release of geothermal brine. It was not feasible to rank the soils according to their susceptibility to long-term contamination as the effects of a spill depend on the interactions of a large number of factors: characteristics of the brine, including relative proportions of

Figure 20. Soils Subject to Erosion, Cuero Study Area. (Source: Soil Conservation Service, 1978b.)

the constituent ions, hardness, and pH; soil characteristics including pH, drainage, texture and composition, and cation exchange capacity or adsorption rate; and amount of rainfall available to flush the soil (McKee and Wolf, 1973; Brady, 1974; Texas Board of Water Engineering, 1954). Effective recovery of soils from a brine spill will require management based on knowledge of the above factors and of the movement of brines through the soils and of brine components through the water/soil/plant system. Studies to obtain this information should be initiated early in the use of a test site (Gustavson and others, 1978). However, soils with a high clay content are generally more vulnerable to long-term contamination due both to their slow infiltration rate extending the time that brine would remain in the soil profile and to their high adsorption capability. Coarse grained soils, however, could increase the risk of ground water contamination due to their more rapid infiltration rates (fig. 16). It is possible that if subsidence were to occur with the withdrawal of fluids some soils may be flooded more frequently than at present which could result in slight alterations in their development.

Effect of Soils on the Test Well

The major importance of soils to the test well is the effect they have on the associated construction. The soils table (table 12) includes an analysis of the suitability of each soil series for construction of a test well. The analysis is based largely on information provided in tables 5 and 6 of the DeWitt County Soil Survey. The Soil Conservation Service gives each soil a rating for various land uses based on the limitations the soil places on these uses. Ratings were based on such factors as soil texture, flooding, mineralogy, strength, corrosivity, stability and drainage. Depth to seasonal high water table was not considered as it is not a problem of the soils in the Cuero area. Slope is not a separate constraint either as the expense of construction of even eight percent slopes is small compared to the total cost of the test well.

Method of Suitability Analysis

Suitability for construction of test sites, roads, and pipelines (hereafter referred to as construction) was considered separately from that for ponds and dikes because these different uses have different requirements. The results were then combined into an overall suitability unit for location of a geothermal test well. In addition, suitabilities for construction of small buildings and septic tanks were combined to give an indication of suitability for possible future development associated with maintenance and monitoring of the test well.

The method of analysis to determine the various suitabilities was as follows:

The suitability of the soils for uses associated with a test well were given numerical values:

++ = 0

+ = 1

± = 2

- = 3

-- = 4

a) Suitability for Construction of Rigs, Roads and Pipelines

The four factors considered here were suitability for:

i) shallow excavations

ii) pipelines

iii) local roads

iv) roadfill

The values for these were summed, giving a possible range of totals from 0 to 16. These were divided into:

1-6	A	Most suited
7-11	B	Moderately suited
12-16	C	Least suited

b) Suitability for Ponds & Levees

The factors considered here were suitability for:

i) pond reservoir areas

ii) pond embankments

The summed values (with a possible range of 0 to 8) were divided into:

0-2	A'	Most suited
3-5	B'	Moderately suited
6-8	C'	Least suited

c) Combined Suitability for Test Well

Here the values for the previous two sections were combined and divided as follows according to the possible combinations.

Final Suitability Unit	Combinations	Relative Suitability
1	(AA')* BA' AB'	Most suited
2	BB' AC' CA'	Moderately suited
3	BC' CB' (CC')*	Least suited

* There were no AA' or CC' combinations.

Within the #2 or moderately suited category are combinations of BB, AC, and CA. Because of the C-ranking of some of the suitabilities, it was considered relevant to distinguish between suitability for construction, suitability for wells, and overall suitability on the suitability map (fig. 21).

It should be emphasized that this suitability analysis is not of an exclusionary nature. It only serves to identify those areas whose soil characteristics may be greater or lesser factors in engineering or construction consideration of a test well.

d) Suitability for Further Development Associated with Test Well

Further development associated with a test well might include construction of monitoring and maintenance facilities. As an indication of suitability for this type of development, suitability for construction of buildings without basements and for septic tank absorption fields were combined in the same manner as in the analysis of suitability for ponds and dikes.

If and when a commercial operation such as a canning factory or power plant is contemplated, a further analysis will be required.

Figure 21. Soil Suitability for Construction and Ponds, Cuero Study Area. (Source: Soil Conservation Service, 1978b.)

Soils of the Study Area

Due to the complexity of the soil series as mapped by the Soil Conservation Service, it was not feasible to include a map of soils for the entire study area. Instead, two maps were prepared: a map of soil associations within the entire study area (fig. 22), and a map of soil series within the test well prospect area (fig. 23).

Study Area--Soil Associations

A soil association is a landscape that has a distinctive pattern of soils in defined proportions (Soil Conservation Service, 1978b). Four associations are found in the Cuero study area, two on the uplands, one north and one south of the Guadalupe River, one on the river terraces and another in the river valley.

1. The Silvern-Ellen association is found in the area north and east of Cuero. These are noncalcareous, neutral to acid, gravelly and very gravelly sandy soils. They are well drained to moderately well drained, have a high available water capacity and are moderately to moderately slowly permeable. Straber and Tremona soils are also found in this association.

2. The Crockett-Mabank association stretches in a band along the terraces north of the Guadalupe River. These are alkaline noncalcareous loamy soils, moderately well drained to somewhat poorly drained and very slowly permeable. Also in this association are Sarnosa, Catilla, Tremona, Wilson, Denhawken, and Elmendorf soils. Wilson soils are in the lower areas, and the other soils are on the irregular gently sloping, slightly higher areas.

3. The Meguin-Trinity association is found in the river bottomland and consists of alkaline largely calcareous loamy and clayey soils. Most of the area is subject to at least infrequent flooding. They are slowly permeable, have a high water capacity and are rather poorly drained. Also in this association are Buchel, Sinton, and Degola soils.

4. The Leming-Papalote association covers the larger part of the study area. The soils in this group are neutral to acid, noncalcareous sandy and loamy soils. They are slowly permeable and moderately well drained. Also in this association are Sarnosa, Runge, Nueces, and Sarita soils occupying the higher positions on the landscape and Orelia the lower. Miguel soils also commonly occur in this association.

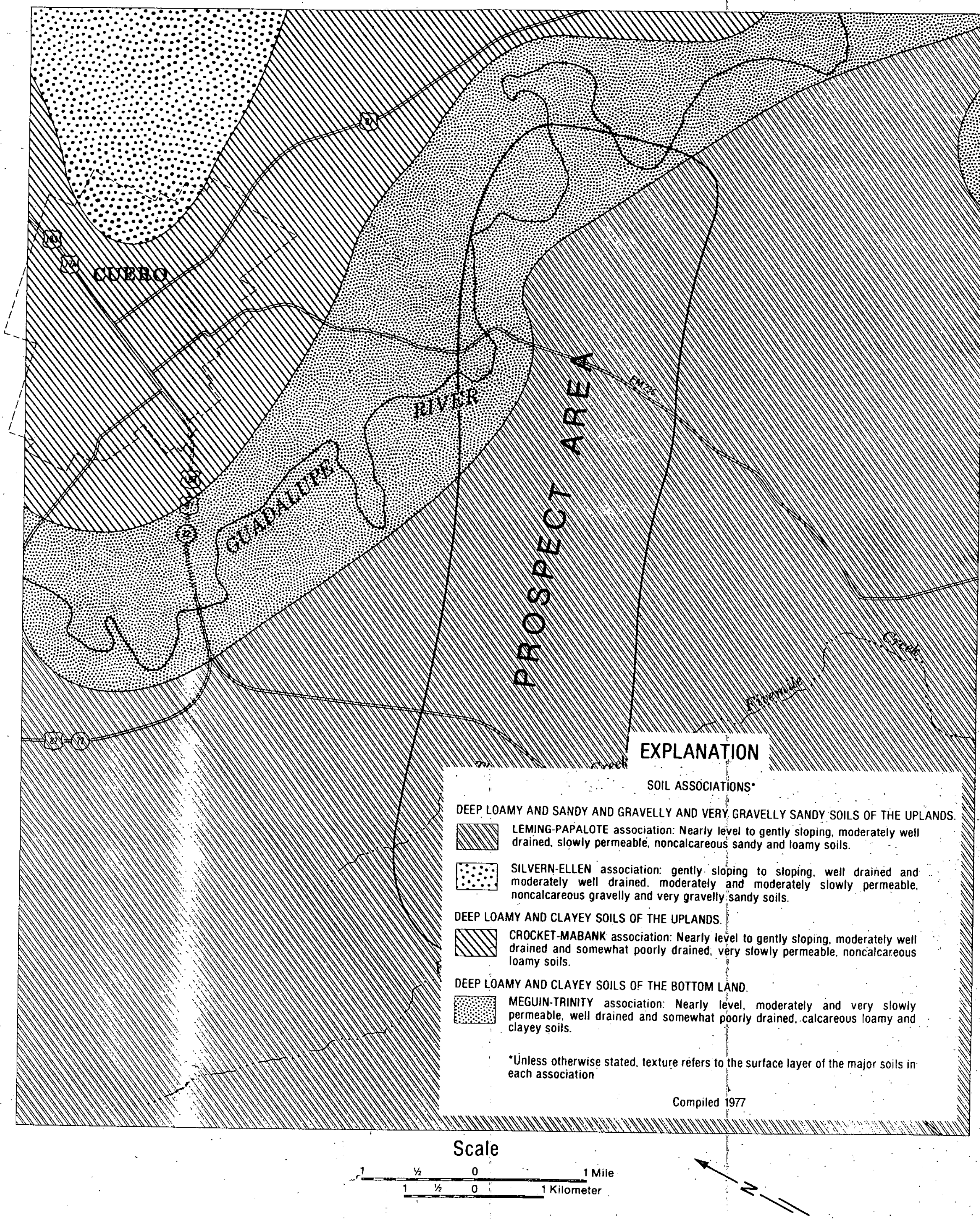


Figure 22. Soil Associations, Cuero Study Area. (Source: Soil Conservation Service, 1978b.)

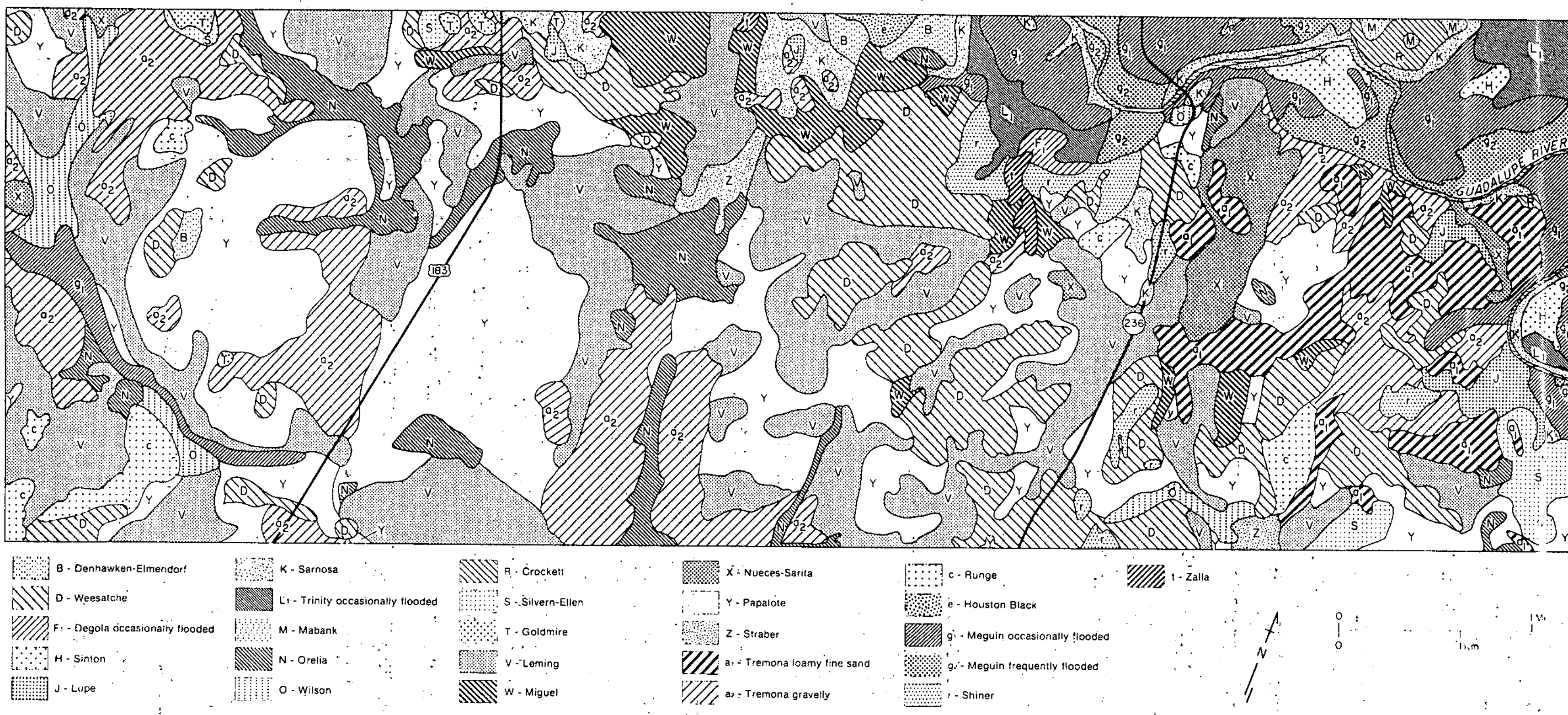


Figure 23. Soils of the Cuero Prospect Area.

Prospect Area Soil Series

Most of the prospect area is within the Leming-Papalote association. A small area of the Meguin-Trinity association is also included. A brief description of the soil series of the prospect area follows. Much of these data plus additional information can be found on table 12.

The descriptions include general information on the soil depth, drainage slope, and texture. The references to: nearly level, gently sloping and sloping, refer to slopes of 0 to 1 percent, 1 to 5 percent, and 5 to 8 percent, respectively. The texture profiles are representative of soil units in that series although the precise depth at which a change occurs may vary within a series.

The effect of the test well on the soil is not discussed separately for each series but, with reference to the preceding section on "Effect of Test Well on Soils," it should be noted that (1) soils with a clay texture in their profile protect against groundwater contamination; (2) soils containing clay may increase the duration of residual effects of a fluid escape; (3) soils with a slope of over one percent have a tendency to erode when vegetation cover is removed.

1. DENHAWKEN-ELMENDORF Complex. These soils are deep, nearly level to gently sloping well drained soils of the uplands. The Elmendorf soils are calcareous whereas the Denhawken are not.

The Denhawken-Elmendorf complex displays microtopographic features known as "gilgais." The Denhawken soils are found as microhighs 2 to 8 in higher than the adjoining microdepressions in which the Elmendorf soils occur. Due to severe problems of shrink-swell, high corrosivity of steel and low strength, these soils are not well suited to construction. They do not pose problems for pond location, but pose moderate problems to levees because of shrink-swell and unstable fill.

2. RUNGE. The Runge series consists of deep, nearly level to gently sloping, well drained noncalcareous soils of the uplands. Although the surface texture is fine sandy loam, it is sandy clay in the subsurface (at a depth of 15 in). These soils pose only moderate problems of corrosivity to steel, shrink-swell and low strength to construction, and moderate limitations of seepage and compressibility to pond and levee construction.

3. WEESATCHE. These are deep, gently sloping, well drained, noncalcareous upland soils. They are sandy clay loam throughout their profile. They are very corrosive steel, have moderate shrink swell, and low strength. They have some limitations for pond and levee location having moderate problems of seepage and piping.

4. DEGOLA. The Degola series consists of deep, nearly level, well drained noncalcareous soils of the bottomland. These are clay loam soils, with sandy clay at depth (30 in and below). Only moderately corrosive to steel, and having moderate low strength problems their main drawback is occasional to frequent flooding. Moderate problems to pond and levee location are posed by seepage and piping.

5. MEGUIN. The Meguin soils are deep, nearly level, well drained calcareous bottomland soils, with a texture of silty clay loam.

These soils have low strength, a moderate corrosivity to steel and moderate shrink-swell, as well as being occasionally to frequently flooded. They also pose moderate problems of seepage and piping to pond and levee location.

6. SINTON. These are deep, nearly level, well drained, calcareous soils of the bottomlands. They are loam and sandy clay loam to a depth of 26 in where they become loam. Sinton soils have a low suitability for construction partly due to low strength but largely because many areas of Sinton soils are subject to flooding although a few areas are seldom, if ever, flooded. They are also unsuited to pond and levee construction, posing problems of seepage, compressibility and piping.

7. LUPE. The soils of the Lupe series are deep gently sloping to sloping well drained calcareous soils of the uplands. They are gravelly sandy clay loams, the amount of clay often being reduced with depth whereas the concentration of gravel is often increased. The only problems for construction are the gravelly texture and moderate corrosivity of steel. They do however have severe problems of seepage for ponds although they are suitable for levees.

8. SARNOSA. These soils are deep, nearly level to gently sloping, well drained calcareous soils of the uplands. Their texture is fine sand in the surface layers, sandy clay loam in the subsurface. The only problem that these soils pose for construction is moderate corrosivity to steel, and although posing a serious problem to pond location because of seepage, they are well suited to levee location.

9. TRINITY. The soils of this series are deep, nearly level, somewhat poorly drained, calcareous soils of the bottomlands. They have a clay texture throughout their profile. They pose many severe problems to construction being very corrosive to steel, having high shrink-swell, low strength and being subject to occasional to frequent flooding. They are, however, well suited to pond location and pose only moderate problems of compressibility and instability to levee construction.

10. ORELIA. These are deep, nearly level to gently sloping, somewhat poorly drained soils of the uplands. The surface texture is fine sandy loam but soon changes (at 4 in) to sandy clay loam. They pose some problems for construction having high corrosivity to steel, moderate shrink-swell and wetness as well as low strength, but are well suited to pond and levee location only having moderate problems of compressibility.

11. LEMING. These are deep, nearly level to gently sloping moderately well drained, noncalcareous soils of the uplands. Loamy fine sand in the surface layers they become more clayey in the subsurface at a depth of 26 in, but are again more sandy below 68 in. The clay layers are corrosive to steel, and this together with low strength pose some problems for construction. They are well suited to pond and levee location having only moderate problems with piping.

12. MIGUEL. The soils of the Miguel series are deep gently sloping, well drained, noncalcareous soils of the uplands. The upper 6 in is fine sandy loam; the subsoil being clay and sandy clay. They have high corrosivity to steel, moderate shrink-swell and low strength and so pose many problems to construction. They are however well suited to the location of ponds and levees.

13. NUECES-SARITA Complex. The Nueces and Sarita soils are deep, nearly level to gently sloping moderately well to well drained noncalcareous upland soils. The texture in the upper layers is fine sand turning to clay at depth of 34 in in the Nueces and 50" in the Sarita.

Soils were mapped as one unit although they have slightly different characteristics. The Nueces soils are found in swales and the Sarita on "ridges." The Nueces is moderately corrosive to steel with a moderate shrink-swell, characteristics the Sarita does not have. They both however have low strength and pose moderate problems to pond and levee location due to seepage, instability, and erodibility.

14. PAPALOTE. This series consists of deep, nearly level to gently sloping moderately well drained, noncalcareous soils of the uplands. The first 9 in is sandy loam, below which is sandy clay. The main problem of these soils for construction is high steel corrosivity although there are moderate problems of shrink-swell and low strength. They are well suited to pond and levee location having only moderate problems of seepage.

15. STRABER. This series consists of deep, nearly level to gently sloping moderately well drained noncalcareous soils of the uplands. The surface texture is loamy fine sand up to a depth of 14 in, below which it becomes more clayey. Due to the high corrosivity and moderate shrink swell of the clay layers as well as to low strength these soils pose some problems for construction. They are well suited to pond location having only moderate problems of compressibility.

16. TREMONA. These are deep, nearly level, somewhat poorly drained, noncalcareous soils of the uplands. While the surface texture is loamy fine sand with variable amounts of gravel, the subsurface (28 in and below) is more clayey consisting of clay, sandy clay and sandy clay loam. The high corrosivity and shrink-swell of these soils combine with low strength and wetness to make it poorly suited for construction. It is, however, well suited to pond and levee location, only posing moderate problems of piping.

17. SHINER. These are shallow gently sloping to sloping, well drained, calcareous soils of the uplands. The surface texture is fine sandy loam (to 6 in) below which it becomes more gravelly. A layer of weakly cemented calcareous sandstone occurs from 16 in to 24 in; below this is sandy loam. These soils pose moderate problems to construction due to moderate steel corrosivity, shallow depth to bedrock and low strength, and are unsuited to pond and levee location because of severe problems of seepage.

LAND USE

Mapping

Current land use was mapped using 1975 color IR aerial photographs (scale 1:83,000) plus larger scale (1:40,000) 1975 black-and-whites. The map was updated wherever possible through field checking during the spring and summer of 1979, (fig. 24).

For the purposes of this study, the following definitions of land uses were established:

- Cropland--those areas presently under cultivation or showing evidence of having supported a crop in the last year. It includes both row crops and annual grass crops.

- Pastureland--areas of managed grazing land or grassland areas without undergrowth or brush. Pastureland includes areas of planted perennial grasses as well as areas of native grasses managed to keep down woody undergrowth. Shade trees may be present.

- Rangeland--consists of unimproved grazing land and previously cultivated land which has been allowed to revert to range. Vegetation cover may vary from grasses and low shrubs to woodland. The vegetation map distinguishes several types of rangeland (fig. 25). A few small areas mapped as rangeland may be open or vacant land.

- Bottomland hardwoods, untended and unharvested.

- Pecan woods, harvested .

- Gravel pits.

- Builtup residential and commercial land.

In actuality, some fields did not fit neatly into the defined categories, especially pasture and rangeland. Subjective judgments were sometimes necessary in categorizing these land uses.

Figure 24. Land Use, Cuero Study Area.

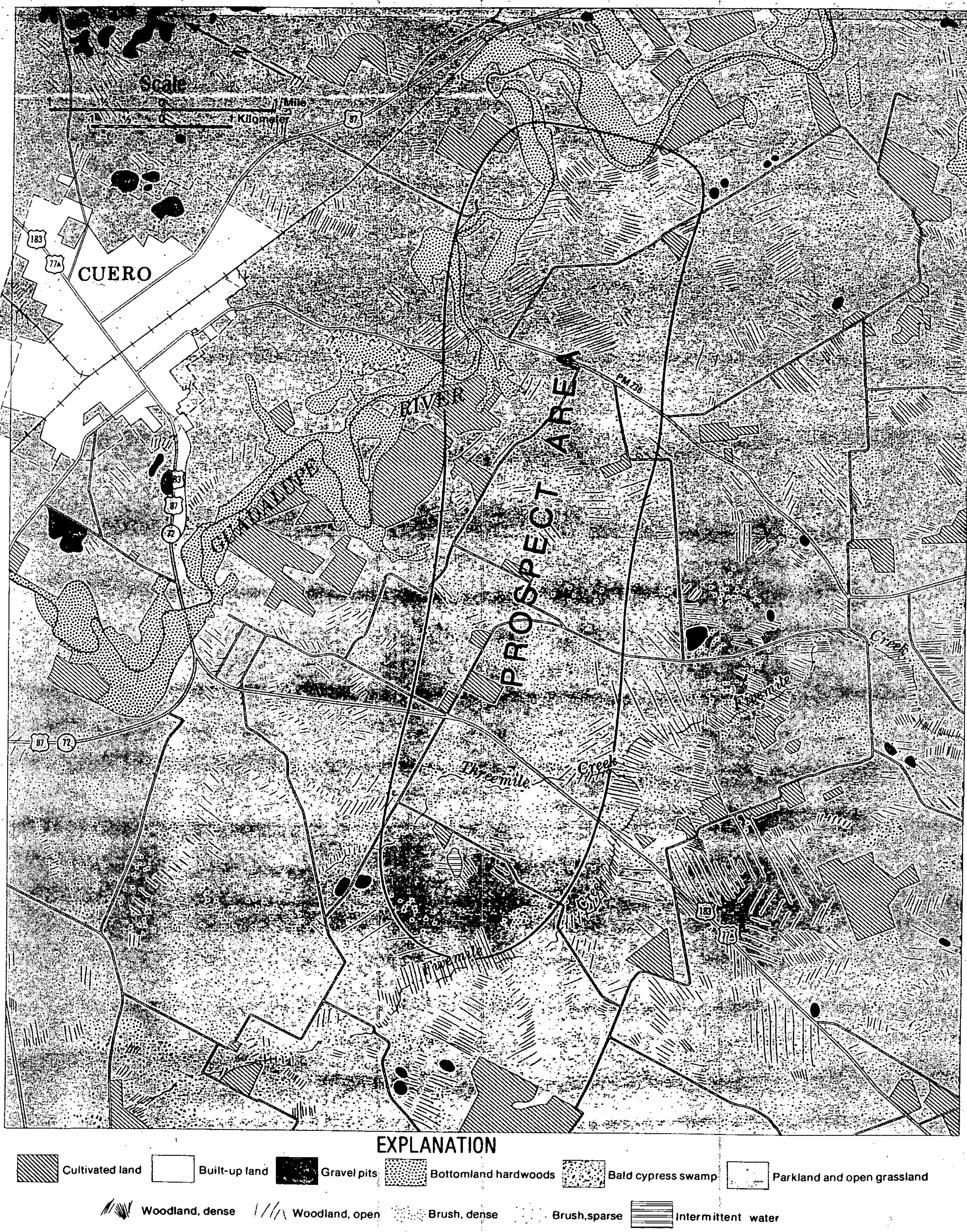


Figure 25. Vegetation, Cuero Study Area.

Description

The study area, exclusive of the city of Cuero, is rural and dominated by agricultural activities, primarily cattle raising. Other economically important land uses are oil and gas wells and gravel pits.

Agriculture

Agriculture in the study area revolves around cattle raising. The single most extensive land use is unimproved rangeland on which large numbers of cattle are grazed. Large acreages of pasture are grazed by cattle or mown for hay. Pastureland may be in native grasses maintained by mowing, or planted with introduced or improved native grasses such as bermuda grass or bluestems (B. Paul, personal communication, 1979). The distribution of cropland and pasture may vary from year to year as fields are allowed to lie fallow.

The two main crops, grain sorghum and corn, are used almost exclusively as cattle feed. Other row crops include peanuts and small grains such as wheat and oats. Annual grass crops include hay sorghum and ryegrass. In several places pecan trees occurring naturally on the Guadalupe River terraces are tended and harvested.

Several of the major soils of the Cuero area have been designated as Prime Agricultural Land (see Soils, p. 60). Many of these soils are used for row, feed, and forage crops and perennial pasture; but there appears to be some underutilization of prime lands in the study area.

Mineral Exploitation

There are many active and abandoned gravel pits in the Cuero area. They are most numerous to the northeast of the city, but also occur on scattered hills throughout the study area. Oil and gas production is indicated by the presence of wells, separators, and pumping stations.

Residential and Commercial

Most residential and commercial development is found within the Cuero city limits although some development extends southwest of the city along Route 183. The community of Arneckeville is found along Farm Road 236; other small communities include those of Green Dewitt, Hopkinsville and Clinton (fig. 2). In addition, there are many individual and clustered farm houses and buildings located throughout the area. In addition, four highways and three farm and market roads meet in Cuero, and railways enter the city from three directions.

Relationship of Land Use to Natural Factors

Perhaps the most obvious example of the link between land use and substrates is the presence of gravel pits. These are most numerous on the gravelly deposits of the Willis Formation. Less significant deposits on river terraces and hills are also exploited. The soils associated with gravel pits include Goldmire, Tremona, and Silvern-Ellen.

Cropland and pastureland found along the Guadalupe River usually occurs on the Meguin soils that are occasionally flooded. Those Meguin soils that are frequently flooded support floodplain forests. Away from the river, the relationship between crop- and pastureland and soils is not so clear. However, Papalote and Weesatche, prime agricultural soils, are often occupied by cropland and pastureland, while Leming and Miguel, non-prime soils, are often associated with rangeland. Topography is another indicator of agricultural land use, the steeper slopes usually being occupied by unimproved range.

Location of Test Well on the Basis of Land Use

Effect of Land Use on Test Well

The most appropriate locations for a test well, in terms of current land use, are those with the smallest economic value or investment for other uses and the least cost for construction of the test well and related facilities. Table 13 summarizes these criteria for the land uses in the study area.

Economic Value

High-value land uses include residential and commercial areas, active gravel pits, cropland, and harvested pecan groves. Pecan wood is also valuable, as is that of bald cypress, both of these growing in the bottomlands. Pasture and rangeland are valuable in terms of the cattle produced there. Rangeland also produces oak and mesquite trees, used for fence posts, firewood or charcoal, and railroad ties (Texas Forest Service, 1971; Vines, 1960). Abandoned gravel pits are of low value.

Table 13. Relative site preparation costs and land use values. Cuero study area.

Land use in order of decreasing suitability for test well	Relative cost of site preparation	Relative value of land use
Gravel pits, abandoned	mod-high	low
Open range	low	low-mod
Scrub range	low-mod	low-mod
Wooded range	mod	low-mod
Pasture	low	mod
Cropland	low	mod-high
Pecan groves	mod-high	mod-high
Gravel pits, current	mod-high	high
Built-up	mod-high	high

Cost Savings

The least expensive areas to locate a well, from the standpoint of land use, are cropland and pastureland as no clearing would be necessary. Shrubby rangeland would pose some expenses for clearing of vegetation, but these are small compared to the total cost of the well. The bottomland forests, the denser upland wooded areas, gravel pits, and built-up areas would pose the greatest cost for preparation of the test site.

Effect of Test Well on Land Use

The major effect of the test well would be removal of 5 to 6 acres of land from its original use, and, possibly, the use of additional land for an industrial facility in the future. An accidental spill or blowout could affect the vegetation for a variable distance around the well site. A slow leak may subtly alter the species composition and balance whereas a more serious spill or blowout could destroy vegetation in the affected area. Hot brine expelled by a blowout could be directly injurious to livestock grazing in the immediate vicinity. In the event of a spill the high salinity of the brines could destroy surrounding crops and forage grasses by direct toxicity and osmotic interference. The brine could also have a marked effect on soil chemistry and nutrition, reducing water absorption by clays, inhibiting moisture movement through the solum, reducing nutritional absorption by the soils and retarding the action of various soil microorganisms, thus affecting the agricultural capability of the land (Gustavson and others, 1978).

Components of geopressured fluids such as boron may also have a deleterious effect on crops. Boron, although essential for plant growth, is toxic to sensitive crops at 1 mg/l or less (USEPA 1976). The concentration in geopressured water is 20-60 times this level (Gustavson and others, 1978). Other possibly detrimental substances that could occur in higher than recommended limits include beryllium, silica, magnesium, manganese, sodium and others (Appendix B). In addition to injuring the crops growing at the time, the possibility of residual effects could affect the yield or the choice of crops grown in following years, depending of course on the nature and extent of the spill.

Table 14 is a summary of the possible effects of the test well on land uses and the relative significance and area of impact of these effects. Although the numbers are only relative, the totals serve to indicate which land use areas would be most seriously affected by a test well, and, the type of test well activity that would be most deleterious to land use.

Table 14. Significance of test well for land use.

Cuero	Site preparation	Normal operations	Small leak or spill	Major blowout	Subsidence	Subsidence and faulting	Cumulative	Rel. effect*
Active gravel pits	4 / 1	2 / 1	1 / 1-2	1 / 3	1 / 5	1 / 4	10 / 16	26
Abandoned gravel pits	1 / 1	1 / 1	1 / 1-2	1 / 3	1 / 5	1 / 4	6 / 16	22
Range	1 / 1	1 / 1	3 / 1-3	3 / 3	1 / 5	1 / 4	10 / 16	26
Pasture	2 / 1	1 / 1	3 / 1-3	4 / 3	1 / 5	1 / 4	12 / 16	28
Cropland	3 / 1	1 / 1	4 / 1-3	5 / 3	1 / 5	1 / 4	15 / 16	31
Residential/ commercial	5 / 1	3 / 1	4 / 1-3	5 / 3	3 / 5	5 / 4	25 / 16	41
Overall	16 / 45	69 / 46	16 / 11	20 / 18	8 / 30	10 / 24	Significance of effect / Relative area affected	
Relative importance of test well activities on land use	21	15	27	38	38	34		

*Relative effect of test well on land uses.

Land Use Suitability for Test Well

Abandoned gravel pits would be well suited for a test well since their value is low, but they might pose costs for preparation of the construction site. In addition, they occur only in isolated plots of limited size. The most suitable agricultural areas for test well location are those areas at present under rangeland as these are the least economically valuable. They may pose some expenses for clearing of vegetation, but these would be small compared to the total cost of the well. An additional advantage is that rangeland generally occupies large tracts of land that would be similarly suitable if full scale energy production should develop. These larger areas could also provide a buffer zone betwen the well and more valuable land should an accidental spill occur.

Pastureland, especially where it is isolated from cropland by range, would be the next most suited. Areas under pasture are however often large or in conjunction with cropland thus exposing extensive areas of relatively valuable land to the possible effects of an accident.

To locate the well on cropland (cultivated land or pecan groves) would be removing land more valuable than rangeland from its original use, although the removal of the few acres needed to support the test well would probably be inconsequential. Patches of cropland isolated within range could accommodate a test well without significant loss, but large tracts of cropland (or cropland and pasture together) would not be as well suited as explained for pastureland.

The river forest would be expensive to clear and would remove valuable trees. A spill or blowout could seriously damage other trees in the vicinity. These areas are also unsuitable for other reasons (see Hydrology and Soils).

The least suited locations for the test well are those in proximity to residential and commercial development due to the remote possibility that human well-being or even life, could be endangered. The location of individual residences to be found within agricultural land should not be overlooked.

BIOLOGICAL RESOURCES

VEGETATION

The information on vegetation in the Cuero area comes from aerial photographs, field investigation, the DeWitt County Soil Survey, and personal communications with DeWitt County Soil Conservation Service personnel and the County Agricultural Agent. Major references include Vines (1960) and Correll and Johnston (1970).

Mapping

A vegetation cover map for the Cuero area was prepared based on aerial photographs and field checking (fig. 25). Map units were described as follows:

- Parkland and Open Grassland—Grassland areas without woody vegetation or with scattered individuals or clumps of shrubs and trees.

- Brush Land—Grassland areas with a significant cover of shrubs and small trees. On the map, they are stippled to show dense and sparse woody cover.

- Woodland—Areas with a significant cover of medium-sized or large trees. They are striped on the map to show open and dense tree cover.

- Pecan Forest—Areas of large trees, generally with a continuous canopy cover primarily of pecan trees.

- Bald Cypress Swamp—Swamp forest with the canopy primarily of bald cypress trees.

- Cultivated Land—As on the land use map, areas planted to row crops or annual forage crops.

- Built-up Land—As on the land use map, areas wich a high density of residential or commercial buildings.

Description

The vegetation of the study area has affinities to both the more humid-climate vegetation north of DeWitt County and the hotter, drier-climate vegetation to the southwest.

Uplands

Annual rainfall in the study area is high enough to support tall prairie grasses; the original grasses included: little bluestem (Schizachyrium scoparium), switchgrass (Panicum virgatum) and Indian grass (Sorghastrum nutans), climax species of the tallgrass prairies (Gould, 1975; Soil Conservation Service, 1978). Drier-prairie mid- and short grasses were also among the climax species: silver bluestem (Bothriochloa saccnaroides), buffalo grass (Buchloë dactyloides), curly mesquite (Hilaria belangeri), and grama grasses (Bouteloua spp.). Originally, the uplands of the study area were open grassland or grassy savannah with scattered individuals of woody species such as oaks and mesquite (Gould, 1969).

Years of cattle grazing have put great pressure on the climax grasses with the result that they have declined while other grasses and woody plants have increased tremendously. There are now large areas of shrubland covered with mesquite (Prosopsis juliflora), huisache (Acacia farnesiana), blackbrush (A. rigidula), and retama (Parkinsonia aculeata), as well as an increase in the density of trees, particularly live oak (Quercus virginiana), blackjack oak (Q. marilandica), and post oak (Q. stellata). Grasses more tolerant to cattle grazing have increased or invaded. Increasers common in the study area include balsam scale (Elyonurus tripsacoides), Texas wintergrass (Stipa leucotricha), Texas grama (Bouteloua rigidiseta), and brownseed paspalum (Paspalum plicatulum). Invaders include red lovegrass (Eragrostis secundiflora), splitbeard bluestem (Andropogon ternarius), and broomsedge (A. virginicus). Common bermuda grass (Cynodon dactilon) has become naturalized and is ubiquitous. Many species of forbs have also increased or invaded (Soil Conservation Service, 1978; Shaw, D., personal communication).

The pasture and range (see Land Use) within the study area is described as Parkland/grassland, Brushland, or Woodland, depending on the density and type of woody cover. Upland woodland is generally found on the steepest slopes (over 3 percent) and in gravelly areas such as that northeast of Cuero. Upland cropland is generally found on flat hilltops.

Bottomlands

Several distinctive types of vegetation are found in the varied environments of the Guadalupe flood plain. Cut-off meanders and overflow channels support bald cypress (Taxodium distichum) swamps. Bald cypress is also found scattered along the banks of the river. Although found throughout the southern states, bald cypress is at the southern edge of its Texas range in DeWitt County (Preston, 1976). Frequently-flooded bottomlands are covered by pecan forest. Most of this is natural growth and is not harvested, but a few landowners maintain and harvest the native trees; there are also a few planted pecan orchards. Those bottomlands which are infrequently flooded are generally planted to forage or row crops.

Vegetation on the floodplains of the smaller streams consists of a variety of trees and shrubs, such as ash (Fraxinus spp.), Western soapberry (Sapindus drummondii), cedar elm (Ulmus crassifolia), sycamore (Platanus occidentalis), and willow (Salix sp.). The three oaks common to the area are also found along the creeks and form woodlands on valley slopes. Some species rather unusual for the area include American beautyberry (Callicarpa americana), wooly buckeye (Aesculus discolor), and Amorpha. The creek floodplains provide good rangeland, typical grasses being silver bluestem, sideoats grama (Bouteloua curtipendula), Panicums, windmill grass (Chloris verticillata), and threeawns (Artistida spp.) (Paul, B., personal communication).

Appendix D includes a list of species identified in the study area or likely to be found there. Time and resources did not permit a comprehensive survey; broad-leafed species which are likely to be in the area but were not seen are included and indicated as such.

Rare and Endangered Plant Species

One rare plant, Calliandra biflora, may very possibly occur in the study area (Johnston, M., personal communication; Texas Organization of Endangered Species, 1977). It is a subshrub in the legume family and is known only from grasslands in DeWitt and Goliad Counties (Correll and Johnston, 1970). It is endangered throughout its range, and is proposed for the Federal Listing of Endangered and Threatened Species (Talbot, S., personal communication).[1]

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[1] In November 1979 all proposed species will be either listed, dropped, or reproposed. A biological assessment and status report is being prepared on C. biflora by William Mahler of Southern Methodist University.

The vegetation of Texas is still relatively little known, especially on a local level; therefore, it is quite possible that other threatened, rare, or endangered species may occur in the study area. A survey should be made of potential well locations to ascertain the presence or absence of rare plants.

Location of Test Well on the Basis of Vegetation

Effect of Vegetation on Test Well

From the point of view of cost savings for construction of the well, open grassland or cropland would be more suitable locations since clearing of brush and trees would not be required. (See Land Use for detailed discussion.)

Effect of Test Well on Vegetation

The initial impact of a test well on vegetation would be the elimination of 5 to 6 acres for the test well site, which, if carefully chosen, need not have a significant effect on the environment. Surface spills or blowouts could, however, eliminate vegetation in a larger area and residual effects could prevent the return of vegetation for many years (See Effect of Test Well on Land Use). The absence of vegetation on the Saratoga oil field in Hardin County, Texas, is believed to be the result of large-scale brine and/or hydrocarbon spills 30 to 80 years ago (Gustavson and others, 1978).

Vegetation Suitability for Test Well

Several factors should be considered when considering the suitability of vegetation for a test well: the presence of rare and endangered species, the recovery time required for vegetation to return to its previous condition, the abundance of the vegetation type in the region, the fauna dependent upon it, and its economic value.

Presence of rare and endangered species: This can only be determined from a site-specific survey; in particular, the native grasslands may harbor Calliandra biflora.

Recovery time: Wooded areas would take longer to recover from clearing activities or from destruction by an accidental spill than would grasslands.

Abundance: Of the vegetation types mapped in the study area, pecan forest and bald cypress swamps are the scarcest. (As mentioned, bald cypress is near the southern edge of its range in DeWitt County.) Vegetation along the smaller streams is not mapped separately, but some of the species occurring there are unusual within the study area.

Economic Value: In terms of present or potential economic value cultivated vegetation, pecan and grassland have a high value due to their continual productivity while brushland areas are of a moderate value due to lower productivity. Cypress forest and oak woodland are less valuable due to the many years between harvests.

Wildlife Value: Cultivated land is of the least overall value to wildlife, although grain left in the field after harvest is valuable to flocks of migratory birds and small animals. Parkland/grassland is used by small mammals such as rabbits and foxes, and birds such as quail, dove, meadowlarks, and field sparrows. Brushland is good habitat for wild turkeys, skunk, deer, coyotes, and raccoons. Mesquite seeds are an important wildlife food, being eaten by quail, doves, squirrels, coyotes, skunks, jackrabbits, and deer. Woodland provides acorns for turkey, deer, and squirrel in autumn and winter. Pecan forest provides food and habitat for birds, squirrels, opossum, and raccoon. Bald cypress seeds are eaten by many birds, including ducks. However, most of the bald cypress trees are found on Sarnosa soils, which are rated Very Poor overall for wetland habitat (Soil Conservation Service, 1978; Vines, 1960).

From the above analysis it appears that cropland and grassland/parkland are the most suitable vegetation types for location of a test well. They pose the least costs for clearing, having the shortest recovery times, are relatively abundant in the area, and have a relatively low wildlife value. Although a more valuable wildlife habitat, rangeland is also suitable since it is abundant and clearing of the brush would not be a significant expense. Woodland is common but would be more expensive to clear. Pecan forest and bald cypress swamps are the least suitable locations, due to their relative scarcity, high cost to clear, and value to wildlife.

WILDLIFE

Due to lack of data specific to the Cuero area, information on the fauna of the study area was gathered largely from data pertaining to DeWitt County as a whole. Sources include personal communications with personnel of the Texas Parks and Wildlife Department, publications of this agency, the DeWitt County Soil Survey, and several publications on wildlife in the State of Texas. Table 15 indicates endangered or threatened species of DeWitt County and table 16 gives information on the hunted species of the county. The Appendix contains lists of the mammals, birds, amphibians, and reptiles.

Description

Mammals

DeWitt County falls within the range of many common species of mammals as well as that of the endangered ocelot (Felis pardalis) (Potter, F., personal communication, 1979). The ocelot's preferred habitat is thick brush or forest, its status being due in part to clearing of this vegetation within its range, and to predator control activities of the Fish and Wildlife Service. White-tailed deer are an important resource on the rangeland of many of the larger ranches in DeWitt County.

Birds

Many birds occur in DeWitt County including the endangered Attwater prairie chicken (Tympanuchus cupido attwateri). The endangered whooping crane (Grus americana), interior least tern (Sterna albifrons athalassos) and, possibly, the eskimo curlew (Numenius borealis) may pass through the county during their annual migrations. A short comment on these species can be found in the Colorado County section on Wildlife. Threatened birds whose occurrence has been verified for the county include white-tailed hawk (Buteo albicaudatus hypospodius), swallow-tailed kite (Elanodies f. forficatus), osprey (Pandion haliaetus carolinensis), and wood stork (Mycteria americana). The white-faced ibis (Plegadis chihi) probably occurs in the county. The reddish egret (Dichromanassa r. rufescens) and the golden cheeked warbler (Dendroica chrysoparia) may be found there (Potter, F., personal communication, 1979).

Table 15. Endangered and threatened species: DeWitt County

Species protected by Texas Parks and Wildlife Dept. regulations		Presence in county	Comments
ENDANGERED			
Mammals			
Ocelot	Felis pardalis	Probable	Dense brush
Birds			
Attwaters prairie chicken	Tympanuchus cupido attwateri	Verified	Resident
Whooping crane	Grus americana	Verified	Migratory
Interior least tern	Sterna albifrons athalassos	Probable	Migratory
Eskimo curlew	Numenius borealis	Possible	Migratory
Reptiles			
American alligator	Alligator mississipiensis	Verified	Waterways
THREATENED[1]			
Birds			
Whitetailed hawk	Buteo albicaudatus hypospodius	Verified	Resident
Swallowtailed kite	Elanoides f. forficatus	Verified	Migratory
Osprey	Pandion haliaetus carolinensis	Verified	Migratory
Wood stork/ibis	Mycteria americana	Verified	Migratory
Whitefaced ibis	Plegadis chihi	Probable	Resident
Reddish egret	Dichromanassa r. rufescens	Possible	Resident
Golden-cheeked warbler	Dendroica chrysoparia	Possible	Migratory
Reptiles			
Texas tortoise	Gopherus berlandieri	Probable	
Texas horned lizard	Phrynosoma cornutum	Probable	
Mexican milk snake	Lampropeltis triangulum annulata	Probable	
Texas indigo snake	Drymarchon corais erebennus	Possible	
Amphibians			
Black-spotted newt	Notophthalmus m. meridionalis	Possible	Waterways
Rio Grande siren	Siren intermedia texana	Possible	Waterways
Fish			
River darter	Hadropterus shumardi	Verified	Guadalupe
Blue sucker	Cycleptus elongatus	Probable	Waterways
Species not protected			
From the Texas Organization of Endangered Species Watchlist			
Birds			
Prairie falcon	Falco mexicanus	Probable	T[2]
Reptiles			
Reticulate collard lizard	Crotaphytus reticulatus	Possible	T[2]
Northern cat-eyed snake	Leptodeira s. septentrionalis	Possible	T[2]

[1] Protected non-game species

[2] *T: depleted by man; likely to become endangered in the near future*

Sources: Potter; Brownley; personal communication
TOES watchlist of endangered, threatened, and peripheral vertebrates of Texas, 1979

Table 16. Approximate figures from 1978 inventory of hunted species Dewitt County.

Species	Number available for harvest[1]	% of Total Population	Total Population
[3]White-tailed Deer	2,828	20	14,140
[3]Javalina	200	20	1,000
[3]Bobwhite Quail	58,000	40	145,000
[3]Squirrel	35,000	40	75,000
Rabbit/Hare	58,000	40	145,000
[2,3]Bobcat	320	35	1,914
Coyote	900	40	2,250
[3]Furbearers*	1,000	35	2,850
[3]Fox	100	35	285

Regulated Game Birds Known to Occur in DeWitt County

Snow Goose
Wood Duck
Wild Turkey

*Muskrat, nutria, raccoon, badger, opossum, skunk, ringtail, beaver, mink, fox. See Appendix for Latin names.

1. Based on production or carrying capacity.
2. On Federal Register of Protected Species.
3. Regulated by hunting laws.

Sources: Hergots; pers. comm.
Hope, McMahan, pers. comm. TPWD.

Reptiles and Amphibians

The endangered American alligator (Alligator mississipiensis) occurs in the waterways of DeWitt, the county supporting a population of about 30 in its approximately 9 mi^2 of alligator habitat. Other protected reptiles probably occurring in the county include the Texas tortoise (Gopherus berlandieri), Texas horned lizard (Phrynosoma cornutum), the Mexican milk snake (Lampropeltis triangulum annulara) plus, possibly, the Texas indigo snake (Drymarchon corais erebennus). Protected amphibians that may be found in DeWitt are the black spotted newt (Notophthalmus m. mendionalis) and the Rio Grande siren (Siren intermedia texana) (Potter, F., personal communication, 1979).

Fish

The only abundant population known in Texas of the protected river darter (Hadropterus shumardi) is found in the Guadalupe River in the vicinity of the proposed Cuero reservoir, the latter located just north of the study area (Texas Parks and Wildlife, 1978). The protected blue sucker (Cycleptus elongatus) is also likely to occur in DeWitt County (Potter, F., personal communication, 1979).

Location of the Test Well on the Basis of Wildlife

Although construction of the test well will only destroy about 5 to 6 acres of habitat (value of vegetation as wildlife habitat was considered in the vegetation suitability analysis), wildlife in a wider area may be affected by the noise and activities associated with the construction and normal operations of the well. As DeWitt County does not appear to have any crucial habitats of endangered species this should be inconsequential to wildlife especially as it is likely that the majority will become habituated to these disturbances. A spill or leak could affect vegetation and therefore wildlife over a larger area and if occurring as a blowout of hot saline water could also be directly injurious to both the wildlife and vegetation in the area. Most of the habitats (grassland, brush, woodland) of the Cuero area are relatively widespread and, with the possible exception of during the breeding season, wildlife should have no problems moving to nearby suited areas.

If the well were to be located near the Guadalupe River, further investigations on the distribution and habits of the river darter should be made, especially with reference to their tolerance to changes in salinity and temperature and the effect of these changes on their food sources.

LOCATION OF TEST WELL ON THE BASIS OF ALL ENVIRONMENTAL CHARACTERISTICS

Mapping

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 more fully in Appendix A, but basically they involve using matrices to assist in making relative suitability comparisons (tables A1 and A3) and transparent-translucent overlays constructed from mappable characteristics. Each mapped unit was given a ranking from 1 to 6, depending on its relative suitability for a geopressured geothermal test well. Units with rankings of 1, 2, or 3 pose minor problems which can be mitigated relatively easily. They are left transparent on the overlay maps. Units with rankings of 4, 5, and 6 are shaded light, medium, and dark gray, respectively, while preempted areas (the city of Cuero and archaeological sites) are blacked out. Thus, the composite suitability map (fig. 26) indicates by the degree of shading the relative suitability and unsuitability of specific locations for a geopressured geothermal test well.

The composite suitability analysis combines information on: soil properties and characteristics, hydrology, land use, vegetation and archaeology. The final map shows that in the Cuero area the boundaries between suitability units often coincide with soil units as several factors were mapped on the basis of soil properties. These boundaries are modified by other mapped characteristics such as land use and vegetation. Environmental factors such as meteorological characteristics and potential for subsidence which could not be meaningfully depicted on the transparencies were considered in the final evaluation of test well locations.

Final Evaluation

The following description is of the test well prospect area since the well site is limited to this area by the location of the geopressured geothermal reservoir.

The overall analysis indicates that, in general, suitability for a test well increases from the Guadalupe River bottomlands in the northeast towards the uplands of the southwest. The two major physiographic divisions in the prospect area--the Guadalupe River bottomlands and the uplands--are clearly differentiated on the composite suitability map, much of the upland area being lightly shaded with shading density increasing towards the bottomland with the latter appearing dark.

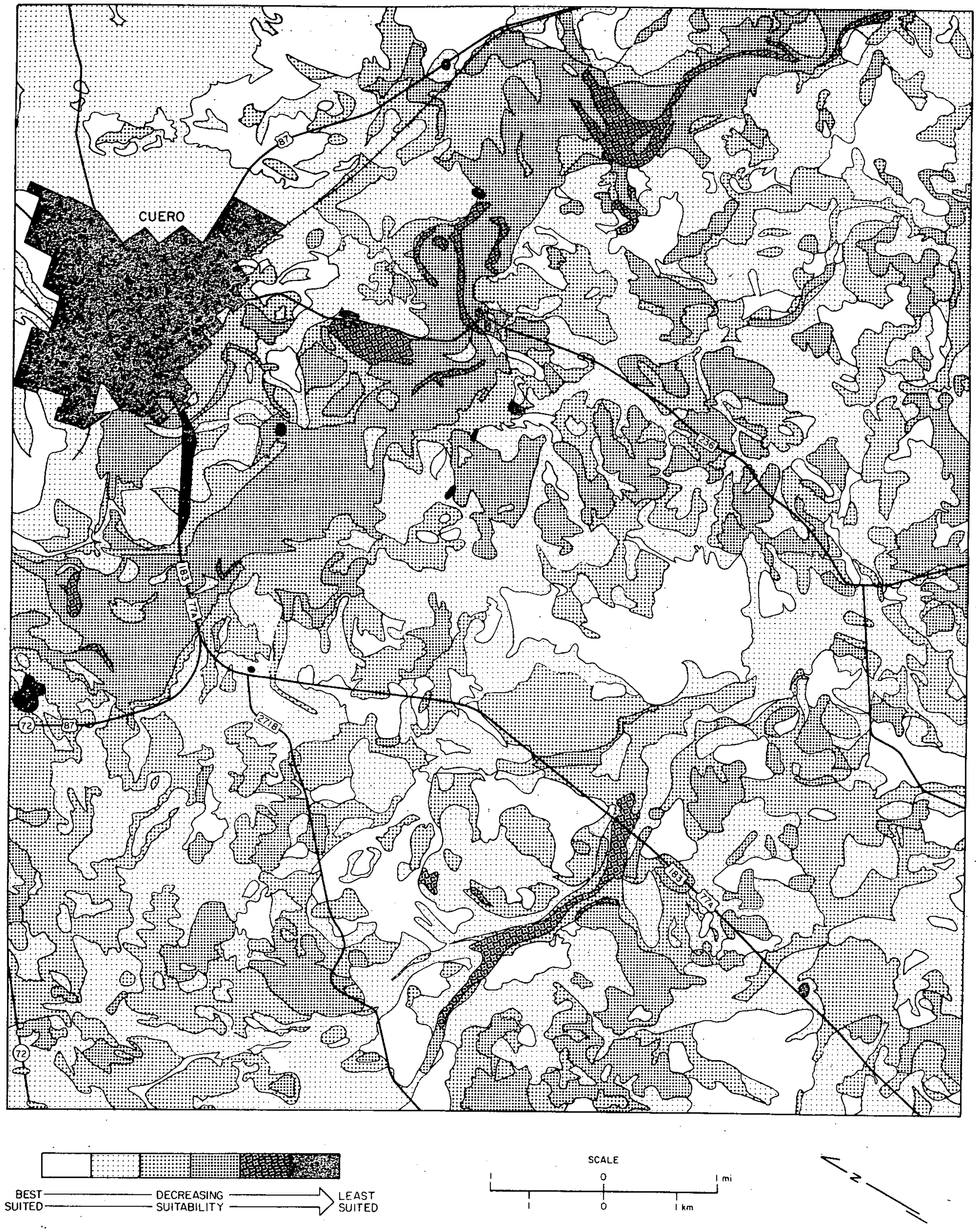

Figure 26. Areas of Varying Suitability for the Location of a Test Well, Cuero Study Area.

The prevailing winds of the Gulf Coast place Cuero on the downwind side of the prospect area. However, although the northeastern part of the prospect area is on a direct line with the prevailing winds, the southwestern half is not, and, in addition, is further from Cuero, placing the uplands again in a more favorable location for a test well. Furthermore, the distance of the uplands from Cuero decrease the chances that the city would be affected should subsidence occur.

Uplands

In the uplands of the prospect area few areas have unsuitable land uses or vegetation and soil related problems are minor and few. The prevailing wind direction is not towards Cuero and the distance from the city lessens the chance that subsidence will affect it. Within the western half of the uplands the areas of Orelia soils show no unsuitable characteristics as they:

1) have low potential for erosion
2) have low potential for groundwater contamination
3) are not prime agricultural soils
4) do not pose problems for well construction or pond location
5) do not support a conflicting land use
6) do not provide a conflict with important vegetation areas
7) the majority of areas these soils occur in are the western half of the prospect area where, due to the prevailing wind direction, air polution from the well would be less likely to affect Cuero; location in the far west would also reduce the likelihood of affecting the small communities at Clinton and Hopkinsville.
8) the increased distance from Cuero reduces the chances of the city being affected by subsidence.

Areas of Orelia soils appear transparent on the overlays and white on the composite map (fig. 26).

There are several soils almost as suited as the Orelia; these include: Leming (shaded due to their erosion potential), Tremona very gravelly soils (unsuited for construction), Lupe (moderate groundwater contamination potential), Straber (prime soils) and Papalote soils with less than 1% slope. (Prime soils over 1% slopes also have a problem of erosion potential.)

Less suited areas of the uplands include frequently flooded areas along streams. The only unsuited areas are the archeological sites which are preempted from construction. The exact location of these is shown on the transparent overlays but, at the request of the Texas Archaeological Research Laboratory, they are not indicated on the composite map.

Bottomlands

The extent of bottomlands in the prospect area is small and relatively unsuited to test well development due to combinations of 100 year, 10 year, or more frequent flood occurrence, moderate goundwater contamination potential and the presence of local shallow aquifers, unsuitability for construction or pond location, the presence of valuable pecan wood habitat and some prime soils, plus the presence of several archaeological sites. In addition, the prevailing wind direction from the bottomlands is towards Cuero, and the relative proximity to the city increases the chance that it would be affected by subsidence.

PRELIMINARY ENVIRONMENTAL ANALYSIS OF A POTENTIAL GEOPRESSURED GEOTHERMAL PROSPECT AREA IN COLORADO COUNTY, TEXAS

The Colorado County prospect area is a possible site for testing geopressured geothermal resources in the Wilcox Formation of the Texas Coastal Plain. Evaluation of the reservoir in terms of its potential as a geopressured geothermal energy resource is reported by Bebout and others (1978). The reservoir consists of 1,050 ft of sandstone in the interval between 10,960 ft - 13,000 ft. Whole core analyses from the reservoir section show a range in porosity from 3.8 to 19 percent and a range in permeability from 0 to 545 millidarcys. Fluid temperatures in the test well would range from approximately 280 to 325°F. Formation fluid salinity was calculated from log analysis and is expected to be about 90,000 ppm.

The site of the test well within the Eagle Lake prospect area will be determined by comparing areas most suitable geologically with areas that have few environmental constraints to identify a site or sites that are acceptable both geologically and environmentally. As for the Cuero area, the Eagle Lake study is in two parts: (1) an environmental inventory and analysis and (2) a suitability analysis identifying more and less suitable locations for a test well. The environmental inventory was conducted for the entire study area to provide baseline data; however, the smaller prospect area was emphasized in the suitability analysis.

GENERAL SETTING--EAGLE LAKE STUDY AREA

The study area in Colorado County encompasses 85 mi^2 (218 km^2) in the eastern corner of Colorado County between the Colorado and San Bernard Rivers (fig. 27). Within its boundaries are the city of Eagle Lake and its namesake. The upland of the study area slopes very gently toward the east. Topography is more rolling in the Colorado River bottomlands. In the study area elevations range from 150 ft (46 m) to 210 ft (64 m) (fig. 28).

The test well prospect area is the surface projection of the geopressured geothermal reservoir and covers approximately 12 mi^2 (31 km^2) (fig. 27). It is mostly in the upland part of the study area and includes the northern half of the city of Eagle Lake; however, the majority of the prospect area is agricultural land.

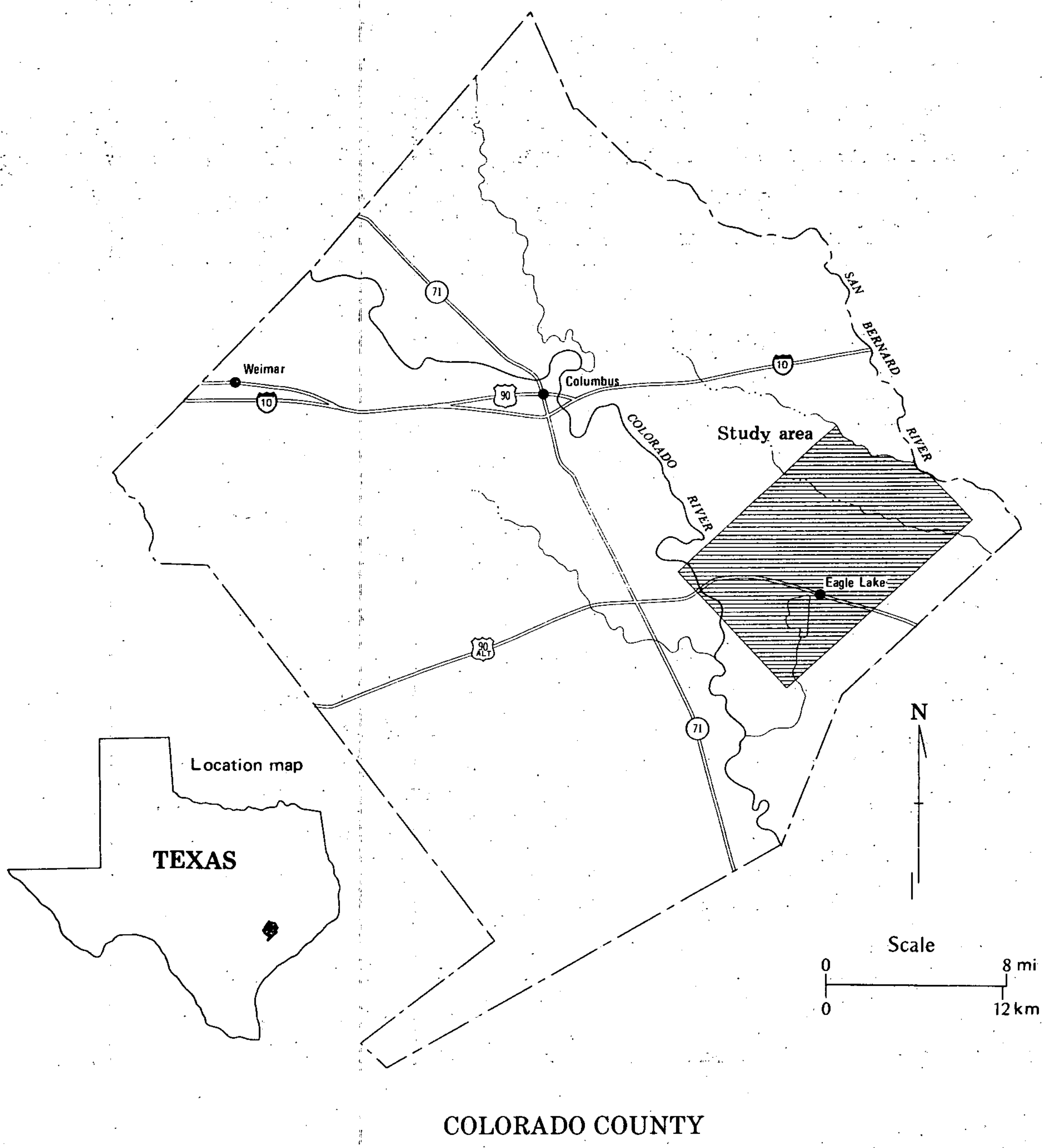

Figure 27. Location of the Eagle Lake Study Area.

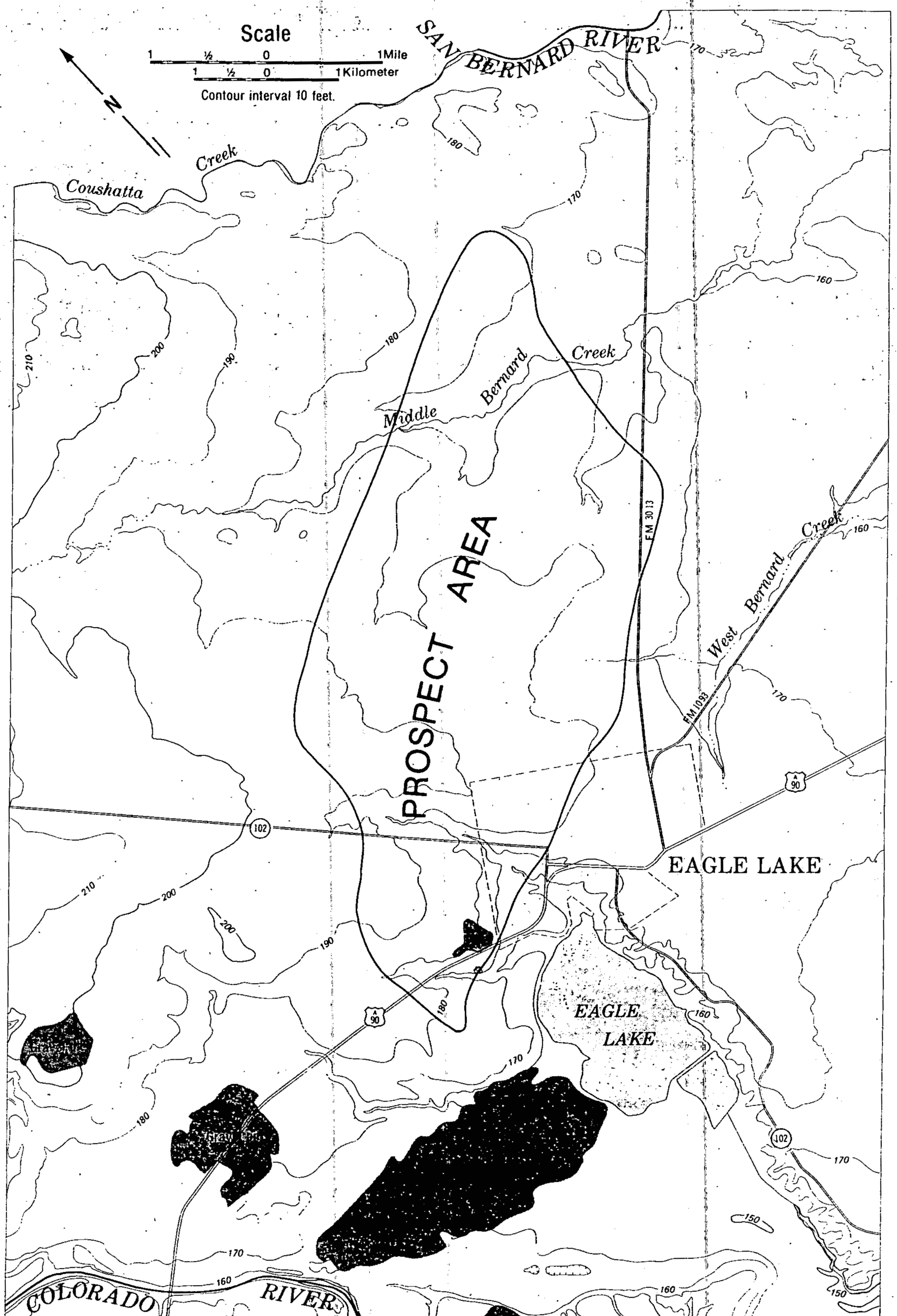

Figure 28. Relief, Eagle Lake Study Area. (Sources: Texas Air Control Board Continuous Air Monitoring Data Summaries, 1978; U.S. Geological Survey Topographic Maps; Texas Highway Department County Maps.)

SUMMARY

Review of Environmental Concerns for the Eagle Lake Prospect Area

Location of a geopressured geothermal test well in the Eagle Lake prospect area is subject to a number of concerns. Major concerns are reviewed below and discussed more fully in the text.

Archaeology. The Eagle Lake area is virtually unstudied archaeologically, although two sites are known from road constuction. A survey of the chosen test well site should be made to ensure there are no archaeological sites in the area.

Subsidence & Fault Activation. As the slope of the land is important in the local irrigation system it is possible that the effects of subsidence could be significant in this area. The presence of near-surface faults, possibly extensions of deep faults, may increase the likelihood of subsidence being accompanied by fault activation, which could be damaging to rigid structures such as roads, buildings and pipelines.

Ground Water Contamination. Ground water occurs at depths of 20 ft to 40 ft in the study area; should a brine spill occur, contamination of shallow water is a possibility.

Depth to the base of slightly saline water is as much as 3,050 ft in the study area; reinjection wells would thus have to be drilled very deep in order to avoid contaminating usable aquifers.

Flooding. Location in the flood plain of Middle Bernard Creek may raise additional considerations in construction and maintenance of a test well. The rise in water level in the prospect area for the 100 year flood is however only about 10 ft and the areal extent is small.

Soils. Some soils may pose problems of shrink-swell, corrosivity, and poor drainage. Due to the high clay content of many of the soils, they are likely to absorb ionic constituents of geothermal brine; thus, a spill could contaminate the soil for a significant length of time.

Land Use. Valuable and unique land uses pose potential conflicts with location of a test well. The most sensitive area is the Attwater Prairie Chicken National Wildlife Refuge, discussed under Vegetation and Wildlife. Land in rice production is valuable in its present use; although the test well facilities will require only 5-6 acres, if a larger facility were to become desirable, location on less valuable land would be preferable. Another consideration is that a spill might destroy a crop and/or contaminate the soil, possibly adversely affecting future rice production. Subsidence could alter drainage in rice fields. The Rice Research Station is an unsuitable location for a test well as it conducts long-term experiments in its fields.

Vegetation. Natural Areas: The prairie grasslands of the National Wildlife Refuge constitute one of the few areas of natural prairie remaining in the Gulf Coast. It is possible that well activities or accidents could detrimentally affect this vegetation.

Valuable Habitat: Prairie grassland is the only vegetation properly suited to the needs of the Attwater Prairie Chicken. Rice lands are an important winter habitat for migratory waterfowl and wooded and scrub areas along stream channels provide refuge for many species.

Rare Plants: It is possible that the southern marsh fern (Thelypteris palustris var. haleana) may occur in suitable habitats in the Eagle Lake area. As the vegetation of Colorado County is poorly known, other rare plants may be present. A study will need to be conducted on the chosen test well site to determine if any rare plants occur there.

Wildlife. A conflict of interest could arise if the test well were to be located within certain areas of the Eagle Lake area. The northern tip of the prospect area falls within the Attwater Prairie Chicken National Wildlife Refuge, while the range of this endangered species extends further into the prospect area; endangered Bald Eagles also use the refuge. Rice fields and water bodies of the area also provide prime habitat for a wide variety of resident and migratory birds including several endangered and threatened species. Eagle Lake itself supports a large population of the endangered alligator. The endangered Houston toad may possibly occur in Colorado County.

Location of the Test Well on the Basis of Environmental Characteristics

An analysis of the studied environmental characteristics of the test well prospect area suggest that there are no locations in the Eagle Lake area without environmental constraints for test well development. Areas with the fewest constraints include tracts of range and pasture, particularly those areas isolated in the ricelands where distances are greatest from the city of Eagle Lake and the Attwater Prairie Chicken National Wildlife Refuge.

METEOROLOGICAL CHARACTERISTICS

Climate

As Eagle Lake has no weather stations information relevant to the study area was obtained from other nearby National Oceanic and Atmospheric Administration stations. Temperature and precipitation graphs were taken from the nearby station at Sealy, Austin County, located at a similar elevation and distance from the coast as Eagle Lake. Although the climate description comes largely from that of Sealy, it was supplemented and verified for the region as a whole using information from three additional stations in the area.[1] The recently established weather station at the Texas A&M Rice Research Station in Eagle Lake may be able to provide more specific data in the future.

The climate of Eagle Lake is humid subtropical with hot summers. Regional climate is controlled largely by the Tropical Maritime air masses that predominate in the spring, summer and fall and by the proximity of the warm Gulf of Mexico. Prevailing winds throughout most of the year are south-southeasterly except in winter when the frequent passage of high pressure areas bring invasions of cold polar air and northerly winds. (Wind Rose, fig. 29).

Average annual rainfall for the region is about 40 inches (102 cm) (Sealy: 40.45 inches [103 cm]) and is fairly evenly distributed throughout the year (fig. 30). In wet years over 60 inches (152.4 cm) may fall, and in dry years rainfall may be little over 20 inches (50.8 cm) (fig. 31). May usually receives the most precipitation, averaging 4.5 inches (11.4 cm), with another period of high rainfall occurring about September. The driest month is generally March with the average rainfall of only 2.25 inches (5.7 cm). In Sealy the average May rainfall is 4.50 inches (11.4 cm), with the average for March being 2.31 inches (5.8 cm). Spring and summer rainfall is largely in the form of thundershowers, whereas winter precipitation comes as light steady rain. Mean annual lake evaporation for the region is approximately 54 inches (137 cm), exceeding rainfall by some 24 inches (61 cm). Humidity readings are only available for one station, Pierce, which places annual relative humidity at 87 percent at 6 a.m., 60 percent at noon and 65 percent at 6 p.m., with seasonal averages varying only slightly. The

[1] Pierce, Wharton Co.; El Campo, Wharton Co.; and Columbus, Colorado Co.

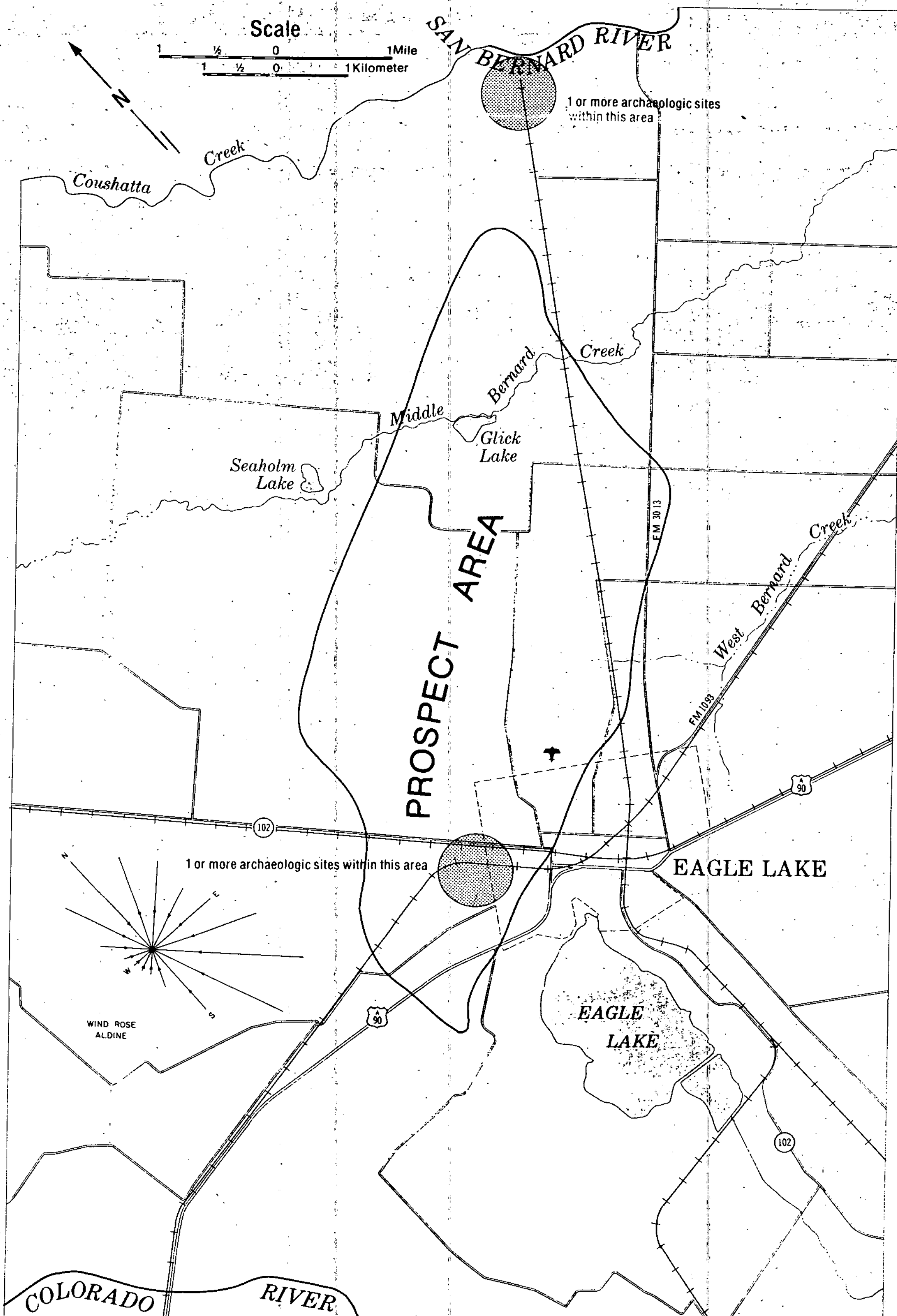

Figure 29. General Setting of the Eagle Lake Study Area, Location of Prospect Area, and Wind Rose. (Source: U.S. Geological Survey Topographic Maps.)

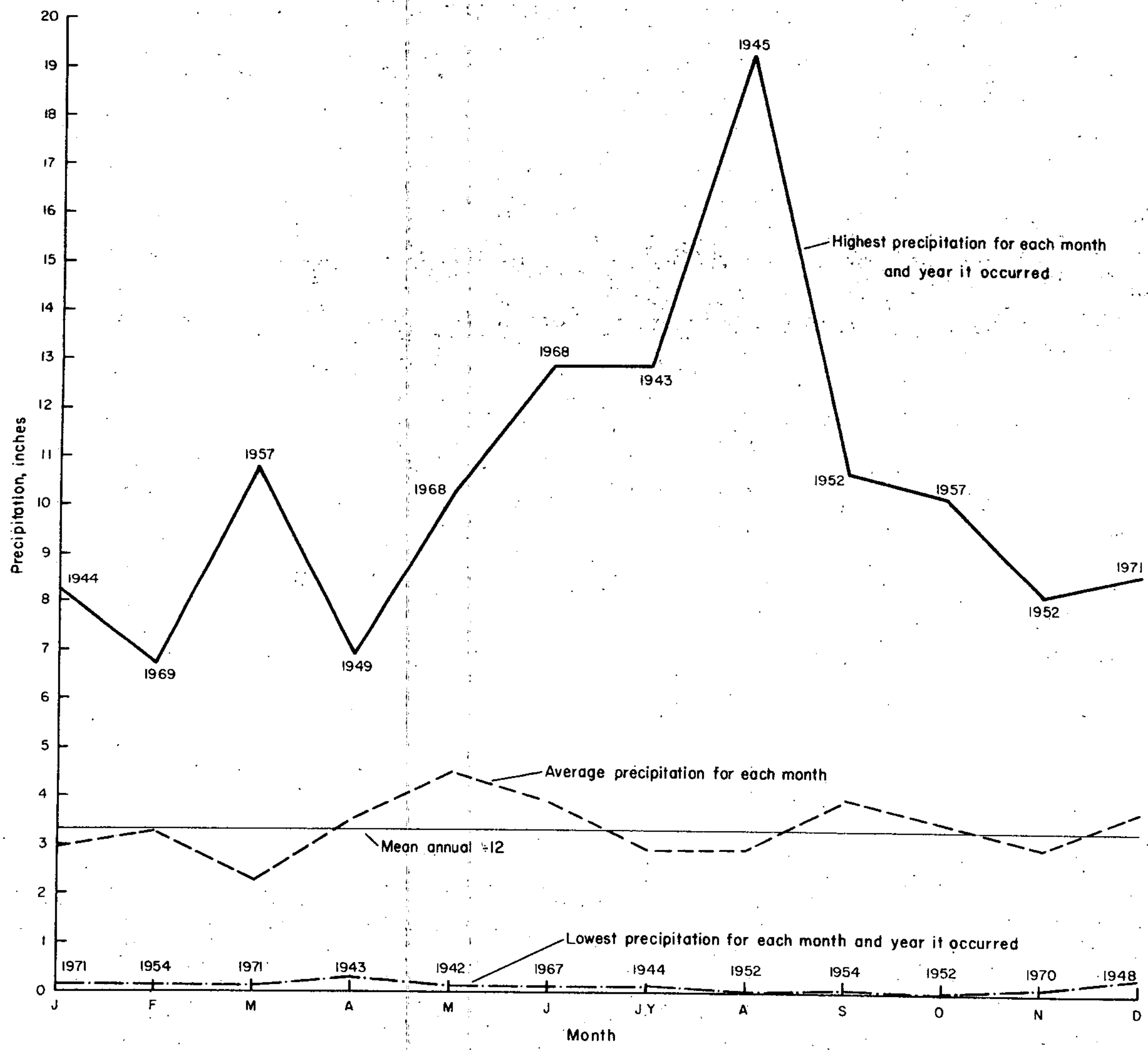

Figure 30. Monthly Precipitation, Sealy 1942-1976.

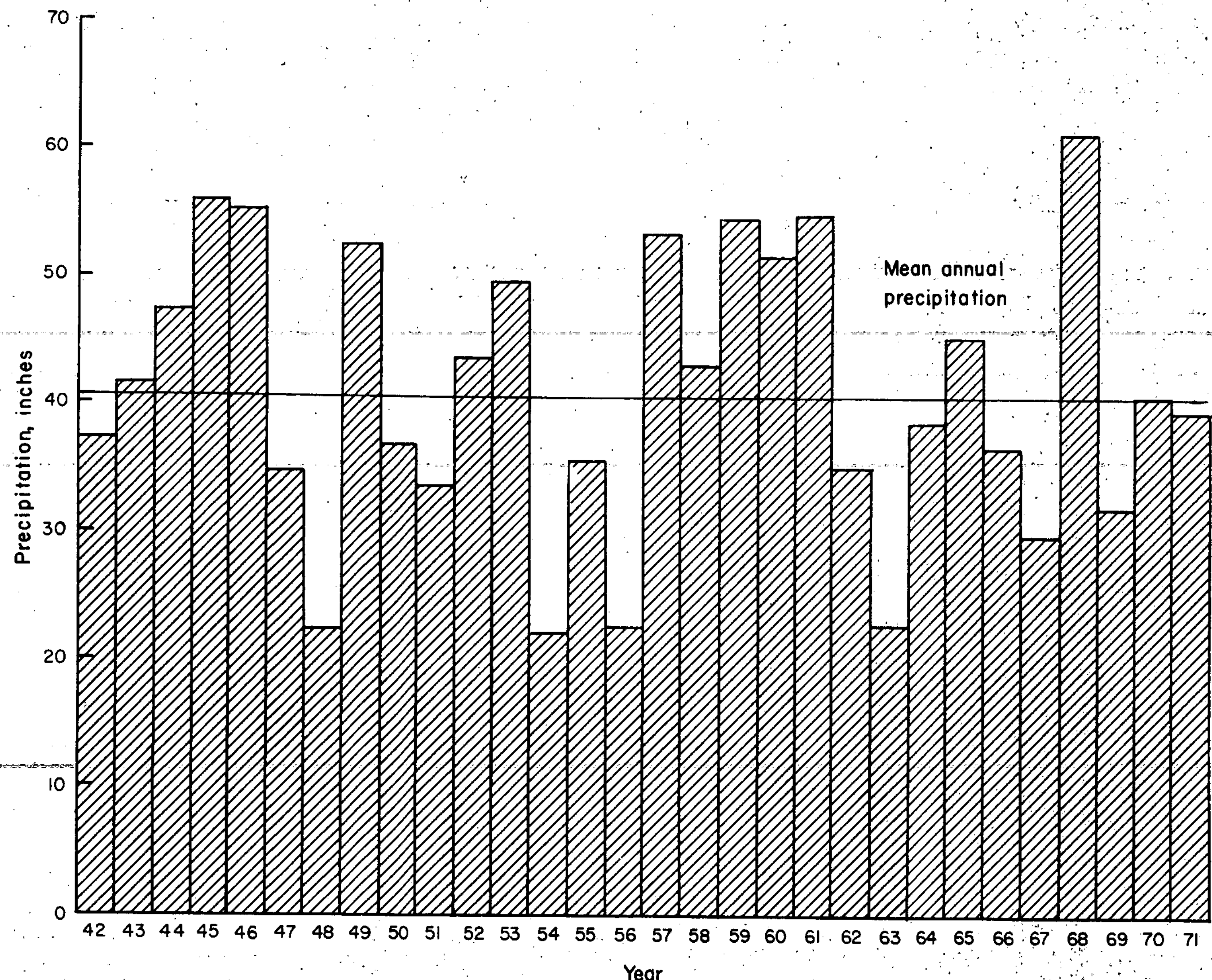

Figure 31. Annual Precipitation, Sealy 1942-1976.

average daily maximum for the summer months ranges from the mid 80's to the mid 90's with the record high in Sealy being 108°F (42°C) (fig. 32). Average minimum for the summer months are in the mid 70°'s to the mid 80°'sF (20's° C). Winter weather is generally mild, although variable with minimum averages for the winter months being in the 40's (4-10°C), the highs in the 60's and low 70's (15-20°C). The record low for Sealy is 2°F (-16°C). An average of 282 frost free days occurs in Sealy with the mean dates of the frost free season being February 26th to December 6th. Other locations in the region have as few as 266 frost free days. The area receives approximately 64 percent of the total possible sunshine annually.

Weather Hazards

The major hazards posed by weather are hurricanes, tornadoes, and flooding following heavy rainstorms. Flood-prone areas are discussed under Hydrology.

Eagle Lake is located about 60 miles from the coast and is not subject to storm surge caused by hurricanes. Tropical storms that make landfall in the vicinity of Eagle Lake may bring heavy rains and high winds to the area.

The tornado density for Colorado County, based on the years 1951-1971, is about 1.3 tornadoes per 1000 sq mi per year (National Weather Service, Austin 1979). For the 85 sq mi study area 1 tornado every 9 years or so could be expected.

Air Quality

Colorado County is in Region 7 of the air monitoring network of Texas. Due to the presence of the Houston metropolitan area in region 7 it is a non-attainment area; however, the Texas Air Control Board lists Colorado County itself as an attainment area for air quality. As there are no monitoring stations within the county, this is only the expected rather than the actual air quality. Due to the prevailing south-southeasterly winds off the Gulf of Mexico, it is likely that the components of the air in the vicinity of Eagle Lake would be influenced by pollution from the Houston area. Although the 50 mile distance from Houston would enable many pollutants to be broken down, concentrations of ozone are likely to remain. Air quality data from the continuous air monitoring stations (table 17) of region 7 (all of which are located in the vicinity of Houston or other industrial coastal cities) indicate that ozone and non-methane hydrocarbons are commonly at levels that exceed the maximum allowable as defined by national ambient air standards (Texas Air Control Board 1978b). Total suspended particulate levels (TSP) for the region recorded by non-continuous air

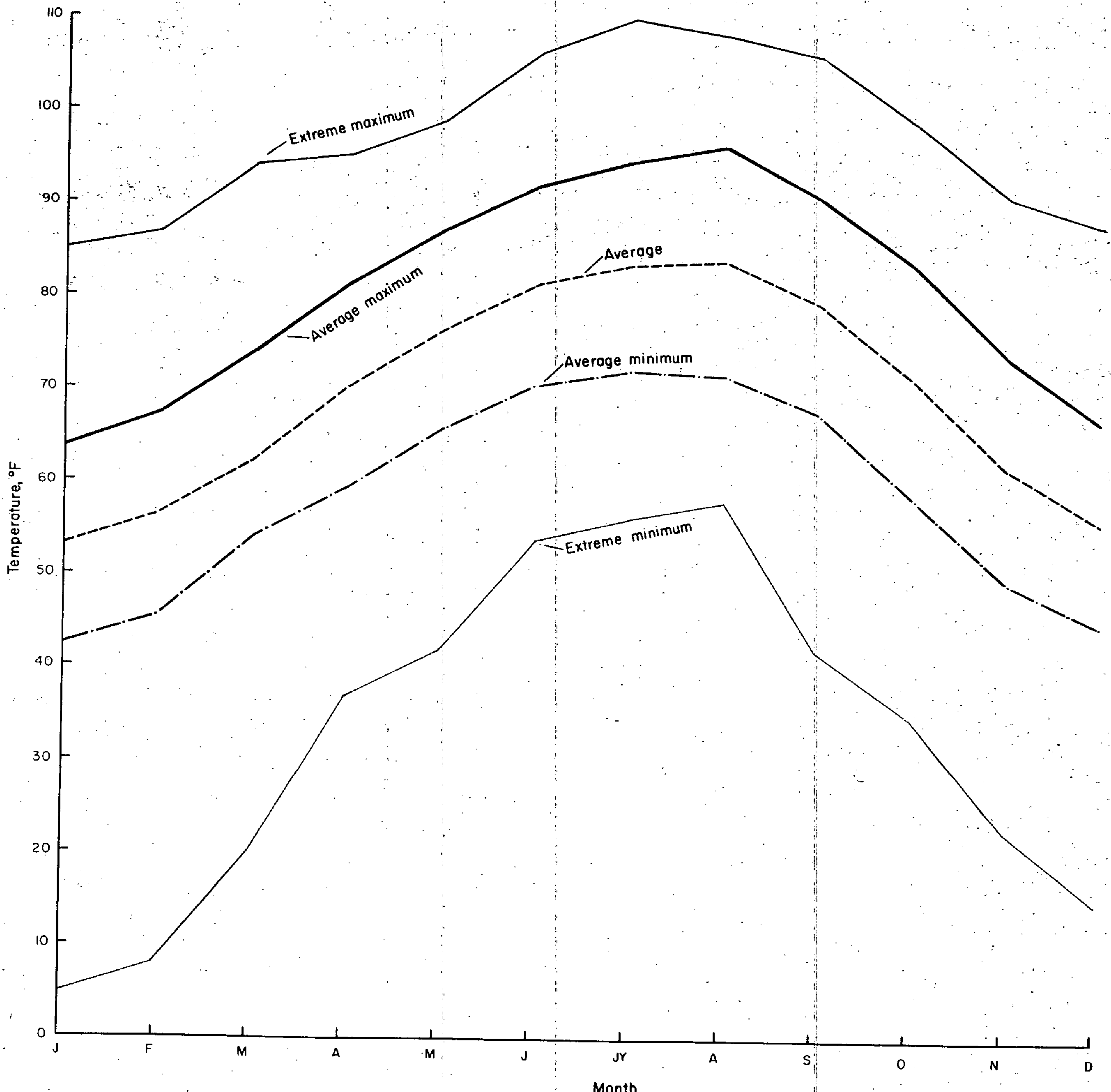

Figure 32. Monthly Temperature, Sealy 1942-1976.

Table 17. Comparison summary of continuous air monitoring station data with ambient standards.
(Data compiled from Texas Air Control Board Continuous Air Monitoring Network Data Summaries, 1974–1978)

Selected stations in region	CAMS no.	Ozone —high 1-hour average	Ozone —second highest hour	Ozone— % of time >0.08 ppm	Carbon monoxide —second highest hour	Carbon monoxide —second highest 8 hrs	Nonmethane hydrocarbons —6-9 am high	Sulfur dioxide —second highest 24 hrs	Sulfur dioxide —annual mean	Sulfur dioxide —second highest 3 hrs	Nitrogen dioxide —annual mean	Methane —high 1-hour average	Methane— % 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	no standards
1974													
Houston, East	1	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)	8	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	10	0.277	0.234	4.2	6.0	4.2	2.3	0.02	0.00	0.00	——	10.5	2.8
Clute	11	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	1	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)	8	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	10	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	11	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	1	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)	8	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	10	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	11	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													
Houston, East	1	0.22	0.220	3.4	12.5	5.8	5.1	0.01	0.00	0.06	0.03	10.7	3.1
Harris County (Aldine)	8	0.27	0.261	5.0	10.7	7.2	3.8	0.00	0.00	0.00	0.02	7.4	0.6
Texas City	10	0.23	0.221	3.4	6.2	2.3	2.9	0.00	0.00	0.01	0.02	9.2	0.6
Clute	11	0.18	0.176	1.9	6.8	2.7	5.7	0.00	0.00	0.01	0.01	5.1	0.0
1978													
Houston, East	1	0.23	0.21	0.6	11.8	5.9	4.6	0.03	0.00	0.04	0.03	10.5	3.6
Harris County (Aldine)	8	0.21	0.21	1.5	10.6	5.6	4.2	0.02	0.00	0.03	0.02	10.0	1.2
Texas City	10	0.31	0.29	0.9	4.8	2.4	2.2	0.01	0.00	0.04	0.02	9.7	1.5
Clute	11	0.18	0.16	0.4	6.4	2.8	2.6	——	0.00	——	0.02	4.5	0.0

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

†1978 standard: 0.12 ppm

monitoring stations are often high and sometimes exceed national standards, although these levels are often the result of dust storm activities (table 18) (Texas Air Control Board, 1978a). Selected gaseous concentrations measured show that although sulfur dioxide did not exceed standards in Region 7 during 1978 levels of nitrogen dioxide were frequently higher than the acceptable concentration.

Suitability of Locations for Test Well Based on Meteorological Characteristics

Affect of Test Well on Air Quality

A test well may affect air quality by increasing dust or particulate levels during site preparation and drilling phases or by increasing hydrocarbon levels during the production phase. Air pollutants associated with geopressured geothermal fluid production may include volatile carbon compounds, ammonia and hydrogen sulfide. The possible effect of a test well on air quality is discussed more fully for the Cuero study area.

Location of Test Well on the Basis of Meteorological Characteristics

As the prevailing winds are from the southeast, daily emisions from the test well facilities would most consistently affect areas located northwest of the site. However, a blowout or other unexpected emission could occur at any time; the effects on specific locations would depend largely on the wind direction at the time of the accident. Thus, not only should prevailing wind directions be considered in locating the test well, but also proximity to vulnerable areas.

Vulnerable areas include the city of Eagle Lake located in the southeast of the prospect area, the Attwater Prairie Chicken Refuge located to the northeast, the Rice Research Station to the northwest and any surrounding cropland in production at the time.

Table 18. Summary of non-continuous air monitoring station data with ambient standards. Concentrations in micrograms per cubic meter.

REGION 07		Sampling interval (months)	Start date	End date	Number of samples	Max. 24 hour	Sec. high	Arith. mean	Standard arith. dev.	Geo. mean	Standard geo. dev.
Particulate data standard											
ALIEF	TSP	12	1-02-78	12-28-78	53	136	109	63	22	60	1.4
Aldine (CAMS 8)	TSP	12	1-02-78	12-28-78	50	150	133	79	31	72	1.6
Gaseous data											
ALIEF	SO_2 [1]	12	1-02-78	12-28-78	52	21	20	9	6	7	2.3
	NO_2 [2]	12	1-02-78	12-28-78	49	108	87	40	25	31	2.3
	Aldehyde[3]	12	1-02-78	12-22-78	49	18	14	5	4	4	2.0
	Ammonia[3]	12	1-02-78	12-28-78	49	47	16	6	7	4	2.2
Aldine (CAMS 8)	SO_2 [1]	12	1-20-78	12-04-78	25	33	33	10	10	6	2.8
	NO_2 [2]	11	2-01-78	12-28-78	46	98	89	50	22	42	2.2
	Aldehyde[3]	12	1-20-78	12-28-78	44	14	14	5	4	4	2.0
	Ammonia[3]	12	1-20-78	12-28-78	43	25	22	7	6	5	2.3

STANDARDS: [1] SO_2 Max 24 hour 365. Arith mean 80.
[2] NO_2 Arith mean 100.
[3] No standards set.

SOURCE: Texas Air Control Board 1978 Annual Data Summary for Noncontinuous Monitoring

ECONOMY AND INDUSTRY

Description

Agriculture

Income from crops and livestock in 1977 totalled $46.4 million for Colorado County. In 1978 $20 million was obtained from more than a million barrels of rice, a significant proportion of which came from around Eagle Lake (Eagle Lake Chamber of Commerce, 1979). Within the study area, soybeans increasingly provide an income between rice crops. Corn and milo are the most important crops on non-irrigated land. Livestock, mainly beef cattle, are frequently grazed on fallow rice fields and are also significant in the agricultural economy (table 19).

The Eagle Lake area is a wintering ground for hundreds of thousands of geese and ducks. Hunters provide additional revenue to landowners through leasing of hunting rights.

Mineral Resources

Colorado County produced $91.4 million worth of minerals in 1975, primarily from gas, oil, sand and gravel (table 20) (Dallas Morning News, 1978; Zlatkovich and others, 1978). Large deposits of sand and gravel are found along the Colorado River valley. These have been extensively mined for many years west of Eagle Lake and are processed at several plants in the vicinity. The transport of these materials largely to Houston and surrounding areas, accounts for a significant proportion of the traffic on the roads and railways in the area.

Oil and gas fields in the study area include the Chesterville Oil and Gas Field located to the east of the city of Eagle Lake and the Ramsey Oil and Gas Field located west of the city. Numerous pipelines are found in the study area (fig. 33).

Industry and Commerce

Many of the commercial activities of Eagle Lake are support services for agriculture, including grain dryer operations and farm implement and seed sales. The Lakeside Irrigation Company which provides water to a total of 98,000 acres (25,000 a year) in Colorado and Wharton Counties is based in Eagle Lake (Winterman, personal

Table 19. Agricultural statistics, Colorado County.

		Acres
County land area		607,104
Proportion in farms (1974)		91.5%
Average farm size (1974)		429
Agricultural land use (1974)		
Total cropland		201,907
Harvested cropland		87,578
Cropland used for pasture or grazing		106,747
Irrigated land		52,177
Improved pasture and rangeland		52,367
Unimproved pasture and rangeland		179,782
Crops (1977)	Planted (Acres)	Harvested (Acres)
Rice	46,500	46,500
Soybeans	13,200	12,700
Corn	9,600	9,400
Sorghum	6,700	5,700
Oats	6,400	400
Upland cotton	1,200	1,200
Livestock (1977)	Numbers	
All cattle	112,000	
Milk cows calved	900	
Beef cows calved	57,000	
Hogs	13,800	
Hens and pullets of laying age	120,000	

Sources:

1974 data: "1974 Census of Agriculture"; U.S. Bureau of the Census, 1977.

1977 data: "1977 Texas County Statistics," Texas Crop and Livestock Reporting Service, 1978.

Table 20. Industrial and economic statistics, Colorado County.

Year				Source
1975	Value of minerals produced		$91,447,000	1,2
1974	Minerals in order of value			
	Natural gas		$25,479,639	4
	Natural gas liquids		n/a	
	Sand and gravel		n/a	
	Oil		n/a	
1976	Oil production		702,368 barrels	1
	Total oil production to January 1, 1974		20,581,898 barrels	1
1976	Cash receipts from agricultural products		$42,764,000	3
	From crops	59%		
	From livestock	41%		
1976	Population: County	16,863		1
	Total annual income		$ 7,208,300	1
	Population Eagle Lake	3,515		1
1976	Employment	Total	7,868	1
		Civilian (1970)	6,766	5
		Mining	692	1
		Construction	341	1
		Manufacturing	160	1
		Transport, communication and public utilities	139	1
		Trade	1,432	1
		Financial, insurance and real estate	166	1
		Service	663	1
		State govt.	83	1
		Farm population (1970)	2,899	5

Sources:

1. "Texas Almanac 1978," Dallas Morning News.
2. "Texas Fact Book 1978," Zlatkovich and others, 1978.
3. "1977 Texas County Statistics," Texas Crop and Livestock Reporting Service, 1978.
4. "Atlas of Texas," Bureau of Business Research, 1976.
5. "County & City Data Book 1977," Bureau of the Census, 1978.

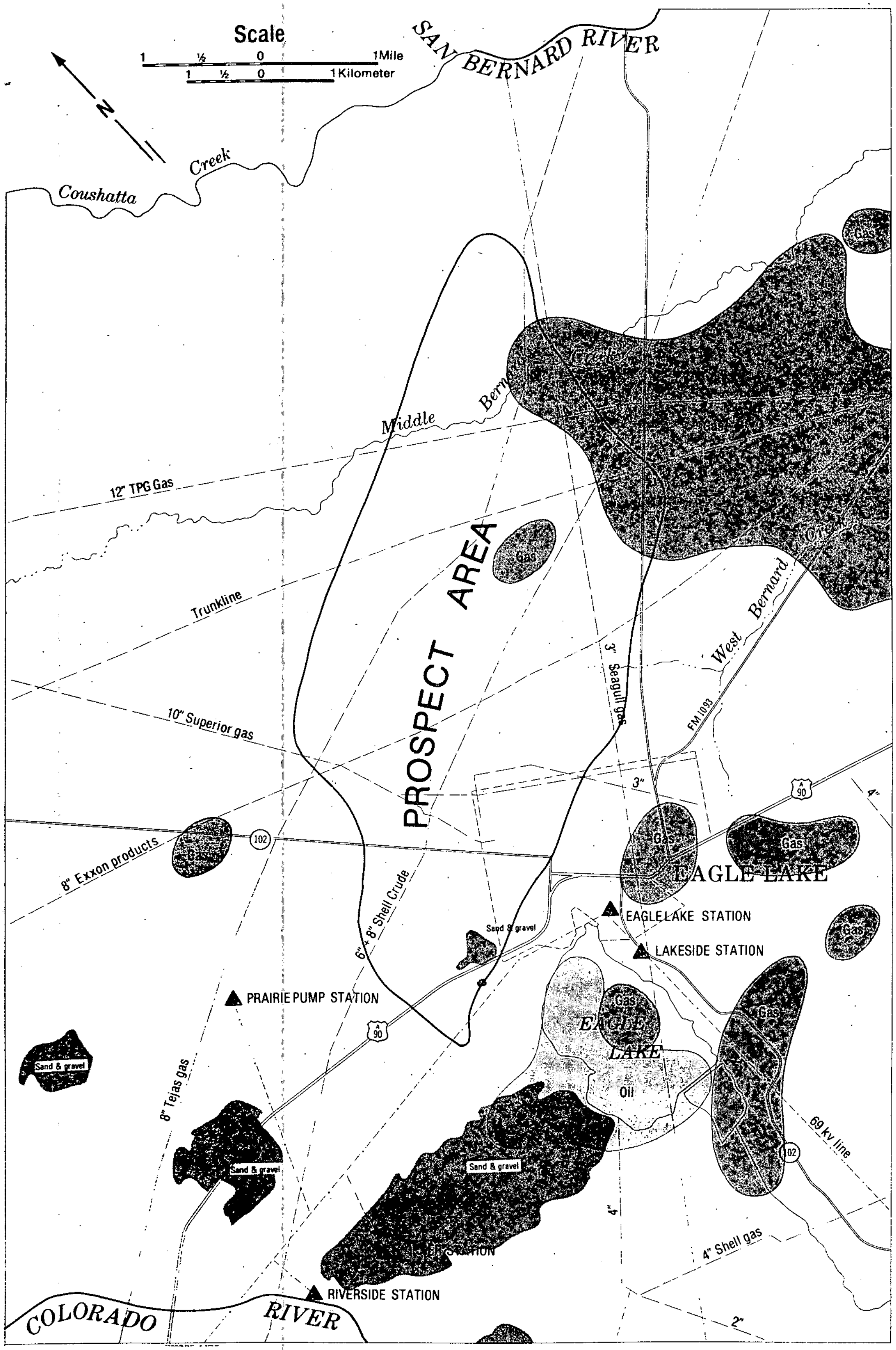

Figure 33. Mineral Resources and Transmission Lines, Eagle Lake Study Area. (Sources: Central Light and Power Co., Corpus Christi, 1979; De Witt and Company, Inc., 1979.)

communication). There are several pumping stations in the area and Eagle Lake is used as a reservoir for much of the water pumped from the Colorado River. Duck and goose hunting produces revenue for local landowners and business operators.

CULTURAL RESOURCES

The Texas Historical Commission has designated 4 places of historical interest in the Eagle Lake area. No archaeological studies have been completed in the Eagle Lake area, but the Texas Archaeological Research Laboratory lists 2 sites in the area, discovered during road-building and gravel pit activities (table 21 and fig. 28).

Table 21. Historical markers and archaeological sites, Eagle Lake study area.

Official Texas Historical Markers	
Town of Eagle Lake	
Rice culture in Colorado County	Main & Commerce St., Eagle Lake
Lakeside sugar refinery	2 mi. w. of Eagle Lake, FM 102
Navigation of the Colorado River	2 mi. w. of Eagle Lake, US 90A
Archaeological*	
CD 39	Open lithic site
CD 63	Lithic material, tools, unmodified flakes and projectile point, 2 scrapers and blade.

*Source: Texas Archaeological Research Laboratory

GEOLOGY

Pleistocene and Recent sediments comprise the Eagle Lake study area. The fluvial deposits of the Lissie Formation cover the majority of the area. Along the Colorado River west of Eagle Lake are found Pleistocene terraces and Recent alluvium (fig. 34).

Lissie Formation

The Lissie Formation, which forms the uplands of the study area, is composed of fine sands, clayey sands, and sandy clays ranging in color from pinkish buff to orange red and red, depending on the distribution of calcareous material and iron oxide. This material is finer grained than that of the Willis Formation. It was deposited along the edge of the Willis cuesta as a series of fans which grew and met to form a continuous plain. This surface has since been slightly tilted coastward and modern streams have cut down into the Lissie, providing low relief. However, between many of the streams are broad, flat divides which have been untouched by erosion. A common feature of the Lissie Formation in the study area is the presence of small, shallow depressions, often water filled. It has been postulated that these are areas of wind deflation. Also discernible on the surface of the Lissie are old meander scars. Recent alluvial deposits of sand, silt, and mud are found in the river and stream floodplains.

Terrace and Floodplain Deposits

Pleistocene fluviatile terrace deposits ranging from muds to sand and gravel are present along the Colorado River bottomlands. The most recent deposits in the area occur along the rivers and streams where they are deposited by floodwaters. These alluvial deposits range from gravels to muds and may include low terraces that are also subject to flooding.

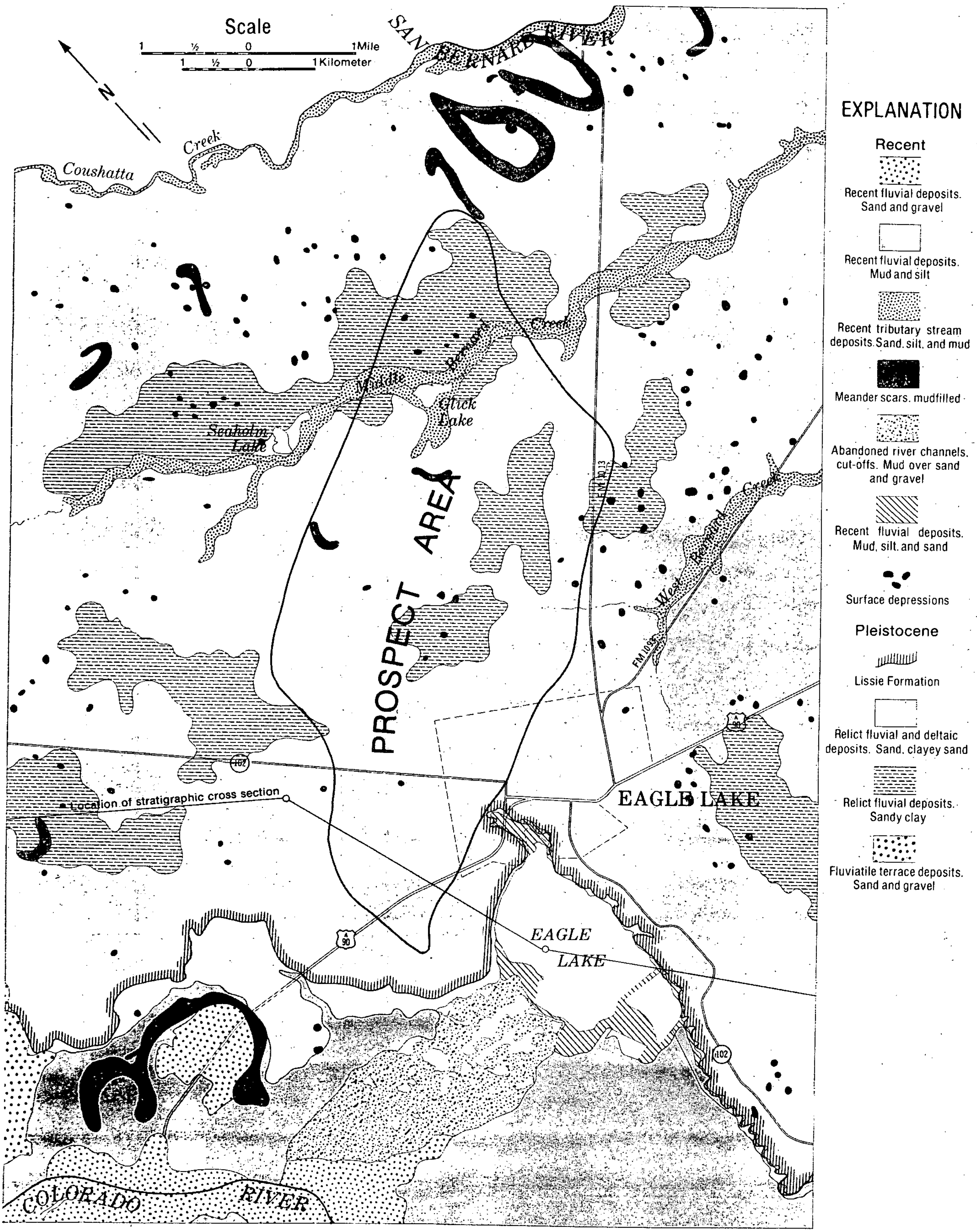

Figure 34. Geology, Eagle Lake Study Area. (Sources: St. Clair and others, 1975; Bureau of Economic Geology, 1974.)

SUBSIDENCE AND FAULT ACTIVATION

As noted in the discussion of the Cuero area (Subsidence and Fault Activation), reservoir compaction resulting in subsidence and fault activation may accompany geopressured geothermal fluid production.

SUBSIDENCE

Because many of the characteristics of the two geopressured geothermal reservoirs are similar, much of what has been said about subsidence for the Cuero area applies to the Eagle Lake area. Factors which may contribute to subsidence include the large volumes of fluid to be withdrawn, the large drop in pore pressure that may occur, the possible lack of preconsolidation in the sedimentary reservoir material, and the large thickness to width ratio of the reservoir (table 22). Seventy percent of the known reservoir characteristics, or 55 percent of the total number of factors, are similar to those factors that may contribute to subsidence, thus the possibility of reservoir compaction and subsidence is high. On the other hand, the positive factors of cementation of reservoir sands, plus overburden thickness and cementation are also present, the absence of these being prime requisites for subsidence. A fuller discussion of reservoir characteristics and estimates of subsidence can be found in the section on Subsidence and Fault Activation for the Cuero Area (p.30).

FAULTS

Description

Deep Faults

Deep faults are mapped at two horizons, the top of the Wilcox Formation (approx. 8,000-9,500 ft) and the top of the Yegua Formation (approx. 5,400-5,800 ft) (Geomap, 1979) (fig. 35). These are growth faults that roughly parallel the coast. They dip steeply near the surface and flatten and converge at depth. Five faults, including the two that bound the geothermal reservoir, occur at the top of the Wilcox Formation. Two faults are found at the top of the Yegua Formation. It is possible that one or both of the faults in the Yegua Formation are extensions of faults in the Wilcox.

Table 22. Factors tending to influence geothermal subsidence (from Atherton and others 1976) compared to factors that characterize the Eagle Lake prospect area

Factor type (● major; ○ minor)	Factors which may contribute to subsidence susceptibility	Factors which may contribute to surface stability	Factors characterizing prospect area (⊕ similar to characteristics listed in column 2)
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
○ Dissolved solids			High
○ Temperature			250–325°F
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	?
GEOHYDROLOGY			
Natural recharge[1]	Low rates	High rates	?
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	⊕ None
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)	Eocene
● Thickness (in communication)	Great vertical section	Small vertical section	Small
● Deformation properties[4]	Highly deformable	Slightly deformable	?
ASSOCIATED MATERIALS			
Type	Clays, siltstones, shales	Volcanic flows shallow intrusions	⊕ 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)		
RESERVOIR GEOMETRY			
Width/thickness ratio[5]	Large	Small	⊕ Large (for several wells)
OVERBURDEN			
● Thickness	Small (<3000 ft)	Great	Great (>11,000 ft)
● Competence	Incompetence, unconsolidated sediments	Competent, consolidated	Possibly competent
● Deformation properties[6]	Highly deformable	Slightly deformable	?
Density	High	Low	Low
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	Reserve or thrust	⊕ Normal
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 possibly respond more slowly than the reservoir materials below

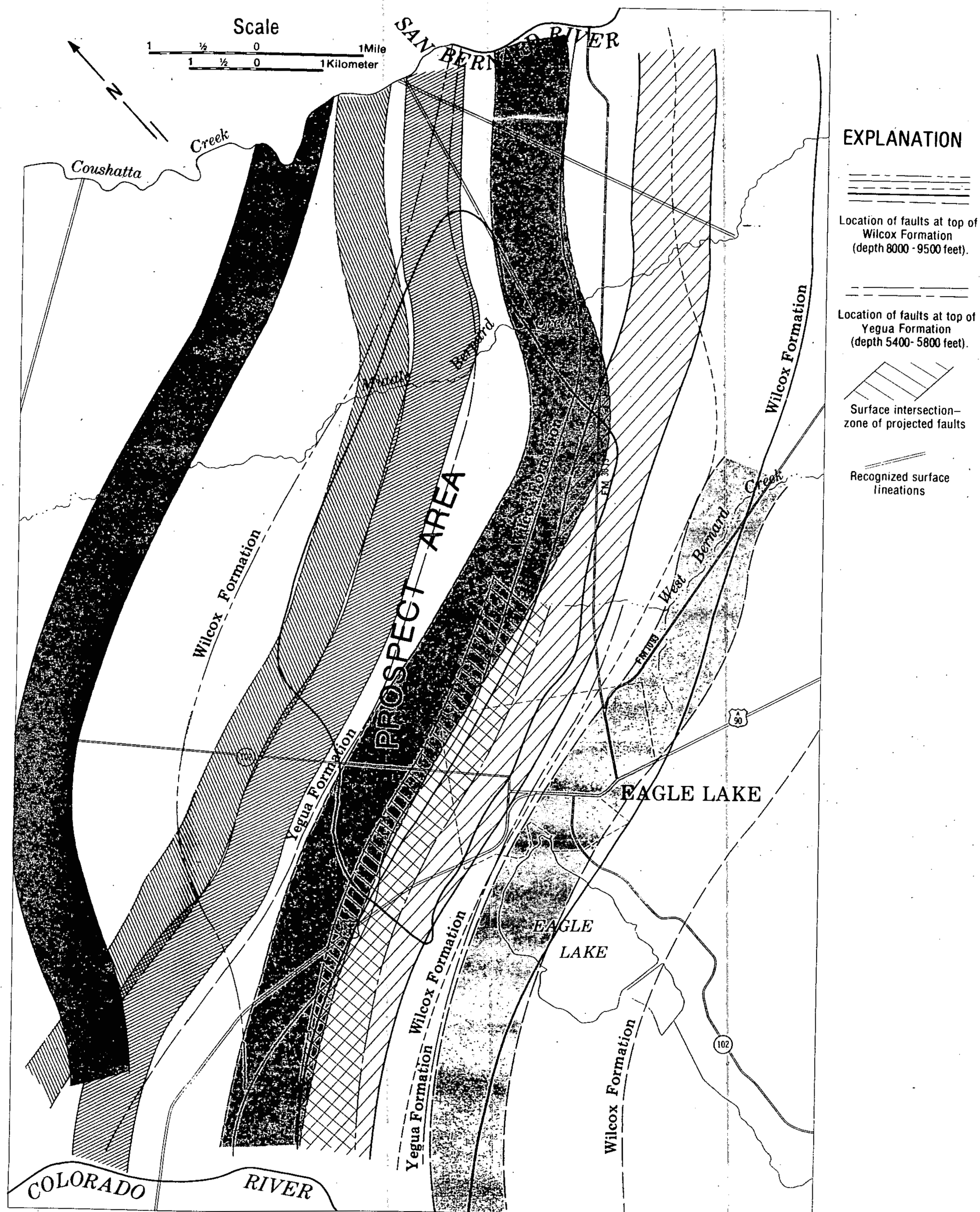

Figure 35. Location of Subsurface Faults and their Projected Zone of Surface Intersection, Eagle Lake Study Area. (Sources: Geomap, 1979; Bureau of Economic Geology, 1973.)

Near Surface Faults

Several near-surface faults apparently occur in the Eagle Lake area. The Tectonic Map of the United States (USGS/AAPG, 1962) shows a surface fault in the vicinity of Eagle Lake but the scale of the map is too small to permit an exact placement of the fault within the study area. Rogers (1965) describes this fault in the Eagle Lake area, based on evidence from Pleistocene terraces along the Colorado River and on the Recent history of Eagle Lake. Achalabhuti (1973) mapped 3 faults in the vicinity of the lake, based on interpretations of aerial photography. Figure 36 shows the approximate locations of these faults.

Further evidence of near-surface faulting in the study area was obtained from electric logs. Seismic data from wells in the vicinity of Eagle Lake indicated two potential fault lines extending across the lake from the southwest to northeast (Winterman, personal communication). A cross section through the study area shows a thickening of the sediments between wells 3 and 5 and between wells 5 and 6 which cannot be explained from deposition alone, and which suggests the presence of at least one, and possibly two, near-surface faults (fig. 37). There is not sufficient electric log data in the area to map the lateral extent of, or to precisely locate, the faults.

Fault Activation

Fault Activation from Fluid Withdrawal

Because faults may be present, the possibility of fault activation must be considered. Should removal of geopressured fluids lead to reservoir compaction the faults, being zones of weakness, may act as limits to the zones of compaction. This could result in propagation of the faults to the surface where they would be expressed as a zone of differential subsidence. An attempt was therefore made to show where the deep faults in the study area might appear if propagated to the surface. Subsurface faults were projected upwards at angles of 45^{o} and 60^{o} to the horizontal. The Wilcox and Yegua Formation faults and projections to the surface are shown on fig. 35.

Fault Activation from Fluid Disposal

Reinjection of waste fluids could also induce fault activation at depth. Increased pore fluid pressures along fault planes could induce fault movements. Furthermore, in shallow strata excessive injection pressures could lead to induced fracturing of the disposal reservoir.

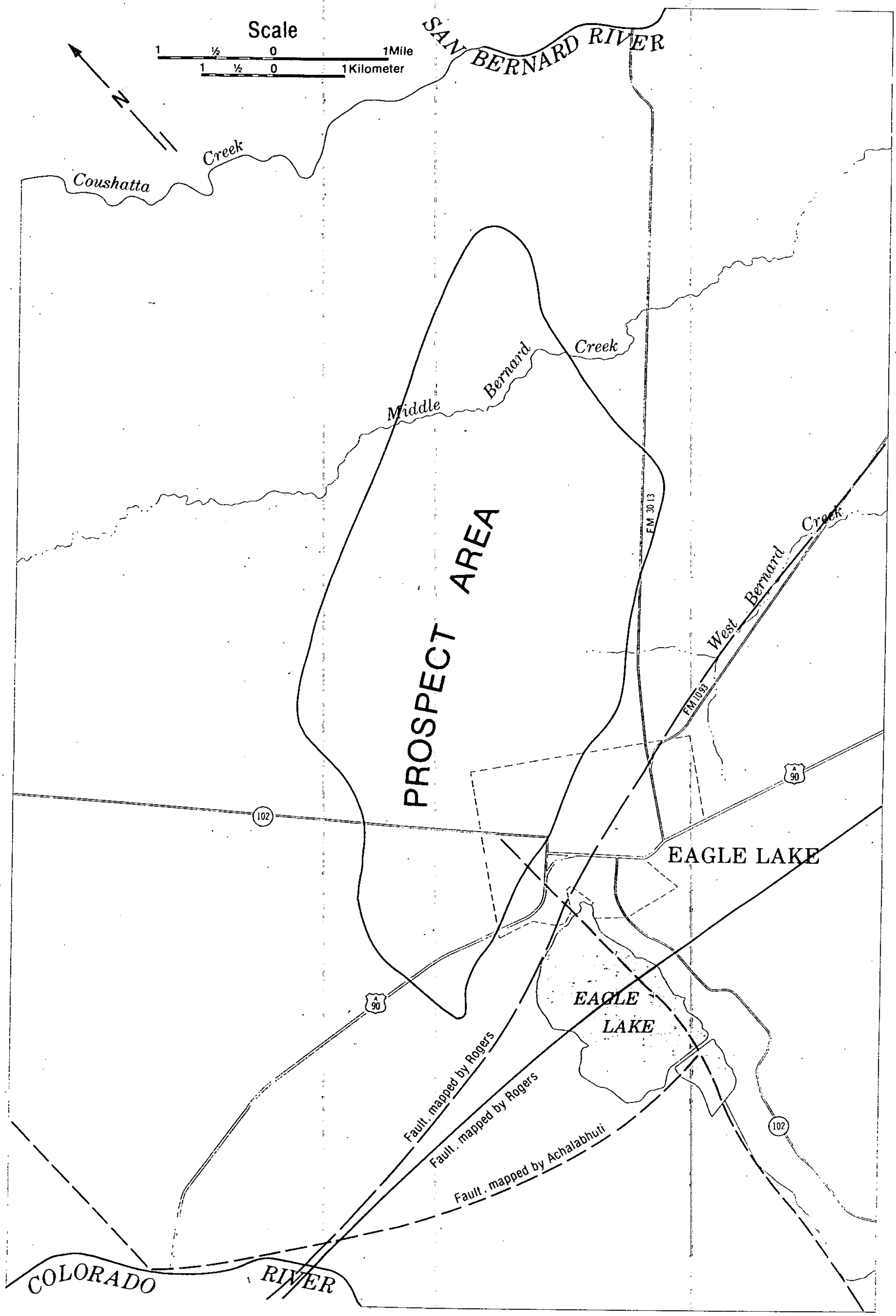

Figure 36. Location of Near Surface Faults, Eagle Lake Study Area, as Mapped by Rogers and Achalabhuti. (Sources: Rogers, 1965; Achalabhuti, 1973.)

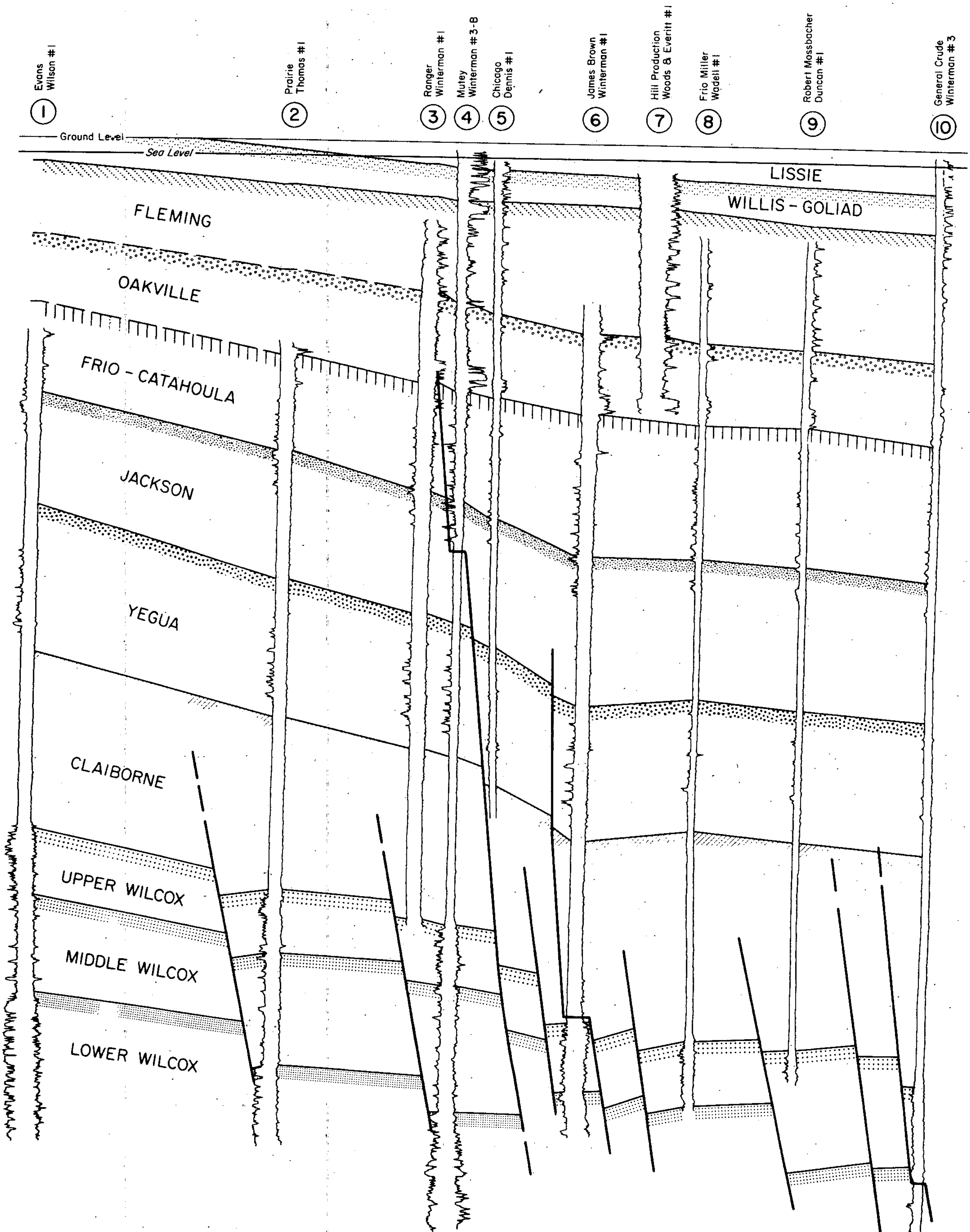

Figure 37. Geological Cross Section, Eagle Lake Study Area.

Effects of Subsidence and Fault Activation

The natural gradient of the land is important in the Eagle Lake study area. The rice growing areas are supplied with water via naturally flowing irrigation ditches and drainage from the fields is again natural. Rice fields are contoured using precise surveying techniques, with as little as 3 inch changes in elevation between levees. It is therefore possible that even small amounts of subsidence could require releveling of rice field levees. If a substantial amount of subsidence were to occur, areas subject to flooding could be increased in extent and frequency of flooding. In addition, rigid man-made structures such as pipelines, roads and buildings could be affected, causing distortion and fractures. If subsidence was compartmentalized between faults, the risk to rigid structures crossing the fault line would be increased. Movement along faults as a result of reinjection of geothermal fluids would similarly concentrate damage along the fault lines.

Location of the Test Well on the Basis of Subsidence Effects

In order to minimize the possibility of environmental or social damage associated with subsidence and faulting, the test well should be located away from areas that would be severely affected by subsidence. Major areas to be avoided are the city of Eagle Lake and Eagle Lake. Areas of rice irrigation may also be impacted by subsidence and should if possible be avoided.

HYDROLOGY

GROUNDWATER RESOURCES[1]

Description

Aquifers

The main aquifers in the Eagle Lake area are the Chicot and the Evangeline aquifers. The Jackson Group, Catahoula Sandstone, and Jasper aquifer are minor groundwater sources (fig. 38). Both the Chicot and Evangeline aquifers consist of discontinuous layers of sand and clay. In Colorado County, the Evangeline aquifer includes the Goliad Sand and the upper part of the Fleming Formation. The Chicot aquifer overlies the Evangeline aquifer and is composed of waterbearing units in the Willis Sand, Lissie Formation, Beaumont Clay, and Quaternary Alluvium, i.e., all deposits from the land surface down to the top of the Evangeline aquifer. The Chicot and Evangeline aquifers generally are in hydraulic continuity and it is difficult to differentiate the two units. Average sand thickness is 250 ft (76 m) in the Chicot aquifer and 200 ft (61 m) in the Evangeline aquifer.

Aquifer Recharge

The principal source of recharge is the infiltration of rainfall in the aquifers' outcrop areas. The Chicot aquifer is at the land surface throughout the study area and over most of Colorado County. The Evangeline aquifer is overlapped by the younger sediments of the Chicot aquifer in Colorado County. As the Chicot aquifer is relatively thin in Colorado County, some of the infiltration of rainfall probably recharges the Evangeline through the Chicot.

Ground Water Movement and Usage

The natural direction of movement of ground water is down-gradient from outcrop areas toward the Gulf of Mexico and toward areas of discharge along major drainage

[1] The following discussion is based on "Groundwater Resources of Colorado, Lavaca, and Wharton Counties," Loskot and others, 1979.

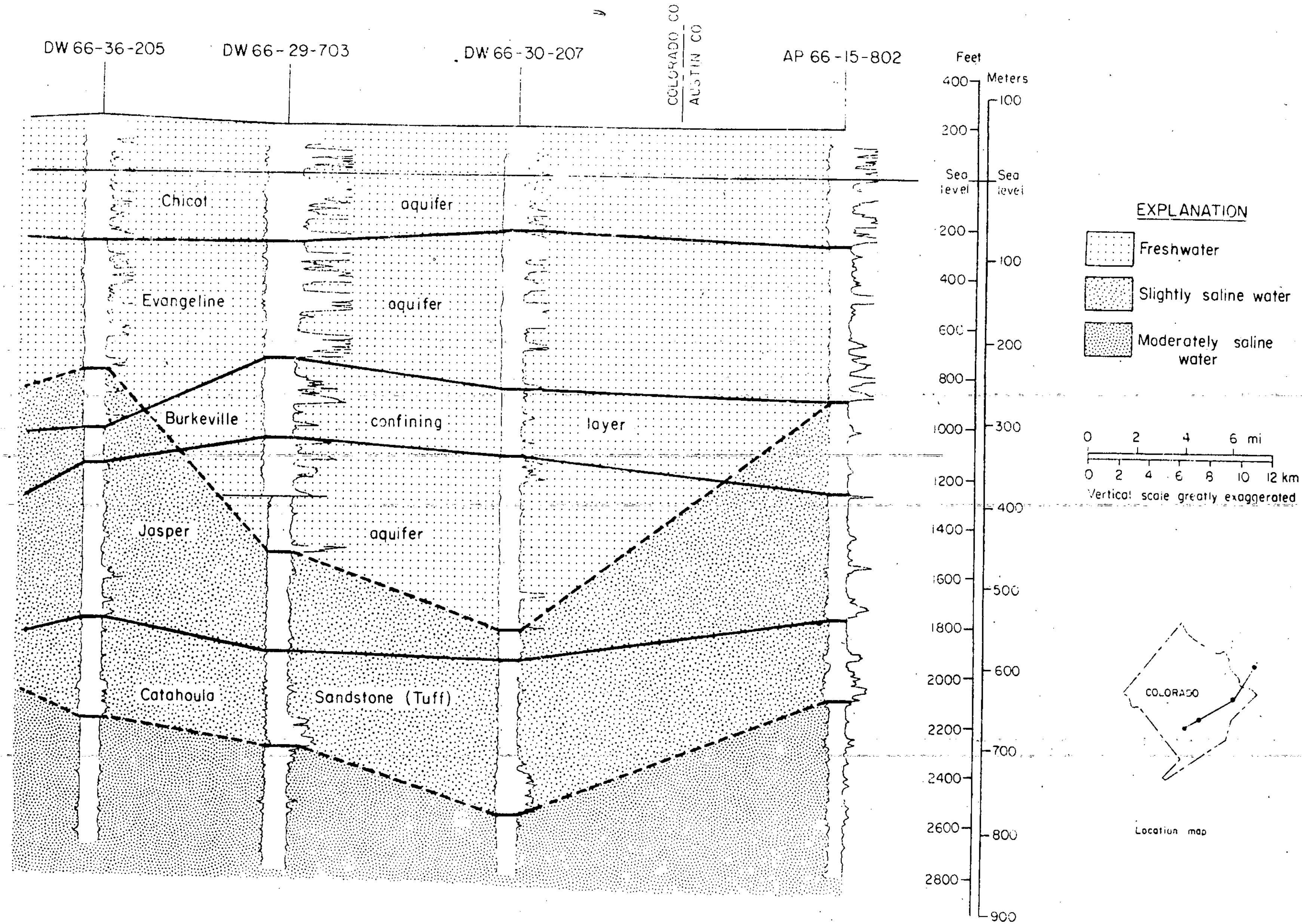

Figure 38. Geohydrological Cross Section, Colorado County.

systems such as the Colorado River. Rate of movement of ground water in Colorado County ranges from tens to hundreds of feet per year. The average rate in the Chicot aquifer is 75 ft (23 m) per year, and for all 5 aquifers is 37 ft (11 m) per year. Rate of movement near pumping wells is much greater.

About 56 percent of the ground water used in Colorado County comes from the Chicot aquifer, the remainder being from the Evangeline aquifer. Within the study area ground water is used primarily for municipal and domestic purposes. Most of the irrigation water comes from the Colorado River. Some well water is used for industrial purposes.

Ground-Water Production

Based on the average hydraulic conductivity of each of the major aquifers (Chicot and Evangeline) and the thickness of freshwater sands in the aquifers, transmissivity values were determined for the aquifers. Transmissivity values for both aquifers combined range from less than 15,000 ft/day to 20,000 ft/day throughout the study area and are among the highest values in Colorado County. However, ground water is presently being produced in amounts in excess of the annual recharge rate. In 1974, pumpage from the Evangeline exceeded by 10,000 acre-ft (12 hectometers^3)[1] the estimated 38,000 acre-ft (47 hm^3) of recharge that is the maximum amount perennially available to the 3-county area studied by Loskot and others; similarly, the perennially available amount of 76,000 acre-ft (94 hm^3) in the Chicot is being exceeded (by an unknown amount). Although the amount of water stored in the aquifers is large enough that there is, at present pumpage rates, no short-term danger of depleting the reservoir, water levels in the wells are declining and some land subsidence has probably occurred.

The amount of subsidence in the study area could not be determined as the National Geodetic Survey has not resurveyed bench-mark altitudes in the study area since 1943. Data from surrounding areas indicate that subsidence of less than 1 ft (0.3m) to as much as 2 ft (0.6 m) had occurred as of 1973, the majority since 1952 (Loskot and others, 1979).

Ground-Water Quality

Natural influences on the quality of ground water include the source of the water, rate of movement of the water, and most importantly, the minerals contained in the

[1] 1 hm = 100 m.

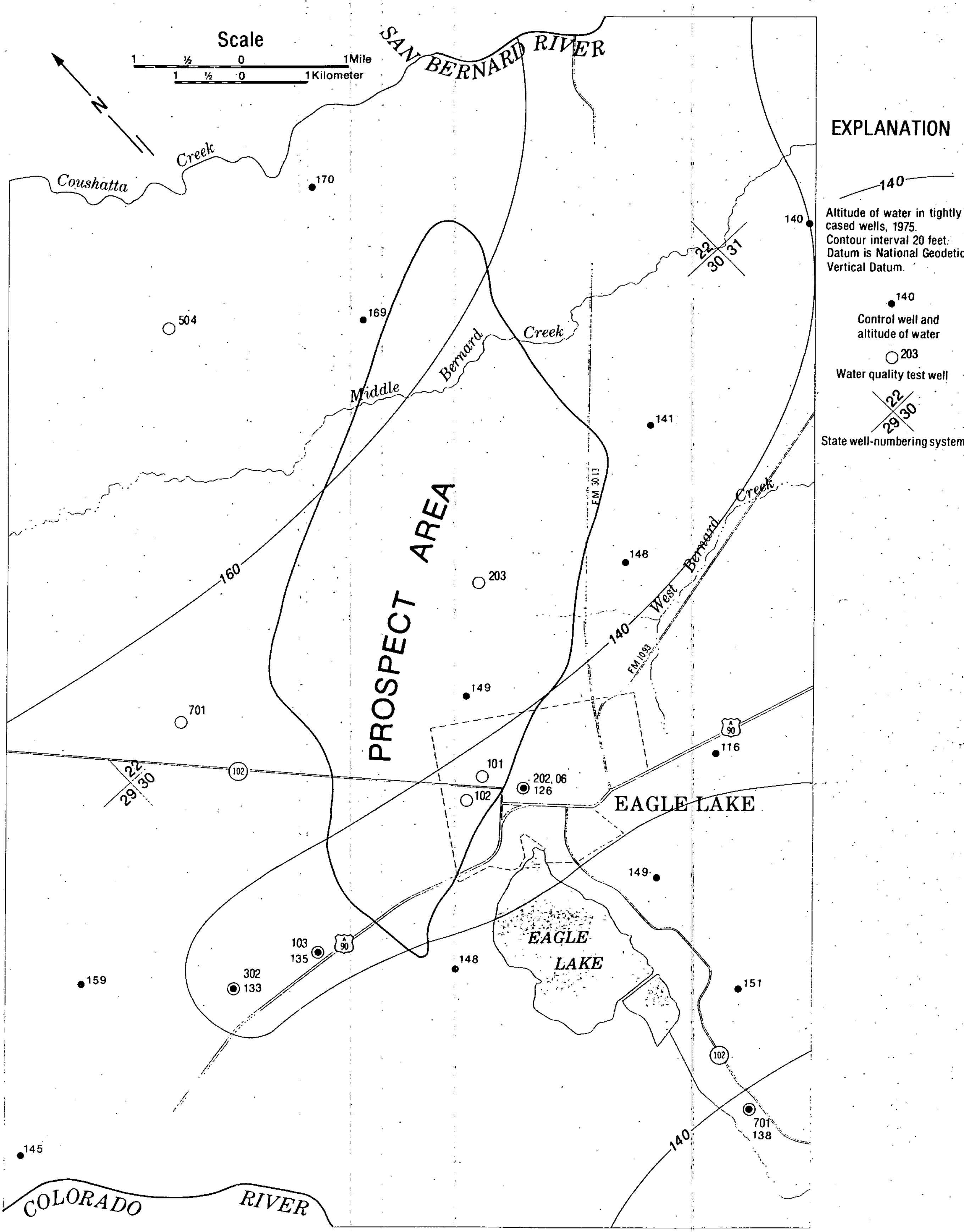

Figure 39. Altitude of Water Table and Location of Wells Sampling Chemical Quality of Groundwater, Eagle Lake Study Area. (Source: Loskot and others, 1979.)

Table 23. Chemical analysis of water from wells in the Eagle Lake study area.[1]

Well	66- 22-504	22-701	29-302	29-501	501	30-101	101[2]	30-102	30-103	30-202	202	30-203	30-206	30-701
Depth or producing interval (ft)	931	209-947	157-395	—	—	350-527	350-527	350-527	190-490	274-460	274-460	340-806	442-462	152-427
Water-bearing unit	E-C	E-C	C-E	C	C	E-C	E-C	E-C	C-E	C	C	E-C	C	C
Date	5-22-74	5-22-74	5-24-74	7-8-69	5-24-74	12-28-55	9-3-68	5-17-50	5-9-60	4-22-37	2-21-44	5-24-74	2-21-44	5-24-74
Dissolved silica SiO_2 *mg/l*	28	30	29	22	30	29	—	27	30	—	25	29	24	29
Dissolved iron Fe *ug/l*	—	—	20	—	—	10	<20	30	—	—	50	—	40	10
Dissolved manganese Mn *ug/l*	—	—	—	—	—	0	<50	—	—	—	—	—	—	—
Dissolved calcium Ca *mg/l*	42	54	51	48	71	44	46	45	91	22	58	45	49	99
Dissolved magnesium Mg *mg/l*	6.1	4.3	4.2	7	5.3	3.2	3	3.5	8.1	7	4.3	4.0	3.3	12
Dissolved sodium Na *mg/l*	43	44	22	98	41	16	15	15	42	120	16	25	12	21
Dissolved potassium K *mg/l*	2.9	1.4	1.5	—	1.6	1.4	—	7.2	1.6	—	2.3	1.7	4.1	2.0
Bicarbonate HCO_3 *mg/l*	205	70	?	273	227	144	142	146	228	238	167	164	124	322
Carbonate CO_3 *mg/l*	0	0	0	—	0	0	0	0	0	—	0	0	11	0
Dissolved sulfate SO_4 *mg/l*	11	7.2	7.9	14	14	4.2	6	5.5	14	54	7.6	7	4.7	9.7
Dissolved chloride Cl *mg/l*	33	76	42	93	66	28	27	30	110	64	41	29	29	49
Dissolved fluoride F *mg/l*	0.2	0.2	0.2	0.4	0.1	0.2	0.1	0.1	0.2	—	0.3	0.2	0	0.2
Dissolved nitrite plus nitrate N *mg/l*	0.08	0.11	0.13	0.09	0.31	0.11	0.09	0.11	0.34	—	0.23	0.14	0.11	0.01
Dissolved ortho phosphorus P *mg/l*	—	—	—	—	—	0.01	—	—	—	—	—	0	—	—
Dissolved boron B *ug/l*	60	70	—	—	—	30	—	110	170	—	—	50	—	70
Dissolved solids (sum of constituents) *mg/l*	267	301	237	416	341	197	167	205	409	382	236	221	198	380
Hardness Ca, Mg *mg/l*	130	150	140	150	200	120	130	130	260	80	160	130	140	300
Percent sodium	41	38	25	59	31	22	20	19	26	75	17	29	16	13
Residual sodium carbonate (RSC)	0.8	0	0	1.5	0	0	0	0	0	2.2	0	0.1	0	0
Sodium adsorption ratio (SAR)	1.6	1.6	0.8	3.5	1.3	0.6	0.6	0.6	1.1	5.6	0.5	1.0	0.4	0.5
Specific conductance *micromhos*	461	550	420	—	605	326	342	340	742	—	422	379	425	668
pH *units*	7.5	7.7	7.8	—	7.0	?	?	7.6	7.1	?	8.6	7.7	8.6	7.2
Temperature (°C)	25.5	24.5	23.0	—	23	24	—	27	24.5	—	21.5	23	23.5	22

[1] Analyses are given in milligrams per liter (mg/l) or micrograms per liter (ug/l), except sodium adsorption ratio, residual sodium carbonate, specific conductance, pH, and temperature. When no potassium (K) is reported, sodium and potassium are calculated and reported as sodium (Na). Aquifer units: C—Chicot aquifer; E—Evangeline aquifer.

[2] Analyzed by Texas State Department of Health.

SOURCE: Loskot and others (1979).

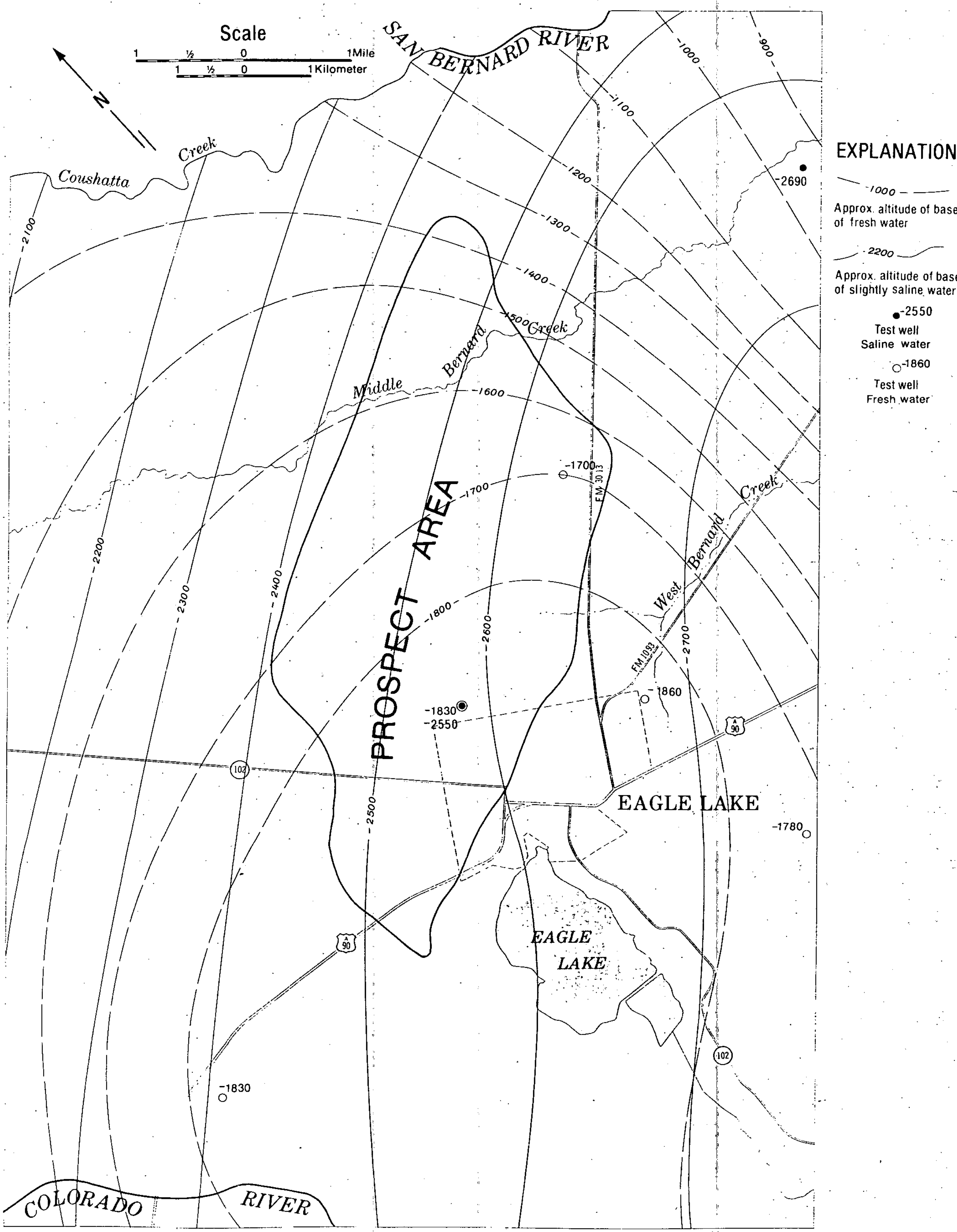

Figure 40. Altitude of the Base of Fresh and Slightly Saline Water, Eagle Lake Study Area. (Source: Loskot and others, 1979.)

rocks and soils through which the water moves. Because the rate of ground-water movement is generally slow, water tapped in different locations will reflect the differences in composition of the material tapped. In general, the deeper sands of the Evangeline aquifer (ca. 1060 ft/323 m) yield a sodium bicarbonate-type water, while shallower sands (ca. 230 ft/70 m) tend to contain calcium bicarbonate-type water. Water from the Chicot aquifer is generally a calcium bicarbonate type, and is hard to very hard.

Ground-water quality data was available for 11 wells (fig. 39) in the Chicot to upper Evangeline aquifers (table 23). Although concentrations of the constituents varied considerably, all the analyses were within limits for domestic consumption, as suggested by EPA (1976) and McKee and Wolf (1963).

Altitude of Water Table

Although flowing wells were reported in Colorado County as recently as 1940, ground-water pumping has since lowered artesian pressures and no flowing wells are known within the study area. The present altitude of water in wells in the Chicot aquifer ranges from 140 ft to 180 ft. Depth to the water table ranges from 20 ft to 40 ft or more (fig. 39). The water level has fallen by less than 10 ft to more than 20 ft in southern Colorado County since 1959.

Relationship of Fresh Water to Saline Water

Within the study area, fresh water (less than 1000 mg/l dissolved solids) is relatively deep; the base of fresh water ranges from -900 ft to -1860 ft under the city of Eagle Lake (fig. 40). This fresh water is found in the Jasper aquifer as well as the shallower Evangeline and Chicot aquifers and may occur in the deeper Catahoula Sandstone as well. Fresh water is also found beneath a layer of slightly saline water (see below). With the exception of an area south of the city of Wharton, where fresh water occurs to depths of more than 2,000 ft, the Eagle Lake-Garwood area has the deepest occurrence of a continuous layer of fresh water in the 3-county area of Lavaca, Colorado, and Wharton Counties studied by Loskot and others (1979).

The base of slightly saline water (1,000-3,000 mg/l dissolved solids) is also deep in the study area, ranging from -2200 ft along the northwestern boundary to -2800 ft along the southeastern boundary (fig. 40). This is the deepest occurrence of slightly saline water within the 3-county area. Loskot and others (1979) presented evidence that vertical layering of fresh and slightly saline water occurs under the study area. One well contains a zone of fresh water in sand units between depths of 2,800 ft and 2,950 ft with slightly saline water above this zone and moderately saline water (3,000-10,000 mg/l) below it (figs. 38 and 40).

Location of Test Well Based on Ground-Water Resources

Fluid Disposal and Subsurface Contamination

Injection wells to dispose of the geothermal water will be drilled to below the base of slightly saline water. In the Eagle Lake study area, this will impose a large cost because the base of slightly saline water ranges from 2,400 ft to 2,900 ft below the land surface. Another problem is that fresh water is found below a zone of slightly saline water within the study area and an injection well would probably have to be drilled into the zone of moderately saline water below, or 3,050 ft below the land surface.

Information is not yet available on the suitability or extent of disposal aquifers. Possible problems could be (Newchurch and others, 1978):

- limited areal extent, resulting in unacceptable increases in injection pressures
- fracture of injection formation rock followed by vertical flow of brine due to injection pressure
- vertical flow of brines along fault planes or through abandoned wells.

Spills and Surface Contamination

A leak, spill, or accidental blowout could cause shallow ground-water contamination. The Cuero area Hydrology section (Ground-water Hydrology: Aquifer Recharge) provides a table of factors which could minimize or increase the chance of ground water contamination, once a spill has occurred. In the Eagle Lake area, ground water occurs within 20 feet of the surface. However, many of the soils have clay in the subsurface horizons and would thus protect the underlying aquifers due to their slow infiltration rate and absorption of ions. On the other hand, because the area is very flat, the brine would not run off quickly and would have a greater chance of percolating through the soil.

SURFACE WATER

Description

Drainage Basins

Runoff from the study area drains to two major rivers, the Colorado River, which flows through the western corner and the San Bernard River, which forms part of the northern boundary. As the Surface Hydrology map (fig. 41) shows, only a small area drains directly into the Colorado River, although a larger area drains into Eagle Lake and its unnamed outlet, and thence to the Colorado. The rest of the study area drains into tributaries of the San Bernard River--West Bernard Creek, Middle Bernard Creek and Coushatta Creek--or directly into the San Bernard. Of these smaller streams, West Bernard Creek originates in the study area, Middle Bernard Creek originates within 4 miles of the area, and Coushatta Creek originates a considerable distance away. These rivers flow generally toward the southeast, whereas the Colorado River and the outlet of Eagle Lake flow southward. Apparently, the Colorado River used to flow where Eagle Lake is now; the steep area bordering the lake on the east may indicate the location of a previous channel.

The natural drainage patterns in the area have been altered by the construction of railroads and highways with accompanying ditches and by building levees and irrigation ditches for rice farming. Water is pumped from the Colorado River to a high point in the irrigation network, flows to the rice fields and is then released to natural drainage, mostly in the San Bernard River drainage basin. The drainage into Eagle Lake has been altered by the construction of a levee around the lower west side and the southern end of the lake and by strip mining of gravel to the west of the lake which has destroyed the bed of a shallow bayou which used to enter the southwest side of the lake.

Additional surface water features include:

- shallow depressions or "potholes" and small meander scars which hold water except during dry periods (fig. 34).
- marshy areas in large meander scars near the Colorado River in the western corner of the study area (figs. 34 and 41).
- rice fields which are flooded twice a year (fig. 43).
- standing water in abandoned gravel pits and strip mines (fig. 41).
- man-made ponds of various sizes (fig. 41).

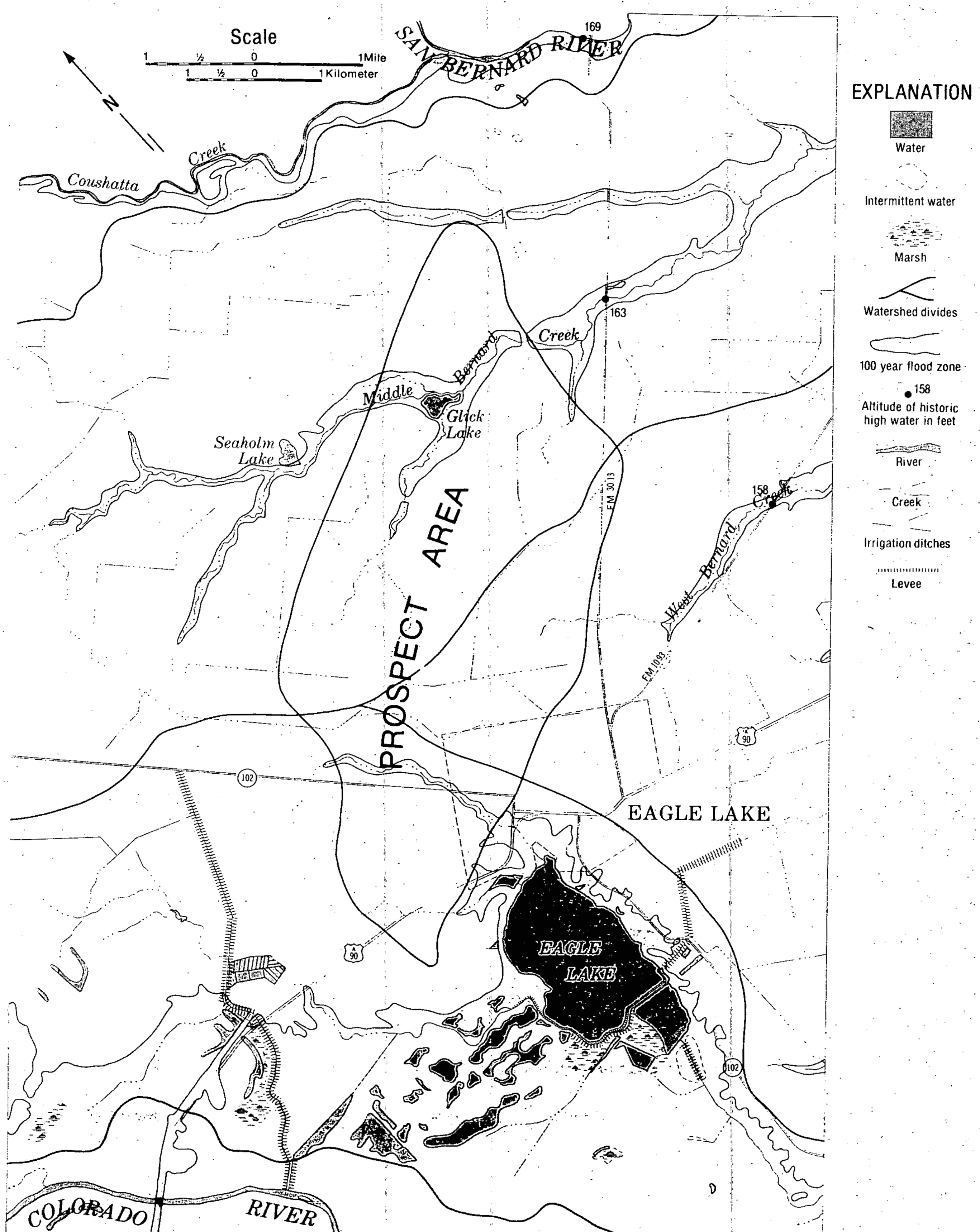

Figure 41. Surface Hydrology and Flood-Prone Areas, Eagle Lake Study Area. (Sources: U.S. Geological Survey Topographic Maps; Federal Insurance Administration Flood Hazard Maps, 1977.)

Possible Effects of Test Well on Drainage Patterns

Production of geopressured geothermal fluids could affect drainage patterns if subsidence occurs. If subsidence is limited to a few centimeters, surface water effects would be minimal. However, greater subsidence could have marked effects due to the natural low relief of the area. The greatest impact would probably be on the rice levees, as these are placed at vertical intervals of .2 to .3 ft. Flow of water in the irrigation ditches might also be altered by subsidence. If subsidence was accompanied by faulting, the drainage effects might include alteration of the flow of Middle Bernard Creek, Coushatta Creek, and/or the San Bernard River (see Faults map). Other drainage effects of subsidence might include ponding of some areas and drainage of existing ponds.

Surface Water Quality

Point Sources

The Texas Department of Water Resources issues permits for municipalities and agricultural and industrial operators to discharge effluent into public waterways. The only discharge permit issued within the study area is to the city of Eagle Lake for its sewage disposal plant, the effluent from which is discharged into Eagle Lake via an unnamed tributary. The effluent does not meet the permit standards; it is overloaded with organic wastes and the facility frequently discharges raw sewage. Because of this the plant is presently "under enforcement" by the Texas Department of Water Resources and a new facility is being planned and will be built within the next 2 or 3 years (Lockley, personal communication). No industrial or agricultural discharge permits are in effect at the present time.

Nonpoint Sources

The major nonpoint sources affecting water quality in the study area are irrigation water from rice fields and runoff from sand and gravel operations. Fertilizers, herbicides, and pesticides are applied to rice fields, primarily before, but also after flooding. Non-persistent substances generally break down in the fields unless a heavy rainstorm shortly after application causes the water to overflow and drain to surrounding waterways. Pollutants found in irrigation water include persistent herbicides and pesticides, suspended solids (mainly sediment washed out along with the water), fecal coliform bacteria (from cattle and migratory birds), and fertilizer residues. Fertilizers in the water cause an increase in biochemical oxygen demand which can lead to a reduction in dissolved oxygen to the detriment of aquatic life (Hydroscience, Inc., 1978).

Sand and gravel extraction occurs over a large area on the Colorado River terrace deposits. The primary waste products are sediments whose adverse effects on receiving waters include light reduction and siltation (Hydroscience, Inc., 1978). Another source of pollution is runoff from the streets and highways of the study area, which carry large numbers of trucks hauling sand and gravel. Other nonpoint sources include oil and gas wells. Construction activities associated with the wells can lead to erosion and sediment runoff and to runoff of chemicals, fuels, and lubricants used in the construction process.

Surface Water Quality Data

None of the rivers or streams are monitored within the study area. It can only be said that the streams in the upland part of the area are influenced by runoff from current and fallow rice fields, while the streams on the Colorado terraces and bottomlands are affected by runoff from gravel operations and non-irrigated fields.

The Texas Department of Water Resources monitors water quality downstream from the study area on the Colorado River at Garwood and on the San Bernard River at Highway 442 near Boling (table 24). Water quality at the Garwood station has been within the standards for that segment of the Colorado River (above tidal to Tom Miller Dam including Town Lake) since monitoring began in 1974. The San Bernard River at Highway 442 has exceeded the segment standards (for the entire river above tidal) for chloride twice and for pH once, and has been below standards for dissolved oxygen twice during the 5-year monitoring period.

Areas Subject to Flooding

Areas subject to flooding approximately once every hundred years were delineated, based on maps published by the Federal Insurance Administration in 1977 (fig 41). The terrace and alluvial deposits along the Colorado River and around Eagle Lake in the southern and western part of the study area are almost entirely in the 100-year floodplain. Flood waters would cover land up to the 185 ft level in the western (upstream) corner and to the 165 ft level along the steep eastern bank of Eagle Lake and its outflow, and would be up to 35 ft deep.

The rest of the study area, including virtually the entire prospect area, is on upland deposits. The streams are small with small drainage basins, and the hundred-year

Table 24. Water quality of the Colorado and San Bernard Rivers near Eagle Lake.

Station	*Factor*	*Unit of Measurement*	*Range*	*Average*	*Number of Measurements*	*Segment*[3] *Standards*	*No. of Times Standards Exceeded*
C[1]	Temperature	° C	8.2-30.6	20.3	22	35° max.	0
SB[2]			8.9-28.3	20.6	41	32° max.	0
C	Specific	μmhos/cm	275-845	559	21	——	——
SB	Conductance		93-9700	907[4]	27	——	——
C	Chloride	mg/l	10-99	46.6	15	100 max.	0
SB			5-130	50.4	28	100 max.	2
C	Dissolved	mg/l	6.8-10.0	8.3	15	5.0 min.	0
SB	Oxygen		3.8-10.5	7.4	38	5.0 min.	2
C	pH	Standard	7.2-8.4	8.0	23	6.5 min. 9.0 max	0
SB		units	7-8.6	7.7	15	9.0 max. 6.5 min.	1
C	Alkalinity	mg/l	128-238	182	3	——	
SB			33-171	110	9	——	
C	Manganese	μg/l	40-50	45	2	——	
SB			Not Available				
C	Ammonia	mg/l	.02-.36	.19	2	——	
SB		as N	0-1.8	0.44	27	——	
C	Boron	μg/l	200		1	——	
SB	Not Available						
C	Total Dissolved		137-422	280	21	500	
SB	Solids as 50% specific conductance		46-4850	454	27	500	

[1]C - Colorado River at Garwood; monitoring period 4/10/74-5/10/78
[2]SB - San Bernard River at Hwy 442 near Boling; monitoring period 1/8/73-6/6/78
[3]Segment standards from "Texas Surface Water Quality Standards" TDWR Draft Report 1978
[4]Due to abnormally large numbers on two occasions; median is 558
Source: Texas Department of Water Resources (T.N.R.I.S.)

Table 25. Historical high water levels recorded at highway bridges in the Eagle Lake study area.

Location	Approximate Elevation of River	Elevation of Historical High Water and Year	Estimated Elevation of 100 Year Flood
FM 3013 and San Bernard River	158'	169.60*	167'
FM 3013 and Middle Bernard Creek	156'	163.4*	165'
FM 1093 and West Bernard Creek	156'	158.32 (1973)	161'
Hwy. 90A and Colorado River	146'	168.6 (1935)	175'

*Bridges at these locations were put in within the last few years, so only a few years of data are available.

Source: Reagan, Texas Highway Department, pers. comm.

flood covers a relatively small strip along these streams. Flood levels are up to 10 ft above the streambed, but generally around 5 ft, for West Bernard and Middle Bernard Creeks. Coushatta Creek and the San Bernard River have larger drainage basins, but the 100-year floodplain is still relatively narrow, and flood levels are no more than 15 ft above the streambed.

There are no streamflow gauges within the study area, but the Texas Highway Department monitors flood depths at highway bridges. Historical high water measurements were obtained for 4 bridges in the study area (fig. 41 and table 25) (Reagan, personal communication). From the information available, it appears that the Colorado River has not approached the 100-year flood level, but the San Bernard River has.

Location of the Test Well on the Basis of Flood Potential

The key factor influencing depth and frequency of flooding is probably elevation above the nearest drainage way. The safest location for the test well is above the 100-year floodplain. At lower elevations relative to drainage ways, flood frequency increases; thus the probability of damage to a test facility increases.

SOILS

Introduction

No published soil survey is available for Colorado County. Mapping of soils has been done when requested by individual landowners, over a number of years and by several different soil scientists (Fair, personal communication). It should be understood, therefore, that the map of soils in the study area is a composite of available information, and that the names and descriptions of the soils are subject to change when an official survey of the county is made. The soils of Victoria County are in the process of being recorrelated by the Soil Conservation Service preparatory to publishing a Soil Survey, and a number of soil names and definitions have been changed (Miller, personal communication). As the upland soils of eastern Colorado County are very similar to those on the Lissie Formation in Victoria County, it is likely that these recorrelations will be extended to the study area.

The Soils Map (fig. 42) for the Eagle Lake area shows the soil associations as the major units, with the individual series included where they have been mapped.

Soil Origins

Parent Material

Most of the soils of the Eagle Lake area are derived from deposits of the Lissie Formation. The finer-grained deposits gave rise to the Katy-Edna Association, while soils of the Kenney-Fordtran-Katy Association developed in sandy deposits overlying clay along the San Bernard River and Coushatta Creek. Recent Colorado River flood-plain deposits have developed into clayey and loamy bottomland soils, often underlain by sand and gravel, of the Brazoria-Norwood Association.

Climate

Colorado County has a humid, subtropical climate. Given enough time, soils which form in such a climate become highly leached and weathered. However, because the parent material of the Eagle Lake area soils was laid down relatively recently, the soils have not developed highly leached horizons.

Topography

The upland Eagle Lake area, on the Lissie Formation, is quite flat except along steambeds, and many of the soils are therefore rather poorly drained. The numerous

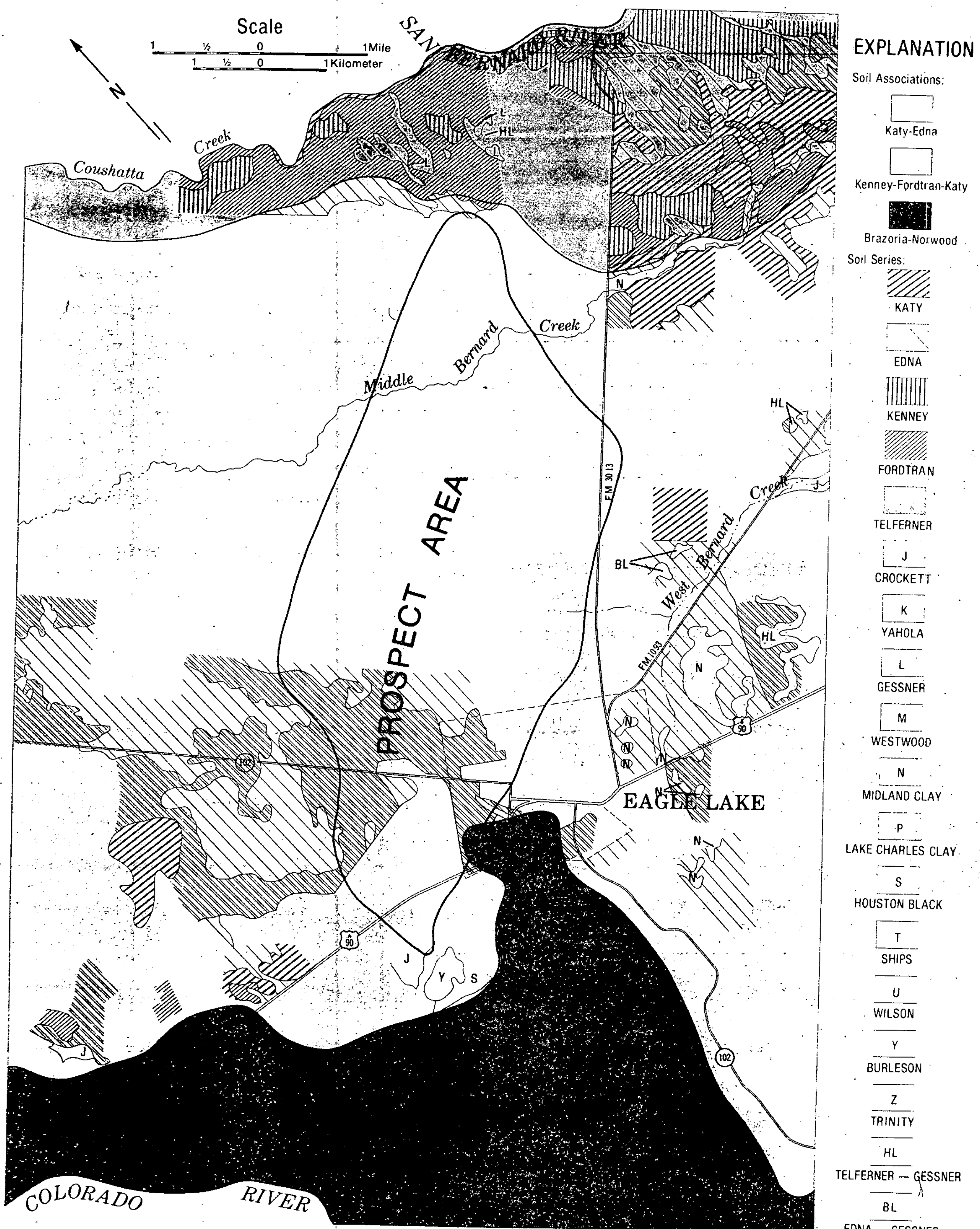

Figure 42. Soils, Eagle Lake Study Area. (Source: Soil Conservation Service, 1978a.)

depressions characteristic of the Lissie Formation are poorly drained and have more clay in the A horizon than surrounding soils. Slight slopes occur along the transition between the upland and Colorado River bottomland; at the base of these slopes are flat, low-lying areas of clay soils (e.g., Houston Black, Lake Charles clay). The topography of the bottomland is irregular due to the movements of the Colorado River across its valley and the soils are accordingly variable. A noticeable difference between the upland and bottomland is that there are extensive areas of single soils, particularly Telferner and Edna on the uplands, whereas the bottomlands contain a number of different soils each covering a small area.

Soil Problems

Many of the potential soil problems identified for the Cuero test site are also relevant to the Eagle Lake area. Several of the soils are expansive, corrosive, or subject to flooding. Soil drainage ranges from poorly drained to well drained, with the majority of the soils being poorly and somewhat poorly drained. Although slopes throughout the study area are generally very low, many of the soils are subject to erosion when vegetation cover is removed.

Some of the soils of the Eagle Lake area have a high clay content or a clay layer. Due to the high adsorption capability of the clay particles these soils may retain ions from a brine spill for long periods of time (see Cuero area soils: Soil Problems). A high content of humus may have a similar effect.

Prime Agricultural Lands

Prime agricultural soils have been identified in Colorado County in the same manner as described earlier for DeWitt County. Of the major soils in the study area (Edna, Telferner, Katy, Fordtran, Kenney) only Katy is prime. Many of the minor soils, especially the clay soils, are also prime. Prime soils are indicated on the Soils Table (table 26); however, they are not mapped since the soil survey of the area is incomplete. Although much of the study area is therefore not considered to be prime agricultural land as the soils do not meet the optimum criteria, for conventional agriculture, the level topography and poor internal drainage (because of the presence of clay layers) make many of the soils particularly well suited to rice production (Westfall, 1975).

Table 26. Soils Table, Eagle Lake.

Group	Map symbol	Soil series name (proportion of dominant soils in associations)	Surface texture	Slope	Drainage	Infiltration rate	Agricultural capability unit[5/6]	Prime farmland	Range-site[6]	Characteristics: Drainage	Characteristics: Corrosivity: Steel	Characteristics: Corrosivity: Concrete	Characteristics: Shrink-swell potential	Suitability: Shallow excavations	Suitability: Pipelines	Suitability: Local roads	Suitability: Roadfill	Suitability: Pond reservoirs	Suitability: Embankments, dikes, levees	Suitability for test well[1]: Construction[2]	Suitability for test well[1]: Ponds, dikes[2]	Suitability for test well[1]: Overall[3]	Suitability: Septic tank absorption fields	Suitability: Small buildings	Suitability: Suitability for further development[7]	Suitability: Sewage lagoon	Suitability: Sanitary landfill	Suitability: Topsoil	Suitability: Recreation	Wildlife: Open	Wildlife: Rangeland	Wildlife: Wetland
soil associations and major soils		*Katy-Edna association*																														
	A	Katy (40%)	fine sandy loam	0-2%	somewhat poorly drained	slow	IIIw-4	✓	Loamy prairie	-	--	++	++	--	-	--	--	++	±	C	A	2	--	--	C	±	±	++	-	++	--	±
	B	Edna (30%)		0-3%	poorly drained	very slow	III e-1		Claypan prairie	--			--		--											+	--	--	--	±		++
		Kenney-Fordtran-Katy association																														
	C	Kenney (45%)	loamy fine sand	0-3%	well drained	high	III s-1		Sandy prairie	++	++	±			++	++	++	--	--	A	C	2	++	++	A	--	-	--	±	--	--	--
	D	Fordtran (35%)	loamy fine sand	0-2%	somewhat poorly drained	slow	IIIw-3		Sandy prairie	-	++	±	++	--	++	±	±	++	±	B	A	1	--	±	C	--	--	--	-	±	±	++
	A	Katy (15%)	fine sandy loam	0-2%	somewhat poorly drained	slow	IIIw-4	✓	Loamy prairie	-	--	++			-	--	--	++	±	C	A	2	--	--	C	±	±	++	-	++	--	±
		Brazoria-Norwood association																														
		Brazoria (35%)	clay		somewhat poorly drained	slow					--	+	--	--	--	--	--	++	±	C	A	2	--	--	C	++	--	--	--	±	--	--
		Norwood (30%)	silty loam	0-1%	well drained	moderate	I -2			++		++	++	±	-	±		±	++	B		1	±			±	±	++	++	++	±	
minor soil series	H	Telferner Crowley	fine sandy loam	0-1% 1-3%	somewhat poorly drained	very slow	IIIw-4 III e-1		Loamy prairie	-	++	++	--	--	-	--	--	-	++	C	A	2	--	--	C	++	--	±	-	±	±	±
	J	Crockett	fine sandy loam	0-1% 1-3%	moderately well drained	very slow	III s-3 III e-1		Claypan prairie	±	--	++	--	--	--	--	--	++	±	C	A	2	--	--	C	++	--	--	--	++	--	++
	K	Yahola[4]	fine sandy loam	N/A		moderate	I -1	✓	Sandy bottomland	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	L	Gessner	loam	N/A		very slow	IVw-1	✓[5]	Lowland		--	++	++	--	-	--	--	++	±	C	A	2	--	--	C	--	--	--	--	±		++
	M	Westwood[4]	silty loam silty clay loam	N/A	well drained	moderate	II e-9	✓	Loamy bottomland		--	++	++	-	-	± --	--	±	±	C	B	3	±	--	C	±	-	++ ±	±	++	±	--
	N	Midland clay	clay	0-1%	poorly drained	very slow	IIIw-4		Blackland	--	--	++	-	--	--	--	--	++	±	C	A	2	--	--	C	++		--	--	N/A	N/A	N/A
	P	Lake Charles	clay	0-1%	somewhat poorly drained	very slow	IIw-2	✓	Blackland	-	--	++	-	--	--	--	--	++	±	C	A	2	--	--	C	++	--	--	--	++		-
	S	Houston black	clay	0-1% 1-3%	moderately well drained	very slow	IIw-1 II e-1	✓	Blackland	±	--	++	--	--	--	--	--	++	±	C	A	2	--	--	C	++	++	--	--	±	±	--
	T	Ships	clay	N/A		very slow	II s-1	✓	Clayey bottomland		--	++	--	--	--	--	--	++	±	C	A	2	--	--	C	--	--	--	--	±	±	--
	Y	Burleson[4]	clay	0-1%	moderately well drained	very slow	IIw-1	✓	Blackland		--	++	--	--	--	--	--	++	±	C	A	2	--	--	C	++	--	--	--	±	--	--
	Z	Trinity[4]	clay, occasionally flooded	N/A		very slow	IIw-1		Clayey bottomland		--	++	--	--	--	--	--	++	±	C	A	2	--	--	C	--	--	--	--	±	++	--

[1]See text p. —— [2]C⟶A: increasing suitability [3]3⟶1: increasing suitability [4]Local soils [5]Agricultural capability units range from I to VIII—limitation increases with number [6]See Appendix

[7]Determined from soil characteristics of corrosivity to steel and shrink-swell potential

N/A—Information not available at the time of report compilation

Soil Suitability Analysis

A soils table (table 26) and soil suitability analysis were prepared for the soils of Eagle Lake employing the same technique as that used for the Cuero study area. The suitability of soils for activities associated with the test well were analyzed and then combined to give an overall suitability for each soil series. Individual problems associated with major soil series are discussed in the following section.

Soil Associations

The following is a brief description of the major soils within the associations of the Eagle Lake study area. Much of this data as well as additional information can be found on table 26. Information on minor soils not described in the text can also be found in the soils table.

Descriptions include general information on soil depth, drainage, slope, and texture. References to nearly level and to gently sloping or undulating refer to slopes of 0-1% and 1-3% respectively. It should be noted that all the soils have a tendency to erode if vegetation is removed from slopes of over 1%.

Upland Soils

1. Katy Edna Association (Katy 40%, Edna 30%, Others 30%)

The majority of the study area is within this association. These are nearly level, loamy soils of the uplands that are moderately to very slowly permeable.

KATY. These are deep, nearly level to gently sloping, somewhat poorly drained soils. They have a thick fine sandy loam surface layer over a clay loam subsoil. Some soils which are now mapped as Katy may be remapped as Fordtran or Telferner when the Colorado County Soil Survey is published (Miller, personal communication).

These soils pose several problems to construction, due to high corrosivity to steel and low strength. They pose significant problems to pond construction and moderate problems of instability for levee construction.

EDNA. These soils are deep, nearly level to gently sloping, poorly drained and noncalcareous. Their thin surface layer (about 7 inches) of sandy loam is underlain by clay to a depth of about 3 ft, below which is sandy clay. They have a high corrosivity to steel, low strength and high shrink swell, thus posing serious problems for construction. They are suited to pond location, but pose moderate problems of shrink swell and unstable fill for levee location.

2. Telferner-Edna Association (Telferner 35%, Edna 35%, Other 30%)

Although this association does not appear in the study area, it is present in Colorado County. It is included here because the Telferner soils appear to be well represented around Eagle Lake and often occur in association with Edna soils. It is possible that some of these areas were mapped after the association map was produced, or that the overall percentage of Telferner soils throughout Association 1 is small.

The soils in this association are nearly level, very slowly permeable upland soils.

TELFERNER. These are deep, nearly level to gently sloping, somewhat poorly drained soils. They have a thick fine sandy loam surface layer with a sandy clay subsoil. Their main problem for construction is high shrink swell. They are well suited to pond location, and pose moderate problems of stability for levee location.

EDNA. See above, Katy-Edna Association.

3. Kenney-Fordtran-Katy Association (Kenney 45%, Fordtran 35%, Katy 15%, Other 5%)

This association is found along Coushatta Creek and the San Bernard River in the northeastern portion of the study area. These are gently sloping, gently undulating loamy to sandy soils of the uplands that are moderately slowly to moderately rapidly permeable.

KENNEY. The Kenney soils consist of deep, nearly level to gently undulating well drained noncalcareous soils. They have a thick loamy fine sand suface layer over a sandy clay loam subsoil. They pose no significant problems for construction but pose severe problems of seepage and instability for pond and levee location.

FORDTRAN. The Fordtran soils are deep, nearly level to gently sloping somewhat poorly drained calcareous soils. They have a thick loamy fine sand surface layer over a sandy clay subsoil. They have moderate problems with wetness and a tendency to cave, which may be considerations for construction but are suited to pond and levee location and only pose moderate problems of piping for levees.

KATY. See above, Katy-Edna Association.

Scattered throughout the upland soils are the depressions or potholes mentioned under Geology. The soils in these depressions have a surface layer of sandy clay loam or a clay loam, 6-10 inches deep, and a subsurface of clay or sandy clay to a depth of 40 or 50 inches. They are 1 to 2 ft lower in elevation from the surrounding soils, and there is a fairly distinct transition between them. The surrounding soils are generally Edna or similar soils with a fine sandy loam surface layer 6-14 inches deep and a clay or sandy clay subsurface layer to a depth of 40 or 50 inches. (Description based on depressions in Victoria County; Wes Miller, personal communication.)

Bottomland Soils

4. Brazoria-Norwood Association (Brazoria 35%, Norwood 30%, Others 35%)

This association is found in the Colorado River valley, and covers the southwest portion of the study area. These are nearly level clayey and loamy bottomland soils that are very slowly to moderately permeable.

BRAZORIA. These are nearly level, moderately well drained soils. They are clay throughout their profile. These soils pose several serious problems to construction having low strength, high shrink swell, and being subject to flooding. They are, however, suited to pond location and pose only moderate problems of compressibility for levees.

NORWOOD. These are level, well drained, calcareous soils. Their texture is silt loam throughout their profile.

They have high corrosivity to steel, low strength and are subject to flooding, all problems for construction. They pose moderate problems of seepage for ponds but are suited to levee location.

Substrate Suitability Analysis

Because the soils mapping is incomplete for the Eagle Lake area, it was not possible to prepare a soil suitability analysis equivalent to that prepared for the Cuero area. However, the Land and Water Resources map of the Houston-Galveston area (St. Clair and others, 1975) used to prepare the Geology Map includes a general analysis of the physical properties of the map units. This analysis was used to rank the map units according to their suitability for construction of test well facilities. Table 27 shows the physical properties and relative suitabilities of these units (where possible).

Table 27. Substrate suitability for test well, Eagle Lake.

Substrate (fig. 34)	Corrosivity	Shrink-Swell	Bearing Strength	Excavations	Suitability for Construction
Relict fluvial and deltaic deposits. Sand, clayey sand.	+	++	++	+	1
Relict fluvial deposits. Sandy clay.	--	-	-	-	3
Recent fluvial deposits. Sand and gravel.	--	++	++	++	2
Recent fluvial deposits. Mud and silt.	--	--	--	-	3
Recent tributary stream deposits. Sand, silt, and mud.			VARIABLE		
Meander scars, mudfilled.	--	--	--	--	3
Fluviatile terrace deposits. Sand and gravel.	N/A	++	++	++	1
Abandoned river channels, cut-offs. Mud over sand and gravel.	--	N/A	N/A	N/A	-
Recent fluvial deposits. Mud, silt, and sand.	--	N/A	N/A	N/A	-

<u>Properties relevant to test well construction</u>

++ Favorable
+ Moderately favorable
- Moderately unfavorable
-- Unfavorable
N/A Data not available

Source: St. Clair and others, 1975, "Land and Water Resources -- Houston-Galveston Area Council"

LAND USE

Mapping

Land use was mapped using 1975 infrared (1:63,000) and black-and-white (1:12,000) aerial photographs (fig. 43). Mapping was field checked wherever possible during the spring and summer of 1979.

Mapping units are :

- Rice land - Rice land was placed in a separate category from other crops because of the difference in management techniques. Of the fields mapped as rice land, 1/3 to 2/3 are actually in pasture each year.
- Other cropland - Includes non-rice fields presently under cultivation or showing evidence of having supported a crop recently.
- Pastureland - Grassland areas without undergrowth or brush, in native or planted perennial grasses.
- Rangeland - Unimproved grazing land.
- Gravel pits.
- Residential and commercial land.
- Attwater Prairie Chicken National Wildlife Refuge.
- Surface water.
- Texas Agricultural Experiment Station, Rice Research.
- Abandoned catfish pond.

Description

The Eagle Lake study area is primarily rural and agricultural. Most of the land is intensively used for rice farming and cattle grazing; however, much of the land between the lake and the Colorado River is used for gravel mining. Oil and gas wells are common throughout the study area.

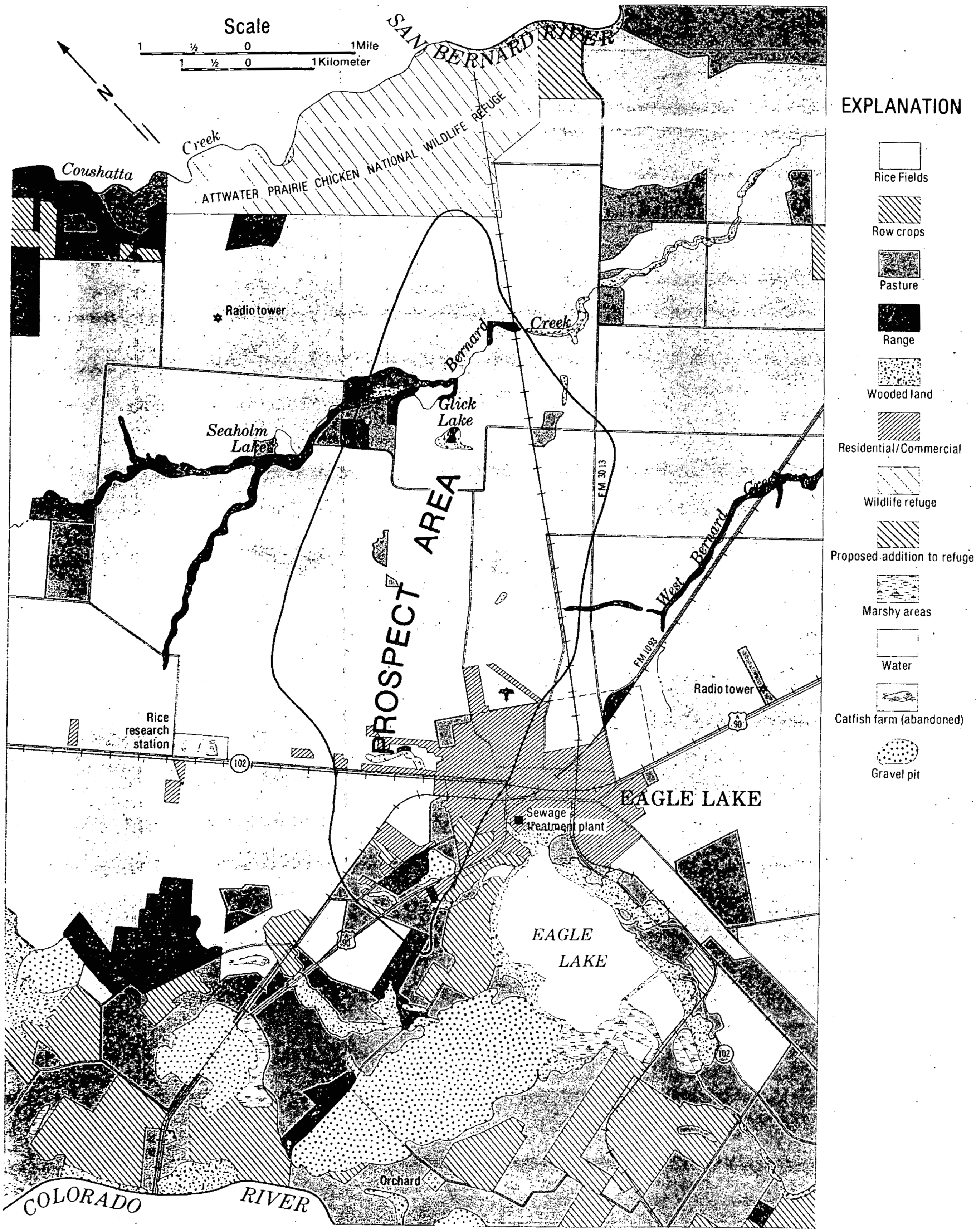

Figure 43. Land Use, Eagle Lake Study Area.

Agriculture

The land to the north and east of Eagle Lake is mostly under irrigated rice production. Water is pumped from the Colorado River, through irrigation ditches to the rice fields. The water when released drains naturally, mainly into Middle Bernard Creek. Usually two harvests are made from one planting of rice, one in August and one in October. Approximately one-third of the rice acreage is irrigated each year; for one or two years out of three the land is used as pasture for cattle or occasionally for field crops. Soybeans have recently increased in importance as a secondary crop, especially south of the Santa Fe railway. Agricultural land which is not used for rice includes a few fields north of Eagle Lake and much of the area south of the lake. It is used for non-irrigated row crops such as corn, milo, or cotton, or for pasture or range. The rangeland is often infested with Macartney rose.

Facilities related to agriculture include the Texas Agricultural Experiment Station for Rice Research located northwest of the city of Eagle Lake, a rice dryer across the highway from the Research Station and an extensive system of irrigation ditches, levees, and pumping facilities.

Mineral Exploitation

Vigorous construction activity in Houston, only 60 miles from Eagle Lake, has led to renewed exploitation of the gravel deposits in the southwest portion of the study area. Abandoned strip mine areas are used for cattle grazing, and the ponds found in the old pits often provide good bass and crappie fishing.

Oil and gas fields in the study area include the Chesterville and Ramsey fields (fig. 33). Many old wells exist and new wells are still being drilled.

Residential and Commercial Land Use

Most residential and commercial development is found within the city limits of Eagle Lake although strip development extends along most of the roads that radiate out from the city, as well as along the eastern shore of the Lake. A small airstrip is located just north of the city. Four state highways and 5 rail lines meet in the city.

National Wildlife Refuge

The southern portion of the 5,600-acre Attwater Prairie Chicken National Wildlife Refuge extends south of Coushatta Creek and thus into the study area. Parts of the refuge are virgin prairie, while other sections were previously cultivated but have been allowed to regenerate prairie grasses. The area is managed to maintain a suitable and undisturbed environment for the Attwater Prairie Chicken and other fauna that use the reserve.

Other Land Uses

Surface water is a common feature in the study area. Larger ponds are maintained in some of the rice fields as habitat for wintering geese and ducks. Abandoned gravel pits are often water-filled and are used for commercial bass fishing as well as by wildlife. Eagle Lake itself is a shallow lake seldom over 8 ft deep which covers about 2 square miles and is partially used as a reservoir by the Lakeside Irrigation Company. The lake and its vicinity support a large alligator population and provide suitable habitat for many birds and other wildlife species.

Relationship of Land Use to Natural Factors

Rice fields are located on the nearly level coastal plain, in clayey soils which retain the water needed for rice growth. Row crops such as maize are grown in areas too sandy or too steep to permit rice farming. Gravel pits are located on alluvium in the Colorado River valley, where thick deposits of coarse material are to be found.

Land Use Suitability for Test Well Development

Effect of Land Use on Well Construction

In terms of current land use, the most suitable locations for a test well are those with the least value for other uses and the least cost for construction of the well and related facilities (table 28). In the Eagle Lake study site, there are few areas which are not actively used. These include abandoned gravel pits and small areas of range along the creeks. Less valuable land uses include rangeland, pasture, and non-irrigated cropland. These areas too are small in extent, especially in the prospect area. Most of the land is in high-value uses: irrigated rice land or residential and commercial development. Construction would be least costly on land with no obstructions, i.e. cropland and pastureland. Rangeland and wooded land would pose additional costs for clearing. The most expensive areas to build a test well would be gravel mine sites and built-up areas.

Table 28. Relative site preparation costs and land use values. Eagle Lake study area.

Land use in order of decreasing suitability for test well	Relative cost of site preparation	Relative value of land use
Gravel pits, abandoned	mod-high	low
Rangeland	low-mod	low-mod
Pastureland	low	mod
Waterfowl lakes	mod	mod
Cultivated land	low	mod-high
Gravel pits, current	mod-high	high
Attwater Prairie Chicken Refuge	low-mod	high
Built-up land	mod-high	high

*"Value" includes both monetary and intangible values.

Effect of Well Construction on Land Use

The major effect of the test well would be the removal of 5-6 acres of land from its original use. Any future expansion of the facility to industrial uses would require more land. Should subsidence occur, rice farming would be affected since the fields are carefully leveled. Flow in the irrigation ditches could also be adversely affected. An accidental spill or blowout would affect a larger area than the test site and might result in elimination of crops in the area of the spill. The effect could have a long-lasting impact on the future of the cropland, facilitated by the fact that many of the soils of the Eagle Lake area, especially those in the rice growing area, have a high clay content or clay layer likely to retain geothermal contaminants.

Effect of Geothermal Fluids on Cropland

Geothermal fluids, in addition to their high temperatures, have a high dissolved solids content and contain many substances in concentrations that could be detrimental to crops (table B1).

The major crop in the area, rice, is grown in levees which are flooded with water for several weeks during the growing season. Rice has variable tolerances to salinity depending on the growth stage. Young rice is very sensitive, but gains tolerance as it matures. According to Shutts (1953), the commonly accepted tolerances of rice are as follows:

Concentration of salts as sodium chloride (mg/l)	Tolerance
600	Tolerant at all stages.
1,300	Rarely harmful and only to seedlings in dry, hard soil.
1,700	Harmful before tillering; tolerable from jointing to heading.
3,400	Harmful before booting; tolerable from booting to heading.
5,100	Harmful at all stages.

Of the other substances in geothermal fluids manganese, although an essential micro-nutrient, is toxic to plants at concentrations of 1 to a few mg/l from irrigated water applied to soils with pH lower than 6.0 (U.S.EPA, 1976). Manganese concentrations in some geopressured fluids are twice the recommend level for irrigated water on most acid soils. Beryllium concentrations also exceeded levels for irrigated water on acid soils. Boron, although an essential trace element for plants, is toxic to crops at low concentrations; sensitive plants may show effects below 1 mg/l (U.S.EPA, 1976), and the recommended standard for long term irrigation of sensitive crops is 0.75 mg/l. Boron concentrations in geopressured waters are 30-80 times the recommended irrigation limits. In addition, salinity can have a significant effect on soil chemistry and nutrition, and this, combined with possible residual concentrations of toxic substances, and effects on this soil could have an effect on crop production in affected areas. (See Cuero, Effect of Test Well on Land Use.)

If a spill of brine were to affect the Rice Research Station, ongoing experiments could be invalidated and depending on the severity of the accident, the future of the station in that location could be jeopardized.

Table 29 is a summary of the possible effects of the test well on land use and the relative significance and area of impact of these effects. Although the numbers are only relative, the totals serve to indicate which land use areas would be most seriously affected by a test well, and, the type of test well activity that would be most deleterious to land use.

Location of the Test Well on the Basis of Land Use

Within the test well reservoir area, nearly all the land is under valuable rice production, residential and commercial development, or National Wildlife Refuge.

The area of the reservoir that falls within the Attwater Prairie Chicken Refuge and the range of the bird would be very unsuitable as construction could disturb the birds, induce behavioral changes or destroy vital microhabitats. Although natural prairie recovers better than many other vegetation types, a spill could at least temporarily reduce the already limited area of habitat suited to this endangered species. A blowout emitting hot saline water may be lethal to wildlife found in the vicinity at the time of the accident.

Residential and commercial areas are also clearly unsuitable for a test well, due not only to the cost of construction and removal of land from a more valuable use, but also to the albeit remote possibility of endangering human life and well-being. The permanent removal of 5-6 acres of rice land would mean a loss of production of approximately 270 cwts of rice every 2-3 years plus loss of income from alternate uses

Table 29. Significance of test well for land use.

Eagle Lake	Site preparation	Normal operations	Small leak or spill	Major blowout	Subsidence	Subsidence and faulting	Cumulative	Rel. effect*
Active gravel pits	4 / 1	2 / 1	1 / 1–2	1 / 3	1 / 5	1 / 4	10 / 16	26
Abandoned gravel pits	1 / 1	1 / 1	1 / 1–2	1 / 3	1 / 5	1 / 4	6 / 16	22
Range	1 / 1	1 / 1	2 / 1–3	3 / 3	1 / 5	1 / 4	10 / 16	26
Pasture	2 / 1	1 / 1	3 / 1–3	4 / 3	1 / 5	1 / 4	12 / 16	28
Cropland	3 / 1	1 / 1	4 / 1–3	5 / 3	1 / 5	1 / 4	15 / 16	31
Rice production (including irrigation system)	3 / 1	1 / 1	4 / 1–3	5 / 3	2 / 5	3 / 4	18 / 16	34
Residential/ commercial	5 / 1	3 / 1	4 / 1–3	5 / 3	3 / 5	5 / 4	25 / 16	41
Prairie chicken refuge	5 / 1	3 / 1	4 / 1–3	5 / 3	2 / 5	2 / 4	21 / 16	37
Cumulative	21 / 11	13 / 8	23 / 15	29 / 24	12 / 40	15 / 32	Significance of effect / Relative area affected	
Relative importance of test well activities on land use	32	21	38	53	52	47		

*Relative effect of test well on land uses.

on that acreage during non-rice years. This may not in itself be significant, but a blowout or a spill could affect a large area of surrounding cropland.

The section of range and pastureland along Middle Bernard Creek would perhaps be one of the more suited locations for a test well as valuable cropland would not be taken out of production. In the event of a spill the surrounding cropland could, however, be affected. Another problem of this location would be the possibility of contaminating Middle Bernard Creek and Glick Lake. One gravel pit occurs in the prospect area. If abandoned it would be a suitable location from the point of view of alternative uses; but the cost of reclaiming the land for construction and its proximity to residential areas are disadvantageous.

BIOLOGICAL RESOURCES

Introduction

The biological resources of the Eagle Lake study area consists of a group of interacting plants and animals, or biological assemblages, whose composition and dynamics are affected both by natural factors such as drainage, soils, disease and weather, and man-induced factors including agricultural practices (clearing land, introducing species, pesticide application), waste disposal and commercial and industrial development. The existing biological assemblages in the Eagle Lake study area are a result of the effects of many of these factors, over time, on the original tall grass prairie assemblages native to the region. As little specific information exists on biological assemblages of the area, per se, two of the major components, vegetation and wildlife, are considered separately here.

Mapping

Vegetation and wildlife in the Eagle Lake area were mapped (fig. 44) using 1:48,000 color infrared and 1:12,000 black-and-white aerial photographs, field investigation, and communication with personnel of the Attwater Prairie Chicken Refuge and David Winterman of the Lakeside Irrigation Company. Mapping units include:

- Wildlife Refuge and prairie grassland.
- Range of Attwater prairie chicken in study area.
- Proposed addition to wildlife refuge.
- Alligator habitat.
- Areas of sightings of bald eagles.
- Rice fields - prime habitat for migratory waterfowl.
- Other cultivated land.
- Woodland.
- Grassland.
- Marsh.

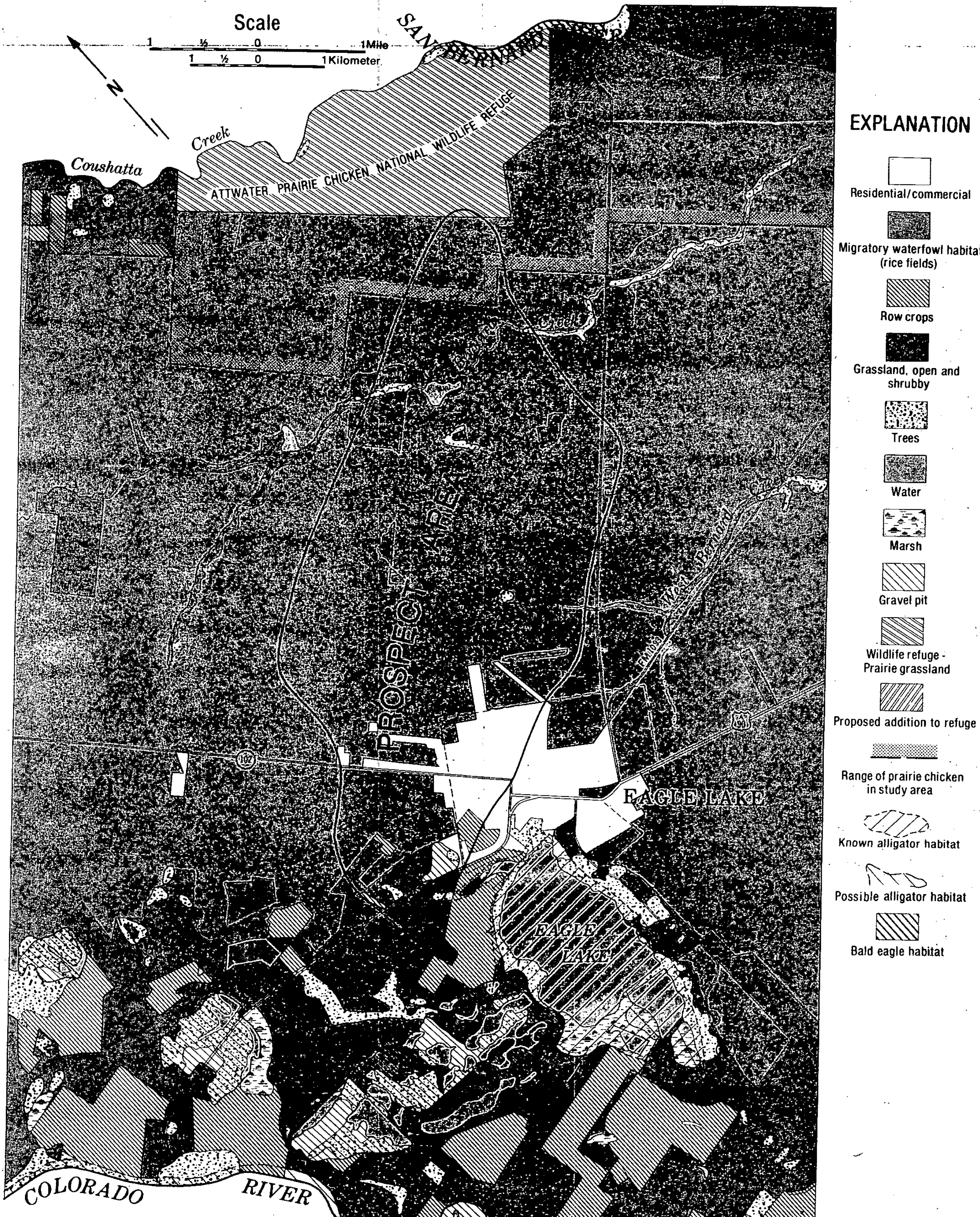

Figure 44. Vegetation and Wildlife, Eagle Lake Study Area.

* Gravel pits.
* Surface water.

VEGETATION

Description

Most of the land in the Eagle Lake study area is cultivated, therefore only vegetation which has not been specifically planted will be discussed here. Where not referenced, information on vegetation was obtained from field survey. Appendix D contains a species list for the study area.

Uplands

Grassland

Much of the following information on the vegetation of prairie lands and fallow rice fields comes from studies conducted by Kessler (1978) in the Attwater Prairie Chicken Refuge and surrounding rice lands. The vegetation of the refuge consists of tall grass prairie, a little of which is original but most of which has been reclaimed from past agricultural use. The area is managed on a system of rotational grazing, burning and mowing in order to simulate the natural conditions of the prairie. These practices do not significantly affect the floristic composition but provide the habitat variation required by the prairie chicken. The climax vegetation of the two main range sites of the refuge, Sandy Prairie and Coarse Sand*, is dominated by little bluestem (Schizachyrium scoparium). On both range sites total basal cover is about 10-12 percent. Percentage botanical composition afforded to total basal cover by grasses, forbs (broadleaf plants) and sedges and rushes in the summers of 1967 and 1974 can be seen on the table below.

	Grazed		Ungrazed	
	1967	1974	1967	1974
Grasses	95.4	98.4	97.0	93.4
Forbs	3.3	1.0	1.7	2.3
Sedges & Rushes	1.3	0.6	1.3	4.3

*See Appendix C for description of range sites.

Species balance on the two range sites varies, as it does between grazed and ungrazed sections, as discussed below for the summer of 1974.

Sandy Prairie. Grazed: Forb density on these sites is estimated at 675,000/ha with narrowleaf sumpweed (Iva angustifolia) and common broomweed (Xanthocephalon dranunculoides) combined contributing 50 percent of this cover. Dominant grasses are brownseed paspalum (Paspalum plicatulum) and little bluestem contributing 64 percent of the grass cover.

Ungrazed: Forb density on ungrazed sites is lower (162,500/ha); of the 36 forb species commonly occurring, the two most abundant are western ragweed (Ambrosia psilostachya) and small head boltonia (Boltonia diffusa) together contributing 30 percent of forb composition. Brownseed paspalum and gaping panicum (Panicum hians) contribute 60 percent of grass composition.

Coarse Sand Prairie. Grazed: The major difference between the coarse sand range site and the sandy range site is the increased density of forbs to 1,167,000/ha, dominant forbs being camphorweed (Heterotheca subaxillaris) and fleabane (Erigeron sp.), these contributing 59 percent of the forb cover. Brownseed paspalum and common carpet-grass (Axenopus affinis) contribute 49 percent of the grass cover.

Ungrazed: Ungrazed sites have a forb density of about 1,693,700/ha with slender goldenweed (Croptilon divaricatum) and camphorweed together contributing 73 percent to forb cover. Brownseed paspalum and little bluestem make up 50 percent of the grass composition.

Information on the percentages of the more abundant species of these sites can be found on tables D3 and D4, appendix D.

Macartney rose (Rosa bracteata), a vigorous growing woody plant, is a problem not only within the refuge but in most grazing lands throughout the Eagle Lake area. Introduced to serve as a fence border it has been rapidly spread by cattle and wildlife and, where unchecked, rapidly reduces the grass cover available for grazing. An eradication program for the Macartney rose on the Refuge is underway.

Within the Refuge approximately 1,000 acres of recently acquired fallow rice fields are being allowed to return to native rangeland. This is being facilitated by the splitting and disking of existing levees and the construction of drainage ditches.

Fallow Rice Fields.

Although information on the vegetation of fallow rice fields was obtained from a study of fields in the vicinity of the Attwater Prairie Chicken Refuge, the data should be applicable to fallow rice fields in general throughout the Eagle Lake area.

First year fallow: The vegetation cover in these fields is primarily forbs with densities up to 431,000/ha, the dominant plant being western ragweed, contributing 55 percent to the total composition, followed by purple gerardia. Two grass species, fall panicum (Panicum dichotomiflorum) and barnyard grass (Echinochloa sp.) comprise 57 percent of the grass cover of fields.

Second year fallow: Forb densities in second year fallow rice fields are generally higher than on first year fields, around 8,029,600/ha, with narrowleaf sumpweed providing 89 percent of this composition. Of the grass species common Bermuda grass is the most abundant, contributing 17 percent to grass composition,with Scribners panicum (Dicanthelium oligosanthes), rice cutgrass (Leeris oryzoides), gaping panicum (Panicum lians) and barnyard grass contributing 12-15 percent each.

Further information on species composition in fallow rice fields can be found on tables D3 and D4, appendix D.

Rivers and Streams.

Trees occur intermittently in clumps along the San Bernard River and the creeks of the upland area. Generally small Chinese tallow (Sapium sebiferum), willow (Salix sp.), chinaberry (Melia azedarach) and hackberry (Celtis sp.) trees grow over a thick ground cover of Macartney rose along the streams and drainage ditches. These trees plus water oak (Quercus nigra), elm (Ulmus americana) and sycamore (Platanus occidentalis) occur with yaupon (Ilex vomitoria) brush in a ground cover of Macartney rose, dewberry (Rubus spp.) and peppervine (Ampelopsis arborea) along the San Bernard River.

Depressions.

The intermittent prevalence of wet conditions in the numerous depressions that occur throughout the upland area has often resulted in the growth of more water tolerant species.

Bottomland

Vegetation in the bottomland of the Colorado River differs from that of the uplands largely because of the difference in soils and water regimes, which in turn have affected the type of land use and management.

Grassland

Grasses of the bottomland on range and unimproved pasture include Dallis grass (Paspalum dilatum), bermuda grass (Cynodon dactylon), sandbur (Cenchrus incertus), and moisture-tolerant grasses such as smutgrass (Sporobolus indicus), and carpet grass (Axonopus affinis) (Hajdik, personal communication).

Woodland

Pecans (Carya illinoenis) and cottonwoods (Populus deltoides) are common along the Colorado River, with sycamore also evident. Liveoak (Quercus virginiana), water oak, pecan, hackberry and anaqua (Ehretia anacua) occur around the lake and its tributary while scattered stands of liveoak, postoak (Quercus stellata) and mesquite (Prosopsis juliflora) occur on the low ridge surrounding the bottomlands. An often dense growth of willow with some Chinese tallow is commonly present in abandoned gravel pit areas.

Brush species of the bottomland include huisache (Acacia farnesiana), retama (Parkinsonia aculeata), desert willow (Chilopsis linearis) and prickly ash (Xanthoxylum clava-herculis).

Marsh

Marshlike vegetation consisting of cattails, sedges and rushes is present in lowlying areas and some abandoned gravel pits of the bottomland. The largest area of marsh occurs directly south of Eagle Lake.

Rare and Endangered Plants

No official protection exists for the majority of rare or endangered plants in Texas, and although about 110 species native to the state have been proposed as additions to the 1973 Endangered Species Act List of Endangered and Threatened Plant Species, only one, Texas wild rice (Zizania texana), has been so far accepted (Talbot, Lodwick, personal communication).

The only rare plant thought to occur in the study area of Colorado County is the Southern marsh fern (Thelypteris palustris var. Haleana); although rare in Texas, its overall status nationwide is not known (Johnston, personal communication). It is not a proposed species for the Federal listing (Talbot, personal communication). It grows in open sandy bogs, swamps and meadows, or in open low woodland and in seepage about lakes and ponds and along rivers (Correll & Johnston). Many of these habitats occur in the Eagle Lake area.

Colorado County is very poorly collected and very poorly known (Turner, personal communication). Thus, it is possible and even likely that other plants, rare or endangered in the county or larger regions, may occur in the study area. This is especially likely on areas of private land that have been undisturbed for many years and have not been available for study.

Vegetation Suitability for Test Well Development

Effect of Test Well on Vegetation

Site preparation for a geothermal well will necessitate the elimination of 5-6 acres of vegetation, not necessarily a significant amount if the location is well chosen. A spill or blowout could, however, destroy vegetation in a larger area, and, due to the effect of brine on soils (see Cuero Land Use: Effect of Test Well on Land Use) and residual concentrations of ions, revegetation may not take place for many years. The absence of vegetation on areas of the Saratoga Oil Field in Hardin County, Texas has been attributed to large scale brine and/or hydrocarbon spills that occurred 30-80 years ago (Gustavson and others, 1978).

The suitability of various vegetation types for the location of the test well depends on several factors including the presence of rare and endangered species, the recovery time needed for the vegetation to return to its previous condition, the abundance of the vegetation type in the study area and surrounding counties and the fauna dependent upon it.

Location of the Test Well on the Basis of Vegetation

Prairie

Based on the above factors, the area of natural prairie would be the least suited for test well development. This is due in part to the fact that the acreage of prairie in Colorado County represents one of the few areas of natural prairie remaining in the Gulf Coast. In addition, this vegetation supports a variety of faunal species including the endangered Attwater prairie chicken for which it constitutes the critical habitat.

As a test well site would only require utilization of about 5 acres of land, if carefully located with reference to the needs and habits of the prairie chicken, it would not necessarily seriously affect the bird. Should, however, a spill or blowout occur, a larger area of the habitat, possibly including critical nesting or booming ground sites, could be affected which could significantly disturb the prairie chicken population. Furthermore, if the well proved successful and further construction in the locality was to be desired, this could lead to a serious conflict of interests.

Woodland

The major factor against locating a well in native woodland is the length of time needed for this community to become reestablished. Mature woodland such as is found along the Colorado and San Bernard Rivers, or around Eagle Lake, could take decades to reattain their present stage. In addition, woodland, especially native woodland, is relatively uncommon in the study area and in the southeastern portion of Colorado County.

Grassland

Due to the fact that grassland communities take relatively less time to recover their original composition, and that grassland, in the form of pasture, rangeland, or fallow rice fields, is quite abundant in the study area, this vegetation type would be more suited to test well development. The fallow rice fields are, however, prime habitat for migratory birds during the winter and early spring months.

Rare Plants

As research on rare plants in the county is incomplete, a detailed study on the location chosen for the test well, whatever the vegetation type, will be needed to determine if any rare species occur in the area and what measures should be taken to protect them.

WILDLIFE

Information on the fauna of the Eagle Lake area was gathered largely from information pertaining to Colorado County as a whole although publications of the Attwater Prairie Chicken Refuge and personal communication with David Winterman enabled much of the data to be verified for the study area. Endangered species that may occur within the county are indicated on table 30 and discussed below. A list of 1978 hunting statistics for the county can be found in table 31. Appendix E contains

Table 30. Endangered and threatened species: Colorado County

Species protected by Texas Parks and Wildlife Dept. regulations		Presence in county	Comments
ENDANGERED			
Birds			
Southern bald eagle	Haliaeetus leucocephalus	Verified	Migratory
Arctic perigrine falcon	Falco peregrinus tundrius	Verified	Migratory
Attwaters prairie chicken	Tympanuchus cupido attwateri	Verified	Resident
Whooping crane	Grus americana	Verified	Migratory
Interior least tern	Sterna albifrons athalassos	Probable	Migratory
Eskimo curlew	Numenius borealis	Possible	Migratory
Mammals			
Red wolf	Canis rugus	Verified	Previously
Reptiles			
American alligator	Alligator mississipiensis	Verified	Waterways
Amphibians			
Houston toad	Bufo houstonensis	Possible[6]	Sandy soil
THREATENED[1]			
Birds			
Whitetailed hawk	Buteo albicaudatus hypospodius	Verified	Resident
Swallowtailed kite	Elandoides f. forficatus	Verified	Migratory
Osprey	Pandion haliaetus carolinensis	Verified	Migratory
Wood stork/ibis	Mycteria americana	Verified	Migratory
Whitefaced ibis	Plegadis chihi	Probable	Resident
Least tern	Sterna albifrons antillarum	Probable	Migratory
Reddish egret	Dichromanassa r. rufescens	Possible	Resident
Reptiles			
Texas tortoise	Gopherus berlandieri	Probable	
Texas horned lizard	Phrynosoma cornutum	Probable	
Louisiana milk snake	Lampropeltis triangulum amaura	Probable	
Fish			
Blue sucker	Cycleptus elongatus	Probable	
Species not protected **From the Texas Organization of Endangered Species Watchlist**			
Birds			
Fulvous whistling duck[2]	Dendrocygna bicolor	Verified	T[3]
Prairie falcon	Falco mexicanus	Verified	T[3]
Merlin	Falco columbarius	Verified	T[3]
Reptiles			
Western smooth green snake	Opheodrys vernalis blanchardi	Probable	P[4]
Reticulate collared lizard	Crotaphytus reticulatus	Possible	T[3]
Northern cat-eyed snake	Leptodeira s. septentrionalis	Possible	P[4]
Colorado water snake	Nerodia harteri paucimaculata	Possible	E[5]

[1] Protected non-game species
[2] Totally protected from hunting by state game laws
[3] T: Likely to become endangered in the near future
[4] P: Threatened or endangered in the U.S., especially in Texas, although not in its range as a whole
[5] E: In danger of extinction in all or most of its geographic range in the U.S., particularly in Texas
[6] Verified in past

Sources: Potter; Brownley; personal communication TPWD
TOES watchlist of endangered, threatened, and peripheral vertebrates of Texas, 1979

Table 31. Approximate figures from 1978 inventory of hunted species, Colorado County.

Species	Number available for harvest[1]	% of Total Population	Total Population
[3]White-tailed Deer	9,254	20	46,270
[3]Bobwhite Quail	50,000	40	125,000
[3]Squirrel	50,000	40	125,000
Rabbit/Hare	60,000	40	150,000
[2,3]Bobcat	335	35	960
Coyote	1,000	40	2,500
[3]Furbearers*	15,000	35	42,860
[3]Fox	500	35	1,430
[2,3]Alligator	25	5	500

Regulated Game Birds Known to Occur in Colorado County

Snow Goose	Scaup
Speckle belly	Shoveller
Canada goose	Blue wing teal
Ross goose	Green wing teal
Mallard hens	Cinnamon teal
Wood Duck	Wigeon
Gadwall	Bobwhite Quail
Dove	Wild Turkey

*Muskrat, nutria, raccoon, badger, opossum, skunk, ringtail, mink, beaver, otter, fox. See Appendix for Latin names.

1. Based on production or carrying capacity.
2. On Federal Register of Protected Species.
3. Regulated by hunting laws.

Sources: Hope, McMahan, pers. comm. TPWD.

lists of the mammals, birds, reptiles, and amphibians of the county, plus a short description of the status and habitat of protected non-game species.

Birds

The Eagle Lake area is renowned for its bird life. The lake, rice fields, and Prairie Chicken Refuge provide a variety of habitats suited to a wide variety of bird species that attract both naturalists and hunters. Birds are especially abundant in winter when this section of the Central Flyway supports one of the largest concentrations of wintering geese in the United States (U. S. Fish and Wildlife Service, 1978).

Endangered Species

Attwater Prairie Chicken. The endangered Attwater prairie chicken (*Tympanuchus cupido attwateri*) is a chicken-like bird, native grasses and forbs of the prairies constituting the only habitat capable of continuously satisfying all its needs (U. S. Fish and Wildlife Service, 1975). The three month mating season of the prairie chicken begins in early February when males congregate on "booming" (courtship) grounds. Booming grounds have short scanty plant cover or none at all and vary in shape and size. Females are attracted to these sites by the active fighting and booming of the males. Mating usually occurs here and nests are normally located within one-half mile. Medium to heavy grass cover is the preferred nesting habitat. The 12-14 eggs laid are incubated for 26-28 days and chicks are escorted from dense cover soon after hatching.

The Attwater prairie chicken is a subspecies of the Greater prairie chicken and was once one of the most abundant resident birds occupying the 8 million acres of tall grass prairie in the Gulf Coast. Its former range extended from near Corpus Christi (Texas) northward to the Mississippi River in Louisiana and inland for about 75 miles. Its present range covers only about 250,000 acres within which it is represented only by scattered and local populations. In Louisiana, the Attwater prairie chicken became extinct in 1919, and in 1965 a population of less than 1,000 was estimated to exist in Texas. By the spring of 1975 the population had increased to an estimated 2400 birds. In recent years the populations in the Refuge have fluctuated from about 25 birds in the spring of 1965 to about 125 in the spring of 1975 (U. S. Fish and Wildlife Service, 1975).

Approximately 30 percent of the present 5,600 acres of the Attwater Prairie Chicken National Wildlife Refuge falls within the study area (fig. 44). The refuge was established in 1972 to preserve and restore habitats critically needed for the endangered prairie chicken. Much of this refuge became in effect a preserve in the mid-60's when The Nature Conservancy of Texas and the World Wildlife Fund purchased 3,500 acres; with land acquisition still underway the proposed size of the refuge is 8,000 acres. The range of the birds extends outside of the present refuge into surrounding rice fields and grazing land (Shifflet, personal communication).

A wide variety of common birds, including abundant bobwhite quail and mourning doves, are found within the refuge, and less common birds such as the roseate spoonbill, white faced ibis, Sennet's white-tailed hawk, Audubon's caracara and prairie falcon have also been documented. Endangered bald eagles use the refuge and peregrine falcons are expected to do so in the future (U. S. Fish and Wildlife Service, 1978).

Bald Eagle. The bald eagle (*Haliaetus leucocephalus*) is an endangered species whose occurrence has been documented in Colorado County. Although considered essentially a non-migratory bird, most bald eagles move between summer nesting grounds and winter roosting areas. Found from Canada to the Gulf states its presence on and near the central Texas coast is scarce and local. The bald eagle has a diet of small birds, mammals and fish and preferred habitat, especially during the breeding season, is wooded areas containing tall old trees near large streams or water bodies (Oberholser, 1974). During the winter bald eagles concentrate along the San Bernard River feeding on dead and wounded waterfowl (fig. 44). Bald eagle use days in the Attwater Prairie Chicken Wildlife Refuge are about 100 days annually (U. S. Fish and Wildlife Service, 1978). The status of this bird is a result of hunting pressure and reduced reproductive efficiency caused by pesticide absorbtion.

Peregrine Falcon. The endangered peregrine falcon (*Falco peregrinus*) has been seen in Colorado County in spring and fall. Although it used to breed in Texas, in North America breeding is now restricted to the northern part of its range. The status of the peregrine falcon is a result of impaired reproduction induced by pesticide contamination, and trapping by falconers. Its preferred habitat is open country, especially along rivers, lakes and the coast (Oberholser 1974).

Whooping Crane. The whooping crane (*Grus americana*) is a migratory bird that winters on the Aransas National Wildlife Refuge on the Texas Gulf Coast. There is an old (1889) account of whooping cranes breeding in Colorado County but sightings along the Gulf Coast are now rare and irregular. Never abundant, the decline of these cranes was a result of the transformation of their habitat into farmland. Since being protected, the population of whooping cranes in the wild has increased from 21 to 83 in the last 18 years although its position is still very precarious. Their preferred habitat is wetland marshes. The occurrence of whooping cranes over Colorado County is likely to be during their migratory periods, northwards in late March to late April and southwards in mid-October to late November (Oberholser, 1974).

Interior Least Tern. Although sightings have not been verified for Colorado County, the interior least tern (Sterna albifrons athalassos) probably occurs there. Wintering from South Texas to Mexico, summers are spent in the continental interior as far south as north Texas. Their preferred habitat is along river systems and nesting occurs on sandy flats or on bars along rivers. Interior least terns are usually seen singly or in small groups (Oberholser, 1974).

Eskimo Curlew. The Eskimo curlew (Numenius borealis) is another endangered bird that might be found within Colorado County and the study area. This almost extinct species winters in South America and although it passes through Texas in spring (mid-March to late April) on its way to the American Arctic, recent sightings in the State have been scattered and few. The Eskimo curlew's diet is of insects, especially grasshoppers and their eggs (Oberholser, 1974).

Other protected bird species occurring in Colorado County whose status is not considered to be as severe as those discussed above include the white-tailed hawk (Buteo albicandatus hyposposius), swallow-tailed kite (Elandoides f. forficatus), osprey (Pandion haliaetus carolinensis), wood stork (Mycteria americana), white-faced ibis (Plegadis chihi), least tern (Sterna albifrons anrillarum) and reddish egret (Dichromanassa r. rufescens) (Potter, personal communication). A short description of the status and habitat of these species can be found in appendix E, as can a list of the more common birds of the county.

Mammals

The Eagle Lake area provides a variety of habitats suited to many mammals. Common species identified on the Prairie Chicken Refuge include white-tailed deer (Odocoileus virginianus), coyote (Canis latrans), striped skunk (Memphitis memphitis), opossum (Didelphis virginianus), armadillo (Dasypus novemcinctus), cottontail rabbit (Sylvilagus floridanus), nutria (Myocastor coypus), mink (Mustela vison), pocket gopher (Geomys bursarius), and several other species of small rodents (U. S. Fish and Wildlife Service, 1978). Although county records indicate that the red wolf (Canis rufus) used to be present in Colorado County (Davis, 1978), this species now only occurs in an unhybridized form in a few specific east coast counties of the state (Brownley, personal communication; Blevins and Novack, 1975).

Reptiles

Protected Species

American Alligator. The American Alligator (Alligator mississippiensis) reached its endangered status largely because of excessive hunting. The waterways of Colorado County support a growing population of over 318 alligators (Smith, 1975a) (the sixth largest in the state), over 100 of which live in and around Eagle Lake (Winterman, personal communication) (fig. 44).

Other protected reptiles of the county include the Texas tortoise (Gopherus berlandieri), Texas horned lizard (Phrynosoma cornutum) and Louisiana milk snake (Lampropeltis triangulum amaura). More common reptiles also occur in the study area. Snakes commonly observed in the Prairie Chicken Refuge include Western cottonmouth moccasin (Agkistron piscivorus levecostoma), Texas coral snake (Micrurus fulvirus tenere), banded water snake (Natrix fascciata), Texas garter snake (Thampophis sirtalis annectens), rough green snake (Opheodrys acstivus), Eastern hog nose snake (Heterodon platyrinos), western coach whip (Masticophis flagellum testaceus) and Great Plains rat snake (Elaphe guttata emoryi). Common turtles observed include the red-eared (Chrysemys scripta elegans), smooth softshells (Tronys muticus) and box turtles (Terraphene ornata) (U. S. Fish and Wildlife Service, 1978).

Amphibians

Houston Toad. Although formerly found in Colorado County (specific localities are undetermined) in the last decade the Houston toad (Bufo houstonensis) has only been reported from Bastrop and Burleson Counties (Smith, 1975b). Data on this species is incomplete but as all known specimens have been taken during the breeding season (late February-June) it is presumed that they remain burrowed in the soil during the remainder of the year. Their habitat is restricted to loose, sandy, normally well-drained soils and associated vegetation occurring in prairie, cutover fields or hilly wooded areas. The Houston toad appears to require some ground cover in the form of logs and other debris and to favor temporary water for breeding. The reasons for their current endangered status is the destruction and modification of suitable habitats. Especially significant is the alteration of watersheds resulting in the deletion of temporary rain pools which forces the Houston toad into permanent ponds where they frequently hybridize with a similar species Bufo valliceps. Also detrimental is the deposition of unfavorable soils over the preferred sand, although land clearing, if accompanied by adequate vegetation to prevent erosion, seems to have little effect

(Smith, 1975b). The Eagle Lake area appears to offer areas of potentially suitable habitat for the Houston toad.

Fish

It is possible that the threatened river darter (Hadropterus shumardi) may occur in the flowing rivers of Colorado County.

Suitability of Wildlife Areas for Test Well Development

Effects of a Test Well on Wildlife

A test well could affect wildlife in a variety of ways, one of the more significant of which is habitat destruction or modification. The construction of a well and associated facilities would involve radical alteration of a few acres of land, whereas a leak or blowout could affect a much larger area. A slow leak may subtly influence surrounding vegetation or waterways affecting their suitability for the species currently utilizing them. In addition, the emission of hot saline water in the unlikely event of a blowout could be directly injurious to species found within the area. The noise and activities associated with construction and normal operations of the well could also have a disturbing influence on wildlife in the area, possibly inducing a change in behavior, range or breeding.

The abundance of wildlife in the Eagle Lake area makes the locating of the test well on the basis of wildlife especially difficult. An additional factor to be considered in this area is the seasonality of the biological activities. For example, the bird population of Eagle Lake is much higher in winter due to the influx of migratory species, and spring is the breeding season of many of the resident birds and mammals, whereas late summer and early autumn are periods of relative inactivity. The timing of the test well construction could therefore also influence the relative suitability of locations.

The least suited areas for a test well would therefore be areas of, or adjacent to, critical habitat or breeding sites of endangered species, especially during the season of maximum use.

Location of a Test Well on the Basis of Wildlife Resources

Attwater Prairie Chicken Refuge

The refuge of the endangered Attwater prairie chicken supporting one of the last populations of this prairie chicken would be one of the least suited sites for test well development. A variety of critical microhabitats suited to different times of the year and of the breeding season are present within the refuge and destruction or alteration of these could have a detrimental effect on the prairie chicken population. The noise and activities associated with well construction and normal operations could have a disturbing influence on the behavior of these shy birds that would be especially critical during the breeding season.

The refuge is also a temporary or permanent refuge for many other endangered, rare and common animals. Location of the well in or near to this area could therefore affect many species of wildlife.

Although with careful planning the problems of locating the test well on the refuge may be overcome, the possibility of expansion of the geothermal facility in future years could lead to a revival of the conflicts on a larger and more serious scale.

Eagle Lake

Placing the test well on the shore or marshland around Eagle Lake could affect the habitat of the alligator population. The effect could be in the form of destruction of nesting sites, disturbance induced by construction and operation activities of the well, or alteration of the salinity of the lake inducing changes in the alligators' food supply. Location of the well in this area would therefore also be undesirable.

Houston Toad Habitat

As the possibility exists that the Houston toad may occur in Colorado County, the test well should not be located on areas of potentially suitable habitat until it has been ensured that the site does not support a toad population.

Fallow Rice Fields

Fallow rice fields are prime habitat for migratory birds during the winter and spring months and are also used by many other birds and animals throughout the year. However, the rice fields are widespread within the study area, so if precautions are taken as to the timing of drilling, little wildlife disturbance need take place.

Stream Corridors

Vegetation along streams, especially in the rice areas where cover is scarce, supports and provides cover for wildlife.

Gravel Pits

A series of ponds and trees can often be found in the excavations and on the spoil heaps of abandoned gravel pits. These areas provide nesting sites for many birds and are a valuable habitat for a variety of other animals. This is especially true for the gravel pits adjacent to Eagle Lake. Only one gravel pit occurs in the prospect area, however.

Other Areas

The most suited areas for a test well initially appear to be areas of pasture or rangeland but as the Eagle Lake area supports such a variety of wildlife, including many protected species, a careful investigation should be made of any location chosen to ensure that any such animals will not be affected by well activities, or if they may be, to determine how this effect could be minimized.

LOCATION OF TEST WELL ON THE BASIS OF ALL ENVIRONMENTAL CHARACTERISTICS

Mapping

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 more fully in appendix A, but basically they involve using matrices to assist in making relative suitability comparisons (tables A2 and A4) and transparent-translucent overlays constructed from mappable characteristics. Each mapped unit was given a ranking from 1 to 6, depending on its relative suitability for a geopressured geothermal test well. Units with rankings of 1, 2, or 3 pose minor problems which can be mitigated relatively easily. They are left transparent on the overlay maps. Units with rankings of 4, 5, and 6 are shaded light, medium, and dark, respectively, while preempted areas (the city of Eagle Lake, archaeological sites, and the Attwater Prairie Chicken Wildlife Refuge) are blacked out. Thus, the composite suitability map (fig. 45) indicates by the degree of shading the relative suitability and unsuitability of specific locations for a geopressured geothermal test well.

Major categories from which mapped units were chosen for the composite suitability analysis were: substrate characteristics, hydrology, land use, vegetation, wildlife, and archaeology. Environmental factors such as meterological characteristics and potential for subsidence which could not be meaningfully depicted on the transparencies were considered in the final evaluation of test well locations.

The following description is of the test well prospect area as the well site would be within this area.

Unmapped Characteristics

Major unmapped characteristics are meteorological characteristics, subsidence, and fault activation. No communities are downwind of prevailing winds through the prospect area. However, as the city of Eagle Lake is within the prospect area, a greater distance between a test well site and the city would decrease the chances of its being affected by air pollution when unfavorable wind conditions occur. Subsidence is potentially a serious problem to the city of Eagle Lake and to the rice growing system as described in the text. Additionally, as several near surface faults have been

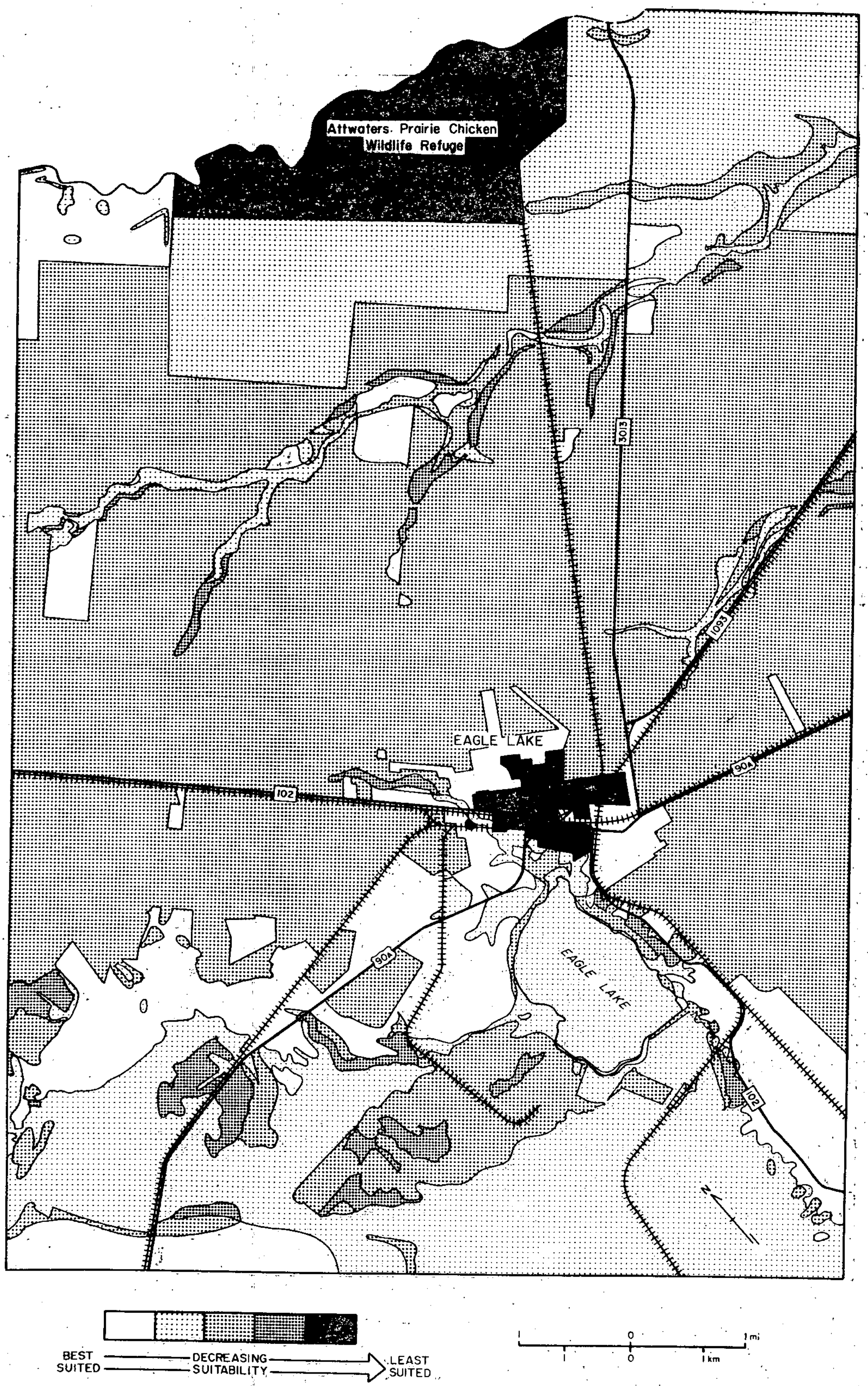

Figure 45. Areas of Varying Suitability for the Location of a Test Well, Eagle Lake Study Area.

postulated near the southern and southeastern sides of the prospect area, the farther the well is located from these areas the less chance there is for their activation.

Suitability of Locations for a Test Well

In the Cuero prospect area there were few areas of valuable land uses or biological resources; thus, constraints were based mainly on unsuitable characteristics of soils and hydrology. However, much of the Eagle Lake area is valuable in terms of land use and biological resources--specifically, rice producing land, prime migratory waterfowl habitat, prime prairie chicken habitat, and virgin prairie.

Although no areas of the Eagle Lake prospect area appear to be without environmental constraints for test well development, the more suited areas are the tracts of range and pasture grasslands. The areas of range and pasture isolated in the upland rice fields would probably be the most suited areas as they only pose a problem of either flooding, unsuitable substrate for construction, or, groundwater contamination potential. The prevailing wind direction here is not towards Eagle Lake and location in those areas furthest from Eagle Lake would decrease the chance of subsidence affecting the city. Tracts further from Eagle Lake are however nearer to the range and refuge of the Attwater prairie chicken. The large area of range and pasture located in the western corner of the prospect area only poses possible problems of groundwater contamination based on substrate characteristics. The proximity of this area to Eagle Lake does however increase the chance of the city being affected by subsidence or air pollution.

The large majority of the prospect area is rice land and has three constraints of: valuable land use, waterfowl habitat, and either vulnerability to groundwater contamination or substrate poorly suited to well construction. The rice land at the northeastern end of the prospect area has the additional constraint of being within the range of the endangered Attwater Prairie Chicken Refuge. The most unsuitable locations for a test well are at either end of the prospect area: the city of Eagle Lake and the Attwater Prairie Chicken National Wildlife Refuge. The city of Eagle Lake and nearby archaeological site are preempted due to the value of their land uses, as is the Attwater Prairie Chicken National Wildlife Refuge. In addition to being a wildlife refuge this area is preempted on its wildlife value and most unsuited because of the valuable/rare prairie grassland it supports.

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.

Table A1. Relative suitability of mapped environmental units in the Cuero area as sites of geothermal test wells

Mapping unit	Relative suitability	Relative unsuitability
SOILS		
Suitability for construction		
most suited (1)	1	
moderately suited (2)	2	
least suited (3)		4
Suitability for ponds		
most suited (1)	1	
moderately suited (2)	2	
least suited (3)		4
Prime soils		4
Erosion potential		
lesser (1)	1	
greater (2)		4
HYDROLOGY		
Groundwater contamination		
very low (1)	1	
low (2)	2	
moderate (3)		4
high (4)		5
Water courses		pre-empt
Surface water	3	
Flood potential		
none	1	
100 years		4
10 years		5
LAND USE		
Range	1	
Pasture	2	
Crops	3	
Pecan groves		5
Pecan woods	3	
Gravel pits		5
Commercial/residential		pre-empt
ARCHAEOLOGY		
Sites		pre-empt
VEGETATION		
Parkland and open grassland	2	
Brushland	2	
Woodland	3	
Pecan forest		4
Bald cypress swamp		4
Cultivated land	1	
WILDLIFE		
Guadalupe River		pre-empt
Stream corridors	3	

Table A2. Relative suitability of mapped environmental units in the Eagle Lake area as sites of geothermal test wells

Mapping unit	Relative suitability	Relative unsuitability
SUBSTRATE		
Sand	1	
Sandy clay		4
Sand and gravel (recent fluvial deposit)	2	
Mud and silt		4
Sand, silt, mud (recent tributary deposits)	—	
Mud, relict meander		4
Sand and gravel terraces	2	
Mud over gravel	3	
Mud, silt, and swamp (recent swamp)	4	
GROUNDWATER CONTAMINATION		
Outside 100-year flood zone	1	
Inside 100-year flood zone		4
VEGETATION		
Prairie		6
Cultivated	1	
Woodland		4
Grassland	2	
Marsh		4
Gravel pits	3	
WILDLIFE		
Prairie chicken refuge		pre-empt
Prairie chicken range		6
Bald eagle		6
Alligator		6
Waterfowl — Surface water		4
Waterfowl — ponds (Glick and Seaholm Lakes)		5
Woodland		4
Riceland		4
Stream corridors		4
Gravel pits		4
Other	2	
LAND USE		
Range	1	
Pasture	2	
Row crops	3	
Rice		4
Wildlife refuge		pre-empt
Proposed addition to refuge		6
Residential/commercial		pre-empt
Research station		6
Glick and Eagle Lake		4
Glick and Seaholm Lakes (hunting ponds)		4
Other surface water	3	
Abandoned catfish pond	1	
Gravel pits		4
ARCHAEOLOGY		
Sites		pre-empt

Table A3. Environmental constraints of mapped units unsuited for test well development.

CUERO *Mapped units unsuited for test well development:*	*Environmental constraints:* Increase construction or maintenance costs of well	Resource quality deterioration	Important or scarce biological areas	Rare or endangered species habitat or range	Valuable alternate land use (archaeological, residential, gravel)	Long recovery time; long term or irreversible effect
SOILS						
Soils least suited for construction	X					
Soils least suited for ponds	X					
Prime soils		X				X
Areas of greater erosion potential		X				X
HYDROLOGY						
Moderate groundwater contamination potential		X				X
High groundwater contamination potential		X				X
Water courses	X	X				
FLOODING						
100-year flood zone	X					
10-year flood zone	X					
LAND USE						
Pecan groves	X				X	X
Gravel pits	X				X	
Residential/commercial	X				X	
ARCHAEOLOGY						
Sites					X	X
VEGETATION						
Pecan forest	X		X			X
Bald cypress swamp	X		X			X
WILDLIFE						
Guadalupe River			X			

Table A4. Environmental constraints of mapped units unsuited for test well development

EAGLE LAKE *Mapped units unsuited for test well development:*	*Environmental constraints:* Increase construction or maintenance costs of well	Resource quality deterioration	Important or scarce biological areas	Rare or endangered species habitat or range	Valuable alternate land use (archaeological, residential, gravel)	Long recovery time; long term or irreversible effect
SUBSTRATE						
Sandy clay	X					X
Mud and silt	X					X
Mud, relict meander	X					X
GROUNDWATER CONTAMINATION						
Sand and gravel		X				X
FLOOD POTENTIAL						
100-year flood zone	X					
VEGETATION						
Prairie		X	X			X
Woodland			X			X
Marsh			X			
WILDLIFE						
Prairie chicken refuge			X	X		X
Prairie chicken range			X	X		
Bald eagle habitat			X	X		X
Alligator habitat			X	X		X
Surface water			X			
Waterfowl ponds			X			
Woodland	X		X			
Riceland			X			
Stream corridors			X			
Gravel pits			X			
LAND USE						
Rice					X	
Wildlife refuge		X		X	X	X
Proposed addition to refuge		X		X	X	X
Residential/commercial	X				X	
Gravel pits	X				X	
Research station		X			X	X
Eagle Lake	X	X			X	
Hunting ponds	X				X	
ARCHAEOLOGY						
Sites					X	X

APPENDIX A

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). Mappable environmental units in the suitability ratings of 4, 5, and 6 are represented on large-scale (1:24,000) transparent-translucent overlay maps in tones of light gray (4), medium gray (5), and dark gray (6). Units with ratings of 1, 2, or 3 remain transparent. On individual overlay maps, where 2 units overlapped, they were shaded the color of the worse unit.

By superimposing the overlay maps on a base map of the prospect area, the least suitable areas (as determined by mappable characteristics) for the geothermal test well are defined by those areas with the darkest shadings. Areas remaining transparent have fewer constraints for locating a test well. 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 (figs. 26 and 45).

As this report was designed primarily to identify areas environmentally unsuited to a test well, while increasing density of shading indicates increasing environmental vulnerability and restraints, those areas remaining white do not distinguish between better suited areas but portray them all as equally suited. The most suited locations within this area of equal suitability can be identified by considering the location characteristics classified 1, 2, or 3 on the matrix. For both the least and most suited areas consideration should not be given only to the composite map but also to interactions involving environmental units that could not be adequately mapped (such as air and surface water quality, and subsidence potential).

JUSTIFICATION FOR THE METHODOLOGIES

Matrices in which activities are plotted against environmental characteristics (Leopold and others, 1971), serve as checklists in which the interactions between the activities and natural environment may be identified for the purpose of analysis and evaluation. Complete matrices 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 (see tables 1, 12 and 29).

Table B1. Constituents of Geothermal Water Compared to Standards for Domestic, Agricultural, and Other Uses.

Element, ion, or compound	Geopressured formation waters: Gardiner Well #1	Mayo Owens Well #1	Portland Well #A3	W.F. Lehman Well #1a	Lehman Gas Unit #1a	LR-67-01-802	Maximum safe limit in domestic water supplies	Maximum economic limit in industrial water supplies *(ppm)*	Maximum safe limit in irrigation water supplies or aquatic environments
Silica (SiO_2)	87	34	93	68	71		50 (turbidity problems)	0.3-40.0 (boiler feed); 0.1 (turbine blades); 20-100 (pulp and paper mills)	10-50 suggested limit
Calcium (Ca)	2,000	200	89	71	52		30 (drinking and cooking) 75-200 maximum limit	10-500	Often desirable for irrigation, depending on soil type
Magnesium (Mg)	235	31	15	90	110		30-125 0.05 mg/l recommended	5-300	24 to protect underground water basins
Strontium (Sr)	380	25	7.0	126-252	38-72	95	~30 (drinking and cooking) 75-200 maximum limit	~10-500	
Copper (Cu)				0.17-0.38	0.11-930	0.01	1.0		0.0018-7.5 depending on species and conditions
Iron (Fe)	8.0	70	2.3	8.4-16.8	2.7-3.8	16	(0.3)[1]		1.0 freshwater
Manganese (Mn)	2.7	1.4	0.16	ND	ND	<0.02	(0.05)[1]		0.2 for irrigation water on acid soils 0.1 for protection of consumers marine molluscs
Sodium (Na)	24,000	9,250	6,500	16,000	14,000		Harmful to humans suffering from cardiac, renal and circulatory disease	50	106-212 in sprinkler irrigation may cause serious foliage damage
							10-115 is conservative limit		Cumulative deterioration of soil likely—2,000 limit for livestock water
Potassium (K)	300	70	68	230	150		1,000-2,000 extreme limit for drinking		Essential in small quantities for stock and plant nutrition
Rubidium (Rb)	0.80	0.30	0.30						1.4-100 freshwater
Ammonia (NH_3)	26	11	5.8						Toxic to fish 0.02 freshwater
Bicarbonate (HCO_3)	520	1,200	1,600	526	581		0-150 desirable or permissible	100-200	200 causes decline of sugar in apples and pears
Sulfate (SO_4)	0.6	22	84	30	30		200-400	20-300	576-960 maximum limit may cause precipitation of calcium and, thus, toxicity
Chloride (Cl^-)	40,500	14,000	9,270	25,000	21,000		Harmful to humans with heart and kidney disease; 5-600 depending on climate and other factors—USPHS recommended limit is 250	20-1,500	1,500-3,000 limit for livestock watering
Beryllium (Be)				0.13-0.26	0.11-0.22		?		0.011-1.100 freshwater; 0.1-0.5 for irrigation depending on soil type
Boron (B)	30	24	62				Total at 5-45 grams in drinking water OK		Deleterious for certain crops at the following concentrations: • In excess of 0.5: pecans, artichokes, plums, pears, apples, cherries, grapes, peaches, oranges, avocados, grapefruit, and lemons • 1.0-2.0: potatoes, tomatoes, peas, wheat, corn, oats, and lima beans • 2.0-4.0: asparagus, date palms, sugar beets, alfalfa, onions, turnips, cabbages, lettuce, and carrots
Cadmium (Cd)						0.008	0.01		0.0004-0.012 freshwater; 0.005 marine
Lead (Pb)						<0.2	0.05		0.0052-560.0 fish, depending on species and conditions
Hydrogen sulfide (H_2S)	0.32	ND	ND						0.002 freshwater and marine
pH (acidity)	6.3	6.7	6.8				5-9		6.5-9.0 freshwater; 6.5-8.5[2] marine

[1] based on aesthetic criteria [2] . . . but not more than 0.2 units outside normally occurring range.

Data on brines are from Kharaka, Callender and Wallace (1977), Gustavson and Kreitler (1976), and unpublished data of the Bureau of Economic Geology, University of Texas. Suggested ambient units are from McKee and Wolf (1963) and U.S. Environmental Protection Agency (1976).

EFFECTS AND COMMENTS ON CONSTITUENTS OF GEOTHERMAL FLUIDS[1]

Alkalinity	Alkalinity is a measure of the power of a solution to neutralize hydrogen ions and is expressed in terms of an equivalent amount of calcium carbonate. Alkalinity is caused by the presence of carbonates, bicarbonates, hydroxides, and to a lesser extent by borates, silicates, phosphates, and organic substances. Domestic: In itself alkalinity is not thought to be detrimental but it is generally associated with high pH values, hardness and excessive dissolved solids, all of which may be harmful. Irrigation: Similarly, alkalinity is detrimental in that it adds to total salinity and is frequently accompanied by high pH. Aquatic Life: The best waters for diversified aquatic life are those with pH between 7 and 8, having a total alkalinity of 100-120 mg/l or more. This alkalinity serves as a buffer to help prevent sudden changes in pH. Also, some components of alkalinity, e.g. carbonate and bicarbonates, will complex some heavy metals and reduce their toxicity markedly (1).
Ammonia NH_3 Ammonium ion NH_4^+ Ammonium hydroxide NH_4OH	Rare in nature except as one of the products of the nitrogen cycle. Large amounts produced industrially for fertilizer but rapidly changes to nitrites and nitrates. Aquatic: Toxicity related to pH as at high pH undissociated ammonium hydroxide concentration is higher.
Beryllium Be	Rare element in nature. Animals: Not harmful when ingested by animals and people, but very toxic when inhaled even at concentrations of less than .001 mg/m^3, also toxic through skin contact. Irrigation: Inhibits photosynthesis in terrestrial plants (1). More toxic in acid than alkaline soils (1).
Boron B	Essential trace nutrient-plants; nonessential-animals (1). Occurs in nature as a borate salt. Irrigation: Boron is absorbed by roots and concentrated in leaf tissue where it can reach toxic levels within days. Different crops are sensitive to different levels of boron.

[1]Except where noted all information is from McKee & Wolf, Water Quality Criteria.
(1): U.S. E.P.A., Quality Criteria for Water.
(2): Gustavson & Others, Ecological Implications of Geopressured-Geothermal Energy Development, Texas-Louisiana Gulf Coast Region.

Cadmium Cd	Non essential and non beneficial. (1) Domestic: Accumulates in various human tissues and is implicated in certain diseases and pathological processes. Toxic effects may result from inhalation or ingestion (1). Wildlife: Some species are much more sensitive to cadmium than others; also, water hardness affects toxicity--increased hardness and/or alkalinity decreases toxicity (2).
Calcium Ca	Essential for plants and animals. Exists in nature as salts or ions. Domestic: Limits based not on health hazard but on disadvantages of water hardness. Irrigation: Beneficial to soil tilth; normally desirable in irrigation water. Aquatic: Calcium reduces toxicity of many chemical compounds: lead, zinc, aluminum. However, calcium salts may be toxic in soft water at concentrations of 300-10000 mg/l.
Carbonates CO_3 Bicarbonates HCO_3 Carbon dioxide CO_2 Carbonic acid H_2CO_3	In solution, exist in equilibrium with each other, depending on temperature, pH, and concentration of other dissolved solids. At the slightly acid pH of geopressured geothermal waters, bicarbonates and carbonic acid predominate, with carbonate at very low concentrations (2). Irrigation: Bicarbonates in themselves are not harmful, but by aiding in the precipitation of calcium carbonate they adversely affect the sodium ratio. Aquatic: CO_2 and H_2CO_3 concentrations are very harmful to fish, more so where level of dissolved oxygen is low. In U.S. waters with good fish fauna, 95% have less than 5.0 mg/l of free carbon dioxide. Domestic: High concentrations of CO_2 accelerate corrosion of iron and steel and promote the solution of lead. Bicarbonates-700 mg/l unhealthful to most people. Carbonates - 350 mg/l unhealthful to most people.
Chlorides Cl^-	Found in practically all natural waters. Domestic: Recommended levels based on palatability rather than health; however, may be harmful to humans with heart or kidney disease.
Copper Cu	Essential trace elements--plants and animals. Domestic: Limit of 1 mg/l based on taste (aesthetic limit). Little danger of poisoning from consumption of copper in water.

	Irrigation: Copper retention in soil correlated more with organic matter content and soil alkalinity than clay content.
	Aquatic: Copper has synergistic effect with chlorine, zinc, cadmium, and mercury. Sodium nitrite and sodium nitrate decrease toxicity of Cu. Toxicity depends also on species, stage of development, alkalinity, and pH of water, and concentration of organic compounds (2). More toxic at lower alkalinities.
Dissolved Solids	Consist mainly of carbonates, bicarbonates, chlorides, sulfates, phosphates, and nitrates of calcium, magnesium, sodium, and potassium, as well as iron, manganese, and other substances.
	Domestic: Water supplies have contained up to 4,000 mg/l dissolved solids; concentrations over 4,000 mg/l are unfit for human use.
	Irrigation: Under 700 mg/l usually suitable; over 2,100 mg/l unsuitable.
	Aquatic: 95 percent of U.S. waters with good fish fauna have concentrations under 4,000 mg/l.
Hardness	Water hardness is caused by polyvalent metallic ions dissolved in water, in fresh water principally calcium and magnesium (plus iron, strontium, and manganese) (1).
	Domestic: Hardness is negatively correlated with death rates from degenerative cardiovascular disease.
	Aquatic: Hard water decreases sensitivity of fish to toxic metals.
Hydrogen Sulfide H_2S	Highly poisonous water-soluble gas. Most toxic at low levels of temperature, pH and dissolved oxygen (2).
Iron Fe	Essential trace nutrient-plants and animals.
	Domestic: Recommended levels based on aesthetic and taste considerations rather than toxic effects.
Lead Pb	No known desirable effect for plants and animals (1). Exists in nature principally as lead sulfide (galena) (1).
	Irrigation: May be toxic to plants at any concentration although very low concentrations may have temporary stimulating effect.
	Animals: A cumulative poison to animals and humans, whether through food, air, or water.
	Aquatic: Concentrations as low as 0.1 mg/l are toxic to fish. Toxicity affected by pH, hardness, organic materials and presence of other metals (2). More soluble in soft water, therefore more toxic.

Magnesium Mg	Essential for plants and animals. Exists not in elemental state but as soluble salts. With calcium, forms the bulk of hardness. <u>Domestic</u>: Limit based mainly on taste. Mg is relatively non-toxic to man and not a public-health hazard because taste becomes quite unpleasant before toxic concentrations are reached. <u>Irrigation</u>: Helps keep soil permeable and in good tilth. Some forms toxic at very high concentrations. <u>Aquatic</u>: Some salts more toxic than others.
Manganese Mn	Essential micronutrient - plants and animals. <u>Domestic</u>: Limits based on taste considerations. Toxic at levels much higher than taste threshold. <u>Irrigation</u>: May be toxic at 1 to a few mg/l in soils with $pH < 6.0$. In soils with $pH > 6.0$, long term irrigation at concentrations of 10 mg/l may be harmful (1).
pH	Affects the toxicity of many compounds. The slightly acid pH of geothermal fluids may tend to make other components more toxic because of synergicistic effects (2).
Potassium (K)	Essential - plants and animals. Not found free in nature but in ionized or molecular form. Less harmful to soil than sodium.
Salinity	<u>Irrigation</u>: Deleterious effects of salt can be from (a) osmotic effects, (b) toxic effects, (c) indirect effects through changes in soil structure, permeability, and aeration.
Silica SiO_2	Silicon not found free in nature; exists in minerals and as silica (SiO_2). Silica found in water as a suspended solid increases turbidity. <u>Domestic</u>: In concentrations found in natural or treated waters, silica or silicates appear to have caused no adverse physiological effects. <u>Irrigation</u>: Silica per se is of little importance in irrigation practice. <u>Aquatic</u>: No toxic effects are described. An abundance of silica promotes algal growth if other nutrients are available as well.
Sodium (Na)	Essential micro nutrient for plants. Present in very large concentrations in geopressured geothermal water. Does not occur free in nature—usually occurs as a salt.

Domestic: May be harmful to humans suffering from renal, cardiac, and circulatory disease.

Irrigation: Cumulative effect in soil likely. Frequently causes problems in soil structure, infiltration, and permeability rates (1).

Aquatic: 95 percent of U.S. waters supporting good fish fauna have concentrations of Na + K less than 85 mg/l.

Sulfate SO_4	Essential for plants. Domestic: Limits of 250 mg/l based on effects on new users; probably safe up to 1000 mg/l or more.
Suspended Solids	Natural solids include erosional silt, detritus, and plankton. Many industrial solids now present. Aquatic: When suspended screen out light and cause abrasive injuries. On settling, trap bacteria and organic wastes on bottom, promoting oxygen depletion; destroy spawning beds
Strontium Sr	Nonessential - plants. Essential trace nutrient - animals. Toxicity of non-radioactive strontium is probably on the same order of magnitude as calcium. It is not absorbed readily by soils and may be expected to travel with ground waters.

APPENDIX C.

SOIL CLASSIFICATION

The Soil Conservation Service of the U.S. Department of Agriculture classifies soil series according to the Comprehensive Soil Survey System. Soils are classified by "diagnostic horizons": as soils develop, minerals and organic matter are leached from the surface horizon and accumulate in the subsurface (Brady, 1974). The degree to which this process has occurred, in combination with the distinctive properties imparted by the five soil-forming factors, results in the diagnostic horizons.

Table C1, below, summarizes and defines the classification categories for soils in the Cuero study area. (Due to the preliminary nature of the soil survey in the Eagle Lake area, similar information is not available.) Of the 10 soil orders (the largest classification unit), 5 are represented in the Cuero area. The orders are further subdivided into suborders and great groups, as shown on the Soils Table and defined on table C1, below.

Table C1. Summary of soil classification in Cuero area[1]

Order	Suborder	Great group
Alfisols: Moist mineral soils with a light-colored surface layer low in organic matter, over a developed, more clayey subsoil; base saturation of more than 35 percent. Surface horizons usually thin and loamy over very clayey slowly permeable B horizons, making the soil very droughty for plants. The clayey B horizons can also pose engineering problems.	*Aqualfs:* Seasonally wet (saturated)	*Albaqualfs:* Bleached layer abruptly on clayey subsoil *Ochraqualfs:* Surface layer grading to subsoil
	Ustalfs: Usually moist; dry more than 90 cumulative days per year	*Paleustalfs:* Very deep, reddish subsoil or reddish mottles in subsoil; on old landscapes
Entisols: Mineral soils with little or no evidence of horizonation, usually found on recent geomorphic surfaces; in the study area, due to frequent stream flooding.	*Fluvents:* Brownish to reddish colors; formed in recent flood plains and deltas; irregular distribution of organic matter	*Ustifluvents:* Usually moist, dry more than 90 cumulative days per year
Inceptisols: Young soils with some surface horizon development but little clay accumulation in the B horizon. Within the study area, Shiner and Denhawken are Inceptisols: Shiner soils occur on steep slopes where erosion removes soil material as it forms, while Denhawken soils are part of a complex of expansive soils, the overturning action of the shrink-swell process preventing nature horizon development.	*Ochrepts:* Light colored (brownish to reddish); freely drained	*Ustochrepts:* Usually moist; dry more than 90 cumulative days per year
Mollisols: Deep soils characterized by a thick, dark surface horizon high in organic matter; base saturation more than 50 percent. Often good agricultural soils, usually having developed under prairie vegetation.	*Aquolls:* Wet, saturated seasonally to year-round; low chromas (dull colors)	*Haplaquolls:* Surface layer grades to underlying layers with no to little increase in clay content
	Ustolls: Seasonally moist; dry in some part more than 90 cumulative days per year	*Haplustolls:* Surface layer grades to underlying layers with no or little increase in clay content *Argiustolls:* Subsoil significantly more clayey than surface layer with clay content of subsoil either decreasing with depth or lacking reddish colors *Calciustolls:* Distinct lime ($CaCO_3$) accumulation within 1 m (40 in) depth; surface layer grades to underlying layer with no or little increase in clay content
Vertisols: Mineral soils with a high content of expansive clays which swell when wet and shrink and crack when dry. These properties limit their agricultural and construction value.	*Usterts:* Cracks open 90 or more cumulative days, closed at least 60 consecutive days each year	*Pellusterts:* Gray to black in the surface 30 cm (12 in) *Chromusterts:* Brownish or reddish in surface 30 cm (12 in) or deeper

[1] *Sources:* Compiled primarily from Texas A & M University, *General Soil Map of Texas*, with additional information from the *DeWitt County Soil Survey* (S.C.S., 1978), and Brady (1974).

APPENDIX C.2

RANGE SITE DESCRIPTIONS[1]

On the following pages the range sites of DeWitt & Colorado Counties are described and the potential annual yield of air-dry herbage is estimated for each site in excellent condition. Range sites of each soil series are listed on table _.

Blackland Range Site

The soils of this site are deep, nearly level to sloping clays and clay loams. They are very slowly permeable and have mainly a high available water capacity.

The climax plant community is a true-prairie type of tall and mid grasses and associated forbs. The potential plant community is 60 percent little bluestem; 15 percent indiangrass; 10 percent big bluestem, eastern grama, and switchgrass; 10 percent brownseed paspalum, sedges, Texas wintergrasss, knotroot bristlegrass, Scribner panicum, and 5 percent annual forbs.

If this site is in excellent condition, it produces approximately 6,000 pounds of air-dry herbage per acre in favorable years and 3,200 pounds per acre in unfavorable years. Approximately 95 percent of this production furnishes forage for cattle.

Under continuous heavy grazing by cattle, little bluestem, indiangrass, big bluestem, eastern grama, and switchgrass decrease. Such plants as brownseed paspalum, Texas wintergrass, and knotroot bristlegrass increase. If overgrazing is prolonged, annual and total productions are greatly reduced and ragweed, broomweed, mesquite, Texas grama, and annuals invade the site.

Chalky Ridge Range Site

The soils of this site are shallow, gently sloping to sloping fine sandy loams underlain by weakly cemented sandstone. They are moderately permeable and have a very low available water capacity.

The climax plant community is true prairie and scattered large live oak. The potential plant community is 55 percent little bluestem; 15 percent indiangrass; 10 percent side-oats grama, silver bluestem, and dropseeds; 5 percent slim tridens, Texas wintergrass, threeawn, low panicums, buffalograss, and fall witchgrass; 5 percent live oak, coralberry, bumelia, and spiny hackberry; and 10 percent such forbs as gayfeather, penstemon, halfshrub sundrop, bundleflower, sensitivebrier, yellow neptunia, and annual forbs.

If this site is in excellent condition, it produces approximatley 3,000 pounds of air-dry herbage per acre in favorable years and 1,250 pounds per acre in unfavorable years. Approximately 90 percent of this production furnishes forage for cattle.

[1]Reprinted from Soil Conservation Service, 1978.

Under continuous heavy grazing by cattle, little bluestem, indiangrass, side-oats grama, and silver bluestem decrease. Such plants as slim tridens, Texas wintergrass, and threeawn increase. If overgrazing is prolonged, annuals, woody plants, and bare soil dominate the site and annual and total productions are greatly reduced.

Clay Loam Range Site

The soils of this site are deep, nearly level to gently sloping sandy clay loams. They are moderately permeable and have a high available water capacity.

The climax or potential plant community is an open grassland and scattered trees or woody shrubs, dominantly mid grasses and associated forbs. The climax plant community is 35 percent little bluestem; 5 percent indiangrass; 10 percent silver bluestem; 10 percent plains and southwestern bristlegrass; 15 percent buffalograss and curly mesquite; 15 pecent other grasses; 5 percent woody plants, such as Texas colubrina, wolfberry, and vine-ephedra; and 5 percent bundleflower, sensitivebrier, and orange zexmenia.

If this site is in excellent condition, it produces approximately 5,800 pounds of air-dry herbage per acre in favorable years and 3,000 pounds per acre in unfavorable years. Approximately 95 percent of this production furnishes forage for cattle.

Under continuous heavy grazing by cattle, little bluestem, indiangrass, silver bluestem, and bristlegrass decrease. Such plants as threeawn and curly mesquite; 15 percent other grasses; 5 percent woody plants, such as Texas columbrina, wolfberry, and vine-ephedra; and 5 percent bundleflower, sensitivebrier, and orange zexmenia.

If this site is in excellent condition it produces approximately 5,800 pounds of air-dry herbage per acre in favorable years and 3,000 pounds per acre in unfavorable years. Approximately 95 percent of this production furnishes forage for cattle.

Under continuous heavy grazing by cattle, little bluestem, indiangrass, silver bluestem, and bristlegrass decrease. Such plants as threeawn and curly mesquite increase. If overgrazing is prolonged, annual and total productions are greatly reduced and mesquite, whitebrush, and other mixed brush dominate the site.

Clayey Bottomland Range Site

The soils of this site are deep, nearly level clays. They are very slowly permeable and have a high available water capacity. They are subject to overflow.

The climax plant community is a mixture of tall and mid grasses and hardwoods. The potential plant community is 15 percent trees, such as oak, elm, and pecan; 20 percent indiangrass, switchgrass, and rusty-seed paspalum; 15 percent little bluestem; 30 percent Virginia wildrye, southwestern bristlegrass, and vine-mesquite; 5 percent sedges; 5 percent perennial forbs; and 10 percent annual forbs and weeds. Spiny aster and some cordgrass are on low wet and slightly saline soils.

If this site is in excellent condition, it produces approximately 7,000 pounds of air-dry herbage per acre in favorable years and 5,000 pounds per acre in unfavorable years. Approximately 80 percent of this production furnishes forage for cattle.

Under continuous heavy grazing by cattle, indiangrass, rustyseed paspalum, switchgrass, and little bluestem decrease. Such plants as bristlegrass and paspalums increase. If overgrazing is prolonged, annual weeds, common bermudagrass, and woody vegetation make up a substantial part of the annual production, and total production is greatly reduced.

Claypan Prairie (BL) Range Site

The soils of this site are deep, nearly level to gently sloping fine sandy loams to clay loams. They are very slowly permeable and have a medium to high available water capacity.

The climax plant community is a true prairie and scattered trees along watercourses. The climax plant community is 55 percent little bluestem; 15 percent indiangrass; 10 percent switchgrass, big bluestem, wildrye, side-oats grama, and silver bluestem; 5 percent other grasses; 5 percent oak, elm, and hackberry; and 10 percent such forbs as scurfpea, halfshrub sundrop, penstemon, gayfeather, sensitivebrier, yellow neptunia, and annual forbs.

If this site is in excellent condition, it produces approximately 5,000 pounds of air-dry herbage per acre in favorable years and 3,000 pounds per acre in unfavorable years. Approximately 90 percent of this production furnishes forage for cattle.

Under continuous heavy grazing by cattle, little and big bluestem, indiangrass, switchgrass, and wildrye decrease, and silver bluestem, side-oats grama, Texas wintergrass, and dropseeds increase. Low quality grasses, such as three-awn and brush, dominate the community. Annual and total production are greatly reduced.

Claypan Prairie (CO) Range Site

The soils of this site are deep, nearly level fine sandy loams. They are very slowly permeable and have a high available water capacity.

The potential plant community is an open grassland, dominated by mid grasses. The potential plant community is 30 percent little bluestem; 15 percent switchgrass; 5 percent indiangrass; 35 percent vine-mesquite, silver bluestem, and longtom paspalum; 10 percent buffalo and curly mesquite, and 5 percent such forbs as bundleflower, sensitivebrier, and yellow neptunia.

If this site is in excellent condition, it produces approximately 7,000 pounds of air-dry herbage per acre in favorable years and 5,000 pounds per acre in unfavorable years. Approximaltey 95 percent of this production furnishes forage for cattle.

Under continuous heavy grazing by cattle, little bluestem, switchgrass, and vine-mesquite decrease. Such plants as knotroot bristlegrass, windmillgrass, huisache, and mesquite increase and invade. If overgrazing is prolonged, annual and total production are greatly reduced.

Claypan Prairie (RG) Range Site

The soils of this site are deep, nearly level to gently sloping fine sandy loams. They are very slowly permeable and have a medium available water capacity.

The potential plant community is an open grassland, dominated by mid grasses. The potential plant community is 25 percent little bluestem and four-flower trichloris; 35 percent Arizona cottontop, side-oats grama, vine-mesquite, and silver bluestem; 10 percent plains bristlegrass; 15 percent buffalograss and curly mesquite; 10 percent other grasses; a trace of woody plants; and 5 percent such forbs as bundleflower, sensitivebrier, yellow neptunia, western indigo, bush sunflower, guara, ruellia, and annual forbs.

If this site is in excellent condition, it produces approximately 5,000 pounds of air-dry herbage per acre in favorable years and 2,500 pounds per acre in unfavorable years. Approximately 95 percent of this production furnishes forage for cattle.

Under continuous heavy grazing by cattle, trichloris, little bluestem, Arizona cottontop, side-oats grama, and vine-mesquite decrease. Plains bristlegrass, buffalograss, and silver bluestem increase. If overgrazing is prolonged, low quality grasses, such as threeawn, fall witchgrass, and brush, dominate the site.

Deep Sand Range Site

The soils of this site are deep, nearly level to gently sloping fine sands. They are moderately rapidly to moderately slowly permeable and have a low available water capacity.

The climax plant community is an open grassland and scattered mesquite and live oak. The potential plant community is 40 percent seacoast bluestem; 10 percent crinkle-awn and switchgrass; 10 percent brownseed paspalum and tanglehead; 10 percent knotroot panicum and hooded windmillgrass; 10 percent spike and plains bristlegrass; 5 percent threeawn and other grasses; 5 percent mesquite, live oak, lantana, and condalias; and 10 percent orange zexmenia, snoutbean, western indigo, sensitivebrier, croton, and other annual forbs.

If this site is in excellent condition, it produces approximately 4,500 pounds of air-dry herbage per acre in favorable years and 2,000 pounds per acre in unfavorable years. Approximately 95 percent of this production furnishes forage for cattle.

Under continuous heavy grazing by cattle, seacoast bluestem, crinkle-awn, and switchgrass decrease. Such plants as brownseed, paspalum, knotroot panicum, and threeawn increase. If overgrazing is prolonged, the soils become bare and soil blowing is a hazard.

Deep Sand Savannah Range Site

The soils of this site are deep, nearly level to gently sloping fine sands. They have moderately slow permeability and low available water capacity.

The climax plant community is an open prairie and scattered motts of live oak or mesquite. The potential plant community is 50 percent seacoast bluestem; 20 percent big bluestem, crinkle-awn, and switchgrass; 10 percent brownseed paspalum; 5 percent other grasses; 5 percent live oak and mesquite; and 10 percent bundleflower, milkpea, American and least snoutbeans, and annual forbs.

If this site is in excellent condition, it produces approximately 4,500 pounds of air-dry herbage per acre in favorable years and 2,000 pounds per acre in unfavorable years. Approximately 95 percent of this production furnishes forage for cattle.

Under continuous heavy grazing by cattle, seacoast bluestem, big bluestem, crinkle-awn, and switchgrass decrease. Such plants as brownseed paspalum and gulf-dune paspalum and trees increase. If overgrazing is prolonged, the site becomes bare and starts to blow and shifting dunes form. Revegetation is extremely difficult.

Eroded Blackland Range Site

The soils of this site are deep, gently sloping clays that have been damaged by erosion. They are very slowly permeable and have a high available water capacity.

The potential plant community is a tall grass prairie and scattered live oak, elm, or hackberry trees. The climax plant community is 50 percent little bluestem, 20 percent indiangrass and big bluestem; 15 percent wildrye, switchgrass, Florida paspalum, side-oats grama, tall dropseed, silver bluestem, Texas wintergrasss, and other grasses; 5 percent woody plants such as live oak, hackberry, elm, and bumelia; and 10 percent Engelmann daisy, penstemon, gayfeather, bundleflower, sensitivebrier, prairie-clover, and other forbs.

If this site is in excellent condition, it produces approximately 6,000 pounds of air-dry herbage per acre in favorable years and 4,000 pounds per acre in unfavorable years. Approximately 95 percent of this production furnishes forage for cattle.

Under continuous heavy grazing by cattle, big and little bluestem and indiangrass decrease, and such plants as silver bluestem, side-oats grama, Texas wintergrass, and buffalograss, become strong increasers. If overgrazing is prolonged, Texas wintergrass, buffalograss, hairy tridens, threeawn, ragweed, and broomwood dominate the site, thus greatly reducing annual and total production.

Gravelly Range Site

The soils of this site are deep, gently sloping to sloping, gravelly to very gravelly loamy sands. They are moderately to very slowly permeable and have a low to very low available water capacity.

The climax plant community is a post oak, blackjack oak savannah. The potential plant community is 55 percent little bluestem; 15 percent indiangrass, switchgrass, beaked panicum, and purpletop; 10 percent brownseed paspalum, side-oats grama, purple lovegrass, and other grasses; 10 percent post oak and blackjack oak; 5 percent hawthorns, American beautyberry, and greenbrier; and 5 percent lespedezas, tickclover, bundleflower, snoutbean, and annual forbs.

If this site is in excellent condition, it produces approximately 4,500 pounds of air-dry herbage per acre in favorable years and 2,200 pounds per acre in unfavorable years. Approximately 85 percent of this production furnishes forage for cattle.

Under continuous heavy grazing by cattle, little bluestem, indiangrass, switch-grass, beaked panicum, and purpletop decrease. Such plants as fall witchgrass, low panicums, three-awn, and annual weeds invade and increase. If overgrazing is

If this site is in excellent condition, it produces approximately 4,500 pounds of air-dry herbage per acre in favorable years and 2,000 pounds per acre in unfavorable years. Approximately 95 percent of this production furnishes forage for cattle.

Under continuous heavy grazing by cattle, seacoast bluestem, big bluestem, crinkle-awn, and switchgrass decrease. Such plants as brownseed paspalum and gulf-dune paspalum and trees increase. If overgrazing is prolonged, the site becomes bare and starts to blow and shifting dunes form. Revegetation is extremely difficult.

Eroded Blackland Range Site

The soils of this site are deep, gently sloping clays that have been damaged by erosion. They are very slowly permeable and have a high available water capacity.

The potential plant community is a tall grass prairie and scattered live oak, elm, or hackberry trees. The climax plant community is 50 percent little bluestem, 20 percent indiangrass and big bluestem; 15 percent wildrye, switchgrasss, Florida paspalum, side-oats grama, tall dropseed, silver bluestem, Texas wintergrasss, and other grasses; 5 percent woody plants such as live oak, hackberry, elm, and bumelia; and 10 percent Engelmann daisy, penstemon, gayfeather, bundleflower, sensitivebrier, prairie-clover, and other forbs.

If this site is in excellent condition, it produces approximately 6,000 pounds of air-dry herbage per acre in favorable years and 4,000 pounds per acre in unfavorable years. Approximately 95 percent of this production furnishes forage for cattle.

Under continuous heavy grazing by cattle, big and little bluestem and indiangrass decrease, and such plants as silver bluestem, side-oats grama, Texas wintergrass, and buffalograss, become strong increasers. If overgrazingis prolonged, Texas wintergrass, buffalo grass, hairy tridens, threeawn, ragweed, and broomwood dominate the site, thus greatly reducing annual and total production.

Gravelly Range Site

The soils of this site are deep, gently sloping to sloping, gravelly to very gravelly loamy sands. They are moderately to very slowly permeable and have a low to very low available water capacity.

The climax plant community is a post oak, blackjack oak savannah. The potential plant community is 55 percent little bluestem; 15 percent indiangrass, switchgrass, beaked panicum, and purpletop; 10 percent brownseed paspalum, side-oats grama, purple lovegrass, and other grasses; 10 percent post oak and blackjack oak; 5 percent hawthorns, American beautyberry, and greenbrier; and 5 percent lespedezas, tickclover, bundleflower, snoutbean, and annual forbs.

If this site is in excellent condition, it produces approximately 4,500 pounds of air-dry herbage per acre in favorable years and 2,200 pounds per acre in unfavorable years. Approximately 85 percent of this production furnishes forage for cattle.

Under continuous heavy grazing by cattle, little bluestem, indiangrass, switchgrass, beaked panicum, and purpletop decrease. Such plants as fall witchgrass, low panicums, three-awn, and annual weeds invade and increase. If overgrazing is prolonged, annual and total production are greatly reduced. In some areas oak, yaupon, and other woody plants form a dense overstory.

Gravelly Loam Range Site

The soils of this site are deep, gently sloping to sloping gravelly sandy clay loams. They are moderately permeable and have a medium available water capacity.

The potential plant community is a tall and mid grass prairie and widely scattered trees or motts of oak, elm, or hackberry. The climax plant community is 50 percent little bluestem; 10 percent indiangrass; 20 percent side-oats grama, silver bluestem, tall dropseed, Texas wintergrass, Texas cupgrass, and vine-mesquite; 5 percent other grasses; 5 percent oak, hackberry, elm, and bumelia; and 10 percent such forbs as Engelmann daisy, penstemon, bundleflower, sensitivebrier, and other forbs.

If this site is in excellent condition, it produces approximately 4,000 pounds of air-dry herbage per acre in favorable years and 2,000 pounds per acre in unfavorable years. Approximately 95 percent of this production furnishes forage for cattle.

Under continuous heavy grazing by cattle, little bluestem and indiangrass are the primary decreasers, and side-oats grama, silver bluestem, dropseeds, and Texas wintergrass are aggressive increasers. If overgrazing is prolonged, hairy grama, hairy tridens, Texas grama, tumblegrass, three-awn, and annual weeds and brush invade, thus greatly reducing annual and total production.

Gray Sandy Loam Range Site

The soils of this site are deep, nearly level to sloping fine sandy loams. They are moderately permeable and have a medium available water capacity.

The climax plant community is an open grassland and scattered chaparral. The potential plant community is 20 percent little bluestem; 40 percent Arizona cottontop, pinhole bluestem, lovegrass tridens, plains lovegrass, and plains bristlegrass; 10 percent hooded windmillgrass; 10 percent pink pappusgrass; 10 percent other grasses; 5 percent kidneywood, range ratany, guajillo, and cenizo; and 5 percent forbs.

If this site is in excellent condition, it produces approximately 4,500 pounds of air-dry herbage per acre in favorable years and 2,500 pounds per acre in unfavorable years. Approximately 95 percent of this production furnishes forage for cattle.

Under continuous heavy grazing by cattle, little bluestem, Arizona cottontop, lovegrass tridens, and plains lovegrass decrease. Such plants as hooded windmillgrass, Texas bristlegrass, pink pappusgrass, and fall witchgrass increase. If overgrazing is prolonged, red grama, red lovegrass, Halls panicum, three-awn, mixed brush, and annuals become dominant, and total production is greatly reduced.

Loamy Bottomland Range Site

The soils of this site are deep, nearly level loams, clay loams, silty clay loams and fine sands. They are moderately to rapidly permeable and have a low to high available water capacity.

The climax plant community is a savannah of varying plants. The potential plant community is 20 percent trees, such as oak, pecan, hackberry, elm, ash, and woody vines; 20 percent sedges, Virginia wildrye, and rustyseed paspalum; 45 percent indiangrass and switchgrass; 10 percent uniolas, redtop panicum, long-tom and other grasses; and 5 percent such forbs as snoutbean, wildbean, and partridgepea.

If this site is in excellent condition, it produces approximately 7,000 pounds of air-dry herbage per acre in favorable years and 4,000 pounds per acre in unfavorable years. Approximatley 80 percent of this production furnishes forage for cattle.

Under continuous heavy grazing by cattle, wildrye, rustyseed paspalum, indiangrass, switchgrass, and uniolas decrease. Such plants as panicums and longtom paspalum increase. If overgrazing is prolonged, annual weeds and woody vegetation make up a substantial part of the annual production, and total production is greatly reduced.

Loamy Sand Range Site

The soils of this site are deep, nearly level to gently sloping loamy fine sands. They are slowly permeable and have a medium available water capacity.

The climax plant community is an open grassland and a few scattered mesquites and oaks. The potential plant community is 20 percent little bluestem; 20 percent crinkle-awn and brownseed paspalum; 20 percent indiangrass and switchgrass; 20 percent Arizona cottontop; 10 percent side-oats grama and pink pappusgrass; 20 percent hooded windmillgrass, knotroot panicum, and plains bristlegrass; and 10 percent such forbs as snoutbean, western indigo, and annual forbs.

If this site is in excellent condition, it produces approximately 4,500 pounds of air-dry herbage per acre in favorable years and 2,000 pounds per acre in unfavorable years. Approximately 95 percent of this production furnishes forage for cattle.

Under continuous heavy grazing by cattle, little bluestem, indiangrass, big bluestem, and crinkle-awn decrease. Such plants as brownseed paspalum and low panicums increase. If overgrazing is prolonged, red lovegrass, fringed signalgrass, white snakeroot, croton, pricklypear cactus, and three-awn invade.

Sandy Range Site

The soils of this site consist of deep, nearly level to gently sloping loamy fine sands. They have slow to very slow permeability and low to medium available water capacity.

The climax plant community is an open savannah and a few blackjack and post oak trees or motts of live oaks. The climax plant community is 50 percent seacoast bluestem; 10 percent indiangrass and switchgrass; 10 percent big bluestem and crinkle-awn; 5 percent brownseed paspalum; 5 percent other grasses; 15 percent blackjack, post oak, and live oak; and 5 percent American snoutbean, western indigo, and annual forbs.

If this site is in excellent condition, it produces approximately 6,000 pounds of air-dry herbage per acre in favorable years and 2,500 per acre in unfavorable years. Approximately 95 percent of this production furnishes forage for cattle.

Under continuous heavy grazing by cattle, seacoast bluestem, indiangrass, switchgrass, big bluestem, and crinkle-awn decrease. Such plants as brownseed paspalum, low panicums, and panamerican balsamscale increase. If overgrazing is prolonged, red lovegrass, fringed signalgrass, white snakecotton, croton, and threeawn invade, and bare areas of dunes appear.

Sandy Loam Range Site

The soils of this site are deep, nearly level to gently sloping fine sandy loams. They are moderately permeable and have a high available water capacity.

The potential plant community is an open grassland dominated by mid grasses and some forbs and woody plants. The climax plant community is 40 percent little bluestem; 20 percent Arizona cottontop and silver bluestem; 20 percent plains and southwestern brittlegrass and hooded windmillgrass; 10 percent other grasses; 5 percent kidneywood, spiny hackberry, and wolfberry; and 5 percent bundleflower, sensitivebrier, western indigo, and other forbs.

If this site is in excellent condition, it produces approximately 5,400 pounds of air-dry herbage per acre in favorable years and 3,000 pounds per acre in unfavorable years. Approximately 95 percent of this production furnishes forage for cattle.

Under continuous heavy grazing by cattle, little bluestem, and Arizona cotton decrease. Such plants as silver bluestem, bristlegrass, and hooded windmillgrass increase. If overgrazing is prolonged, red lovegrass, red grama, blackbrush, and spiny hackberry become dominant, and total production is greatly reduced.

Sandy Prairie Range Site

The soils of this site are deep, nearly level to gently sloping loamy fine sands and gravelly loamy fine sands. They are very slowly permeable and have a low to high available water capacity.

This climax plant community is a true prairie. The potential plant community is 55 percent little bluestem; 20 percent indiangrass, crinkle-awn, and big bluestem; 10 percent Florida paspalum and switchgrass; 10 percent brownseed paspalum, longspike tridens, low panicums, fringeleaf paspalums, and other grasses; and 5 percent gayfeather, sensitivebrier, herbaceous mimosa, bundleflower, yellow neptunia, snoutbean, and annual and other forbs.

If this site is in excellent condition, it produces approximately 6,000 pounds of air-dry herbage per acre in favorable years and 3,500 pounds per acre in unfavorable years. Approximately 95 percent of this production furnishes forage for cattle.

Under continuous heavy grazing by cattle, big and little bluestem, indiangrass, crinkle-awn and switch-grass decrease, and brownseed paspalum, low panicums, and others increase. As retrogression continues, gulf muhly, panamerican balsamscale, smutgrass, and annuals dominate this site, thus greatly reducing total production.

Tight Sandy Loam Range Site

The soils of this site are deep, nearly level to gently sloping fine sandy loams. They are slowly to very slowly permeable and have a medium available water capacity.

The climax plant community is an open grassland and scattered woody plants. The potential plant community is 25 percent little bluestem and fourflower trichloris; 15 percent pinhole bluestem and tanglehead; 10 percent Arizona cottontop and plains bristlegrass; 10 percent hooded windmillgrass; 15 percent buffalograss and curly mesquite; 15 percent other grasses; 5 percent kidneywood, vine-ephedra, and spiny hackberry; and 5 percent bush sunflower, orange zexmenia, American snoutbean, sensitivebrier, yellow neptunia, and other forbs.

If this site is in excellent condition, it produces approximately 4,800 pounds of air-dry herbage per acre in favorable years and 3,500 pounds per acre in unfavorable years. Approximately 90 percent of this production furnishes forage for cattle.

Under continuous heavy grazing by cattle, little bluestem, fourflower trichloris, and Arizona cottontop decrease. Such plants as bristlegrass, buffalograss, curly mesquite and woody species increase (fig. 5). If overgrazing is prolonged, total production is greatly reduced.

Sandy Bottomland Site[1]

Deep, sandy, alluvial sediments. Climax vegetation is a savannah of oak, elm, ash, sycamore, cottonwood, and black willow trees; with woody understory and switchgrass, indiangrass, bluestems, purpletop, virginia wildrye, sedges, uniolas, tick-clover, snoutbean, wildbeans, ironweed, white crownbeard.

Lowland Flat Site[1]

Low lying clay loam and fine sandy loam over very tight subsoil. Nearly level with slow drainage or ponded. Capable of growing a wet prairie of switchgrass, little bluestem, some indiangrass, brownseed paspalum, and longtom. Annual weeds, annual threeawn, smutgrass, and rattlebox invade.

Loamy Prairie Site[1]

Nearly level loamy soils having a heavy subsoil with very slow drainage. The original natural vegetation was indiangrass, switchgrass, little bluestem, brownseed paspalum, and some forbs. With deterioration, carpetgrass becomes abundant. Wax myrtle, annual weeds, and rattlebox are common invaders.

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[1] Fair, C., 1979, personal communication.

APPENDIX C.3

Capability Classes

Capability classes, the broadest groups, are designated by Roman numerals I through VIII. The numerals indicate progressively greater limitations and narrower choices for practical use, defined as follows:

Class I soils have few limitations that restrict their use.

Class II soils have moderate limitations that reduce the choice of plants or that require moderate conservation practices.

Class III soils have severe limitations that reduce the choice of plants, require special conservation practices, or both.

Class IV soils have very severe limitations that reduce the choice of plants, require very careful management, or both.

Class V soils are not likely to erode but have other limitations, impractical to remove, that limit their use largely to pasture or range, woodland, or wildlife.

Class VI soils have severe limitations that make them generally unsuited to cultivation and limit their use largely to pasture or range, woodland, or wildlife.

Class VII soils have very severe limitations that make them unsuited to cultivation and that restrict their use largely to pasture or range, woodland, or wildlife.

Class VIII soils and landforms have limitations that preclude their use for commercial crop production and restrict their use to recreation, wildlife, or water supply or to esthetic purposes.

Capability Subclasses

Capability subclasses are soil groups within one class; they are designated by adding a small letter, e, w, s, or c, to the class numeral for example, IIe. The letter e shows that the main limitation is risk of erosion unless close-growing plant cover is maintained; w shows that water in or on the soil interferes with plant growth or cultivation (in some soils the wetness can be partly corrected by artificial drainage); s shows that the soil is limited mainly because it is shallow, droughty, or stony; and c, used in only some parts of the United States, shows that the chief limitation is climate that is too cold or too dry.

In class I there are no subclasses, because the soils of this class have few limitations. Class V can contain, at the most, only the subclasses indicated by w, s, and c, because the soils in class V are subject to little or no erosion, though they have other limitations that restrict their use largely to pasture or range, woodland, wildlife, or recreation.

Capability Units

Capability units are soil groups within the subclasses. The soils in one capability unit are enough alike to be suited to the same crops and pasture plants, to require similar management, and to have similar productivity and other responses to management. Thus the capability unit is a convenient grouping for making many statements about management of soils. Capability units are generallly designated by adding an Arabic numeral to the subclass symbol, for example, IIe-3 or IIIe-6. Thus, in one symbol, the Roman numeral designates the capability class, or degree of limitation; the small letter indicates the subclass, or kind of limitation, as defined in the foregoing paragraph; and the Arabic numeral specifically identifies the capability unit within each subclass.

On the following pages the capability units in the Cuero & Eagle Lake study areas are described and use and management of the soils is suggested.

Capability Units - Cuero Area

Capability Unit II-e-1. These soils are deep, gently sloping, well drained to moderately well drained, and very slowly permeable. The surface layer is clay, and the lower layers are clay.

Grain sorghum, cotton, and corn are the main crops. Controlling water erosion and maintaining soil tilth are the main concerns of management. Terracing and contour farming help to control water erosion. Managing crop residue on the surface improves tilth and also helps in controlling erosion.

Capability Unit IIe-2. The one soil in this unit, Papalote fine sandy loam, 1 to 3 percent slopes, is deep, gently sloping, moderately well drained, and slowly permeable. The surface layer is underlain by sandy clay.

Grain sorghum is the main crop. Controlling water erosion is the main concern of management. Terracing and contour farming help to control water erosion.

Capability Unit IIe-3. These soils are deep, gently sloping, well drained, and moderately permeable. The surface layer is fine sandy loam to sandy clay loam. The lower layers are sandy clay loam.

Grain sorghum, cotton, and corn are the main crops. Controlling water erosion is the main concern of management. Terracing and contour farming help to control water erosion. Managing crop residue on the surface improves tilth and also helps in controlling erosion.

Capability Unit IIe-4. The one soil in this unit, Cuero sandy clay loam, 0 to 2 percent slopes, is deep, nearly level to gently sloping, well drained, and moderately permeable. The surface layer is underlain by sandy clay loam.

Grain sorghum, corn, and cotton are the main crops. Managing crop residue on the surface and otherwise keeping the soil in good tilth is the main concern of management. It also helps to control erosion.

Capacility Unit IIw-1. The one soil in this unit, Trinity clay, occasionally flooded, is deep, somewhat poorly drained, and very slowly permeable. The surface layer is underlain by clay.

Grain sorghum and corn are the main crops. Flooding and wetness reduce yields in some years. Surface drainage is needed. Managing crop residue on the surface and otherwise keeping the soil in good tilth is the main concern of management.

Capability Unit IIw-2. These soils are deep, nearly level, well drained, and moderately permeable. The surface layer is loam, clay loam, or silty clay loam. The lower layers are silty clay loam, loam, or sandy clay loam.

Grain sorghum and corn are the main crops. Flooding damages crops and reduces yields in some years. Managing crop residue on the surface and otherwise keeping the soil in good tilth is the main concern of management.

Capability Unit IIw-3. These soils are deep, nearly level, moderately well drained, and very slowly permeable. The surface layer and lower layers are clay.

Grain sorghum and corn are the main crops. Managing crop residue on the surface and otherwise keeping the soil in good tilth is the main concern of management. Excess water is a concern in some seasons and surface drainage is needed.

Capability Unit IIs-1. The one soil in this unit, Monteola clay, 0 to 1 percent slopes, is deep, moderately well drained, and very slowly permeable. The surface layer is underlain by clay.

Grain sorghum, corn, and cotton are the main crops. Managing crop residue on the surface and otherwise keeping the soil in good tilth is the main concern of management.

Capability Unit IIs-2. The one soil in this unit, Papalote fine sandy loam, 0 to 1 percent slopes, is deep, moderately well drained, and slowly permeable. The surface layer is underlain by sandy clay.

Grain sorghum is the main crop. Managing crop residue on the surface and otherwise keeping the soil in good tilth is the main concern of management.

Capability Unit IIc-1. These soils are deep, nearly level, well drained, and moderately permeable. The surface layer is fine sandy loam. The lower layers are sandy clay loam.

Grain sorghum, corn, and cotton are the main crops. Managing crop residue on the surface and otherwise keeping the soil in good tilth is the main concern of management.

Capability Unit IIIe-1. These soils are deep, gently sloping, moderately well drained to somewhat poorly drained, and slowly to very slowly permeable. The surface layer is fine sandy loam to loamy fine sand. The lower layers are clay to sandy clay.

Grain sorghum and corn are the main crops. Controlling erosion and maintaining soil tilth are the main concerns of management. Terracing and contour farming help to control water erosion. Managing crop residue on the surface maintains tilth and also helps in controlling erosion.

Capability Unit IIIe-2. These soils are deep, gently sloping, well drained to moderately well drained, and very slowly permeable. The surface layer and lower layers are clay.

Grain sorghum is the main crop. Controlling erosion, conserving moisture, and maintaining soil tilth are the main concerns of management. Terracing and contour farming help to control erosion and conserve moisture. Managing crop residue on the surface improves tilth and also helps in conserving moisture.

Capabiltiy Unit IIIe-3. The one soil in this unit, Leemont clay, 3 to 5 percent slopes, is deep, moderately well drained, and very slowly permeable. The surface layer is underlain by clay.

Grain sorghum and corn are the main crops. Controlling erosion is the main concern of management. Terracing and contour farming help to control water erosion. Managing crop residue on the surface improves tilth and also helps in controlling erosion.

Capability Unit IIIe-4. The only soils in this unit are those in the Denhawken-Elmendorf complex, 0 to 3 percent slopes. These soils are deep, well drained, and very slowly permeable.

Grain sorghum, corn, and cotton are the main crops. Controlling water erosion and mantaining soil tilth are the main concerns of management. Terracing and contour farming help to control water erosion. Managing crop residue on the surface improves tilth and also helps in controlling erosion.

Capabilty Unit IIIe-5. The only soils in this unit are those in the Nueces Sarita complex, 0 to 5 percent slopes. These soils are deep, well drained to moderately well drained, and moderately rapidly to moderately slowly permeable. The surface layer is fine sand, and the lower layers are sandy clay loam.

Watermelons are the main crop. Managing crop residue on the surface and otherwise controlling soil blowing is the main concern of management.

Capability Unit IIIe-6. The one soil in this unit, Termona loamy fine sand, 0 to 5 percent slopes, is deep, nearly level to gently sloping, somewhat poorly drained, and very slowly permeable. The surface layer is underlain by sandy clay.

This soil is used mainly for forage crops, such as bermudagrass. Growing bermudagrass and other pasture crops that provide continuous cover and otherwise controlling soil blowing and water erosion are the chief needs of management.

Capability Unit IIIe-7. The one soil in this unit, Weesache sandy clay loam, 3 to 5 percent slopes, is deep, well drained, and moderately permeable. The surface layer is underlain by sandy clay loam.

Grain sorghum is the main crop. Controlling water erosion is the main concern of management.

Capabilty Unit IIIe-8. These soils are deep, gently sloping, well drained, and moderately permeable. The surface layer is fine sandy loam, and the lower layers are sandy clay loam.

Grain sorghum is the main crop. Controlling water erosion is the main concern of management. Terracing and contour farming help to control water erosion. Managing crop residue on the surface improves tilth and also helps in controlling erosion.

Capability Unit IIIe-9. These soils are deep, moderately well drained, and slowly to moderately slowly permeable. The surface layer is loamy fine sand to fine sand. The lower layers are sandy clay loam to sandy clay.

These soils are used mostly for forage crops, such as bermudagrasss. Growing bermudagrass and other pasture crops that provide continuous cover and otherwise controlling soil blowing are the chief needs of management.

Capability Unit IIIe-10. The one soil in this unit, Wilson clay loam, 1 to 3 percent slopes, is deep, gently sloping, somewhat poorly drained, and very slowly permeable. The surface layer is underlain by clay.

Grain sorghum, corn, and cotton are the main crops. Controlling erosion and maintaining soil tilth are the main concerns of management. Terracing and contour farming help to control water erosion. Managing crop residue on the surface improves tilth and also helps in controlling erosion.

Capability Unit IIIw-1. These soils are deep, nearly level to gently sloping, poorly drained to somewhat poorly drained, and very slowly permeable. The surface layer is fine sandy loam, and the lower layers are clay to sandy clay loam.

These soils are used mostly for pasture and forage crops. Growing bermudagrass and other pasture crops that provide a continuous cover, managing crop residue on the surface, and otherwise keeping the soil in good tilth are the chief management needs. Excess surface water is a concern in places, and surface drainage is needed.

Capability Unit IIIw-3. The one soil in this unit, Wilson clay loam, 0 to 1 percent slopes, is deep, nearly level, somewhat poorly drained, and very slowly permeable. The surface layer is underlain by clay.

Grain sorghum, corn , and cotton are the main crops. Excess water is a concern in some seasons, and surface drainage is needed. Maintaining soil tilth is the main concern of management. Managing crop residue on the surface helps to maintain soil tilth and also helps in controlling erosion.

Capability Unit IIIs-1. The one soil in this unit, Straber loamy fine sand, 0 to 1 percent slopes, is deep, nearly level, moderately well drained, and slowly permeable. It is used mostly for pasture and forage crops. Managing crop residue on the surface and otherwise keeping the soil in good tilth is the main concern of management.

Capability Unit IIIs-2. The one soil in this unit, Crockett fine sandy loam, 0 to 1 percent slopes is deep nearly level, moderately well drained, and very slowly permeable. These soils are deep, gently sloping to sloping, well drained. The surface layer and lower layers are clay.

This soil is used mostly for pasture and forage crops. Growing bermudagrass and other pasture crops that provide continuous cover, managing crop residue on the surface, and otherwise keeping the soil in good tilth are the chief management needs.

Capability Unit IVe-1. The soil in this unit, Crockett fine sandy loam, 3 to 5 percent slopes, is deep, gently sloping, moderately well draind, and very slowly permeable. The surface layer is underlain by clay.

These soils are used mostly for pasture and forage crops. The main concern of management is water erosion. Growing perennial grass pastures, terracing, and contour farming help to control water erosion. Managing crop residue on the surface improves tilth and also helps in controlling erosion.

Capability Unit IVe-2. These soils are deep, gently sloping to sloping, well drained to moderately well drained, and very slowly permeable. The surface layer and lower layers are clay.

These soils are used mostly for pasture and forage crops, such as bermudagrass. Controlling water erosion is the main concern of management. Growing perrennial grass pastures, terracing, and contour farming help to control water erosion. Managing crop residue on the surface improves tilth and also helps in controlling erosion.

Capabilty Unit IVe-3. These soils are deep, gently sloping, well drained, and very slowly permeable. The surface layer is fine sandy loam, and the lower layers are clay.

These soils are used mostly for pasture and forage crops, such as bermudagrass. Controlling water erosion is the main concern of management. Growing perennial grass pastures, terracing, and contour farming help to control water erosion. Managing crop residue on the surface improves tilth and also helps in controlling erosion.

Capabilty Unit IVe-4. The one soil in this unit, Shiner fine sandy loam, 1 to 5 percent slopes, is shallow, gently sloping, well drained, and moderately permeable. The surface layer is underlain by gravelly fine sandy loam.

This soil is used mostly for pasture and forage crops, such as bermudagrass. Growing bermudagrass and other pasture crops that provide continuous cover and otherwise controlling water erosion is the main concern of management.

Capabilty Unit IVe-5. The only soils in this unit, Crockett soils, 2 to 5 percent slopes, eroded, are deep, gently sloping, moderately well drained, and very slowly permeable. The surface layer is fine sandy loam, and the lower layers are clay.

These soils are used mostly for pasture and forage crops, such as bermudagrass. Growing bermudagrass and other pasture crops that provide continuous cover and otherwise controlling erosion is the main concern of management.

Capability Unit IVe-6. The only soils in this unit, Sarnosa soils, 3 to 5 percent slopes, eroded, are deep, gently sloping, well drained, and moderately permeable. The surface layer is fine sandy loam, and the lower layers are sandy clay loam.

These soils are used mostly for pasture or forage crops. Growing bermudagrass and other pasture crops that provide continuous cover and otherwise controlling water erosion is the chief concern of management.

Capability Unit IVe-7. The one soil in this unit, Sarnosa fine sandy loam, 5 to 8 percent slopes, is deep, sloping, well drained, and moderately permeable. The surface layer is underlain by sandy clay loam.

This soil is used mostly for pasture and forage crops. Growing bermudagrass and other pasture crops that provide continuous cover and otherwise controlling water erosion is the main concern of management.

Capability Unit IVw-1. The one soil in this unit, Zalla fine sand, occasionally flooded, is deep, nearly level, somewhat excessively drained, and rapidly permeable. The surface layer is underlain by loamy sand to sand.

These soils are used for range. Growing bermudagrass and other pasture crops that provide continuous cover and otherwise controlling soil blowing is the chief concern of management. Controlling flooding is also a main concern.

Capability Unit IVs-2. These soils are deep, nearly level to gently sloping, somewhat poorly drained, and very slowly permeable. The surface layer is gravelly loamy sand to loamy fine sand. The lower layers are clay to gravelly clay.

These soils are used mostly for range and pasture. Growing bermudagrass and other pasture crops that provide continuous cover and otherwise controlling soil blowing and water erosion are the chief management needs.

Capability Unit Vw-1. These soils are deep, nearly level, well drained to somewhat poorly drained, and moderately to very slowly permeable. The surface layer is clay loam or silty clay loam to clay. The lower layers are sandy clay loam or silty clay loam to clay.

These soils are used mostly for range. They are not suited to crops. Controlling flooding is the main concern of managment.

Capability Unit VIe-1. The one soil in this unit, Shiner fine sandy loam, 5 to 8 percent slopes, is shallow, sloping, well drained and moderately permeable. The surface layer is underlain by gravelly fine sandy loam. This soil is used for range. It is not suited to crops.

Capability Unit VIs-2. These soils are deep, gently sloping, to sloping, well drained to moderately well drained, and moderately to moderately slowly permeable. The surface layer is gravelly to very gravelly loamy sand to gravelly sandy clay loam. The lower layers are gravelly to very gravelly sandy clay loam to very gravelly loamy sand.

These soils are used mostly for range. They are not suited to crops.

Capability Units - Eagle Lake Area

Capability Unit I-1. Nearly level, well-drained, loamy bottomland soils with moderately permeable subsoils. Cotton, corn, grain sorghum, and native pasture are the main crops.

Capability Unit I-2. Nearly level, well-drained, fine sandy loams with moderately and moderately slowly permeable subsoils. Cotton, corn, grain sorghum, and improved pasture are the main crops.

Capability Unit IIs-1. Nearly level, moderately well drained, slowly permeable, bottomland clays and clay loams. Cotton, corn, grain sorghum, improved pasture and native rangeland are the main crops.

Capability Unit IIw-1. Nearly level to moundy, moderately well to somewhat poorly drained fine sandy loams with slowly permeable loamy subsoils. Cotton, corn, grain sorghum, pasture and native range are the main crops.

Capability Unit IIw-2. Nearly level to moundy, moderately well to somewhat poorly drained fine sandy loams with slowly permeable clayey subsoils. Cotton, corn, grain sorghum, pasture and native range are the main crops.

Capability Unit IIIw-1. Nearly level, somewhat poorly drained clays, very slowly permeable when wet. Cotton, corn, grain sorghum, native range and pasture are the main crops.

Capability Unit IIIw-4. Nearly level, somewhat poorly and poorly drained loamy soils with very slowly permeable clayey subsoils. Rice, corn, grain sorghum, and native range are the main crops.

Capability Unit IIe-1. Gently sloping, well drained, fine sandy loams with moderately and slowly permeable subsoils. Cotton, corn, grain sorghum and native range are the main crops.

Capability Unit IIIs-1. Nearly level to sloping, excessively drained, rapidly permeable sands, some of which have loamy subsoils below 40 inches. Rice, corn, grain sorghum, and native range grasses are the main crops.

Capability Unit IIIs-3. Nearly level to sloping, well drained, sandy soils with slowly permeable clayey subsoils. Cotton, corn, grain sorghum, pasture, and native range are the main crops.

Capability Unit IIIw-3. Nearly level to sloping, moderately well to somewhat poorly drained, rapidly to slowly permeable sands, some of which have loamy subsoils. Rice, peanuts, watermelons, grain sorghums and native range are the main crops.

Capability Unit IIw-1. Level to depressional, poorly drained, loamy soils. Rice, native range, and grain sorghum are the main crops.

Capability Unit IIIe-1. Gently sloping, moderately well and somewhat poorly drained loamy soils with slowly and very slowly permeable clayey subsoils. Cotton, corn, grain sorghum, native and improved grasses are the main crops.

Capability Unit IIe-9. Gently sloping, well drained loamy bottomland soils with moderately permeable subsoils. Common bermuda grass and wooded rangeland are the main crops.

All crop residues should be managed in or near the soil surface until the seed bed is prepared for the next crop.

Appendix C, Section 4.

IDENTIFICATON OF PRIME FARMLANDS[1]

(1) General. Prime farmland is land that has the best combination of physical and chemical characteristics for producing food, feed, forage, fiber, and oilseed crops, and is also available for these uses (the land could be cropland, pastureland, rangeland, forest land, or other land, but not urban built-up land or water). It has the soil quality, growing season, and moisture supply needed to economically produce sustained high yields of crops when treated and managed, including water management, according to acceptable farming methods. In general, prime farmlands have an adequate and dependable water supply from precipitation or irrigation, a favorable temperature and growing season, acceptable acidity or alkalinity, acceptable salt and sodium content, and few or no rocks. They are permeable to water and air. Prime farmlands are not excessively erodible or saturated with water for a long period of time, and they either do not flood frequently or are protected from flooding. Examples of soils that qualify as prime farmland are Palouse silt loam, 0 to 7 percent slopes; Brookston silty clay loam, drained; and Tama silty clay loam 0 to 5 percent slopes.

(2) Specific criteria. Prime farmlands meet all the following criteria: Terms used in this section are defined in USDA publications: "Soil Taxonomy; Agriculture Handbook 436"; "Soil Survey Manual, Agriculture Handbook 18"; "Rainfall-erosion Losses From Cropland, Agriculture Handbook 282"; "Wind Erosion Forces in the United States and Their Use in Predicting Soil Loss, Agriculture Handbook 346"; and "Saline and Alkali Soils, Agriculture Handbook 60."

(i) The soils have:

(A) Aquic, udic, ustic, or xeric moisture regimes and sufficient available water capacity within a depth of 40 inches (1 meter), or in the root zone (root zone is the part of the soil that is penetrated or can be penetrated by plant roots) if the root zone is less than 40 inches deep, to produce the commonly grown cultivated crops (cultivated crops include, but are not limited to, grain, forage, fiber, oilseed, sugar beets, sugarcane, vegetables, tobacco, orchard, vineyard, and bush fruit crops) adapted to the region in 7 or more years out of 10; or

(B) Xeric or ustic moisture regimes in which the available water capacity is limited, but the area has a developed irrigation water supply that is dependable (a dependable water supply is one in which enough water is available for irrigation in 8 out of 10 years for the crops commonly grown) and of adequate equality; or,

(C) Aridic or torric moisture regimes and the area has a developed irrigation water supply that is dependable and of adequate quality; and,

(ii) the soils have a temperature regime that is frigid, mesic, thermic, or hyperthermic (pergelic and cryic regimes are excluded). These are soils that, at a depth

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[1]Reprinted from Federal Register, Vol. 43, No. 21, Jan. 31, 1978, p. 4032.

of 20 inches (50 cm), have a mean annual temperature higher than 32° F(0° C). In addition, the mean summer temperature at this depth in soils with an O horizon is higher than 47° F (8° C); in soils that have no O horizon, the mean summer temperature is higher than 59° F (15° C); and,

(iii) The soils have a pH between 4.5 and 8.4 in all horizons within a depth of 40 inches (1 meter) or in the root zone if the root zone is less than 40 inches deep; and,

(iv) The soils either have no water table or have a water table that is maintained at a sufficient depth during the croping season to allow cultivated crops common to the area to be grown; and,

(v) The soils can be managed so that, in all horizons within a depth of 40 inches (1 meter) or in the root zone if the root zone is less than 40 inches deep, during part of each year the conductivity of the saturation extract is less than 4 mmhos/cm and the exchangeable sodium percentage (ESP) is less than 15; and,

(vi) The soils are not flooded frequently during the growing season (less often than once in 2 years); and

(vii) The product of K (erodibility factor) x percent slope is less than 2.0, and the product of I (soils erodibility) x C (climatic factor) does not exceed 60; and

(viii) The soils have a permeability rate of at least 0.06 inch (0.15 cm) per hour in the upper 20 inches (50 cm) and the mean annual soil temperature at a depth of 20 inches (50 cm) is less than 59° F (15° C); the permeability rate is not a limiting factor if the mean annual soil temperature is 59° F (15° C) or higher; and,

(ix) Less than 10 percent of the surface layer (upper 6 inches) in these soils consists of rock fragments coarser than 3 inches (7.6 cm).

Table D1. Vegetation of Cuero study area.

Common Name	*Latin Name*	*Source*
	1. Trees	
Wooly buckeye	Aesculus discolor	F
Gum elastic	Bumelia lanuginosa	F
Pecan	Carya illinoensis	F
Sugar hackberry	Celtis laevigata	F
Hackberry	Celtis sp.	F
Texas persimmon	Diospyros texana	F
Anaqua	Ehretia anacua	F
Ash	Fraxinus spp.	F
Osage orange	Maclura pomifera	F
Chinaberry[1]	Melia azedarach	F
Mulberry[1]	Morus alba	F
Red mulberry	Morus rubra	F
Retama	Parkinsonia aculeata	F
Sycamore	Platanus occidentalis	F
Eastern cottonwood	Populus deltoides	F
Mesquite	Prosopsis juliflora	F
Blackjack oak	Quercus marilandica	F
Post oak	_____ stellata	F
Live oak	_____ virginiana	F
Willow	Salix sp.	F
Western soapberry	Sapindus drummondii	F
Baldcypress	Taxodium distichum	F
American elm	Ulmus americana	F
Cedar elm	_____ crassifolia	F
	2. Shrubs	
Guajillo	Acacia berlandieri	J
Huisache	_____ farnesiana	F
Catclaw acacia	_____ greggii	J
Blackbrush	_____ rigidula	F
Amorpha	Amorpha sp.	F
Prairie willow	Baccharis angustifolia	F
American beauty-berry	Callicarpa americana	F
Bisbirinda	Castela texana	J
Texas colubrina	Colubrina texensis	S
Condalia	Condalia spp.	S
Dogwood	Cornus sp.	F
Hawthorn	Crataegus spp.	F
Elbow-brush	Forestiera pubescens	S
Yaupon	Ilex vomitoria	F
Coyotillo	Karwinskia humboldtiana	J
Cenizo	Leucophyllum frutescens	J
Wolfberry	Lycium sp.	S
Agarita	Mahonia trifoliolata	F
Prickly pear	Opuntia lindheimeri	F
Trifoliate orange[1]	Poncirus trifoliata	F
Guayacan	Porliera angustifolia	J
Macartney rose[1]	Rosa bracteata	F
Dewberry	Rubus sp.	F
Prickly ash	Zanthoxylum clava - herculis	F
	3. Vines	
Peppervine	Ampelopsis arborea	F
Trumpet creeper	Bignonia radicans	F
Ivy treebine	Cissus incisa	F
Morning glory	Ipomoea sp.	F
Virginia creeper	Parthenocissus quinquefolia	F
Greenbrier	Smilax rotundifolia	F
Poison ivy	Toxicodendron radicans	F
Grape	Vitis sp.	F

Table D1. *(continued)*

Common Name	*Latin Name*	*Source*
	4. Forbs	
Milfoil	Achillea millefolium	Source[2]
Wild onion	Allium sp.	
Western ragweed	Ambrosia psilostachya	
Anemone	Anemone decapetala	
Lazy daisy	Aphanostephus sp.	
Texas prickly-poppy	Argemone albiflora	
Butterfly-weed	Asclepias tuberosa	
Aster	Aster spp.	
Wild indigo	Baptisia leucophaea	
Winecup	Callirrhoe spp.	
Bush pepper	Capsicum annuum	C
Partridge pea	Cassia fasciculata	C
Indian paintbrush	Castilleja sp.	
Star thistle	Cirsium texanum	
Texas bull nettle	Cnidoscolus texanus	
Dayflower	Commelina sp.	
Rain lily	Cooperia sp.	
Golden-wave	Coreopsis grandiflora	
Prairie larkspur	Delphinium virescens	
Tick-clover	Desmodium sessilifolium	C
Cut-leaved daisy	Engelmannia pinnatifida	
Eryngo	Eryngium leavenworthii	
Firewheel	Gaillardia pulchella	
Pincushion daisy	—— suavis	
Wild honeysuckle	Guara suffulta	
No common name	Herbertia drummondii	
Star violet	Hedyotis nigricans	
Sunflower	Helianthus annuus	
Old plainsman	Hymenopappus artemesiaefolius	
Lantana[1]	Lantana camara	
Toadflax	Linaria texana	
Texas star	Lindheimera texana	
Yellow flax	Linum rigidum	
Bluebonnet	Lupinus subcarnosus	
Bluebonnet	—— texensis	
Lemon horsemint	Monarda citriodora	
Yellow horsemint	——punctata	
Texas baby-blue-eyes	Nemophila phacelioides	
Cut-leaved evening-primrose	Oenothera laciniata	
Pink evening-primrose	—— spediosa	
Buttercup	Oenothera spp.	
Blue curls	Phacelia congesta	
Phlox	Phlox spp.	
Texas dandelion	Pyrrhopappus multicaulis	
Mexican-hat	Ratibida columnaris	
Coneflower	Rudbeckia amplexicaulis	
Late coneflower	Rudbeckia serotina	
Meadow-pink	Sabatia campestris	
Blue sage	Salvia azurea	
Scarlet sage	Salvia coccinea	
Sensitive brier	Schrankia uncinata	
Blue-eyed grass	Sisyrinchium sp.	
Thelesperma	Thelesperma sp.	
Ball-moss	Tillandsia recurvata	
Spanish moss	—— usneoides	
Spiderwort	Tradescantia sp.	
Venus' looking glass	Triodanis perfoliata	
Prairie verbena	Verbena bipinnatifida	

Table D1. *(continued)*

Common Name	*Latin Name*	*Source*
	5. Grasses	
Big bluestem	Andropogon gerardii var. gerardii	C
Splitbeard bluestem	_____ ternarius	J
Broomsedge	_____ virginicus	J
Medio bluestem[1]	Andropogon sp.	C
Gordo bluestem[1]	_____ sp.	C
Threeawns	Aristida spp.	A
King Ranch bluestem[1]	Bothriochloa ischaemum var. songaricus	C
Silver bluestem	_____ saccharoides	C
Sideoats grama	Bouteloua curtipendula	C
Texas grama	_____ rigidiseta	C
Buffalo grass	Buchloe dactyloides	T
No common name	Chasmanthium sessiliflorum	J
Windmill grass	Chloris verticillata	A
Coastal bermuda[1]	Cynodon dactilon	C
Common bermuda[1]	_____ dactylon	A
Balsamscale	Elyonurus tripsacoides	C
Red lovegrass	Eragrostis secundiflora	J
Curly mesquite	Hilaria belangeri	C
Kleingrass[1]	Panicum coloratum	C
Vine-mesquite	_____ obtusum	S
Switchgrass	_____ virgatum	C
Brownseed paspalum	Paspalum plicatulum	C
Little bluestem	Schizachyrium scoparium var. frequens	C
Bristlegrass	Setaria sp.	C
Indiangrass	Sorghastrum nutans	C
Smutgrass	Sporobolus indicus	A
Texas wintergrass	Stipa leucotricha	C
Crinkleawn	Trachypogon secundus	C
Purpletop	Tridens flavus	C
Annually Planted:		
Oats	Avena fatua var. sativa	C
Rye grass	Lolium perenne	C
Sudan grass	Sorghum bicolor var. sudanense	C
Haygrazer	Sorghum bicolor	C

[1]Introduced species

Sources:
- F - Field collection and identification.
- C - Don Shaw and others, Dewitt County SCS Personnel, pers. comm.
- A - Billy Paul, Dewitt County Agricultural Agent, pers. comm.
- S - Dewitt County soil survey (1978).
- J - Correl and Johnston (1970) ("Manual of the Vascular Plants of Texas").
- T - Gould (1975) ("The Grasses of Texas").

Identification aided by: Dewitt County SCS personnel, pers. comm.; Correll and Johnston (1970); Willis and Howard (1975); and David Riskind, TPWD, pers. comm.

Nomenclature:
- Trees, shrubs and vines: Vines (1960)
- Forbs: Gould (1962)
- Grasses: Gould (1975)

Table D2. Vegetation of Eagle Lake study area.

Common Name	*Latin Name*	*Source*
	1. Trees	
Ash-leaf maple	Acer negundo	F
Pecan	Carya illinoensis	F
Hackberry	Celtis sp.	F
Anaqua	Ehretia anacua	A
Ash	Fraxinus cf. pennsylvanica	F
Arizona ash	_____ velutina	F
Sweetgum	Liquidambar styraciflua	A
Chinaberry[1]	Melia azedarach	F
Mulberry	Morus sp.	A
Retama	Parkinsonia aculeata	A
Sycamore	Platanus occidentalis	F
Eastern cottonwood	Populus deltoides	F
Mesquite	Prosopsis juliflora	F
Blackjack oak	Quercus marilandica	
Water oak	_____ nigra	F
Post oak	_____ stellata	F
Liveoak	_____ virginiana	F
Chinese tallow	Sapium sebiferum	F
Willow	Salix sp(p).	F
American elm	Ulmus americana	F
	2. Shrubs	
Huisache	Acacia farnesiana	A
Desert willow	Chilopsis linearis	A
Yaupon	Ilex vomitoria	F
Trifoliate orange[1]	Poncirus trifoliata	F
Macartney rose[1]	Rosa bracteata	F
Prickly ash	Zanthoxylum clava-herculis	A
	3. Vines	
Pepper vine	Ampelopsis arborea	F
Trumpet creeper	Bignonia radicans	F
Dewberry	Rubus spp.	F
Greenbrier	Smilax rotundifolia	F
Poison ivy	Toxicodendron radicans	F
Grape	Vitis sp.	F
	4. Forbs	
Western ragweed	Ambrosia psilostachya	K
Toothcup	Ammania coccinca	K
Butterfly weed	Asclepias tuberosa	F
Aster	Aster spp.	K
Wild-indigo	Baptisia sp.	K, F
No common name	Boltonia diffusa	K
Indian plantain	Cacalia tuberosa	K
Partridge pea	Cassia fasciculata	K
Indian paintbrush	Castilleja sp.	F
Butterfly pea	Centrosema virginianum	K

Table D2. *(continued)*

Common Name	*Latin Name*	*Source*
Texas bull-nettle	Cnidoscolus texanus	K, F
Dayflower	Commelina erecta	K
Bindweed	Convolvulus sp.	K
Rainlily	Cooperia drummondii	F
Coreopsis (tick-seed)	Coreopsis basalis	K
Coreopsis	_____ tinctoria	K
Scratch daisy	Croptilon divaricatum	K
Silver croton	Croton argyranthemus	K
Croton	Croton capitatus	K
Croton	Croton glandulosus	K
Poor Joe (rough buttonwood)	Diodia teres	K
Fleabane	Erigeron sp.	K
Stork's-bill	Erodium sp.	K
Yankee weed	Eupatorium compositifolium	K
Boneset	Eupatorium cuneilaris var. semiserrulata	K
Spurge	Euphorbia sp.	K
Ojo de vibora	Evolvulus alsinoides	K
Snake-cotton	Froelichia floridana	K
Indian blanket	Gaillardia aestivalis	K
Bedstraw	Galium sp.	K
Lizard tail	Gaura parviflora	K
Cranesbill	Geranium carolinanum	K
Gerardia	Agalinis purpurea	K
Purple cud weed	Gnaphalium purpureum	K
Star-violet	Hedyotis nigricans	F
Camphor-weed	Heterotheca subaxillaris	K
Golden aster (camphor weed)	Heterotheca sp.	K
Spiderlily	Hymonocallis liriosme	F
Nits-and-lice	Hypericum drummondii	K
Sump-weed	Iva angustifolia	K
Sump-weed	Iva frutescens	K
Gayfeather	Liatris mucronata	K
Toadflax	Linaria texana	F
False pimpernel	Lindernia dubia	K
Sucker flax	Linum medium	K
Seedbox (water primrose)	Ludwigia linearis	K
Seedbox	Ludwigia sp.	K
Loosestrife	Lythrum lanceolatum	K
Lemon horsemint	Monarda citriodora	F
Yellow horsemint	_____ punctata	
Yellow-puff	Neptunia lutea	K
Evening primrose	Oenothera heterophylla	K
Day primrose	_____ serrulata	F
Pink evening primrose	_____ speciosa	F
Wood sorrel	Oxalis dillenii	K
Whitlow-wort	Paronychia drummondii	K
Phlox	Phlox sp.	F
Texas frog-fruit	Phyla incisa	K
Pokeweed	Phytolacca americana	F
Knot weed (smart weed)	Polygonum sp.	K
Juniperleaf	Polypremum procumbens	K

Table D2. *(continued)*

Common Name	*Latin Name*	*Source*
Mountain mint	Pycnanthemum tenuifolium	K
Dandelion	Pyrrhopappus sp.	K
Mexican hat	Ratibidia columnaris	F
Meadowbeauty	Rhexia mariana	K
Coneflower	Rudbeckia nitida	K
Black-eyed-Susan	Rudbeckia hirta	K, F
No common name	Ruellia humilis	K
Meadow-pink	Sabatia campestris	K, F
Arrowhead	Sagittaria sp.	K
Sensitive-briar	Schrankia uncinata	K, R
Axocatzin	Sida rhombifolia	K
Rosin-weed	Silphium sp.	K
Blue-eyed grass	Sisyrinchium sp.	F
Hoary pea	Tephrosia onobrychoides	K
Thelesperma	Thelesperma sp.	F
Spiderwort	Tradescantia	F
Venus' looking glass	Triodanis perfoliata	F
Cattail	Typha latifolia	F
Verbena	Verbena halei	K
Broomweed	Xanthocephalum dranunculoides	K
	5. Grasses	
Big bluestem	Andropogon gerardii	K
Broomsedge	_____ virginicus	K
Threeawn	Aristida sp.	K
Common carpetgrass	Axonopus affinis	K
Silver bluestem	Bothriochloa saccharoides	K
Sideoats grama	Bouteloua curtipendula	A
Red grama	_____ trifida	A
Fringed signalgrass	Brachiaria ciliatissima	K
Sand bur	Cenchrus incertus	K
Hooded windmillgrass	Chloris cucullata	A
Carolina jointtail	Coelorachis cylindrica	K
Common Bermuda[1]	Cynodon dactylon	K
No common name	Dichanthelium oligosanthes	K
Crabgrass	Digitaria sp.	K
Saltgrass	Distichlis spicata	A
No common name	Echinocloa sp.	K
Canada wildrye	Elymus canadensis	A
Balsam scale	Elyonurus tripsacoides	K
Lovegrass	Eragrostis sp.	K
Rice cutgrass	Leersia oryzoides	K
Witchgrass	Leptoloma cognatum	K
Bush muhly	Muhlenbergia porteri	A
Muhly	Muhlenbergia sp.	K
Blue panicum[1]	Panicum antidotale	K
Fall panicum	_____ dichotomiflorum	K
No common name	_____ hallii	K
Gaping panicum	Panicum hians	K
Switchgrass	_____ virgatum	K
Dallis grass[1]	Paspalum dilatatum	K

Table D2. *(continued)*

Common Name	*Latin Name*	*Source*
Florida paspalum	_____ floridanum	K
Brownseed paspalum	_____ plicatulum	K
Vasey grass[1]	_____ urvillei	K
Tumblegrass	Schedonnardus paniculatus	K
Little bluestem	Schizachyrium scoparium	K
Bristlegrass	Setaria geniculata	K
Indiangrass	Sorghastrum nutans	K
Dropseed	Sporobolus asper	K
Smutgrass[1]	_____ indicus	K
White tridens	Tridens albescens	A
Longspike tridens	_____ strictus	K
Texas tridens	_____ texanus	A
Planted Grasses:		
Oat	Avena fatua	
Ryegrass	Lolium perenne	
Rice	Oryza sativa	
Sorghum (Haygrazer variety)	Sorghum bicolor	

[1]Introduced species

[2]Source: Field identification except where noted

Sources:

F - Field collection and identification.

A - Leroy Hajdik, Colorado County Agricultural Agent, pers. comm.

K - Kessler (1978).

Identification aided by: Correll and Johnston (1970); Wills and Howard (1975); and David Riskind, TPWD, pers. comm.

Nomenclature:

Trees, shrubs and vines: Vines (1960)

Forbs: Kessler (1978) and Gould (1962)

Grasses: Gould (1975)

Table D 3. Percentage botanical composition of major (over 3%) grass species on fallow rice fields and prairies, Summer 1975.

	Fallow Rice		Prairie			
			Grazed*		Ungrazed	
	1st Year	2nd Year	Sandy	Coarse	Sandy	Coarse
<u>Grasses</u>						
Andropogon gerardii				3.2		
Andropogon virginicus				9.1		6.0
Aristida sp.				4.3		
Axenopus affinis			12.5	26.8	3.7	6.0
Cenchrus incertus				7.4		
Coelorachis cylindrica						7.5
Cynodon dactylon	10.8	17.1				
Dicanthelium olgosanthes	10.8	14.7	4.4	5.3		
Digitaria sp.	15.3	9.8				
Echinochloa sp.	26.1	12.3				
Elyonurus tripsacoides					4.9	
Leersia oryzoides		14.7				
Panicum dichotomiflorum	30.4	9.8		3.2		
Panicum hians		14.7	10.4		16.6	8.3
Paspalum flordidanum				4.8		
Paspalum plicatulum			46.4	22.5	43.6	36.1
Schizachyrium scoparium			17.1	5.4	12.3	12.8
Others	6.6	6.9	9.2	8	18.9	23.3
Total	100	100	100	100	100	100

*Source Kessler 1978

Table D 4. Percentage botanical composition of major (over 3%) forb species on fallow rice fields and prairies, Summer 1975.

	Fallow Rice		Prairie			
			Grazed		Ungrazed	
	1st Year	2nd Year	Sandy	Coarse	Sandy	Coarse
<u>Forbes</u>						
Ambrosia psilostachya	54.5	5.2	4.5		14.6	
Boltonia diffusa					13.6	
Croptilon divaricatum				5.1		48.8
Croton capitatus				5.7		
Diodia teres				4.1		
Erigeron sp.				36.1		9.7
Eupatorium compositifolium				4.5		
Eupatorium cuneilaris			4.5			
Evolvulus alsinoides					5.0	
Froelichia floridana				3.5		
Gerardia purpurea	14.2					
Gnaphalium purpureum	7.2					
Heterotheca subaxillaris				22.7		24.2
Iva angustifolia		88.7	32.9		3.0	
Liatris mucronata			8.8		6.3	
Ludwigia linearis	4.3		3.7			
Lythrum lanceolatum					4.3	
Polygonum sp.					9.6	
Rudbeckia serotina	6.3					3.7
Xanthocephalum dranunculoides			16.8		3.0	
Other	13.5	6.1	28.8	18.3	40.6	13.6
Total	100	100	100	100	100	100

Source Kessler 1978.

Table E1. Birds of DeWitt County.

Common Name	*Scientific Name*	*Hunting Status*[1]
Great blue heron	Ardea herodias	
Green heron	Butorides striatus	
Snowy egret	Egretta thula	
Snow goose, blue goose	Chen caerulescens	Game bird, hunting regulated
Wood duck	Aix sponsa	Game bird, hunting regulated
Ring-necked duck	Aythya collaris	Game bird, hunting regulated
Turkey vulture	Cathartes aura	
Black vulture	Coragyps atratus	
Cooper's hawk	Accipiter cooperii	
Red-tailed hawk	Buteo jamaicensis	
Red-shouldered hawk	_____ lineatus	
Swainson's hawk	_____ swainsoni	
Marsh hawk	Circus cyaneus	
Caracara	Caracara cheriway	
American kestrel	Falco sparverius	
Attwater's prairie chicken	Tympanuchus cupido attwateri	
Common bobwhite	Colinus virginianus	Game bird, hunting regulated
Wild turkey	Meleagris gallopavo	Game bird, hunting regulated
American coot	Fulica americana	
Killdeer	Charadrius vociferus	
Plovers	Charadrius sp.; Pluvialis sp.	
Longbilled curlew	Numenius americanus	
Upland sandpiper	Bartramia longicauda	
Yellowlegs	Tringa sp.	
Spotted sandpiper	Actitis macularia	
Common snipe	Capella gallinago	
Rock dove, domestic pigeon[2]	Columba livia	
Mourning dove	Zenaida macroura	Game bird, hunting regulated
Ground dove	Columbina passerina	Game bird, hunting regulated
Yellow-billed cuckoo	Coccyzus americanus	
Roadrunner	Geococcyx californianus	
Screech owl	Otus asio	
Great horned owl	Bubo virginianus	
Burrowing owl	Athene cunicularia	
Barred owl	Strix varia	
Chuck-will's widow	Caprimulgus carolinensis	
Common nighthawk	Chordeiles minor	
Chimney swift	Chaetura pelagica	
Ruby-throated hummingbird	Archilochus colubris	
Belted kingfisher	Megaceryle alcyon	
Green kingfisher	Chloroceryle americana	
Common flicker	Colaptes auratus	
Red-bellied woodpecker	Centurus carolinus	
Golden-fronted woodpecker	Melanerpes aurifrons	
Red-headed woodpecker	_____ erythrocephalus	
Yellow-bellied sapsucker	Sphyrapicus varius	
Ladder-backed woodpecker	Picoides scalaris	
Eastern kingbird	Tyrannus tyrannus	
Scissor-tailed flycatcher	Muscivora forficata	
Great crested flycatcher	Myiarchus crinitus	
Eastern phoebe	Sayornis phoebe	
Horned lark	Eremophila alpestris	
Tree swallow	Iridoprocne bicolor	
Cliff swallow	Petrochelidon pyrrhonota	
Blue jay	Cyanocitta cristata	
Carolina chickadee	Parus carolinensis	
Tufted titmouse	_____ bicolor	
Bewick's wren	Thryomanes bewickii	
Carolina wren	Thryothorus ludovicianus	
Mockingbird	Mimus polyglottos	
Brown thrasher	Toxostoma rufum	
American robin	Turdus migratorius	
Hermit thrush	Catharus guttatus	

Table E1. (*continued*)

Common Name	*Scientific Name*	*Hunting Status*[1]
Eastern bluebird	Sialia sialis	
Blue-gray gnatcatcher	Polioptila caerulea	
Ruby-crowned kinglet	Regulus calendula	
Water pipit	Anthus spinoletta	
Loggerhead shrike	Lanius ludovicianus	
Starling[2]	Sturnus vulgaris	Not protected from hunting (nuisance species).
White-eyed vireo	Vireo griseus	
Tennessee warbler	Vermivora peregrina	
Yellow-rumped warbler	Dendroica coronata	
Common yellowthroat	Geothlypis trichas	
Yellow-breasted chat	Icteria virens	
House sparrow[2]	Passer domesticus	Not protected from hunting (nuisance species)
Western Meadowlark	Sturnella neglecta	
Red-winged blackbird	Agelaius phoeniceus	Not protected from hunting (nuisance species)
Brewer's blackbird	Euphagus cyanocephalus	
Great-tailed grackle	Quiscalus mexicanus	
Common grackle	Quiscalus quiscula	
Brown-headed cowbird	Molothrus ater	Not protected from hunting (nuisance species)
Summer tanager	Piranga rubra	
Cardinal	Cardinalis cardinalis	
Blue grosbeck	Guiraca caerulea	
Painted bunting	Passerina ciris	
Dickcissel	Spiza americana	
American goldfinch	Corduelis tristis	
Savannah sparrow	Passerculus sandwichensis	
Grasshopper sparrow	Ammodramus savannarum	
Vesper sparrow	Pooecetes gramineus	
Lark sparrow	Chondestes grammacus	
Cassin's sparrow	Aimophila cassinii	
Chipping sparrow	Spizella passerina	
Field sparrow	___ pusilla	
White-crowned sparrow	Zonotrichia leucophrys	
Lincoln's sparrow	Melospiza lincolnii	

[1]*Hunting status:* Birds are protected from hunting except as noted on the table.
[2]Introduced species
Source: Texas System of Natural Laboratories, Inc., except for wild turkey, plovers, and yellowlegs, which were indicated by T. Hergots, Game Warden of DeWitt County.

Table E2. Birds of Colorado County.

Common Name	Scientific Name	Source[1] TSNL	F & W	Hunting[2] Status
Least grebe	Podiceps dominicus	x		
Eared grebe	____ nigricollis	x	r	
Pied-billed grebe	Podilymbus podiceps	x	x	
American white pelican	Pelecanus erythrorhynchos	x		
Double crested cormorant	Phalacrocorax auritus	x	r	
Olivaceous cormorant	____ olivaceous	x		
American anhinga	Anhinga anhinga	x	r	
Great blue heron	Ardea herodias	x	x	
Green heron	Butorides striatus	x	x	
Little blue heron	Florida caerulea	x	x	
Cattle egret	Bubulcus ibis	x	x	
Reddish egret	Dichromanassa rufescens	x		
Great egret	Casmerodius albus	x	x	
Snowy egret	Egretta thula	x	x	
Louisiana heron	Hydranassa tricolor	x	x	
Black-crowned night heron	Nycticorax nycticorax	x	x	
Yellow-crowned night heron	Nyctanassa violacea	x	x	
Least bittern	Ixobrychus exilis	x		
American bittern	Botaurus lentiginosus	x	x	
Wood stork, wood ibis	Mycteria americana	x	x	
White-faced ibis	Plegadis chihi	x	x	
White ibis	Eudocimus albus	x		
Roseate spoonbill	Ajaia ajaja	x	x	
Whistling swan	Olor colombianus	x		
Canada goose	Branta canadensis	x	x	H
Greater white-fronted goose	Anser albifrons	x	x	H
Snow goose, blue goose	Chen caerulescens	x	x	H
Ross' goose	____ rossii	x		H
Black-bellied whistling duck	Dendrocygna autumnalis	x		NA
Fulvous whistling duck	____ bicolor	x	x	NA
Mallard	Anas platyrhynchos	x	x	H
American black duck	____ rubripes	x		H
Mottled duck	____ fulvigula	x	x	H
Gadwall	____ strepera	x	x	H
Common pintail	____ acuta	x	x	L
American greenwinged teal	____ carolinensis	x	x	H
Bluewinged teal	____ discors	x	x	H
Cinnamon teal	____ cyanoptera	x	r	H
American wigeon	____ americana	x	x	H
Northern shoveler	____ clypeata	x	x	H
Wood duck	Aix sponsa	x	x	H
Redhead	Aythya americana		r	L
Ring-necked duck	____ collaris	x	x	H
Canvasback	____ valisineria	x	r	L
Greater scaup	____ marila	x	x	H
Common goldeneye	Bucephala clangula	x		L
Bufflehead	____ albeola	x		L
Ruddy duck	Oxyura jamaicensis	x		L
Turkey vulture	Cathartes aura	x	x	
Black vulture	Coragyps atratus	x	x	
White-tailed kite	Elanus leucurus		r	
Mississippi kite	Ictinia mississippiensis	x	x	
Sharp-shinned hawk	Accipiter striatus		x	
Cooper's hawk	____ cooperii		x	
Red-tailed hawk	Buteo jamaicensis	x	x	
Red-shouldered hawk	____ lineatus	x	x	
Broadwinged hawk	____ platypterus		x	
Swainson's hawk	____ swainsoni	x	x	
White-tailed hawk	____ albicaudatus	x	x	
Rough-legged hawk	____ lagopus	x	r	
Ferruginous hawk	____ regalis	x	x	
Baldeagle	Haliaeetus leucocephalus	x	x	

Table E2. *(continued)*

Common Name	*Scientific Name*	*Source*[1] *TSNL*	*F & W*	*Hunting*[2] *Status*
Marsh hawk	Circus cyaneus	x	x	
Osprey	Pandion haliaetus	x		
Caracara	Caracara cheriway	x	x	
Prairie falcon	Falco mexicanus	x	r	
Peregrine falcon	_____ peregrinus	x		
Merlin	_____ columbarius	x		
American kestrel	_____ sparverius	x	x	
Attwater's prairie chicken	Tympanuchus cupido attwateri	x	x	
Common bobwhite	Colinus virginianus	x	x	H
Ring-necked pheasant[3]	Phasianus colchicus		x	H
Wild turkey	Meleagris gallopavo	x		H
Sandhill crane	Grus canadensis	x	x	
King rail	Rallus elegans	x	x	
Sora	Porzana carolina	x	x	
Black rail	Laterallus jamaicensis	x		
Purple gallinule	Porphyrula martinica		x	
Common gallinule	Gallinula chloropus	x	x	
American coot	Fulica americana	x	x	
Semipalmated plover	Charadrius semipalmatus		x	
Wilson's plover	_____ wilsonia		x	
Killdeer	_____ vociferus	x	x	
Mountain plover	_____ montanus		r	
American golden plover	Pluvialis dominica	x	x	
Black-bellied plover	_____ squatarola		x	
Ruddy turnstone	Arenaria interpres		x	
Hudsonian godwit	Limosa haemastica		x	
Longbilled curlew	Numenius americanus	x	x	
Upland sandpiper	Bartramia longicauda	x	x	
Greater yellowlegs	Tringa melanoleuca	x	x	
Lesser yellowlegs	_____ flavipes	x	x	
Solitary sandpiper	_____ solitaria	x	x	
Spotted sandpiper	Actitis macularia	x	x	
Common snipe	Capella gallinago	x	x	
Short billed dowitcher	Limnodromus griseus		x	
Long billed dowitcher	_____ scolopaceus	x	x	
Semipalmated sandpiper	Calidris pusilla		x	
Least sandpiper	_____ minutilla		x	
White-rumped sandpiper	_____ fusciollis		x	
Baird's sandpiper	_____ bairdii	x	x	
Pectoral sandpiper	_____ melanotos	x	x	
Dunlin	_____ alpina		x	
Stilt sandpiper	Micropalama himantopus		x	
Buff-breasted sandpiper	Tryngites subruficollis		x	
Black-necked stilt	Himantopus mexicanus	x	x	
American avocet	Recurvirostra americana		x	
Wilson's phalarope	Steganopus tricolor		x	
Laughing gull	Larus atricilla	x		
Franklin's gull	_____ pipixcan		r	
Forster's tern	Sterna forsteri		r	
Least tern	_____ albifrons	x		
Black tern	Chlidonias niger	x		
Rock dove; domestic pigeon[3]	Columba livia	x	x	
White-winged dove	Zenaida asiatica		r	H
Mourning dove	_____ macroura	x	x	H
Ground dove	Columbina passerina	x		H
Inca dove	Scardafella inca		r	H
Yellow-billed cuckoo	Coccyzus americanus	x	x	
Roadrunner	Geococcyx californianus	x	x	
Barn owl	Tyto alba	x	x	
Screech owl	Otus asio	x		
Great horned owl	Bubo virginianus	x	x	

Table E2. (*continued*)

Common Name	Scientific Name	Source[1] TSNL	F & W	Hunting[2] Status
Burrowing owl	Athene cunicularia	x		
Barred owl	Strix varia	x	x	
Short-eared owl	Asio flammeus	x	x	
Chuck-will's widow	Caprimulgus carolinensis	x	x	
Whip-poor-will	____ vociferous		x	
Common nighthawk	Chordeiles minor	x	x	
Chimney swift	Chaetura pelagica	x	x	
Ruby-throated hummingbird	Archilochus colubris		x	
Belted kingfisher	Megaceryle alcyon	x		x
Common flicker	Colaptes auratus	x		x
Pileated woodpecker	Dryocopus pileatus	x		
Red-bellied woodpecker	Centurus carolinus	x		x
Red-headed woodpecker	Melanerpes erythrocephalus	x		
Yellow-bellied sapsucker	Sphyrapicus varius			x
Hairy woodpecker	Picoides villosus	x		x
Downy woodpecker	____ pubescens	x		x
Eastern kingbird	Tyrannus tyrannus	x		x
Scissor-tailed flycatcher	Muscivora forficata	x		x
Great crested flycatcher	Myiarchus crinitus	x		x
Eastern phoebe	Sayornis phoebe	x		x
Acadian flycatcher	Empidonax virescens	x		
Willow flycatcher	____ traillii	x		
Yellow-bellied flycatcher	____ flaviventris	x		x
Eastern wood pewee	Contopus virens	x		x
Olive-sided flycatcher	Nuttallornis borealis	x		
Horned lark	Eremophila alpestris	x		x
Tree swallow	Iridoprocne bicolor	x		x
Bank swallow	Riparia riparia	x		x
Rough-winged swallow	Stelgidopteryx ruficollis	x		x
Barn swallow	Hirundo rustica			x
Cliff swallow	Petrochelidon pyrrhonota	x		x
Purple martin	Progne subis	x		x
Blue jay	Cyanocitta cristata	x		x
Common crow	Corvus brachyrhynchos	x		x
Carolina chickadee	Parus carolinensis	x		x
Tufted titmouse	____ bicolor	x		x
Brown creeper	Certhia familiaris			x
House wren	Troglodytes aedon	x		x
Winter wren	____ troglodytes			x
Bewick's wren	Thryomanes bewickii	x		x
Carolina wren	Thryothorus ludovicianus	x		x
Long-billed marsh wren	Cistothorus palustris	x		x
Short-billed marsh wren	____ platensis			x
Mockingbird	Mimus polyglottos	x		x
Gray catbird	Dumetella carolinensis	x		x
Brown thrasher	Toxostoma refum	x		x
American robin	Turdus migratorius	x		x
Hermit thrush	Catharus guttatus			x
Swainson's thrush	____ ustulatus			x
Veery	____ fuscescens			x
Eastern bluebird	Sialia sialis	x		
Blue-gray gnatcatcher	Polioptila caerulea	x		x
Golden-crowned kinglet	Regulus satrapa	x		x
Ruby-crowned kinglet	____ calendula	x		x
Water pipit	Anthus spinoletta	x		x
Sprague's pipit	____ spragueii			x
Cedar waxwing	Bombycilla cedrorum	x		x
Loggerhead shrike	Lanius ludovicianus	x		x
Starling[3]	Sturnus vulgaris	x		x
White-eyed vireo	Vireo griseus	x		x
Yellow-throated vireo	____ flavifrons			x

Table E2. (*continued*)

Common Name	*Scientific Name*	*Source*[1] *TSNL*	*F & W*	*Hunting*[2] *Status*
Solitary vireo	____ solitarius		x	
Red-eyed vireo	____ olivaceus	x		
Philadelphia vireo	____ philadelphicus		x	
Warbling vireo	____ gilvus	x		
Black-and-white warbler	Mniotilta varia	x	x	
Tennessee warbler	Vermivora peregrina	x	x	
Orange-crowned warbler	____ celata	x	x	
Nashville warbler	____ ruficapilla		x	
Northern parula	Parula americana		x	
Yellow warbler	Dendroica petechia	x	x	
Magnolia warbler	____ magnolia		x	
Yellow-rumped warbler	____ coronata	x	x	
Black-throated green warbler	____ virens		x	
Blackburnian warbler	____ fusca		x	
Yellow-throated warbler	____ dominica	x		
Chestnut-sided warbler	____ pensylvanica		x	
Bay-breasted warbler	____ castanea		x	
Palm warbler	____ palmarum		x	
Ovenbird	Seiurus aurocapillus		x	
Northern waterthrush	____ noveboracensis		x	
Kentucky warbler	Oporornis formosus		x	
Mourning warbler	____ philadelphia		x	
Common yellowthroat	Geothlypis trichas	x	x	
Yellow-breasted chat	Icteria virens	x	x	
Hooded warbler	Wilsonia citrina		x	
Wilson's warbler	____ pusilla	x		
Canada warbler	____ canadensis	x	x	
American redstart	Setophaga ruticilla		x	
House sparrow[3]	Passer domesticus	x	x	NP
Bobolink	Dolichonyx oryzivorus	x		
Eastern meadowlark	Sturnella magna	x	x	
Western meadowlark	____ neglecta	x	r	
Yellow-headed blackbird	Xanthocephalus xanthocephalus		x	
Red-winged blackbird	Agelaius phoeniceus	x	x	NP
Orchard oriole	Icterus spurius	x	x	
Northern oride	____ galbula	x	r	
Brewer's blackbird	Euphagus cyanocephalus	x	x	
Great-tailed grackle	Quiscalus mexicanus	x	x	
Boat-tailed grackle	____ major	x		
Common grackle	____ quiscula	x	x	
Brown-headed cowbird	Molothrus ater	x	x	NP
Summer tanager	Piranga rubra	x		
Cardinal	Cardinalis cardinalis	x	x	
Rose-breasted grosbeak	Pheucticus ludovicianus	x	x	
Blue grosbeak	Guiraca caerulea	x		
Indigo bunting	Passerina cyanea	x	x	
Painted bunting	____ ciris	x	x	
Dickcissel	Spiza americana	x	x	
Purple finch	Carpodacus purpureus		x	
Pine siskin	Carduelis pinus	x		
American goldfinch	____ tristis	x	x	
Rufous-sided towhee	Pipilo erythrophthalmus	x	x	
Lark bunting	Calamospiza melanocorys		r	
Savannah sparrow	Passerculus sandwichensis	x	x	
Henslow's sparrow	Passerherbulus henslowii		r	
Le Conte's sparrow	____ coudacutus		x	
Vesper sparrow	Pooecetes gramineus	x	x	
Lark sparrow	Chondestes grammacus	x	x	
Dark-eyed junco	Junco hyemalis	x	x	
Chipping sparrow	Spizella passerina		x	
Field sparrow	____ pusilla	x	x	
Harris' sparrow	Zonotrichia querula	x	x	

Table E2. (*continued*)

Common Name	*Scientific Name*	*Source*[1] *TSNL*	*F & W*	*Hunting*[2] *Status*
White-crowned sparrow	_____ leucophrys	x		x
White-throated sparrow	_____ albicollis	x		x
Fox sparrow	Passerella iliaca			x
Lincoln's sparrow	Melospiza lincolnii	x		x
Swamp sparrow	_____ georgiana			x
Song sparrow	_____ melodia	x		x

[1]*Sources*: Texas System of Natural Laboratories, Inc.
U. S. Fish & Wildlife Service, Checklist of the Birds of Attwater Prairie Chicken Refuge (Note: r = rare visitor)

[2]*Hunting Status*: Birds are protected from hunting except as noted on the table: H = Game bird, hunting regulated; L = Game bird, hunting severely limited; NA = Game bird, hunting not allowed; NP = Not protected from hunting (nuisance species).

[3]Introduced species

Table E3. Mammals of DeWitt County

Opossum	Didelphis virginiana
Eastern mole	Scalopus aquaticus
Least shrew	Cryptotis parva
Georgia bat	Pipistrellus subflavus
Guano bat	Tadarida mexicana
Raccoon	Procyon lotor
Long-tailed weasel	Mustela frenata
Mink	—— vison
Eastern spotted skunk	Spilogale putorius
Striped skunk	Mephitis mephitis
Hog-nosed skunk	Conepatus mesoleucus
Grey fox	Urocyon cinereoargenteus
Cougar	Felis concolor
Coyote	Canis latrans
Ocelot	Felis pardalis
Bobcat	Lynx rufus
Mexican ground squirrel	Spermophilus mexicanus
Eastern grey squirrel	Sciurus carolinensis
Fox squirrel	—— niger
Plains pocket gopher	Geomys bursarius
Hispid pocket mouse	Perognathus hispidus
Ord kangaroo rat	Dipodomys ordii
Beaver	Castor canadensis
Fulvous harvest mouse	Reithrodontomys fulvescens
Deer mouse	Peromyscus maniculatus
White-footed mouse	—— leucopus
Hispid cotton rat	Sigmodon hispidus
Florida wood rat	Neotoma floridana
Grey wood rat	—— micropus
House mouse	Mus musculus
Roof rat	Rattus rattus
Norway rat	—— norvegicus
Nutria	Myocastor coypus
California jackrabbit	Lepus californicus
Eastern cottontail	Sylvilagus floridanus
Swamp rabbit	—— aquaticus
White-tailed deer	Odocoileus virginianus
Nine-banded armadillo	Dasypus novemcunctus

SOURCE: W. B. Davis, 1978, "The Mammals of Texas"

Table E4. Mammals of Colorado County

Opossum	Didelphis virginiana
Eastern mole	Scalopus aquaticus
Least shrew	Cryptotis parva
Georgia bat	Pipistrellus subflavus
Raccoon	Procyon lotor
Ringtail	Bassariscus astutus
Mink	Mustela vison
Long-tailed weasel	—— frenata
River otter	Lutra canadensis
Eastern spotted skunk	Spitogale putorius
Striped skunk	Mephitis mephitis
Hog-nosed skunk	Conepatus mesoleucus
Red fox	Vulpes fulva
Grey fox	Urocyon cinereoargenteus
Coyote	Canis latrans
Red wolf	—— rufus
Cougar	Felis concolor
Bobcat	Lynx rufus
Thirteen-lined ground squirrel	Spermophilus tridecemlineatus
Eastern grey squirrel	Sciurus carolinensis
Fox squirrel	—— niger
Eastern flying squirrel	Glaucomys volans
Plains pocket gopher	Geomys bursarius
Hispid pocket mouse	Perognathus hispidus
Beaver	Castor canadensis
Fulvous harvest mouse	Reithrodontomys fulvescens
Pygmy mouse	Baiomys taylori
White-footed mouse	Peromyscus leucopus
Northern rice rat	Oryzomys palustris
Hispid cotton rat	Sigmodon hispidus
Florida wood rat	Neotoma floridana
House mouse	Mus musculus
Roof rat	Rattus rattus
Norway rat	—— norvegicus
Nutria	Myocastor coypus
Guano bat	Tadarida mexicana
California jackrabbit	Lepus californicus
Eastern cottontail	Sylvilagus floridanus
Swamp rabbit	—— aquiticus
White-tailed deer	Odocoileus virginianus
Nine-banded armadillo	Dasypus novemcinctus

SOURCE: W. B. Davis, 1978, "The Mammals of Texas"

Table E5. Reptiles of Colorado and DeWitt Counties.

Common Name	*Latin Name*	*County Colorado/DeWitt*
Common snapping turtle	Chelydra serpentina	C
Eastern mud turtle	Kinosternon subrubrum	C, D,
Pond slider	Chrysemys scripta	(C), D
Chicken turtle	Deirochelys reticularia	C
Eastern box turtle	Terrapene carolina	C
Western box turtle	_____ ornata	C, D
Texas tortoise	Gopherus berlandieri	C*, D*
Alligator	Alligator mississipiensis	C, D△
Texas horned lizard	Phrynosoma cornutum	C* D*
Texas spiney lizard	Sceloporus olivaceus	C, D
Eastern fence lizard	_____ undulatus	C
Five lined skink	Eumeces fasciatus	C, D
Prairie skink	_____ septentrionalis	C
Ground skunk	Lygosoma laterale	C
Texas spotted whiptail	Cnemid ophorus gularis	C, (D)
Racer	Coluber constrictor	C
Ringneck snake	Diadophis punctatus	C
Corn snake	Elaphe guttata	D
Common rat snake	_____ obsoleta	C
Mud snake	Farancia abacura	C
Western hognose snake	Heterodon nasicus	C
Eastern hognose snake	_____ platyrhinos	C
Prairie kingsnake	Lampropeltis calligaster	C
Louisiana milk snake	_____ triangulum amaura	C*
Mexican milk snake	_____ triangulum annulata	D*
Common king snake	_____ getulus	C
Coach whip	Masticophis fagellum	C
Green watersnake	Natrix cyclopion	C
Plain-bellied watersnake	_____ erythrogaster	C
Broad banded watersnake	_____ fasciata	C
Diamond-backed watersnake	_____ rhombifera	C
Rough green snake	Opheodrys aestivus	(C)
Brown snake	Storeria dekayi	(D)
Mexican black-headed snake	Tantilla atriceps	(D)
Black-headed snake	_____ nigriceps	D
Checkered garter snake	Thamnophis marcianus	C
Western ribbon snake	_____ proximus	C
Lined snake	Tropidoclonion lineatum	D
Rough earth snake	Virginia striatula	C
Coral snake	Micrurus fulvius	C, (D)
Copperhead	Agkistrodon contortrix	C
Cottonmouth	_____ piscivorus	C
Massasanga	Sistrurus catenatus	C
Western diamondback rattlesnake	Crotalus atrox	(D)
Timber rattlesnake	_____ horridus	C

Sources:
Raun and Gehlbach, 1972: "Amphibians and Reptiles in Texas."
C, D - specimens seen by the authors
(C), (D) - referenced in literature as occurring in that county
Texas Parks and Wildlife Department:
* - F. Potter, personal communication
△ - Nongame Wildlife Reports, Job no. 60: "American Alligator Study."

Table E6. Amphibians of Colorado and DeWitt Counties.

Common Name	*Latin Name*	*County Colorado/ DeWitt*
Lesser siren	Siren intermedia	C
Black-spotted newt	Notophthalmus meridionalis	C
Eastern spadefoot	Scaphiopus holbrooki	C, D
Cricket frog	Acris crepitans	C
Southern grey treefrog	Hyla chrysoscelis	D
Green treefrog	_____ cinerea	C, D
Squirrel treefrog	_____ squirella	C
Northern gray treefrog	_____versicolor	D
Strecker's chorus frog	Pseudacris streckeri	(C) D
Houston toad	Bufo houstonensis	(C)
Texas toad	_____ speciosus	(C), D
Gulf coast toad	_____ valliceps	C, D
Woodhouse's toad	_____ woodhousei	(C)
Bullfrog	Rana catesbeiana	D
Leopard frog	_____ pipiens	C, D
Eastern narrowmouthed toad	Gastrophryne carolinensis	C
Great plains narrowmouthed toad	_____ olivacea	C, D

Source: Raun and Gehlbach, 1972: "Amphibians and Reptiles in Texas"
C, D - specimens seen by the authors
(C) - referenced in literature as occurring in that county

NOTES ON PROTECTED NON-GAME SPECIES
OF DEWITT AND COLORADO COUNTIES[1]

Birds

Reddish egret (Dichromanassa rufescens rufescens)

Over 90 percent of all reddish egrets in the world are in Texas but a few occur in Florida, Louisiana, and Mexico. Formerly located on the lower coast, they are now breeding along the entire coast. Breeding areas are localized, thereby making them sensitive to environmental hazards, especially pesticides. These egrets were at their lowest in Texas in 1969 with 946 pairs recorded for the entire State. They have increased to the present level of 1,600 pairs. (Colorado and DeWitt Counties)

White-tailed hawk (Buteo albicaudatus hypospodius)

Ranges from coastal Texas south through South America to Patagonia. In Texas it is common in central coast and South Texas with occasional observations in north central Texas and Trans-Pecos. Quite numerous locally with heaviest breeding population in Refugio-Victoria Counties. Threatened by the clearing of scattered short trees in otherwise open grassland and the intensification of farming activities within its range. (Colorado and DeWitt Counties)

White-faced ibis (Plegadis chihi)

Ranges locally Pacific Coast, Utah, Nevada, and in coastal regions of Texas and southwest Louisiana and south to Argentina. Utilizes freshwater marshes and rice fields extensively. Population declined from a high of 9,000 pairs in 1969 to approximately 2,000 pairs in 1973. Increased to 6,000 pairs by 1976. Decline attributed to pesticides used in early rice field treatments; use of dieldin and aldin has declined since 1971. (Colorado and DeWitt Counties)

Swallow-tailed kite (Elanoides forficatus forficatus)

Ranges locally from Texas to Florida and South Carolina as well as extreme southern Mexico to northern Argentina. In Texas it ranges over the eastern half of the State with a few sightings in the Trans-Pecos. Extremely rare in the State since 1910. Most recent observations have been along the upper and central coasts and several counties inland from the central coast. Active nests and fledged young were reported near Houston for 1975 and 1976. Decline in the early 1900's was attributed to the decreased edge effect from the removal of wooded creeks and rivers that were in close association with sloughs and grassland. Habitat destruction and increased urbanization have also contributed to its decline. (Colorado and DeWitt Counties.)

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[1]Reprinted from Texas Parks and Wildlife Department. "Species Listing for Nongame Regulations," January, 1978.

Osprey (Pandion haliaetus carolinensis)

Range is cosmopolitan along sea coasts but breeds mainly in Northern Hemisphere and irregularly in Southern Hemisphere (chiefly Australia and associated islands). Northern populations winter in southern Africa, southern Asia, and South America. Breeding records from Concho, Jefferson, Cameron, Webb, and Hays Counties indicate a potential for the species to nest in Texas. In 1975 nests were reported at Amistad and Falcon Reservoirs. Appears to migrate through the State fairly rapidly. Few winter in Texas. The decline in overall population during the 1950's and 1960's is attributed to pesticide use. (Colorado and DeWitt Counties.)

Wood stork (Mycteria americana)

Ranges from Florida through Central America to Peru and Uruguay. Ranges widely over U.S. during postbreeding season. Three nesting records in Texas in Chambers County, Harris County, with the latest in 1960 in Jefferson County. Lumbering, drainage, fire, farming practices, housing developments, and pesticides have reduced the wooded swamps and wet prairies this species requires for nesting and foraging. (Colorado and DeWitt Counties.)

Least Tern (Sterna albifrons antillarum)

The coastal least tern ranges from Massachusetts south to Trinidad. In Texas it nests along the entire coast. Nesting birds require a relatively smooth surface such as sand or small shell, which must be created annually either by water action or spoil deposition. The Texas annual fish-eating bird survey reports a drop in the number of breeding pairs on the Texas coast from 6,000 in 1973 to 600 in 1976. Habitat loss does not appear to be the limiting factor. (Colorado County.)

Golden-cheeked warbler (Dendroica chrysoparia)

Ranges in summer in central Texas and winters in Guatemala, Honduras, and Nicaragua. A 1974 survey of the total breeding range of this species indicated warblers were present in 27 of the 30 "cedar" (juniper) counties of the Hill Country. The warbler has not decreased noticeably in distribution or density since the 1964 survey. The breeding population is estimated to be 15,000 warblers. Habitat requirements consist of "mature" ash juniper stands mixed with Spanish oak with an extensive forest edge. Central Texas is the only place this species breeds. The increased demand and price for cedar posts and cedar oil is expected to reduce cedar acreage in the immediate future. Urbanization will also contribute to its decline. (DeWitt County.)

Reptiles

Texas tortoise (Gopherus berlandieri)

South Texas and northeastern Mexico; Val Verde County to Lavaca County southward in Texas. This species occupies semiarid land habitats in South Texas; and although protected against commercial exploitation along with Texas horned lizards in 1967, has steadily declined in numbers but at a lesser rate than the previous 10 years.

Factors contributing to its current 10-year decline are increases in brush clearing, automobile traffic, urbanization, and pesticide usage. Continued protection against the impact of general scientific and/or commercial collecting is mandatory. (Colorado and DeWitt Counties).

Texas horned lizard (Phrynosoma cornutum)

Although this species is widespread (Kansas and northwestern Louisiana to southeastern Arizona and northern Mexico) including all Texas regions, its commercial exploitation to an extreme and extensive pesticide usage have extripated it from portions of the range where it was once common. The protection afforded it for the last 10 years under legislation still in force has tended to prevent further decimation of numbers and ranges but appparently the impact of the previous exploitation and pesticide usage were of such magnitude as to reduce many local population densities below recovery levels. Continued protection and additional management of this species to include such measures as restocking would seem to be indicated. (Colorado and DeWitt Counties.)

Texas indigo snake (Drymarchon corais erebennus)

South Texas to Veracruz and Hidalgo; Texas distribution is from Val Verde County to Bexar County southward into Mexico. The complete protection of the eastern indigo snake as "endangered" in Florida has placed additional commercially exploitive pressure upon the South Texas form. In addition to commercial uses in carnivals and zoos, this species is in demand by pet stores for sale to amateur snake hobbyists for $50 to $100 depending on size and condition of specimens. (DeWitt County)

Louisiana milk snake (Lampropeltis triangulum amaura)

Southwestern Arkansas and southeastern Oklahoma to the Gulf Coast covering almost all of Louisiana and the eastern third of Texas. Retail prices in 1975 of from $50 to $75 indicate a moderate demand for this brightly-colored mimic of the coral snake. It had been considered scarce even before the advent of massive lumbering and oil-producing activities involving clearing of much available habitat. Increased urbanization, agricultural land modification, and commercial exploitation have also had an adverse effect on the population numbers of this species. (Colorado)

Mexican milk snake (Lampropeltis triangulum annulata)

Central Texas southward through northeast Mexico; this formerly almost common (at least in South Texas) milk snake has been declining in numbers steadily for the last 20 years. Current retail prices range from $100 to $150 depending on size, coloration, and health of the specimen. Habitat loss as well as commercial exploitation have contributed to the declining population numbers of this and other South Texas species. It has historically been rare in the central Texas portion of its distribution. (DeWitt County.)

Amphibians

Black-spotted newt (Notophthalmus meridionalis meridionalis)

This form occurs along the Gulf Coast of South Texas and Tamaulipas. The population decline of this newt has been attributed to habitat destruction as well as pesticides. The high demand by collectors for aquaria creates additional problems. Adults tend to concentrate seasonally at historic breeding sites thus making them more vulnerable to collecting or pesticides accumulating in these pools from runoff. Further, the requirements for aquatic breeding site in an almost arid physiography tends to lower the reproductive capabilities of the species. (De Witt County).

Rio Grande siren (Siren intermedia texana)

Lower Rio Grande Valley including northern Tamaulipas. This eel-like two-legged, aquatic salamander, achieving a total length of a little more than two feet, is in jeopardy from a number of factors, mostly those induced by human activities. It is restricted to a freshwater habitat in a region where water is at a premium. Any habitat disturbance such as pesticide runoff, oil spills, or overutilization of fresh water could lessen water quality to the point of placing the subspecies in jeopardy. Disturbance from overcollecting for whatever reason in the limited areas available to this salamander could likewise encroach to a serious extent upon the ability of this form to survive. (DeWitt County).

Fishes

River darter (Hadropterus shumardi)

Central southern Canada southeastward to Alabama, westward to North Dakota and southeastern Kansas and eastern Oklahoma to some Gulf coastal streams. The East Texas populations are very sparse; the only abundant population known in Texas is from the Guadalupe River in the vicinity of the proposed Cuero Reservoir. This species is adapted to flowing rivers and reservoir construction can only jeopardize it further. (DeWitt County.)

Blue sucker (Cycleptus elongatus)

Large streams and artificial impoundments from the Pearl and Mississippi Rivers to the Rio Grande. The problem with this species is that while it is found in large streams and reservoirs, reproductive adaptation to flowing large streams has caused its depletion to low numbers where found because of increased reservoir construction.

Appendix F[1]

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 F 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 F1 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 Railroad 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

[1]From White and others, 1978.

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 F1

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	State Archeological Landmarks 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)	Water Diversion and Storage Activities 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)	Rights of Way Over Public Lands 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 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]

Agency	Authority and Regulations
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 resource 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 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	<u>Interagency Cooperation - Endangered Species Act of 1973</u> 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

[1] General Land Office of Texas, 1976a

species, formal consultation must be initiated with a U. S. F. W. S. Regional Director. (Title 50, CFR, Chap. IV, Part 402).

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 F2 lists agencies with regulatory responsibilities for transportation of volatile liquids.

Table F2

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 Accomodation Policy** Prescribes and approves accomodation, location and methods for the installation, adjustment, relocation and maintenance of utilities (including pipelines) on highway rights-of-way and 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 TRCC. The permit is issued when the TRCC is satisfied that pipelines are laid, 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 051.02.070 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 TRCC. (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	<u>Structure Permit</u> 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 F3.

Table F3

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 1,000 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 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 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).

*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.

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 constituents 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 F4 lists permitting agencies involved in surface disposal. Based on the decision of who has jurisdiction over geothermal brine disposal, either a TDWR or a TRCC 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 possibility of surface disposal activities presenting a health hazard, the Texas Department of Health Resources should be consulted to avoid this situation.

Table F4

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)
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 is 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. 22.005 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 F5 summarizes the major state and federal agencies responsible for regulating the various activities described.

Table F5

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)
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)

Authority and Regulations

Application to Drill, Deepen or Plug Back

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 F6

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 F
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