DOE-EA-81-901

DOE/EA

ENVIRONMENTAL ASSESSMENT

Geothermal Energy Geopressure Subprogram

Gulf Coast Well Drilling and Testing Activity

(FRIO, WILCOX, AND TUSCALOOSA FORMATIONS, TEXAS AND LOUISIANA)

SEPTEMBER 1981

Prepared for:
U.S. DEPARTMENT OF ENERGY

DISCLAIMER

DOE/EA

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SUMMARY

The Department of Energy (DOE) has initiated a program to evaluate the feasibility of developing the geothermal-geopressured energy resources of the Louisiana-Texas Gulf Coast. As part of this effort, DOE is contracting for the drilling of design wells to define the nature and extent of the geopressure resource. At each of several sites, one deep well (4000-6400 m) will be drilled and flow tested. One or more shallow wells will also be drilled to dispose of geopressured brines. Each site will require about 2 ha (5 acres) of land. Construction and initial flow testing will take approximately one year. If initial flow testing is successful, a continuous one-year duration flow test will take place at a rate of up to 6400 m^3 (40,000 bbl) per day. Extensive tests will be conducted on the physical and chemical composition of the fluids, on their temperature and flow rate, on fluid disposal techniques, and on the reliability and performance of equipment. Each project will require a maximum of three years to complete drilling, testing, and site restoration.

Sites for the wells will be located within any of several prime prospect areas, or fairways, found in a broad band or overlay zone along the Texas and Louisiana coast. Approximately 160 km wide, the overlay zone includes counties and parishes which overlie the Frio geopressured formation in Texas and Louisiana, the Wilcox geopressured formations in Texas, and the deeper Tuscaloosa formation in Louisiana. Selection of specific sites for design wells will be chosen based on geologic, financial, land use, and environmental considerations.

Because each project within the program will involve a small area for a short time, environmental impacts are expected to be local and site-specific, rather than regional, in character. Provided site selection procedures, mitigation measures, and site restoration programs are properly carried out, no significant impacts are expected to occur on land use, air or water quality, socioeconomics, or terrestrial or aquatic ecology as a result of normal drilling and testing.

A well blowout involving discharge of hot geopressured brines on the surface is the principal environmental concern. Although numerous safeguards will be installed to reduce the risk of an accident and to minimize its effect, the great depth, pressure, and temperature of geopressured fluids increase the possibility of a blowout. Wetlands (particularly estuaries), forests, agricultural land, and surface waters could become contaminated by a blowout. Vegetation and, possibly, wildlife could be destroyed. Terrestrial habitats are more commonly associated with the Wilcox and Tuscaloosa test sites, whereas the more sensitive aquatic habitats are generally associated with the Frio test sites. Hence, ecological damage from a blowout is likely to be greater for sites in the Frio. Depending on the severity of a blowout, homes, businesses, and public facilities might require evacuation.

A number of mitigation measures will be instituted for each project. Well pads will be lined and surrounded by a ring dike and will include a mud pit for containment of minor spills and leaks. Pads will be surfaced with gravel, and ring dikes will be planted with a cover crop to minimize erosion. Drilling equipment will be muffled and positioned so as to minimize noise perceived at any nearby residences. Equipment to remove H_2S will be installed when necessary. All brines will be reinjected into a saltwater aquifer. Plank roads will be constructed across wetlands. Topsoil from construction areas will be kept available for use during site restoration when testing is completed. Monitoring before and during testing may include air and water quality, subsidence, seismicity, and ecosystem quality. Specific monitoring needs will be determined for each project based on site-specific considerations and on monitoring results from other projects in the program.

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1. INTRODUCTION

As part of its mandate to assist the development of alternate energy technologies, the Department of Energy (DOE) has initiated a research program on the geothermal-geopressured resource in Texas and Louisiana. The purpose of the research is to define the nature and extent of the resource in order to decide whether its use for energy production would be feasible. The Department of Energy is using two approaches to achieve these aims. One approach, called the Wells of Opportunity (WOO) Program, is to selectively reenter recently drilled abandoned oil or gas dry holes, to complete them into the geopressure zone, and to conduct a one- to two-year schedule of testing. The environmental consequences of this program have been considered by DOE (1978a). In another approach, DOE is contracting for the drilling and testing of new design wells to explore the geopressure resource. Both of these programs involve the flow testing of single wells in the geopressured zones and the disposal of the resulting brines in one or more shallower wells.

These activities are being conducted in two geographic areas: (1) the coastal counties and parishes of Texas and Louisiana, which overlie the Frio geopressured formation, and (2) the contiguous inland band of counties and parishes, which overlie the Wilcox geopressured formation in Texas and the deeper Tuscaloosa geopressured zone in Louisiana. Sites for design wells are located in any of several different prime prospect areas or fairways. Selection of specific sites will be based on geologic, financial, land use, and environmental considerations.

This Environmental Assessment (EA) evaluates the environmental consequences of drilling and testing design wells in the Frio, Wilcox, and Tuscaloosa formations. Potential impacts on land use, air and water quality, socioeconomics, and aquatic and terrestrial ecosystems are considered for normal drilling and testing and for possible accidents. Mitigation measures to be followed and the environmental concerns to be addressed in site-specific evaluations are identified.

The level of detail in the assessment is governed partly by the availability of environmental information, partly by existing assessments of the effects of geopressure research and development, and partly by the fact that specific sites for all design wells have not been identified. Less environmental information is available for the area overlying the Wilcox and Tuscaloosa formations than for the Frio overlay zone. The environment of the Frio region has been described and the impacts of well drilling and testing activities evaluated in existing EAs (DOE 1978a; ERDA 1977). Baseline environmental information has been published for several of the prime prospect areas (DOE 1981b; Gustavson et al. 1980; Newchurch et al. 1978; and White et al. 1978) and for several specific sites (DOE 1978b; 1979; 1980a, b; 1981a, b). The information in these documents in not repeated herein, but it is summarized and referenced in accordance with the Council on Environmental Quantity (CEQ) Regulations for implementation of the National Environmental Policy Act (CEQ 1978). Deficiencies in environmental information for specific well drilling and testing projects will be corrected by site-specific evaluations, which will be conducted for each project.

This EA does not address the impacts of full-scale development of the geopressured resource. Neither the likelihood of such a development occurring nor its precise nature and extent can be predicted until the current research program is completed. A generic discussion of some of the environmental consequences of full-scale development has been presented elsewhere (Gustavson et al. 1978).

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2. ALTERNATIVES, INCLUDING THE PREFERRED ACTION

2.1 THE PREFERRED ACTION

The preferred action is to drill, complete, and test geopressured wells located in Frio, Wilcox, and Tuscaloosa geopressured prospects (referred to as "fairways" in Texas) along the Texas and Louisiana Gulf Coast plain. The DOE and its subcontractors propose to operate one or more of these facilities for two to three years to evaluate the geopressure, geothermal, and methane-producing potential of the subsurface. Tests to be conducted include flow rates, injection rates, fluid composition, temperature, gas content, geologic characteristics, and land subsidence potential for subsequent production.

2.1.1 Location

Figure 2.1 is a location map of all geopressured stratigraphic units of the Texas-Louisiana Gulf Coast plain (Papadopulos et al. 1975). These units geographically overlap one another to some extent. For example, the geopressured Tuscaloosa underlies the Wilcox in Louisiana, and the underlying geopressured Vicksburg and overlying Anahuac units lie within the Frio trend. Although Jackson, Miocene, and other units are also geopressured, only the Frio, Wilcox, and Tuscaloosa trends are presently being evaluated by DOE.

The geothermal fairways (prime prospects) of Texas are areas in which thick, geopressured sandstone sections have subsurface temperatures in excess of 150°C (300°F) (Bebout et al. 1978). Although the general criteria are the same for geothermal prospects of Louisiana, they are not so rigorously defined. In general, the Frio prospects are located in wetlands near the coast, whereas the Wilcox and Tuscaloosa prospects are 100-160 km (60-100 miles) inland (Fig. 2.1). Inland prospects, however, do not necessarily imply the absnece of wetlands (especially in Louisiana).

Nine prime Frio prospect areas have been identified in an earlier EA — three in southwest Louisiana and six in Texas (DOE 1978a). In Louisiana they are in the Calcasieu [near the site of the DOE's proposed Lafourche Crossing No. 1 well site (DOE 1981b)], Acadia, and Cameron parishes [where the DOE's proposed Sweet Lake No. 1 and Gladys McCall well sites are located (DOE 1980; 1981a)]. Texas fairways include one in Brazoria and Galveston counties [where a DOE-sponsored geopressure project is already underway (DOE 1978b)]; two separate prospects in Matagorda County; one covering sections of Nueces, San Patricio, and Aransas counties; one in Kenedy county; and one each in Hidalgo and Cameron counties.

All eight identified prime Wilcox prospects are in Texas (Fig. 2.2) (Bebout et al. 1978; DOE 1980). The characteristics of these prospects are shown in Table 2.1. Fairways located in De Witt, Colorado, Liberty, and Harris counties have significantly larger areal extents and total sandstone thicknesses. Special emphasis is directed toward these four counties because of the relatively high probability that DOE-sponsored well test sites will be lcoated in them.

A single Tuscaloosa prime prospect area extends 140 km (90 miles) along a narrow belt from northwest of Opelousas to east of Baton Rouge, Louisiana (Wallace et al. 1978). In Fig. 2.2, this prospect would appear in the Wilcox trend because the geopressured Tuscaloosa formation lies beneath the Wilcox in Louisiana. While the Wilcox-Tuscaloosa trend extends into Beauregard and Allen parishes in Louisiana, no prime prospect areas have, as yet, been identified there.

2.1.2 Site preparation

Drill site preparation includes construction of the access roads, a storage area, and drill pads. Existing roads will be used whenever possible, but they may require upgrading to accommodate all-weather transport of supplies, heavy drilling, construction, and service equipment. Where new roads are required, an effort will be made to avoid unnecessary cut and fill operations. If a wetlands site is chosen, however, a diked roadbed will probably be required. A typical roadbed will be about 4.2 m (14 ft) wide and designed to carry heavy equipment year-round for the life of the project. A wetlands road would consist of fill dirt topped with rough-cut planks, oyster shells, or crushed stone. An area of approximately 1.5 ha (4 acres) will be cleared and diked (if necessary) to a height of approximately 1.5 m (5 ft) to provide space for

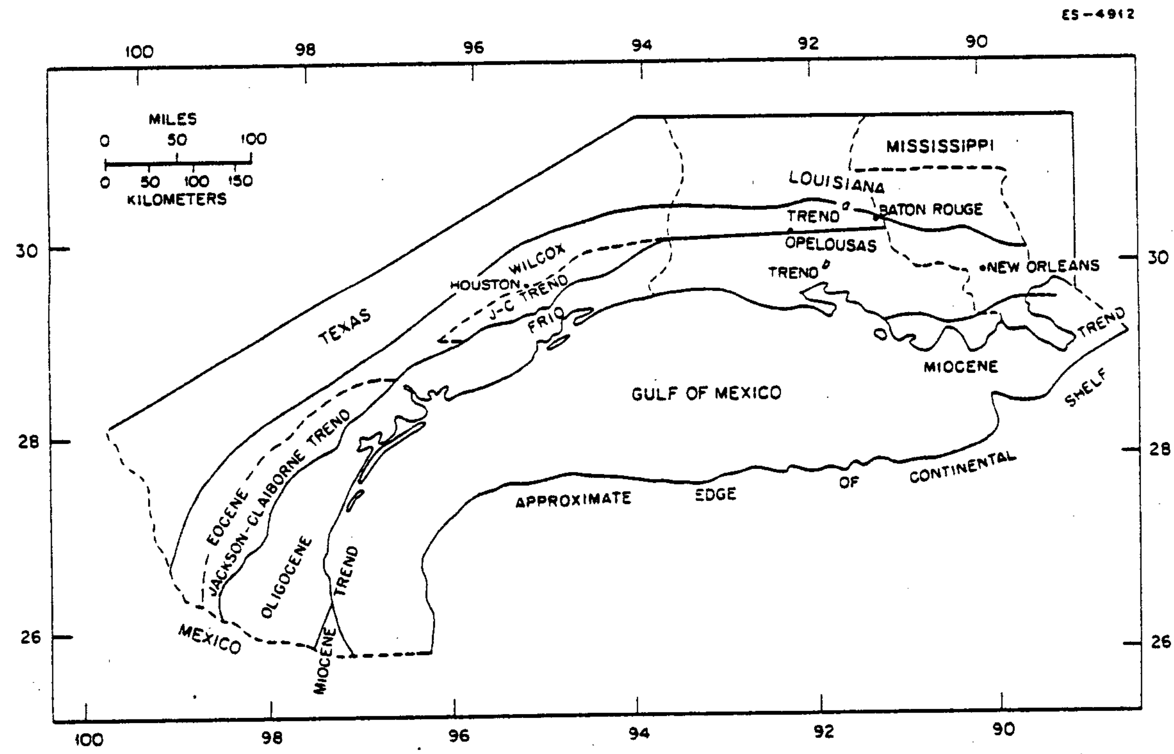

Fig. 2.1. Location map showing the extent of the assessed geopressured zones and their division into various Cenozoic stratigraphic trends (units partially superimposed as indicated by footnotes). (*a*) Wilcox is superimposed on the Cretaceous Tuscaloosa trend in Louisiana. (*b*) Frio includes the Vicksburg formation on the landward side in south Texas and the Anahuac formation adjacent to the coast in Texas and Louisiana. Source: S. S. Papadopulas, R. H. Wallace, Jr., J. B. Wesselman, and R. E. Taylor, "Assessment of Onshore Geopressured-Geothermal Resources in the Northern Gulf of Mexico Basin," *Geological Survey Circular 726*, 1975.

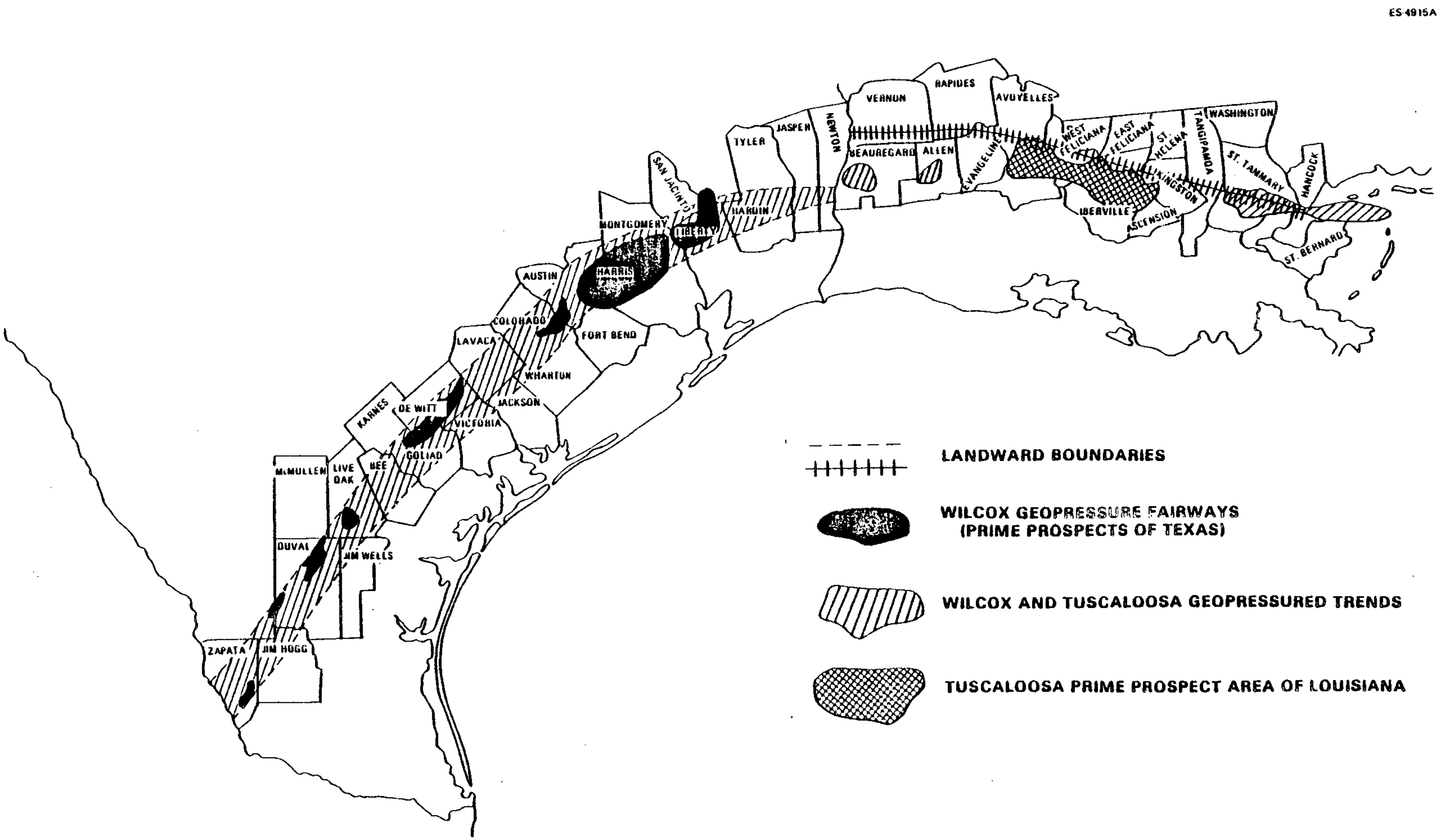

Fig. 2.2. Wilcox and Tuscaloosa prime prospect areas.

Table 2.1. Wilcox geothermal fairways

Name	Areal extent (km^2)	Cumulative sandstone thickness (m)	Depth to	
			150°C (m)	Top of geopressure
Zapata	120	100	3100	NA[a]
Webb	120	120	3300	2700
Duval	360	120	3400	2800–3100
Live Oak	190	70	3500	2900
De Witt	730	210	3200–6100	3100–3300
Colorado	520	260	3800	3500
Harris	3560	1100	3400–4100	3400–4100
Liberty	520	140	3800–4200	3700

[a]Not available.

Source: D. G. Bebout, V. J. Gavenda, and A. R. Gregory, *Geothermal Resources, Wilcox Group, Texas Gulf Coast*, Bureau of Economic Geology, The University of Texas at Austin, January 1978.

service equipment, sumps, material stockpiles, parking, and a turnaround for vehicles. Level drill pads will be about 30 m^2 for the production well and each injection well. All drill pads can probably be accommodated within the test site compound unless an unusual injection problem is encountered. Figure 2.3 is a schematic layout of the drilling operation for the DOE's proposed Gladys McCall well site. A reserve pit about 2 m deep (including freeboard) and a 0.5-ha area will be excavated to accommodate 9000 m^3 (60,000 bbl) of drilling fluid, storm runoff, and seepage (the latter depends on the wetlands). Drill pads will be sloped to drain toward the pit. Soil excavated from the pit will be used for road and dike construction and for grading the site.

Additional construction will follow drilling and well completion. Figure 2.4 is a schematic diagram of a typical well testing facility.

Installations common to all test sites include production and injection wellhead assemblies, flow lines, samplers, liquid-gas separators, metering equipment, production fluid holding tanks, an injection pump station, and laboratory and office facilities (DOE 1978b).

Equipment for handling methane will depend on whether it is to be flared or sold. Scrubbers (to extract sulfur) may be required prior to flaring methane. If methane is to be sold it will also have to be cooled, compressed, and dehydrated before delivery into commercial lines (DOE 1978b; 1979).

Depending on the nature of the production fluid and the reservoir sands to receive spent brine, additional actions or facilities may be required to provide adequate injection performance for maximum anticipated flow rates. The production fluid's temperature may be too high (requiring a cooling tower), its chemistry may be incompatible with formation water in the injection horizon, or it may contain sediment capable of clogging pore spaces in the walls of the injection well. Several options for improving injection performance are possible. Among these options are (1) perforating additional stratigraphic horizons in existing injection wells; (2) drilling new injection wells; and (3) adding preinjection treatment facilities such as scaling inhibitors, filters, or clarifiers (Knutson and Boardman 1978). Although preinjection treatment facilities could be quite elaborate, they may not be justified for flow testing a single well. Installation of a modest pretreatment facility in combination with a redesigned injection well field might be a more likely course of action whenever injection difficulties are encountered.

2.1.3 Drilling

Drilling and completing wells in geopressured formations in Texas and Louisiana are routine procedures. More than 400 wells are drilled annually in the United States to depths greater than 5000 m (15,000 ft), and about 50 of these wells exceed 6500 m (20,000 ft). The number of deep wells along the Texas-Louisiana Gulf Coast exceeds the number of all other deep wells in the United States. Highly sophisticated, specialized drilling equipment and technology have been developed for such deep drilling over the past 20 years. Also, special drilling muds, high strength casing strings, and cements have been developed particularly for drilling into geopressured zones. Drilling and performance histories of nearby deep wells are generally available as aids in the design of specific new wells and for anticipating potential problems. Routine well-logging procedures (geophysical and sample) are used for monitoring progress, for preliminary reservoir analysis, and for verifying the adequacy of completion. Details of these routine procedures are described in DOE, 1979.

2.1.4 Flow testing

Extended flow testing for up to two years is a unique action on the U.S. Gulf Coast. Although similar flow tests of geothermal wells have taken place elsewhere (e.g., Puna District, Hawaii, and Niland, California), the reservoir conditions were quite different.

Future DOE-sponsored flow testing is planned to be modeled after the Pleasant Bayou project. However, flow-test procedures are likely to change gradually through experience and in the future may be different from the description which follows.

A proposed schedule for the Pleasant Bayou test is shown in Table 2.2. Continuous flow tests will take place for each of four 1600-m^3/d (10,000 bbl/d) increments to a maximum of 6400 m^3/d (40,000 bbl/d) for a duration of 30-40 d each. A given increment will be reached by increasing the flow rate by 160 m^3/d (1000 bbl/d) each day while carefully monitoring for sand production. If sand production is detected, the test schedule would require modification (the extent depending on the severity of the problem). If sand production cannot be eliminated or controlled at higher flow-test rates, the project might be abandoned short of attaining its goal of 6400 m^3/d (40,000 bbl/d). If, however, the above test is successful, a long-term (one additional year), continuous flow test will take place at the maximum feasible production rate (DOE 1979).

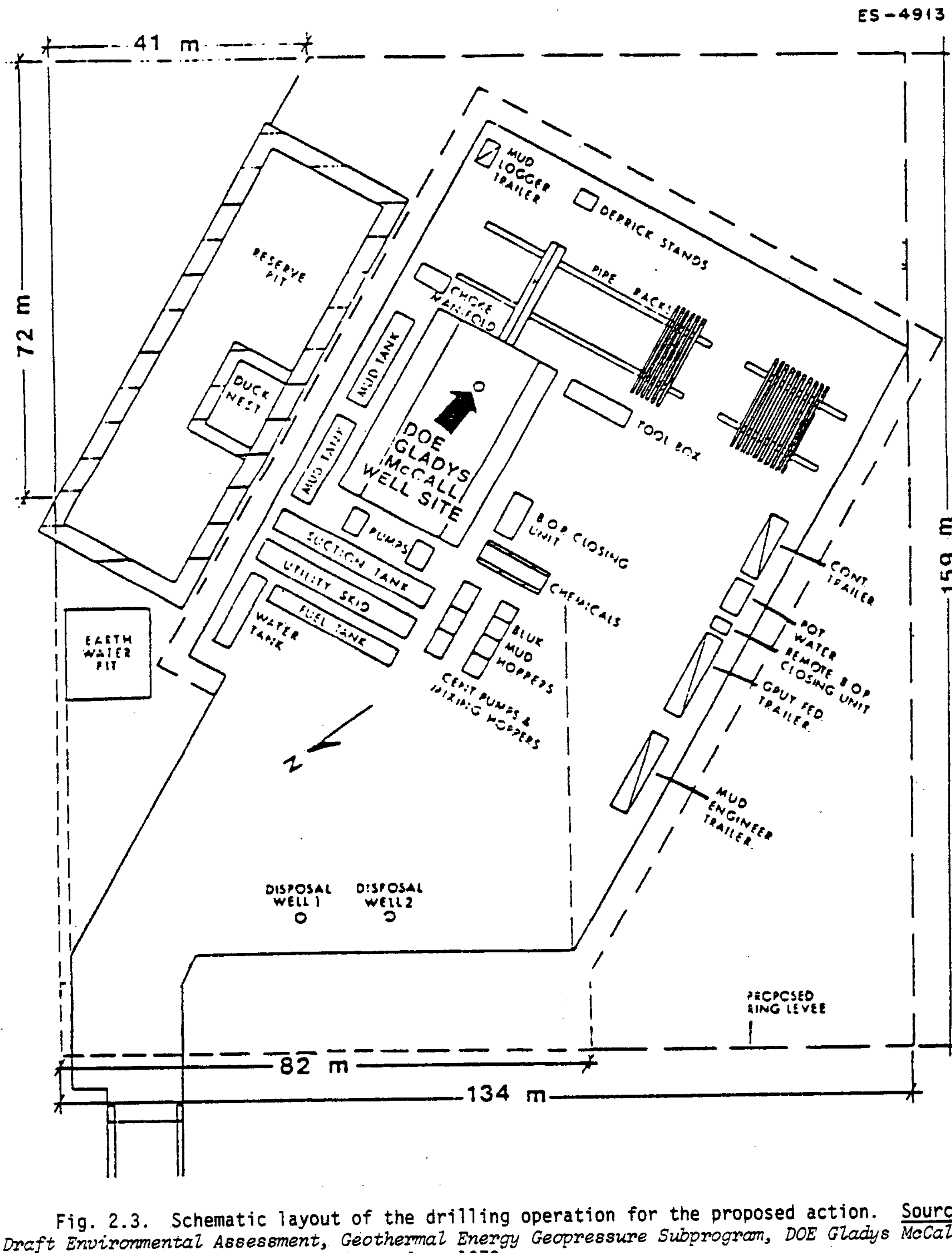

Fig. 2.3. Schematic layout of the drilling operation for the proposed action. Source: DOE, *Draft Environmental Assessment, Geothermal Energy Geopressure Subprogram, DOE Gladys McCall Well Site, Cameron Parish, Louisiana,* June 1979.

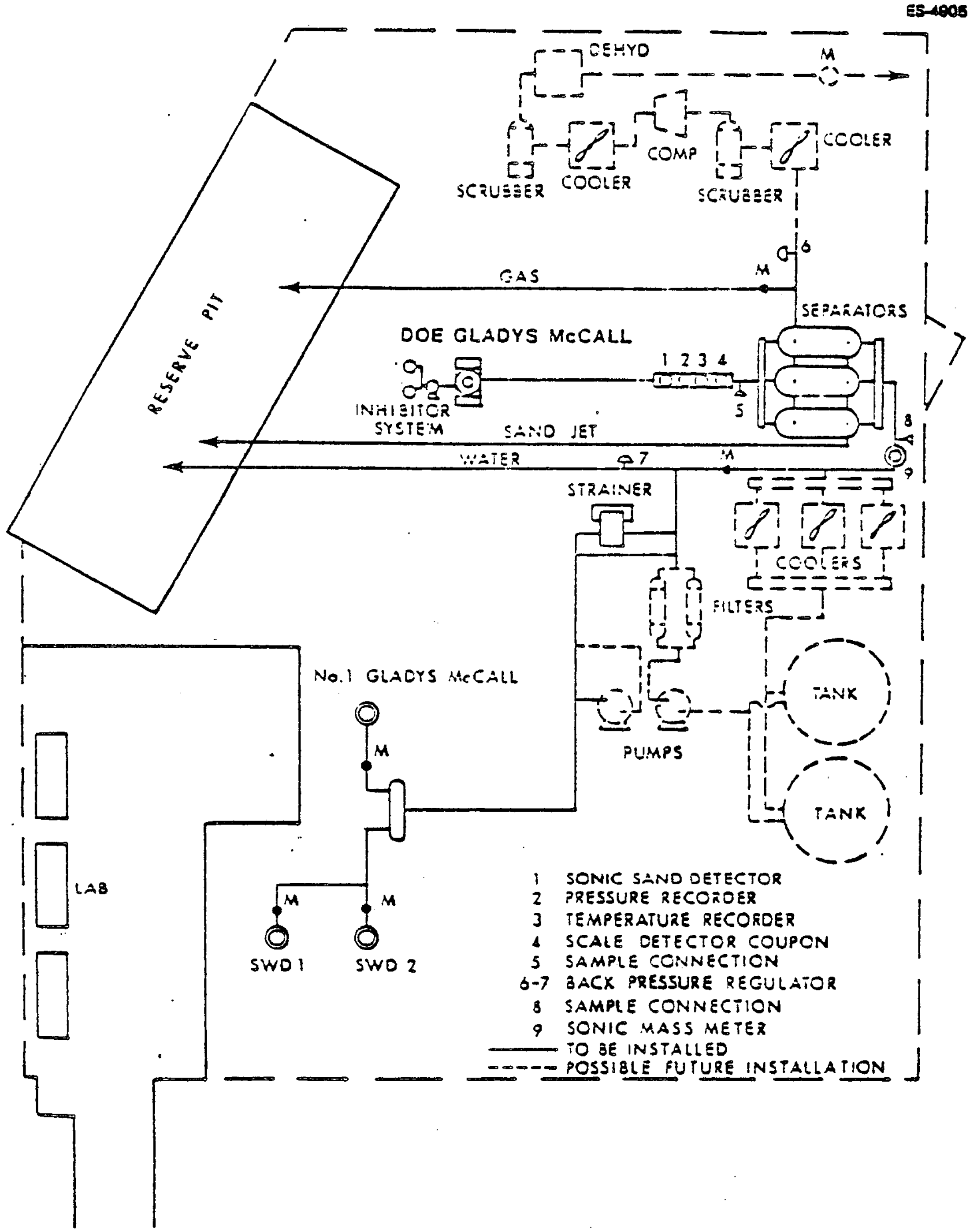

Fig. 2.4. Schematic layout of the well testing facilities of the proposed action. Source: DOE, *Draft Environmental Assessment Geothermal Energy Geopressure Subprogram, DOE Gladys McCall Well Site, Cameron Parish, Louisiana,* June 1979.

Table 2.2. Test schedule for GCO-DOE Pleasant Bayou No. 2

Test period	Test duration (d)	Cumulative test time at end of period (d)	Test rate (m^3/d)	Cumulative fluid production ($m^3 \times 10^3$)[a]
Initial static	3	3	0	0
Initial dynamic				
Phase 1a	63	69	0–1600	50
Phase 1b	40	116	1600	114
Phase 2a	28	134	1600–3200	180
Phase 2b	40	174	3200	308
Second static	3	177	0	308
Second dynamic				
Phase 1a	22	199	0–4800	373
Phase 1b	30	229	4800	516
Phase 2a	12	241	4800–6400	577
Phase 2b	30	271	6400	767
Final static	3	274[b]	0	767
Extended flow	365	639[b]	6400	3100

[a]Multiply by 6.29 to convert to barrels (maximum production rate and total cumulative production are 40,000 barrels and 19.4 million barrels respectively).

[b]Allowing 90 days for drilling and completion of the production well, the short-term and extended-flow tests would be completed one and two years, respectively, after the commencement of drilling.

Source: DOE, *Geopressured-Geothermal Drilling and Testing Plan, Pleasant Bayou No. 2 Well, Brazoria County, Texas*, NVO-194, Rev. No. 1, Nevada Operations Office, April 1979.

2.1.5 Site restoration

After flow testing is completed, the entire site area will be returned to its original condition, unless some other written agreement is made with the surface owner. Wells will be abandoned according to state regulations. All production and disposal equipment and facilities will be removed. Wastes which cannot be reinjected will be trucked to a landfill operated in compliance with applicable local, state, and federal regulations. After pits have been emptied, the liner will be removed. The limestone, board matting, and plastic shield of the pad area will be removed. Materials which cannot be reused will be disposed of in an approved landfill. The topsoil removed during construction will be replaced according to the original contours. Any waterways which were diverted will be routed to their original location, and suitable vegetation will be planted at the site.

2.1.6 Accidents

Although all reasonable precautions will be taken to prevent accidents, the possibility of their occurrence and their consequent environmental impacts must be considered. Ensuring that project site personnel are alert at all times is the best means of preventing all accidents. Possible accidents are small incidental spills, large spills, fires, casing failures, and blowouts.

Small incidental spills are likely to result from the transport of materials (e.g., gasoline, diesel fuel, drilling mud, and lubricants) or from minor leaks from equipment or vehicles. Such spills have few environmental consequences and can be mitigated easily. Small spills or leaks can be collected by a vacuum truck, although residual quantities of the spilled material may remain in the environment. Larger spills, which might result from surface equipment malfunction or failure, could be more damaging to the environment but, because of their size, can be identified readily by onsite personnel and mitigated quickly. Spills resulting from equipment malfunction or failure can be stopped by shutting off the appropriate equipment; the spilled material can then be collected by a vacuum truck and hauled to an approved landfill for disposal. Some residual materials may remain in the environment; however, all spills will be contained within the ring levee.

An accidental fire could result from careless handling of flammable materials or equipment malfunction. Fire extinguishers will be placed at several conspicuous locations on the project site and "no smoking" signs will be located no more than 30 m (100 ft) from the drilling rig and production facilities. The lack of buildings and dense vegetation around the project site greatly reduces the possibility of fire spreading beyond the site boundaries.

Although casing failure is unlikely to occur, it would be a more serious accident than a spill or fire because it would be more difficult to detect and mitigate. A casing failure could result from corrosion or from improperly setting the casing. The monitoring wells (Sect. 2.1.7) will be sampled periodically and should help detect leakage through failed casing if the failure occurs at shallow depths. Indicators at the wellhead may or may not identify this problem. Once a casing failure is detected, drilling or production must stop, and costly workover procedures must be undertaken. If the workover is not successful, the borehole may have to be plugged and the well abandoned. Casing failures may also result in the most serious accident — a blowout.

A blowout is the uncontrolled flow of subsurface fluids through the well into the environment. A variety of circumstances may cause a well blowout; two of the most common causes in the Gulf Coast are casing failures and gas kicks. Gas kicks occur during drilling when gas becomes trapped in the drilling fluids, expands, and, thus, reduces its weight. When the weight of the fluid is reduced to such an extent that it is unable to contain the pressure of the formation fluids, a blowout results. Although blowout prevention equipment (BOPE) is installed to prevent such situations, it sometimes does not work or is not used early enough.

The risk of a blowout occurring in a geopressured zone is greater than that for a normal oil and gas well because of the greater depths and the greater formation pressures involved. In the last two years there have been at least three major blowouts of commercial wells that were drilling in the geopressured zone in Louisiana. The first attempt by DOE to investigate geopressure resulted in a blowout. Estimates of the probability of a blowout based on incidence rates range between 2.4% (Rehms and Goins 1978) and 0.3% (Dow Chemical Company 1980) for all wells. Assuming that geopressured wells are twice as hazardous as the average (Rehms and Goins 1978), the probability of a blowout for a geopressured well is estimated to be between 4.8% and 0.6%. The higher estimate is an aggregation of minor blowout incidences in which minimal harm to equipment, personnel, or the environment resulted and of major blowout incidences in which significant harm resulted. The probability for minor blowouts in the geopressured zone is 4%; for major blowouts it is roughly 0.8% (Rehms and Goins 1978).

If a blowout occurs, the ring levee could probably contain about 6-d flow, assuming a maximum production of 3180 m^3/d (20,000 bbl/d). If the blowout continues after this period, the brine would top the levee and could be diverted to flow into the natural drainages. The blowout could abate on its own, or a relief well, which would take several weeks to drill, might be required. Once the blowout was killed, the brine that collected in the levee could either be pumped into vacuum trucks and suitably disposed of offsite or, if permits could be obtained, be drained into existing waterways. Degradation of the soil and the fresh groundwater caused by infiltration of the brine would be inevitable. Surface cratering around a well that has blown out can also occur.

A recent study for DOE has identified several measures that will minimize the risk of a blowout. These measures include compliance with U.S. Geological Survey rules (OCS Order No. 2 and GSS-OCST1) when applicable (Rehms and Goins 1978). These rules set the highest standards for the operation, the equipment, and the training of personnel for geopressured drilling.

2.1.7 Environmental monitoring program

An environmental monitoring program will be implemented as part of each project (Appendix A). The purposes of the monitoring program are to determine what impacts will result from the project and the level of their significance. The information obtained by monitoring will be used to identify mitigation measures and corrective actions to be implemented to minimize negative impacts of the project. If significant negative impacts cannot be mitigated, DOE will have to evaluate continuation of the project.

2.2 DELAYED ACTION ALTERNATIVE

Flow testing wells at several prime sites along the Texas-Louisiana Gulf Coast are designed to yield important information on fluid and flow properties of geopressured energy resources. Delayed action will postpone or stop the accumulation of data required for an informed appraisal of the technical, economic, and environmental acceptability of these energy resources. The environmental impacts of the Delayed Action Alternative would be the same as those anticipated for the Preferred Action, but they will occur at a later date. However, the cost of the project is likely to increase if the Delayed Action Alternative is implemented. There are currently no unresolved environmental issues which could be mitigated or otherwise resolved prior to the initiation of the project if the Delayed Action Alternative is implemented.

2.3 NO ACTION ALTERNATIVE

The No Action Alternative is not consistent with Congressional mandate as prescribed in the Geothermal Energy Research, Development, and Demonstration Act of 1974. This act directs the federal government to encourage and assist private industry in the development and demonstration of practicable means of producing energy from geothermal resources in an environmentally acceptable manner. This assistance is to include resource assessment and research and development projects.

2.4 SITE SELECTION PROCEDURES

The nature of the geopressured-geothermal resource requires that wells for particular projects be located on or very near the fault block. Opportunities for selection and comparisons of alternate sites for a given project, therefore, will be necessarily rather limited. Because of this difficulty, screening procedures for approval of projects and project sites include consideration of potential environmental impacts. A checklist of items to be considered and actions to be taken in such screening is presented in Appendix C. Moreover, an environmental evaluation will be prepared for each well drilling and testing project. Fortunately, the environmental impacts of these wells are expected to be minor.

2.5 COMPARISON OF THE ENVIRONMENTAL IMPACTS OF THE ALTERNATIVES

Selection of the Preferred Action Alternative would not result in significant impacts to water and air quality, land use, socioeconomics, or cultural and ecological resources for specific projects under normal conditions of drilling and testing. A measurable but negligible amount of induced seismicity, subsidence, and erosion might occur for some projects. In the event of a blowout, locally significant impacts to soils, aquatic and terrestrial biota, air or water quality, and land use could result.

The No Action Alternative, of course, would produce no such impacts. The Delayed Action Alternative would postpone the same impacts to some later time. Neither of the latter two alternatives would satisfy program objectives.

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3. THE AFFECTED ENVIRONMENT

The existing natural and socioeconomic environments throughout the coastal plains of Louisiana and Texas are quite diverse in contrast to the subsurface environment, which is broadly similar. The study area is one of the greatest oil and natural gas provinces in the world, and intense exploration, development, and production of these resources continue vigorously.

3.1 GEOLOGY AND SOILS

3.1.1 Geology

The northwestern portion of the Gulf of Mexico has received vast amounts of sediments from the continental interior. When this deposition began, the coastline was much further inland; the accumulated sediments built the shoreline seaward to its present location. As the earth's crust subsided, a giant depositional trough or geosyncline formed and a thick sequence of sediments accumulated.

The deposition of sediments was so rapid that normal compaction could not take place and the sediments became undercompacted. As a result, the intergranular fluids support some of the weight of the overlying strata, making them "geopressured" (Jones 1975). Since they are thermally insulated, geopressured fluids are also abnormally hot. Table 3.1 lists depths and temperatures for typical geopressured prospects. A more detailed discussion of Gulf Coast geology is provided by DOE 1978a; general characteristics are described in the following sections.

3.1.1.1 Structure

The geosyncline is the predominant structural feature upon which all other structural features are superimposed, and it underlies the entire Gulf Coast plain of Texas and Louisiana. Its axis is thought to be over 15,000 m (∿50,000 ft) below the surface, coinciding with the present-day coastline. The strata in the geosyncline dip very gently toward the axis (generally, <1°), and they characteristically steepen downdip. The geosyncline is modified regionally by embayments and arches normal to it (Fig. 3.1). The Gulf of Mexico geosyncline is tectonically less active than regions located along plate boundaries. Within it there are no seismically active faults, no volcanism or intrusion, and a minimal earthquake history.

Local structure is controlled by two processes — growth faulting and salt diapirism. Growth faults are shallow, small-scale normal faults which approximately parallel the geosynclinal trend, where the block on the coastal side is downthrown in most cases. Movement along growth faults takes place slowly in response to sediment load. The downthrown block is similar to a landside, but it is much larger and develops over a much longer time frame. Since the faulting occurs during deposition, the downthrown blocks receive additional deposition, which results in substantial thickening of the strata on the downthrown side (Fig. 3.2) (Landes 1970). Thousands of these extremely local, small-scale faults coalesce with each other to form broad general trends. Their complexity greatly complicates understanding of the subsurface, yet they are essential to the formation of geopressured zones (Dickey et al. 1968).

Below the sandstone and shale strata in the geosyncline lies the Jurassic Louann formation, a thick evaporite (salt). Because of its plastic behavior at depth and its density, which is less than that of the rock above it, the salt flowed upward, folding the strata over it. Eventually the salt intruded through the strata, causing faulting around it. The resulting columns of salt, known as diapirs or domes, are especially common in southeastern Texas and southern Louisiana (Fig. 3.1) and are notably absent in the San Marcos and Sabine arches (Jones 1975). Incipient salt domes, or salt pillows, are thought to be responsible for many local structural highs.

Table 3.1. Stratigraphic column of the northwest Gulf Coast

Age	Series	Group/formation
	Cenozoic era	
Quaternary	Recent (Holocene)	Undifferentiated
	Pleistocene	Houston
Tertiary	Pliocene	Goliad
	Miocene	Fleming
		Anahuac[a]
	Oligocene	Frio[b]
		Vicksburg
	Eocene	Jackson
		Claiborne
		Wilcox[b]
	Paleocene	Midway
	Mesozoic era	
Cretaceous	Gulf	Tuscaloosa (La.)[b]

[a]Boundary between the Oligocene and Miocene is not well defined.
[b]Prime prospect for development of geopressured resources.
Source: D. G. Bebout, V. J. Gavenda, and A. R. Gregory, *Geothermal Resources, Wilcox Group, Texas Gulf Coast,* Bureau of Economic Geology, The University of Texas at Austin, January 1978.

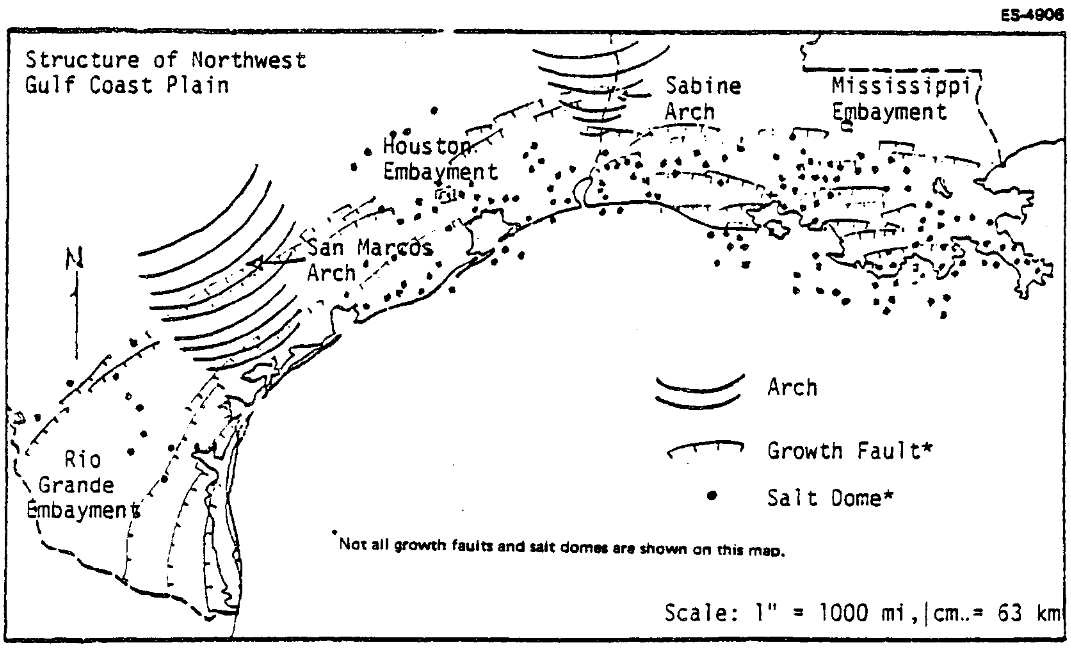

Fig. 3.1. Structural geology of the northwest Gulf Coast plain. Source: ORNL 1979.

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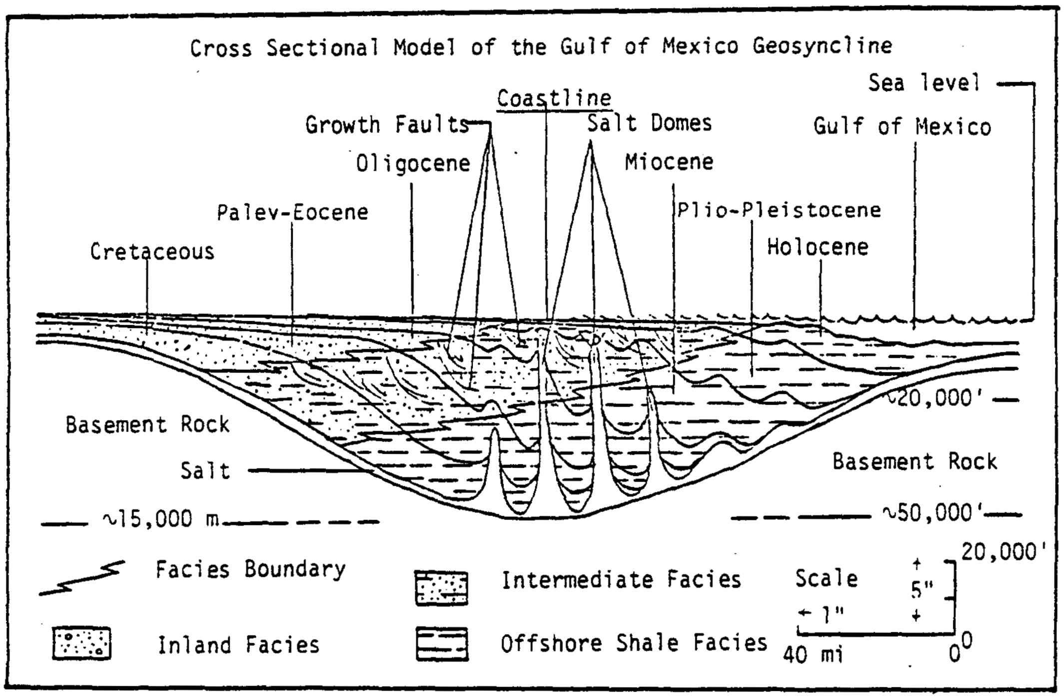

Fig. 3.2. Cross-sectional model of the Gulf of Mexico geosyncline. Source: P. H. Jones, "Geothermal and Hydrocarbon Regimes, Northern Gulf Basin," in *Proceedings, First Geopressured, Geothermal Energy Conference,* Center for Energy Studies, University of Texas at Austin, Austin, Texas, 1975.

3.1.1.2 Stratigraphy

In a simplified sense, at any given time three depositional facies occur. Inland sediments are deposited in alluvial and fluvial systems. These sediments are primarily coarse-grained and shallow and contain isolated, thin strata of shale. Therefore, hydrostatic pressure conditions prevail. The second facies, at the seaward edge of deposition, is comprised of very fine-grained sediments that lithify into shale. Between these two facies exists a zone sensitive to many factors (e.g., changes in sea level). Here, thick sequences of fine- to coarse-grained sediments are deposited in a complex relationship to one another. The geopressured fluids occur in this middle facies because of the abundance of growth faults and the large amounts of undercompacted shale and sandstone within it. These strata are in the form of irregularly shaped bodies such as lobes, lenses, wedges, and strands varying greatly in lateral size, thickness, and lithology.

Broad stratigraphic units have been recognized that are based primarily on microfossil correlation (Fig. 2.1 and Table 3.1) (Bebout 1976). The older the formation, the farther inland and deeper is the intermediate facies containing the geopressured fluids. The greatest opportunity for development of the geopressured resource occurs in the Frio, Wilcox, and Tuscaloosa formations (which are also prolific oil and gas producers) because they are known to contain adequately large bodies of porous sandstone at a drillable depth.

3.1.1.3 Geomorphology

The surface features of most of the study area were formed by deposition of sand, silt, and clay primarily in a deltaic or interdeltaic setting (Fig. 3.3). The largest deltaic plain was formed by the Mississippi River as it migrated across southeast Louisiana. Materials deposited upon a deltaic or interdeltaic plain range from coarse, poorly sorted alluvium to clay. Along the coast, west of the Mississippi deltaic plain, is the chenier plain. It is comprised of sandy beach ridges approximately parallel to the coast that are surrounded by marsh. Southwest of the cheniers, the system of deltaic and interdeltaic plains continues with the addition of a barrier island-lagoon system along the coast formed by long-shore drift. The deltaic plains are similar to, but smaller than, the one formed by the Mississippi River and correspond to present drainages; the interdeltaic plains occur between these.

Further inland and higher in elevation are Pleistocene terraces, which represent similar depositional environments during interglacial, transgressive (advancing sea) phases.

There are two areas where the surface of the land has been formed by wind-related rather than water-related processes. In the northeast corner of Texas, north of the Rio Grande deltaic plain, a veneer of eolian (windblown) sandstone was deposited on top of Pleistocene morphology. In Louisiana, bluffs of loess (windblown loam) occur on the east side of the Mississippi River north of Baton Rouge.

Near the landward limit of the study area, there are outcroppings of Pliocene and Miocene rocks, especially in southern Texas. These were deposited by stream and littoral processes similar to those occurring in Quaternary (recent and Pleistocene) times but are better consolidated and are exposed due to erosion rather than deposition.

3.1.2 Soils

The soils of the coastal plains are highly diverse. Very broadly, they fall into two categories. Approximately south of the Nueces River are the pedocal soils. Due to the arid climate, they are rich in nutrients and relatively homogeneous. They contrast with the pedalfers in the more humid areas to the north where nearly all of the soluble nutrients have been leached out and distinct horizons are evident. More specific soil groupings are shown in Fig. 3.4 (Oxford University Press 1975).

Along the drainages of the larger rivers like the Mississippi and the Rio Grande undeveloped alluvial soils are found. Decomposed muck occurs in the swamps around the Mississippi River delta. The soils produced from the loess deposits east of the Mississippi River are silty and sandy loams. Swelling subtropical clays with abundant montmorillonite predominate the coast areas where the climate is humid. In the more densely forested areas farther inland, soils are characterized by a thin, loamy layer on top and a thick, red- and yellow-clay horizon underneath (podzolic). They are often poorly drained.

As the climate becomes less humid, the soil becomes seasonally dry. In south Texas, where eolian sands have been deposited, homogeneous, loamy sand occurs. In many areas of south Texas, the soil is underlain by a layer of caliche (lime evaporite).

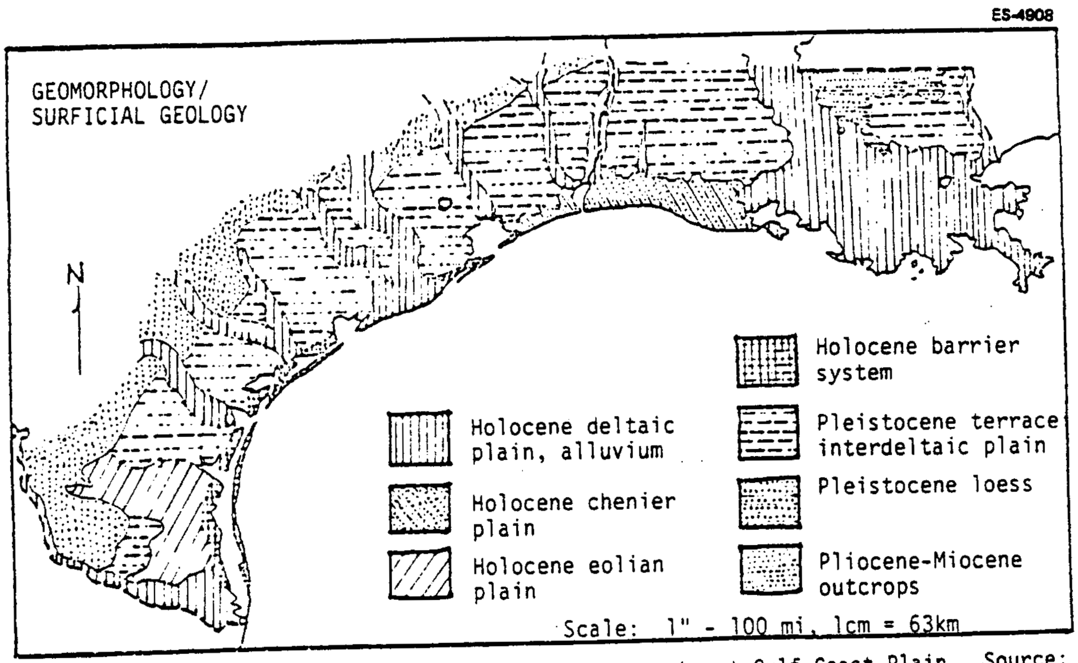

Fig. 3.3. Geomorphology/surficial geology of the northwest Gulf Coast Plain. Source: ORNL 1979.

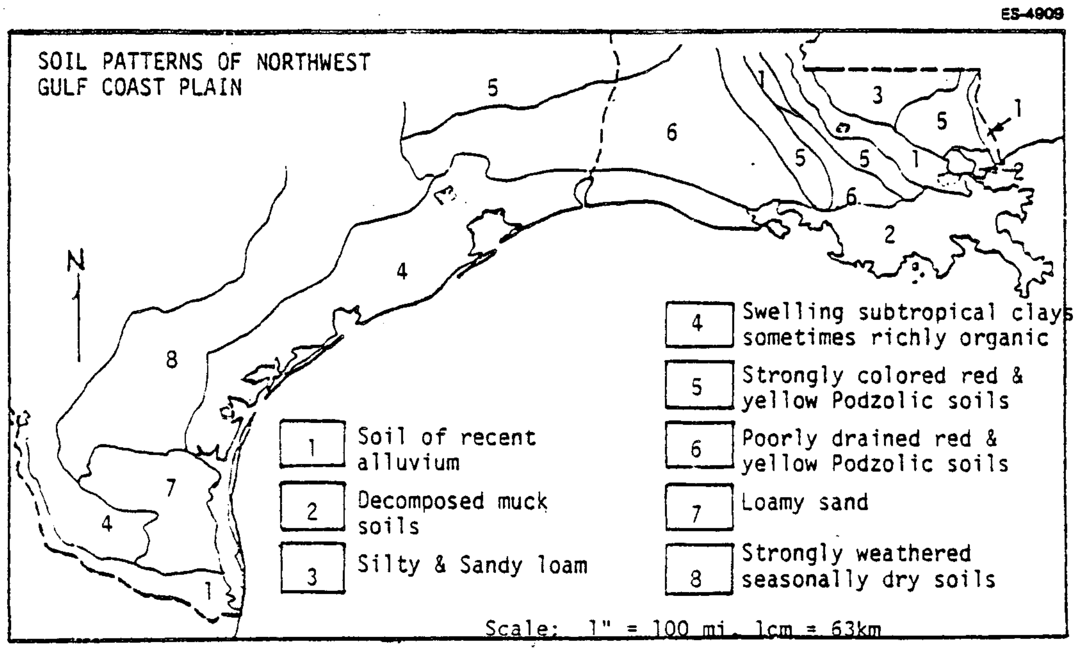

Fig. 3.4. Soil patterns of the northwest Gulf Coast plain. Source: *The United States and Canada,* Oxford Regional Economic Atlas, Oxford University Press, Oxford, 1975.

3.2 HYDROLOGY AND WATER QUALITY

Surface-water and groundwater characteristics and uses are described in this section. The focus of this discussion is on the hydrology of the Wilcox prospect areas. Detailed information regarding the hydrology of Frio prospect areas is available from sources identified in Sect. 1.

3.2.1 Surface water

3.2.1.1 The Frio

A description of the surface-water and groundwater systems of the Texas and Louisiana Frio formations is given in Newchurch et al. (1978), in Appendix A of DOE 1978a, and in White et al. (1978). Department of Energy maps identify surface-water areas along with wild, scenic, or recreational streams (DOE 1978a). In general, surface-water resources in the prime prospect areas of the Texas and Louisiana Frio formations are characterized by coastal marsh and estuarine systems (these may consist of canals, bayous, tidal channels, or open estuarine or bay-water areas), where salinites range from essentially freshwater to that of seawater.

Surface-water use is also described in the above references. The principal surface-water uses in the coastal zones are: (1) irrigation, (2) domestic and livestock use, (3) power generation, (4) navigation, and (5) manufacturing. These productive coastal areas also serve as nursery grounds for various species of recreationally and commercially valuable organisms.

3.2.1.2 Wilcox and Tuscaloosa

The surface-water resources in two prime Wilcox prospect areas of Texas are characterized by freshwater streams, rivers, and small lakes. River systems traversing or originating in the Wilcox areas drain toward the Gulf of Mexico. Several large reservoirs are planned, however, to meet the future water needs of Texas. In the De Witt County prospect area the Guadalupe River and its feeder streams are the main surface-water resources. In the Colorado County area, Eagle Lake and the Colorado River with its tributaries are the main surface-water systems (Texas Water Development Board 1977a). Other principal river systems are the Sabine, Trinity, Brazos, and Nueces rivers. The major reservoirs and lakes of central and eastern Texas include Toledo Bend, Sam Rayburn, Whitney, Bettan, Travis, and Buchanan.

Major water uses in the Texas Wilcox area are municipal, steam-electric power generation, manufacturing, irrigation, mining (petroleum and natural gas), livestock, and navigation (Texas Water Development Board 1977a).

In general, water quality decreases with increasing aridity. Hardness of surface waters generally increases in a southwestward direction from soft (<60 ppm hardness as $CaCO_3$) in the eastern parts of the Texas Wilcox region, to moderate (60-120 ppm) in the Trinity River basin, and to hard (120-180 ppm) in the Colorado and lower Nueces river basins. Total dissolved solids (TDS) in surface waters are highest (>350 ppm) along the coast and in the upper river basins of northwest Texas. Moderate TDS levels (120-350 ppm) are found in eastern and central Texas. Stream sediment levels generally range from low (<270 ppm) in the lower Nueces main stream to high (>1900 ppm) in central Texas.

3.2.2 Groundwater

One of the most valuable natural resources of the northwest Gulf Coast plain is plentiful groundwater (Table 3.2) (Davis and Wiest 1966, DOE 1978a). Many vast aquifers of high quality freshwater exist in gulfward dipping, thickening wedges of semiconsolidated or unconsolidated sandstone that grade from coarse-grained to silty. The deeper aquifers are recharged by precipitation received at outcrop areas to the north of the DOE project region. They are confined by impermeable clay strata above and below them. Other aquifers exist in buried stream or deltaic alluvium that remains unconsolidated. These aquifers are recharged as a result of hydraulic contact with surface drainages.

Along the coast, the freshwater held in aquifers interfaces with saltwater. As a result, the base of the freshwater is shallowest near the coast, and it deepens inland. In some places, freshwater occurs at depths of over 1000 m (~3000 ft). Under the Mississippi River Valley, the eolian plain in the southern corner of Texas, and Matagorda Bay, deep freshwater aquifers are covered by strata containing saline water.

Table 3.2. Hydrologic units of the northwest Gulf Coastal Plain

System	Series	Southwest Texas	Northeast Tex.; southwest La.	Mississippi River area, La.
Quaternary	Holocene	Alluvium/ Eolian sand	Chicot aquifer[a]	Mississippi alluvium[a]
	Pleistocene	Beaumont clay		Older delta deposits
		Lissie formation		
Tertiary	Pliocene	Willis sand		
		Goliad sand[a]	Evangeline aquifer[a]	Pliocene/Miocene deposits
	Miocene	Legarto clay		
		Oakville sandstone	Burkville aquiclude	
		Catahoula sandstone	Jasper aquifer	

[a]Most heavily pumped aquifers.

Source: U.S. Department of Energy, *Geothermal Energy Geopressure Subprogram, Gulf Coast Well Testing Activity, Frio Formation, Texas and Louisiana*, DOE/EA-0023, Vols. 1 and 2, February 1978.

Groundwater is used for urban and industrial needs and for irrigation. The two areas that rely heavily on groundwater for urban and industrial use are the Houston metropolis, including Galveston, and the Baton Rouge-New Orleans industrial corridor. In the Houston area over 2 billion L/d (~530 mgd) were being removed from the ground (Davis and Wiest 1966). Groundwater is used in very large quantities in southwest Louisiana to irrigate rice. Farther south in Texas, groundwater is also used to irrigate rice but not in such a concentrated manner. In the Rio Grande River valley, groundwater is used, in part, to irrigate cotton, vegetable, and citrus fruit crops.

Two problems have resulted from the development of groundwater — salt encroachment and subsidence. In coastal areas, the interface between saline and freshwater moves updip and inland as the freshwater is removed at large rates. Subsidence is a result of the compaction of unconsolidated sediments when fluids are removed from them, and it has been evidenced in the Houston, New Orleans, and Baton Rouge areas. In Houston, land has subsided a maximum of 2.29 m (7.5 ft) over a period of 30 years. The location of maximum subsidence corresponds to the location of the greatest water level decline (Davis and Wiest 1966). These problems have forced more attention and care to be focused on the use of groundwater resources.

3.3 CLIMATE AND AIR QUALITY

Climate and air quality for the Texas and Louisiana coasts are described in the EA for well testing in the Frio (DOE 1978a). The 30-year weather bureau norms for the Wilcox region show that its climate exhibits similar trends. Southern Louisiana and east Texas are warm and humid, with an average annual temperature of 19.7°C (67.5°F) and an average annual rainfall of 1388 mm (54.6 in.). Southwest of Harris County, Texas, however, rainfall and humidity drop progressively and average temperatures rise. For the first seven counties southwest of Harris County in the Wilcox geopressured corridor, the average annual temperature is 21.2°C (69.9°F) and the average rainfall is 937 mm (36.9 in.). The southernmost seven counties of the corridor have 598 mm (23.6 in.) of rain annually and an average temperature of 22.2°C (72.3°F). More detailed information is available from references (DOE 1978a).

Air pollution is generally not significant in the rural areas of Texas and Louisiana. Limited data for the study area show that average concentrations of SO_2, NO_2, and total suspended particulates were well below national primary standards from 1973-1976 (Strand 1979). Data from the air quality control organizations of the two states nevertheless show pollution problems in the Houston-Galveston region and in the Baton Rouge-New Orleans corridor. Industrial emitters, including the petroleum industry, are important sources for pollutants. Episodic events involving dust occur in south Texas in conjunction with dry weather. Additional regional information is available (ERDA 1977, DOE 1978a).

3.4 NOISE

Because of the rural character of much of the region, ambient noise levels are usually relatively low. The Environmental Protection Agency (EPA 1974) reports 44 dBA as a typical outdoor average level on a farm; operation of farm machinery and road traffic will produce higher levels on a localized basis. Urban areas typically will have levels ranging from around 55 dBA (light traffic, residential) through 95 dBA (freeway traffic) and occasionally higher values associated with the use of construction equipment or aircraft (CEQ 1970).

3.5 LAND USE

The principal land uses in the Texas and Louisiana geopressured region are forestry, agriculture, and petroleum production. Land-use statistics for the Frio are available (DOE 1978a). More recent information on land use in the Frio and the Wilcox geopressured regions is summarized below.

Land-use statistics for the Wilcox, Frio, and Tuscaloosa geopressured zones are given in Table 3.3. The land use for Texas is derived from a study of Texas coastal basins (U.S. Department of Agriculture 1977), which covers most of the counties in the Texas geopressured Wilcox and Frio. Land use for Louisiana is derived from parish statistics. Much of Louisiana and east Texas is used for wood and pulp production. Recent data on wood volume and hectares are available from the State Forestry Commissions and from Oak Ridge National Laboratory (ORNL) computerized data bases. Rice and sugercane are major crops on the coastal prairies, and beef ranching is practiced there and in the arid counties of the Texas Rio Grande plain. Detailed county statistics on crop production are available from the agricultural commissions of the two states (Texas Department of Agriculture 1977). Petroleum production is discussed in Sect. 3.7.

Table 3.3. Land use in counties of the Frio, Wilcox, and Tuscaloosa geopressured zones of Louisiana and Texas

Land use	Percentage
Louisiana[a]	
Urban, built up	4
Cropland and pastureland	20
Forest (excluding wetlands)	11
Wetlands	26
Water	39
Barren land	1
Texas[b,c]	
Urban, built up	5
Cropland	20
Pastureland	12
Rangeland	32
Forest[d]	20
Federal land	1
Water	7
Other land	3

[a]Total area: 8,068,233 ha (19,936,605 acres).
[b]Total area: 9,029,098 ha (22,310,900 acres).
[c]Excludes Zapata, Starr, Hidalgo, Willacy, and Cameron counties.
[d]Includes 61,675 ha (152,400 acres) of national forest-land.
Sources: Louisiana State Planning Office and the Texas Soil Conservation Service.

3.5.1 Prime and unique farmland

Due to the agricultural nature of the region, an important aspect of land use is its suitability for crop production. The Soil Conservation Service (SCS) of the U.S. Department of Agriculture (USDA) has expressed concern over losses of some of the nation's best farmlands. SCS has undertaken a national inventory of farmlands considered to be prime or unique. Prime farmlands are those best suited to production of feed, forage, fiber, and oilseed crops. Unique lands are those which are not considered prime but are especially suited to production of certain specialty crops of high value, such as nuts, citrus fruits, certain grains, and vegetables. The SCS has provided the staff with its most recent information on prime farmlands in the Wilcox geopressured zones of Texas. This information is not yet available for Louisiana. Where data are not available, the staff has used estimates of prime farmland based on SCS land capability classes (Frio and Wilcox). Counties and parishes in the Texas and Louisiana geopressured zones with over 50% prime farmland are listed in Table 3.4. Those for which published soil surveys are available to calculate prime and unique farmlands are indicated in Table 3.5. Designation of unique farmlands is not practical on a regional scale with the available data.

3.5.2 Urban areas

The major metropolitan areas in the Frio and Wilcox region are Baton Rouge, New Orleans, and Houston. These and other urban areas are described in Sect. 3.7 of this EA and in DOE 1978a. Houston and Baton Rouge lie in major geopressured fairways. These areas continue to undergo rapid population growth with the consequent increase in urban land. Commercial and residential land in the eight-county, Houston-Galveston region, for example, is expected to double between 1970 and 1990 (Texas Parks and Wildlife Department, Comprehensive Planning Branch 1975). Much of this rapid change is not included in available land-use figures, and the location of geopressured facilities in these areas would require additional data compilation. The broad regional picture described below, however, is likely to remain accurate for some time.

3.6 ECOLOGY

3.6.1 Terrestrial ecology

This section deals with the natural biological features of the terrestrial environment in the geopressured zones. A large proportion of the area no longer exhibits these features because of agricultural or other developments. Current land uses are discussed in Sects. 3.5 and 3.7.

From east to west the geopressured zone traverses four major ecological provinces: (1) outer-coastal plain forest, (2) southeastern mixed forest, (3) prairie parkland, and (4) prairie brushland (Bailey 1978). The natural vegetation and habitats of these regions and comments on the effects of development have been described briefly (ERDA 1977, DOE 1978a). Additional information on flora and fauna is available (Gustavson et al. 1977). The general vegetation for the study area is shown in Fig. 3.5 for Texas and Fig. 3.6 for Louisiana.

From the standpoint of the proposed action, the location of ecologically significant remnants of natural systems is particularly relevant. Information on state and federal parks, wildlife management units, and forests is compiled for the Frio (DOE 1978a). State parks and wildlife management areas not given in DOE 1978a are listed in Table 3.6. One hundred important natural areas in Texas, regardless of ownership, have been compiled and ranked by the State Nature Conservancy and by Texas Natural Surveys. The number of these areas occurring in the geopressured zones is listed by county in Table 3.7.

Three types of natural areas found in the Wilcox zone are particularly noteworthy. The first is the Big Thicket area of east Texas which is internationally recognized for its uniqueness and ecological diversity (DOE 1978a). Its vegetation includes species more commonly associated with such distant regions as the arctic, the subtropics, the U.S. deserts, and the Appalachian Mountains. The vegetation of the Big Thicket is described by Watson (1975). Portions of the Big Thicket National Biological Preserve and of unprotected lands occur in the Liberty Fairway and in other parts of the geopressured corridor of the Wilcox. A second important type is the stands of bottomland hardwood in the river floodplains of the two states. These highly productive ecosystems are an important ecological, recreational, and timber resource. Strategies for protection of this resource have been documented (U.S. Forest Service 1978, U.S. Fish and Wildlife Service 1978). The third is the few remnants of the original prairies of the Texas region that are important for endangered species (see Sect. 3.6.3) and as unique plant communities.

Table 3.4. Counties and parishes with more than 50% prime farmland in the geopressured zones of Texas and Louisiana

Texas	
Jim Hogg[a]	Cameron[b]
Jim Wells[a]	Hidalgo[b]
Live Oak[a]	Willacy[b]
Bee[a]	Nueces[b]
Wharton[a]	San Patricio[b]
Fort Bend[a]	Matagorda[b]
Harris[a]	Brazoria[b]
Louisiana	
Beauregard[b]	
Lafayette[b]	
West Baton Rouge[b]	

[a]Derived from recent Soil Conservation Service (SCS) estimates of prime farmland.

[b]Estimated from 1967 data for Land Capability Classes (LCC) using Prime Land = LCC1 + 0.86LCC2 + 0.40LCC3.

Source: R. F. Olson, C. F. Emerson, and M. K. Nungesser, *Geoecology: A County-Level Environmental Data Base for the Conterminous United States,* Environmental Sciences Division, Oak Ridge National Laboratory Publication No. 1537, ORNL-TM-7351, 1980.

Table 3.5. Counties and parishes in the geopressured zones of Texas and Louisiana having soil surveys published or in press

Texas	Louisiana
Jim Hogg	St. Mary
Jim Wells	St. Martin
Bee	Iberia
De Witt	Assumption
Wharton	St. James and St. John the Baptist
Fort Bend	Terrebonne
Harris	Acadia
Montgomery	Lafayette
Jasper	Iberville
Newton	Ascension
Jefferson	Evangeline
Calhoun	East Baton Rouge
Chambers	

Sources: Soil Conservation Service (SCS), Texas and Louisiana.

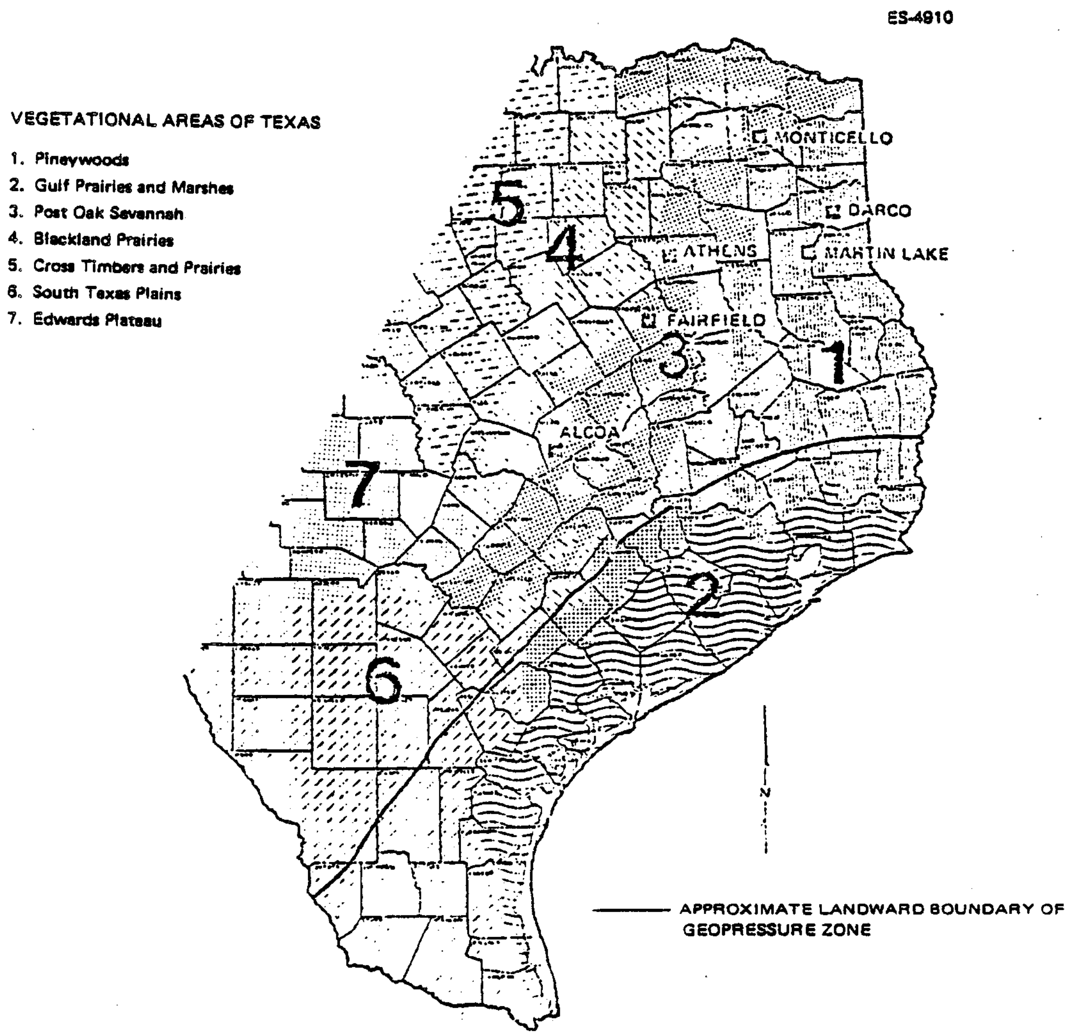

Fig. 3.5. Vegetational areas of Texas. Source: F. W. Gould, *Texas Plants — A Checklist and Ecological Summary*, Texas Agricultural Experimental Station, Texas A & M University, College Station, Texas, 1962.

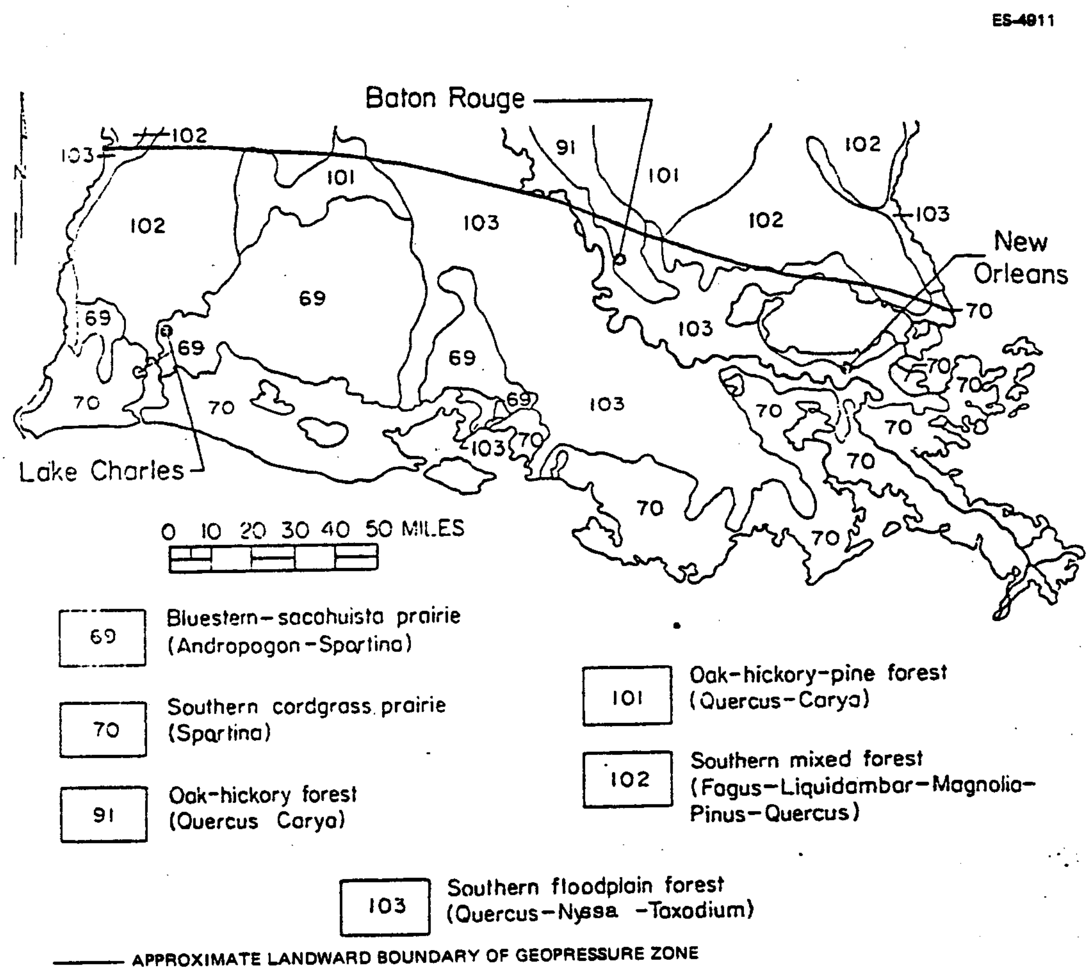

Fig. 3.6. General vegetation map, Louisiana Gulf Coast region. Source: T. C. Gustavson et al., *Ecological Implications of Geopressured-Geothermal Energy Development, Texas-Louisiana Gulf Coast Region,* FWS 10BS-78/60, U.S. Fish and Wildlife Service, U.S. Department of the Interior, 1977.

Table 3.6. State parks and wildlife management areas in the Frio and Wilcox geopressured zones not listed in DOE 1978a

	State and county or parish
State parks and recreational areas	
	Louisiana
Chicot	Evangeline
Cypremort Point	St. Mary
Lafitte	Jefferson
	Texas
Bentsen–Rio Grande	Hidalgo
Hale Ranch Park (site)	Brazoria
Lake Corpus Christi	San Patricio
Wildlife management areas	
	Louisiana
Atakapa Island	Iberia
Thistlewaite	St. Landry
West Bay	Allen
	Texas
Angelina–Neches scientific area	Jasper
Dam B	Jasper

Sources:
1. Texas Parks and Wildlife Dept. 1977, 1979.
2. *Louisiana State Comprehensive Outdoor Recreation Plan*, Department of Culture, Recreation, and Tourism, 1977.
3. Louisiana State Parks and Recreation Commission, 1973.

Table 3.7. Important natural areas by county in the geopressured zone of Texas

County	No. of areas	Total extent [ha (acres)]	Remarks on habitat and biota
Starr	2	1,214 (3,000)	Mesquite; birds
Kenedy	1	27,454 (67,839)	Brown pelican habitat
Nueces	1	[71 lin km (44 miles)]	Mustang island
Aransas	1	13,089 (32,342)	Endangered prairie chickens
Calhoun	1	[40 lin km (25 miles)]	Endangered whooping cranes
Galveston	2	8 (20)	Bird sanctuary
Chambers	2		Alligator, bald eagles; marsh
Jefferson	4	2,849 (7,040)	Big Thicket; red wolf, river otter
Newton	1	809 (1,998)	Wild orchids
Jasper	1	494 (1,220)	Cypress; herons
Hardin	5		Big Thicket
Liberty	3	6,475 (16,000)	
Montgomery	1		Virgin pines
Harris	2	243+ (600+)	Coastal bayou
Refugio	1	243 (600)	Breeding shore birds; fish
Orange	1	1,052 (2,600)	Cypress; marsh
Cameron	1	18 (45)	Dove; south Texas brushland
San Patricio	1		Wildlife; waterfowl

Source: Texas Parks and Wildlife Department 1975. *Outdoor Recreation in the Rural Areas of Texas, Part 1.* Comprehensive Planning Branch, Austin, December 1975.

Wildlife which is found in the study area is discussed extensively in two publications (DOE 1978a, Gustavson et al. 1977). The importance of the Texas and Louisiana coast to waterfowl received particular attention. Recently, the U.S. Fish and Wildlife Service (USFWS) identified coastal areas of particular concern as waterfowl habitat in Texas (U.S. Fish and Wildlife Service 1977) and the location of rookeries in coastal Louisiana (Portnoy 1977). The Texas Parks and Wildlife Department has catalogued coastal and inland rookeries and population numbers for a number of fish-eating bird species (Smith 1975, Brownlee 1978). Important rookeries of various herons and egrets are located in the Wilcox geopressured zone in Texas. The counties involved are Hardin, Polk, San Jacinto, Montgomery, Liberty, Harris, Waller, Austin, and Colorado. A single egret rookery is recorded from Jim Wells County in the western part of the Wilcox.

3.6.2 Aquatic ecology

3.6.2.1 Frio

The Frio areas in Texas and Louisiana are characterized in general by highly diverse and productive coastal aquatic and wetland ecosystems. They account for a large percentage (40%) of the total of such coastal areas in the continental United States. Most of these coastal habitats are ecological transition zones between terrestrial and marine ecosystems. Consequently, these coastal ecosystems are characterized by complex physical, chemical, and biological processes, all of which interact in varying degrees to form distinct estuarine- or saline-marsh ecosystems. Physical gradients are characteristic of coastal and marsh ecosystems, with salinity and elevation being important in controlling ecological processes within these ecosystems. For example, salinity gradients dictate the types of benthic communities and associations occurring in the coastal ecosystems. The major benthic association types and their controlling physiochemical factors are given in Table 3.8. Salinity is determined by the level and frequency of flooding from both upland freshwater and Gulf seawater.

Coastal ecosystems, particularly those of the southeast United States and Gulf Coasts, are valuable both ecologically and economically. They serve as spawning and nursery areas for commercial fish, sport fish, and shellfish, and they provide habitat for waterfowl (Gunter 1967). About 90% of the commercial fish and shellfish of the United States are estuarine-dependent, requiring low salinity for all or part of their life cycle. Besides functioning as nursery areas, coastal ecosystems also perform the following functions:

1. provide a natural treatment of both waterborne and airborne pollutants,
2. afford natural protection against storms and stabilize the shore,
3. produce a high-yield food source for aquatic animals, and
4. perform the vital function of storing and transporting nutrients and energy from upland sources.

The food chain of the coastal marsh or estuarine ecosystem is based primarily on detritus, the decaying remains of organisms. A simplified food chain diagram of a typical coastal marsh or estuarine ecosystem is shown in Fig. 3.7. Marsh vegetation is the principal source of the detritus upon which many primary consumers in the coastal ecosystem depend.

Many of the commercially valuable consumers in these coastal ecosystems depend heavily on detritus as their primary energy source. Shrimp, which are mainly detritus feeders, constitute the most economically valuable single fishery in the Louisiana-Texas coastal waters. Other species which comprise valuable fishery resources are Menhaden (*Brevoortia* spp.), a phytoplankton feeder, oysters (*Crassostrea* spp.), and blue crabs (*Callinectes* spp.). These four species account for about 96% of the total weight and value of all fishery products landed in Louisiana and Texas.

Additional descriptions of aquatic ecology resources in the Frio areas of Texas and Louisiana are available (DOE 1978a, 1978b, 1980, 1981; White et al. 1978; Gustavson et al. 1977).

3.6.2.2 Wilcox

The freshwater aquatic ecosystems in the Wilcox formations include streams, rivers, and lakes. Aquatic communities in these systems are typically freshwater lotic (running water) and lentic (standing water). The nature of the associated ecological communities varies as a function of the physical and chemical characteristics of each aquatic system.

The important fishery resources of the freshwater reservoirs in Texas include native largemouth bass; crappie; white bass; and channel, blue, and flathead catfish. Walleye and striped bass have been successfully introduced into some reservoirs, and shad serve as important forage fish for many predators (Texas Water Development Board 1977b).

Table 3.8. Types of benthic biological associations and their controlling physiochemical characteristics

Benthic association type	Characteristics	
	Physical	Biological
I	Low salinity (<10%), high turbidity, sand or silt bottom, common in river-dominated estuaries	Low diversity, oligohaline (tolerant of salinity changes) species (e.g., blue crabs and the common rangia clam)
II	Low to moderate salinity (10–27%), good water circulation, abundant suspended food	High diversity, high biomass, species sensitive to siltation (e.g., oyster reefs)
III	Normal to high salinity (28–36%), deepest areas in estuary, fine sediments	Low diversity, low biomass, burrowing forms (e.g., polychaetes)
IV	Normal to high salinity, deep areas, strong currents, shell-sand bottom	High diversity, high biomass, suspension feeders and predators (e.g., coelenterates, bivalves, gastropods, and crustaceans)
V	Fluctuating salinities, estuary periphery, sand flats, high current energy, good light penetration	High diversity, high biomass, suspension feeders, seagrasses (e.g., predators, scallops, clams, gastropods)
VI	Fluctuating salinities, intertidal areas, mud flats (clay-organic sediments), low kinetic energy	High diversity, high biomass, large proportion of burrowing suspension feeders (e.g., polychaetes, clams, sea cucumbers, and mud shrimp)

Source: S. M. Adams, "Coastal Zone Systems," *Development Document for Strategies for Ecological Effects Monitoring at DOE Energy Production Facilities*, Oak Ridge National Laboratory, Oak Ridge, Tennessee, 1979.

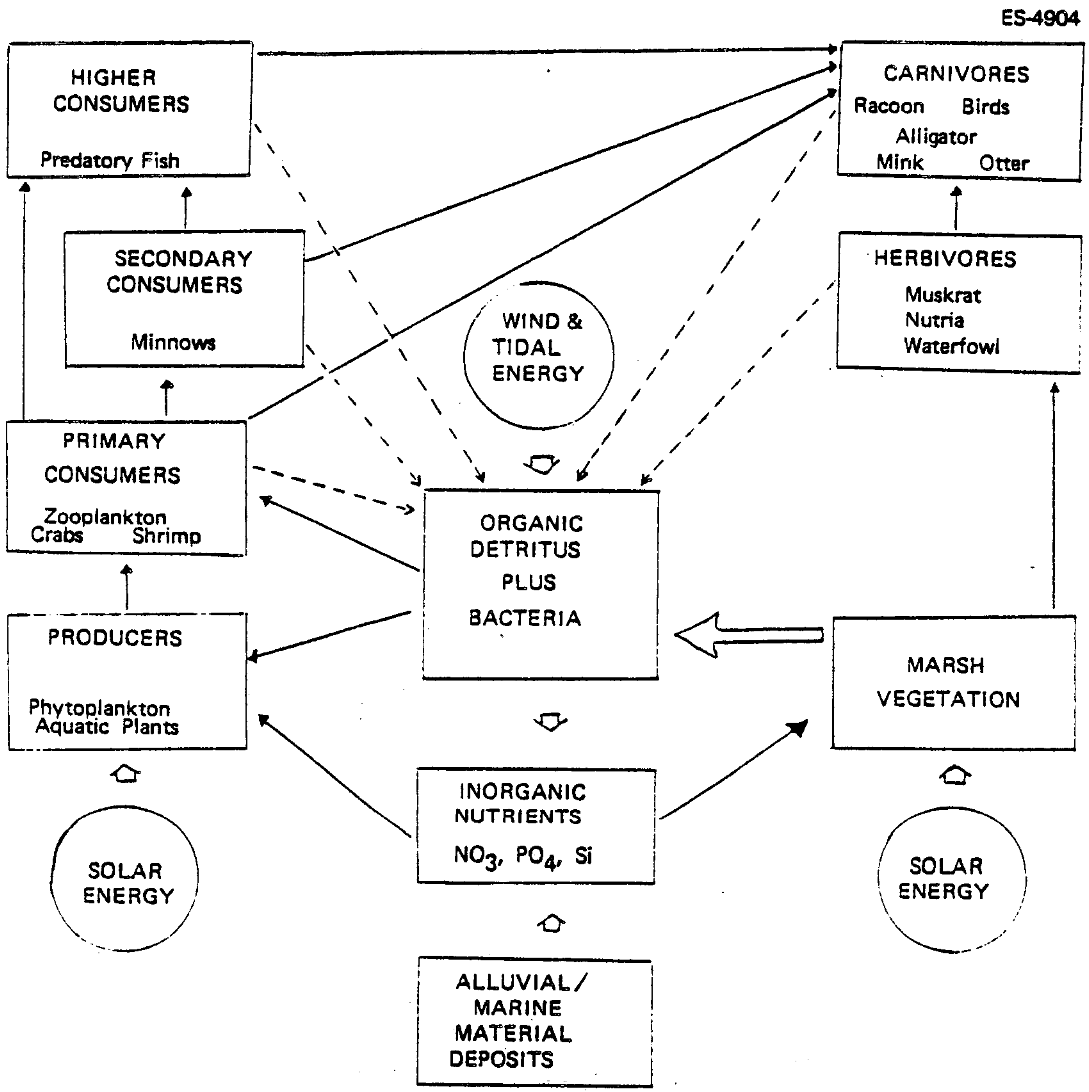

Fig. 3.7. Simplified food web diagram of a typical marsh-estuarine ecosystem showing the dependence of consumers on organic detritus. Source: A. W. Palmisano, *Commercial Wildlife Work Unit Report to Fish and Wildlife Study of the Louisiana Coast at the Atchafalaya Basin, Vol. I,* Louisiana Wildlife and Fish Commission, New Orleans, Louisiana, 1971.

3.6.3 Endangered species

The Texas Organization for Endangered Species (TOES) is a nonprofit private organization devoted to conservation of vanishing plants and animals in Texas. The TOES list of animals considered rare, endangered, or threatened by the state or federal government or by TOES is the most comprehensive and up-to-date listing available (TOES 1979). Rare animals which may be found in the Wilcox geopressured zones of Texas or which were not covered in DOE 1978a are listed in Appendix A. Species which are not listed by the state or federal government are not legally protected at present but may become so. Notes on federally endangered animals in Louisiana also appear in Appendix A. Additional notes and maps for these and other endangered animals are found in various DOE, ERDA, and USFWS documents and references therein (DOE 1978a, ERDA 1977, Gustavson et al. 1977). New information on endangered species is summarized below.

The most recent study of the federally endangered Red Wolf (*Canis rufus*) (McCarley and Carley 1979) suggests that, at most, remnant populations could occur within the study area only in Cameron and Calcasieu parishes in Louisiana and Jefferson and Chambers counties in Texas. The Attwater's Prairie Chicken (*Tympanuchus cupido attwateri*) occurs in several locations in the study area, including a federal game reserve in the Colorado fairway (Fig. 3.8). The Houston Toad (*Bufo houstonensis*) may still occur on the outskirts of Houston, but the critical habitat for this species does not occur in the study area. Eight breeding pairs of the bald eagle (*Haliaeetus leucocephalus*) are reported from Texas in Goliad, Refugio, Calhoun, Victoria, Matagorda, Brazoria, Orange, and Trinity counties; nine active nests are reported from Louisiana, mostly in the coastal parishes.

The Rare Plant Study Center in Austin, Texas, maintains a listing of rare plant species in the state, most of which are not yet protected by law. Information on rare plants in the Wilcox corridor of Texas is given in Appendix A. The status of these plants is currently under review by the USFWS and may change in the near future. Plant species in Louisiana that are proposed for endangered status and that occur in the Wilcox geopressured zone are listed in Appendix A. Information on the endangered plants and animals in the coastal zone (Frio) appears in USFWS and DOE documents (Gustavson et al. 1977, DOE 1978a).

3.7 SOCIOECONOMIC CHARACTERISTICS

3.7.1 Economics and employment

Major employment categories in the area of interest include agriculture, oil and gas recovery, construction, and manufacturing, with wholesale and general retail merchandising, services, schools, and public administration becoming more important in urbanized areas.

Primary agricultural activities include truck farming and the growing of rice and sugarcane. Cotton is the major crop in the southern Texas area, and beef production is important in many counties.

The fishing industry is very important in Louisiana and Texas, primarily along the Gulf Coast area. Preliminary estimates for catch and value of the fisheries for 1975 are 1,125 million pounds with a value of $88 million for Louisiana and 85 million pounds with a $93 million value for Texas (U.S. Bureau of the Census 1977).

Petroleum, natural gas, sulfur, salt, and other minerals are products of both states. Natural gas and petroleum are the most important resources in the area of concern. The value of natural gas, natural gas liquids, and petroleum (crude) for 1973 was about $5.595 billion for Louisiana and $7.830 billion for Texas (U.S. Department of the Interior 1976). Uranium mining and milling are important in the Wilcox fairways of the lower Texas Gulf Coast (principally in Karnes and Live Oak counties).

3.7.2 Demography

Population density throughout the geopressured regions varies from very sparse to very dense. Figure 3.9 shows centers of population in Louisiana and Texas, and Table 3.9 gives the population and population densities of representative counties and parishes in the geopressured areas. Table 3.9 also lists cities in these areas with a population of 20,000 or more. Several metropolitan areas in Texas in the region of interest are among the fastest growing areas (1970-1979) in the United States. These include Brownsville (52.5%), McAllen (39.1%), Harlingen (30.4%), Houston (30.1%), and Edinburg (28.6%) (Rand McNally and Company 1979). New Orleans has declined in population since 1960.

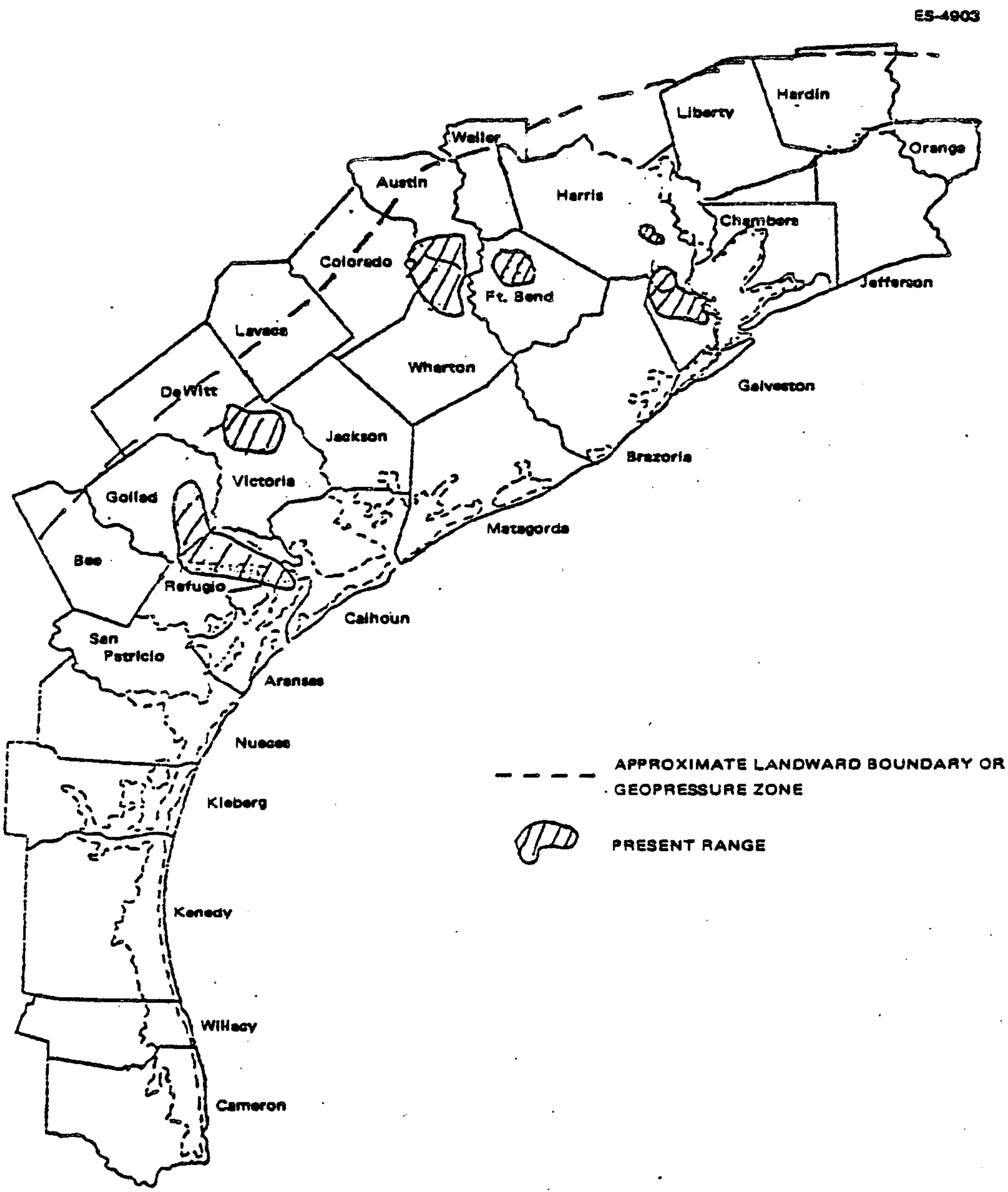

Fig. 3.8. Distribution of Attwater's Prairie Chicken in Texas. Source: Wayne Shifflett, Director, Attwater Prairie Chicken National Refuge, Eagle Lake, Texas, personal communication to Dr. J. W. Webb, Environmental Sciences Division, Oak Ridge National Laboratory, Oak Ridge, Tenn., 1978.

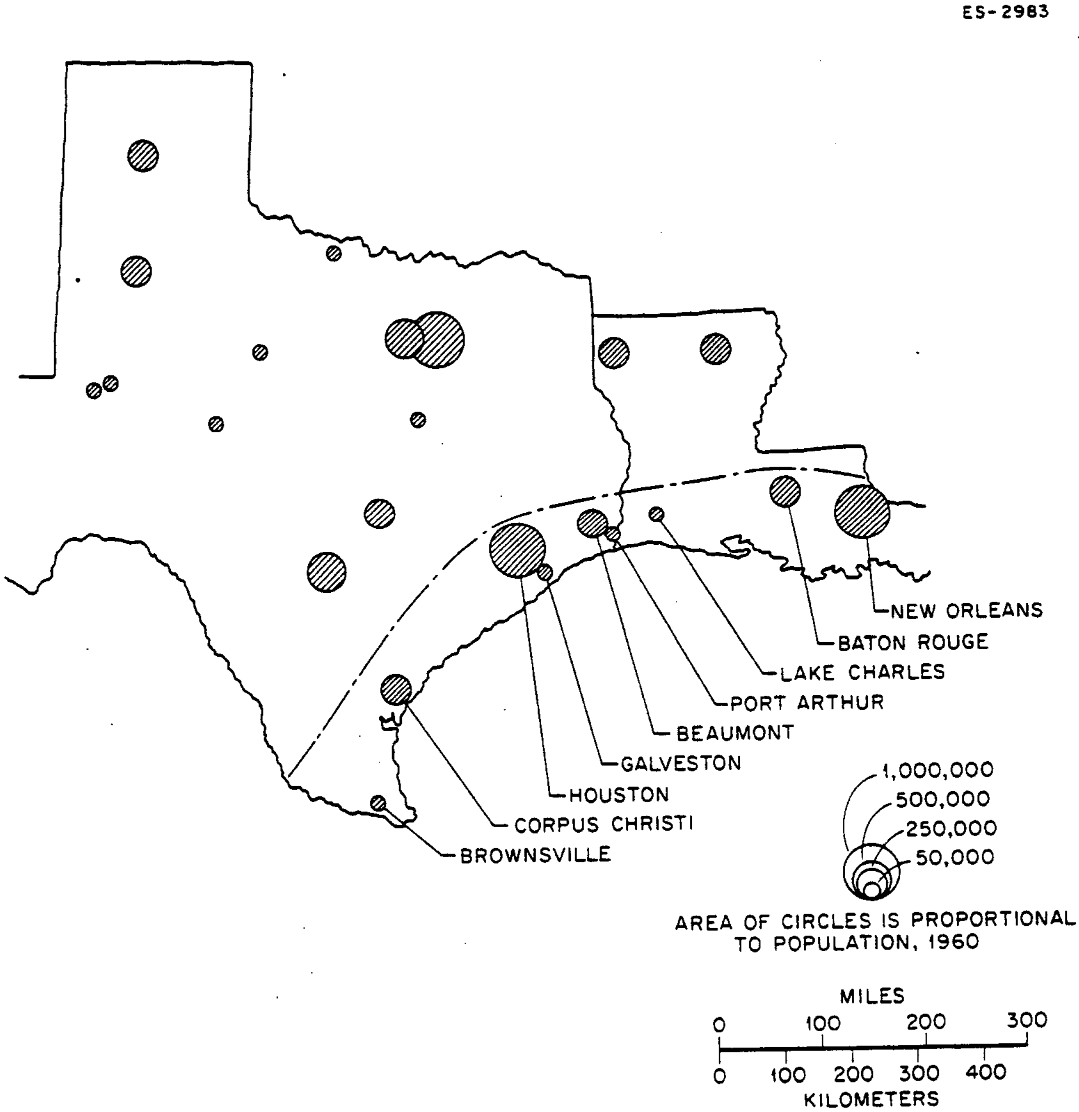

Fig. 3.9. Population distribution in Louisiana and Texas. Source: U.S. Department of the Interior, Geological Survey, *The National Atlas of the United States*, Washington, D.C., 1970.

Table 3.9. Population statistics for representative counties and parishes and for cities of 20,000 or more within the geopressured zones

Representative counties (parishes)	Population[a]		Cities over 20,000 population[b]	
	Number	Density (people/sq mile)		
		Louisiana		
Acadia	52,109	79	Baton Rouge	183,000
Allen	20,794	27	Chalmette	23,400
Ascension	37,086	123	Gretna	24,300
Calcasieu	145,415	132	Houma	31,600
Cameron	8,194	6	Lafayette	80,400
East Baton Rouge	285,167	621	Lake Charles	78,000
Iberia	57,397	97	Kenner	48,000
Iberville	30,746	49	Marrero	40,000
Lafayette	109,716	388	Metairie	160,000
Lafourche	68,941	60	New Iberia	30,700
Livingston	36,511	56	New Orleans	569,000
Orleans	593,471	3,013	Opelousas	21,000
Pointe Coupee	22,002	39	Scotlandville	24,800
St. Charles	29,550	101		
St. James	19,733	78		
St. Landry	80,364	86		
St. Martin	32,453	44		
Terrebonne	76,049	56		
Vermilion	43,071	36		
		Texas		
Arkansas	8,902	32	Baytown	49,400
Austin	13,831	21	Beaumont	114,000
Bee	22,737	27	Brownsville	66,400
Brazoria	108,312	76	Corpus Christi	210,000
Calhoun	17,831	34	Edinburg	20,600
Colorado	17,638	19	Galveston	59,700
De Witt	18,660	21	Harlingen	35,500
Duval	11,722	7	Houston	1,369,000
Goliad	4,869	6	Kingsville	29,200
Hardin	29,996	33	McAllen	45,800
Harris	1,741,912	1,011	Orange	25,000
Hidalgo	181,535	118	Pasadena	103,000
Kenedy	678	0.5	Port Arthur	52,100
Kleberg	33,166	39	Texas City	38,900
Liberty	33,014	28	Victoria	43,300
Matagorda	27,913	24		
Montgomery	49,479	45		
Nueces	237,544	283		
Waller	14,285	28		
Zapata	4,352	5		

[a] U.S. Department of Commerce, Bureau of the Census, *1970 Census of Population, Number of Inhabitants*, Louisiana Report No. PC(10)-A20 La, June 1971, and Texas, Report No. PC(1)-A45 Tex, August 1971.

[b] Rand McNally & Company, *1979 Commercial Atlas & Marketing Guide*. 110th ed., New York, 1979.

3.8 CULTURAL RESOURCES

Archaeological resources in Texas and Louisiana include prehistoric Indian sites, historic European and Indian sites, and shipwrecks. There are numerous sites known within the study area and probably many other undiscovered archaeological remains. The distribution of known sites does not reflect the true distribution because known sites have been located through restricted local surveys or in easily accessible areas. Areas which have a high probability of containing archaeological material include high ground near water, past and present natural levees, flood plains, and stream confluences.

Many archaeological and historical sites are national landmarks, in the National Register of Historic Places, or state landmarks. The Texas Parks and Wildlife Department presently maintains ten historical parks and sites in the Frio and Wilcox study area, and the Louisiana State Parks System operates eight commemorative areas of historical significance in the study area (Texas Parks and Wildlife Department and Louisiana State Parks System 1979). The National Register of Historic Places lists 106 sites in 27 counties of the study area in Texas and 124 sites in 23 parishes in Louisiana (DOI 1979).

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4. POTENTIAL ENVIRONMENTAL CONSEQUENCES

The potential impacts of geopressured activities have been extensively discussed and documented in reports and environmental assessments for specific prospect areas of the Frio in Texas and Louisiana (DOE 1978a, Gustavson et al. 1977). The impacts of drilling, construction, and operation of test wells, in particular, have been dealt with in the environmental assessment for a test well at Pleasant Bayou in Brazoria County (DOE 1978b). Although these assessments deal primarily with impacts in estuarine or marsh coastal environments, they also describe and discuss impacts on upland terrestrial habitats in the coastal zone (Frio). These upland ecosystems of the Frio continue into the Wilcox, and wells drilled in these regions will have impacts primarily on terrestrial habitats. The severity of these impacts will depend on the specific ecology and land use of the particular site.

Because of the generic coverage of impacts to upland habitats in other documents and the site-specific nature of some impacts, the discussion below gives only a brief summary of impacts and emphasizes, wherever possible, the habitats and land uses which could be most seriously affected. A more detailed discussion on the effects of geothermal fluids is given in Appendix B. Release of these fluids to the environment by whatever means appears to be the most serious potential impact of the proposed action.

4.1 IMPACTS RESULTING FROM DRILLING AND CONSTRUCTION

Impacts of drilling, well completion, and construction are analyzed in this section. Land use, water quality, air quality, biota, and cultural and socioeconomic resources are among the environmental parameters to be impacted by drilling and construction. Impacts from drilling and well completion are similar to those experienced in routine oil well drilling activities. However, construction activities around the test well site will be more extensive than those required for a single oil well.

4.1.1 Geology and soils

The normal procedures that will be executed during site preparation and drilling will have no impact on the subsurface. The construction of the mud pit and ring levee will only temporarily alter the natural topography.

Soils will be more susceptible to erosion after vegetative cover is cleared and before it is replaced by boarding and limestone. This hazard can be reduced by clearing and recovering areas in stages so that the soil is uncovered for the minimum amount of time possible. Erosion along the ring levee and the sides of the mud pit can be reduced or prevented by planting appropriate vegetation.

4.1.2 Hydrology and water quality

Land clearing, leveling, road and drill pad construction, dredging, and possibly construction of reserve ponds and flood walls will increase erosion and runoff rates, increasing the turbidity of surface water. Runoff from construction and drilling will contain lubricants from vehicles and equipment and chemicals from drilling mud. Drainage patterns may be altered by road, pond, and levee construction. Flooding of the site could wash toxic materials and pollutants from the well site and storage pits. The biological implications of changes in water quality are discussed in more detail in Sect. 4.1.6.

Water use during construction and drilling will be minimal. Sources of supply will be surface waters from nearby marshes or bayous in wetlands or groundwater in some of the Wilcox prospects of Texas.

4.1.3 Air quality

Construction-related impacts to air quality will arise primarily from dust and exhaust emissions from equipment and gases released from geothermal fluids during drilling operations. Mitigation measures to reduce dust include graveling and sprinkling. Exhaust emissions from machinery should be minor, short-term, and readily dispersed. Release of H_2S during drilling may cause objectionable odors at the site on occasion, but this effect will be local, minor, and short-term.

Typical emissions from drilling rigs are shown in Table 4.1. The emissions from other diesel equipment used to prepare a well pad would be about one-fifth the amount of those shown. Air quality will be monitored prior to and during drilling and testing (Sect. 5).

4.1.4 Noise

Noise at receptors no closer than 300 m (1000 ft) for the drilling are not likely to exceed the criterion established by EPA for the protection of hearing (EPA 1974). The criterion specifies that the 24-h average sound level should not exceed 70 dBA. (The dBA units represent sound pressure in decibels, weighted to account for the frequency response of the human ear.) The criterion for outdoor activity interference and annoyance (a day-night average of 55 dBA) could be exceeded if the drilling rig is not properly oriented. Field measurements of noise emitted by a typical deep-well drilling rig (2100 hp) for distances of up to 275 m (900 ft) (Gustavson 1979) indicate that levels of 300 m are about 60 dBA from the loudest side of the rig. Proper orientation of the rig, with the quietest side towards the nearest receptor, will usually result in levels below the 55 dBA criteron given above.

4.1.5 Land use

Installation of a well-testing facility with one production well and four disposal wells will convert about 0.5 ha (1.25 acres) from its current use to well testing. An additional 0.4 ha will be converted for each kilometer of road constructed (1.7 miles/acre) and about 0.25 ha/km (6 acres/mile) will be converted for pipelines. During construction, about 8 ha (20 acres) will be temporarily disturbed for ancillary construction activities. The completed site will encompass about 2 ha (5 acres), most of which can be restored after completion of the project. For test wells in the Wilcox, it is quite likely that construction will remove agricultural land from current use. In this case, the impacts will be minimized if prime and unique farmlands are avoided. If pipelines to injection wells are laid next to roads and if existing roads are used whenever possible, impacts will be further minimized.

If a particular test site requires additional disposal wells or other modifications, further commitments of land may be required. Although drilling of more injection wells could probably be accomplished from existing pads, construction of water treatment facilities will use an undetermined area. Disposal of wastes from treatment will require additional acreage.

If soil erosion is allowed to occur during and following construction, land use will be further affected on a long-term basis. Erosion will be particularly likely on sites on hilly terrain or near waterways. Erosion can be mitigated by maintaining the natural pattern of surface-water flow as much as possible, by directing runoff through vegetated areas, by graveling, and by replanting vegetation following construction.

4.1.6 Ecology

Impacts to the terrestrial and aquatic ecosystems are discussed separately below.

4.1.6.1 Terrestrial

Drilling of test wells in the Wilcox should occur primarily in terrestrial environments. Adverse impacts to important terrestrial habitats will be avoided if drill sites are selected away from natural areas whenever possible, particularly bottomlands, woodlands, or natural coastal prairie. In the event of siting in a natural area, a total of about 10 ha (25 acres) of habitat plus additional land for roads will be disturbed by construction. If soil erosion is allowed to occur, additional habitat will be affected. Natural vegetation will be destroyed and wildlife disturbed. These actions could be serious in the case of rare or endangered species, particularly plants. Additional possible impacts include decreased growth of vegetation resulting from dust accumulation on leaves during dry weather. Plant and animal productivity may be decreased by accidental runoff of chemicals from equipment. Noise from construction may disrupt normal

Table 4.1. Typical exhaust emissions from drilling machinery

Pollutant	Emissions kg/d	Emissions lb/d
Carbon monoxide	23	51
Hydrocarbons	9	20
Nitrogen oxides	107	236
Sulfur oxides	7	15
Particulates	7.5	17

Source: Energy Research and Development Administration. 1976. *An Environmental Assessment of Proposed Geothermal Well Testing in the Tigre Lagoon Oil Field, Vermilion Parish, Louisiana.*

movements for larger wildlife. Impacts to the terrestrial biota should not be significant provided precautions are taken to minimize dust, spillage, and erosion, and if important natural areas are avoided.

4.1.6.2 Aquatic

Because the principal difference in the aquatic systems of the Frio and Wilcox areas is that between coastal marsh and estuarine habitats (Frio) and freshwater streams and lakes (Wilcox and Tuscaloosa), further discussions related to construction and operational impacts will focus on the nature and magnitude of impacts that could occur as they relate to the characteristics of freshwater (Wilcox and Tuscaloosa) vs coastal marsh and estuarine ecosystems.

Impacts to aquatic biota could accrue from loss of habitat and change in water quality due to construction activities, especially if dredging is involved.

Land clearing will be necessary for the test well site and the disposal wells required for fluid reinjection. Drilling activities require the construction of access roads and/or canal dredging to the drilling sites and disposal wells. Direct loss of aquatic habitat could result from the construction of drill-pads (0.4-0.8 ha), reserve ponds for drilling wastes (0.04 ha), reinjection wells, and access roads or canals to the test well site. It is assumed that wherever possible, existing roads and canals will be used.

One of the major impacts of construction and well drilling activities is the change in water quality. Dredging activities (especially in the canals, channels, and marsh areas of the Frio) could potentially have several deleterious consequences for aquatic organisms. Dredging remobilizes sediments which in some aquatic areas contain fairly high concentrations of pesticides, herbicides, heavy metals, and other toxic materials. These materials may enter and concentrate in aquatic food chains or affect organisms directly. Another adverse effect of dredging is increased turbidity, which may reduce light penetration into the water column and thus limit plant photosynthesis. Particulate material released from dredging (i.e., silt and clay) can affect filter-feeding organisms such as clams, oysters, and clupeid fishes by clogging or irritating their filtering apparatus.

The ecological effects of dredging have been reviewed by Morton (1977) and Sherk (1972).

Case studies of dredging (Mackin 1962), however, show that total suspended solids (TSS) generated by dredging activities generally do not exceed those attained under natural conditions (20 to 200 ppm) beyond a distance of 32 m (105 ft) from the dredge. In the shallow marsh and estuarine systems of the Frio areas, natural TSS may be as high as 500 ppm; therefore, the ecological effects of temporary turbidities created by dredging operations should be minor.

Drainage and circulation patterns in the vicinity of the test well could be altered by site preparation and construction activities that involve dredge and fill. This could be particularly important in the coastal Frio areas of Louisiana where dredge and fill operations have already created intrusions of saline water into previously brackish or freshwater areas. These saline intrusions have greatly altered the ecological characteristics of the impacted areas, converting freshwater marsh into brackish-water marsh (Newchurch et al. 1978). In addition, canals have affected the normally slow discharge and circulation patterns in the marshes and permitted a more rapid flow of water and saltwater intrusion into the fresher marshes. Impoundments have created areas which are cut off from the general discharge and circulation patterns. Spoil banks and levees can also block circulation if they are oriented across the direction of flow. In general, these activities tend to destroy the character of the wetlands and can cause a drop in productivity as well as a loss of land (Newchurch et al. 1978).

During the well drilling phase the main source of contaminants to aquatic systems would be at the wellhead in the form of hydraulic fluid and lubricants. To prevent dispersion of these buoyant materials, the site should be diked and fluids should be directed to sealed reserve ponds constructed at the site.

4.1.7 Socioeconomics

During the drilling and construction period, a total work force of 30 to 50 people may be involved. The number of workers present at the site at any one time is expected to be between 10 and 20. Although the drilling period of a geopressured well is usually 25 to 50 days, the additional time required to complete the well and its associated facilities, including the injection wells, may extend the total construction phase to as much as 6 months. The number of workers will decrease as the project nears completion.

The drilling operation will most likely be an around-the-clock effort and require four shifts since drilling will continue through the weekends. Workers on a more or less continuous basis will include drilling crews, logging geologists, drilling supervisors, and a rig superintendent. Intermittent personnel associated with drilling will include laborers; truck drivers delivering supplies; service personnel specializing in such areas as cementing, down-hole surveys, or formation evaluation tests; and various inspectors. Some intermittent construction workers will also be required.

Oil field well drilling is a common occupation in much of the geopressured areas of Texas and Louisiana. For this reason, recruiting workers from the immediate general vicinity of the project is a good possibility, and few workers will have to move into the area, even on a short-term basis. Further, because of the short duration of the drilling construction period, many employees (even from somewhat farther distances) will choose to commute or possibly move into motels, returning home on weekends or breaks.

For the reasons stated above, the impact on housing, schools, traffic, and community services (e.g., medical, fire, and police protection) is expected to be minor, even in many of the less densely populated areas.

The increased income to the surrounding communities from worker wages and some possible sales of supplies and materials will have a small but beneficial economic impact. This increased income is not expected to impose any significant competition for goods or services. The overall economic impact from drilling and construction is expected to be slight.

4.1.8 Cultural resources

Construction of the test facility could destroy or disturb historical or archaeological sites, and the noise from drilling could lessen the enjoyment of visitors to any nearby cultural or recreational facilities. The sites should be selected initially to avoid these impacts if possible. A site survey will be required, in consultation with state officials, to ascertain whether any archaeological or historical sites are present. Construction activities will be planned to avoid any known material, or, if this is not possible, the material will be salvaged with the approval of the appropriate state officials. If sites are disturbed, or if archaeological/historical artifacts are found during construction, the appropriate state officials will be notified.

4.2 IMPACTS RESULTING FROM FLOW TESTING

The impacts on geology, land use, water quality use, air quality, biota, and cultural and socioeconomic resources of one to two years of flow testing are analyzed in this section. The nature and extent of these impacts will depend largely on the effectiveness and development of procedures used in reinjecting large volumes of geothermal fluid over an extended period of time. The large quantity of brine to be handled has the greatest potential of all the project activities for impact on the environment.

4.2.1 Geology and soils

The geological impacts that might occur as a result of long-term flow testing of geopressured fluids are crucial since they may affect biota, land uses, and all other environmental parameters. The primary geological impact would be subsidence caused by compaction of sediments as the geopressured fluids are removed from them. This may be subsidence over a broad area or differential subsidence along an activated growth fault. Subsidence could disrupt drainage systems, inundate lowlands (or increase their vulnerability to storm surge), damage roads and buildings, and destroy wildlife habitat.

The amount of production anticipated from the proposed project, however, is too limited for any more than a slight chance of impact to occur. It is estimated that about 19 million barrels will be removed from the surface over a period of 2 years, but this rate is not infrequent in commercial fields producing for a period of several years where no subsidence has been observed. The short duration of the project reduces the possibility of subsidence. Baseline leveling should be done in order to monitor any changes in surface elevation as the fluids are produced. For such a short-term project, however, changes brought about by production and geopressured fluids may be difficult to decipher from background events.

Seismicity induced by reinjection of fluids into the subsurface is not considered a reasonable possibility if the fluids are injected at pressures less than the fracture gradient.

4.2.2 Hydrology and water quality

Impacts to surface-water quality from well-testing operations could result from accidental release of geopressured fluid to the surface. Thermal and chemical pollution could alter surface-water quality when geopressured fluids are introduced into drainage basins. Effects of an accidental release of toxic effluents are discussed in Sect. 4.3 and Appendix B. Geopressured fluids are characterized in detail in Table 4.2.

In the unlikely event that subsidence should take place, wetland flow regimes might be altered. Saltwater encroachment would be likely to occur in coastal regions where Frio prospects occur. Potential subsidence in the Wilcox prospects of Texas, however, is unlikely to have any effect on water quality.

A potential for groundwater contamination is caused primarily by the injection of waste fluids during flow testing. Geopressured fluids could contaminate groundwater through improperly cemented casing during production or injection, through faults, or improperly abandoned wells in the vicinity. Likewise, contamination might occur if the shales confining the injection aquifer become hydrofractured. Since contamination of groundwater is a very gradual and subtle process, it may be difficult to monitor effectively.

To prevent groundwater contamination: (1) cement casing must be set properly at depths necessary to protect fresh groundwater from fluids in the drill hole, and the casing must be checked routinely for leakage or effects of corrosion; (2) injection pressures must not exceed the fracture pressure of the receiving aquifer; and (3) the groundwater must be monitored by one or more wells in the vicinity. If contamination is perceived, operation should be discontinued until the cause is determined. Since contamination of groundwater is especially difficult to reserve and might not even become evident until the project is over, care should be taken in choosing aquifers for injection.

4.2.3 Air quality

Well testing will result in the direct release of steam and a variety of other gases and particulates for approximately 640 days (DOE 1978b). The most likely gases that will be emitted are H_2S, CO, NO_x, NH_3, CH_4, N_2, and H_2. Particulates and other pollutants will be released from geothermal fluids, from flaring gases, and from the small cooling tower. Due to the small magnitude of these releases, their effects are not expected to be significant (DOE 1978b).

4.2.4 Noise

Noise impacts during testing will be minor. The noise level from the facility will be lower and of shorter duration than that emitted during drilling. Hence, EPA criteria are unlikely to be exceeded at nearby receptors.

4.2.5 Land use

The major impacts to land use will be caused during drilling or in the event of an accident. If wells are sited near residential areas, however, nuisance effects could result from noise and odors. No significant additional impacts will result from flow testing. Continued care should be exercised, however, to prevent soil erosion which can be a serious long-term impact.

4.2.6 Ecology

4.2.6.1 Terrestrial

Proper containment, isolation, and reinjection of geothermal products during testing should ensure a minimal effect on plant and animal life. Noise from testing will continue to cause larger animals to avoid the site, but other biota may become partially reestablished following construction. The possible effects of an accidental release of geothermal brines are discussed in Sect. 4.3.

4.2.6.2 Aquatic

The two major impacts that could occur to aquatic ecosystems due to well testing operations are related to subsidence and accidental release of geopressured fluids to the environment.

Table 4.2. Comparison of chemical constituents of Texas and Louisiana geopressured fluids with seawater and freshwater (Vermilion River, Louisiana).

EPA water quality criteria are given where available

Chemical constituent[a]	Geopressured fluids			Seawater	Freshwater (Vermilion River, La.)[d,e]	EPA water quality criteria[f]
	Range for Texas and Louisiana[b,c]	Weeks Island[b]	Tigre Lagoon[b]			
TDS	185–345,000	235,700	112,200	34,600	272	500 (irrigation)
Na	10–103,000	78,000	40,000	10,500	63	
K	30–2,590	1,065	265	380	5.4	
Ca	2–33,200	10,250	1,860	400		
Sr	7–920	920	320	8.0		
Li	2–18	16	7.1	0.17		
Rb	0.1–3.4	3.4	0.8	0.12		
Ba	0–1,000	185	8.2	0.03		1 (health)
Cs	0.3–11.8	11.8	3.5	0.0005		
Fe	<0.1–84	84	0.4	0.01	0.088	1 (freshwater life)
Zn	0.0008–45	45	5.0	0.01	0.015	0.009–0.4[g] (freshwater life)
Pb	0–8.3	0.3	0.5	0.0003	0.015	0.2–5.0 (freshwater life)
Mg	0–23,800	1,140	270	1,350	6.0	
B	18–117					
Cl	10–201,000	44	57	4.6	101	0.750 (irrigation)
Br	14–419	419	63	65		
I	5–74	18	26	0.06		
HCO_3	0–3,370	450	1,050	142	64	
SO_4	0–590	6.4	220	2,700	18	250 (welfare)
NH_3	4.2–100	100	69	0.07		0.02 (un-ionized)
H_2S	<0.1–1.4	0.4	0.5	0		0.002 (undissociated)
pH	5.9–7.3	6.2	6.3	8.0	6.9	6.5–9.0 (freshwater life)

[a] All values as mg/L except as noted.
[b] Kharaka, Callender, Chemerys, and Lico 1979.
[c] Wilson, Hamilton, Manning, and Muehlberg 1977.
[d] U.S. Army Corps of Engineers 1976.
[e] Van Sickle 1980.
[f] EPA 1976.
[g] 0.01 of 96-h LC50 for sensitive species.

In the unlikely event of subsidence (Sect. 4.2.1), altered flow regimes and saltwater encroachment might have a substantial effect on aquatic biota, especially within Frio prospects near the coast or Tuscaloosa prospects in the Atchafalaya Swamp. Aquatic biota are unlikely to be affected by subsidence within Wilcox prospects of Texas. Biological consequences of saltwater encroachment are discussed in Sect. 4.1.6.

The most severe impact to aquatic ecosystems would result from accidental release of geopressured fluids. Proposed project operations call for complete reinjection of all fluids produced during well testing. However, reinjection of such a large volume of fluid is far from a proven technology. Release of geopressured fluids to the environment could result from a variety of accidents. The magnitude of the release would determine the severity of the impact. The environmental consequences of accidental release of geopressured fluids is discussed in detail in Sect. 4.3 and Appendix B.

4.2.7 Socioeconomics

Well tests will be run over a period of up to 2 years. During this period, two employees will probably be at the site on a regular basis. Approximately four more persons will be at the site during test preparation, during the early portion of tests of longer duration, and during periods of nonroutine conditions. The income of these few employees and their demand for goods and services will have a negligible economic impact on surrounding communities.

4.2.8 Cultural resources

Flaring of methane gas or noise from pumps and flow testing could lessen the enjoyment of visitors to any nearby cultural or recreational facilities. Sites should be selected initially to avoid these impacts, if possible.

4.3 IMPACTS RESULTING FROM ACCIDENTS

The risks and causes of accidents are discussed at length in Sect. 2.1.6.

4.3.1 Geology and soils

The impact of accidents on the subsurface would be slight. Improper well completion or a blowout could result in formation damage, and the geopressured resource would be wasted during a blowout. At the surface, the worst case would be a blowout that caused cratering of the surface around the borehole.

A greater potential exists for accidents that would have a significant impact on the soil. Spills, a leak in the mud-pit liner, or a blowout would contaminate the soils on the site. The amount of contamination would be directly proportional to the magnitude and duration of the accident. Even though most accidents could be cleaned up, residual materials will remain, the amount of which would depend on the length of time the contaminating substance had to infiltrate the soil. Therefore, the speed with which measures are taken to control and mitigate accidents is very important. These measures are discussed in Sect. 2.1.5. As a worst case, an accident would contaminate the soil to the extent that it could not support vegetation. Soil contamination resulting from the infiltration and leaching of pollutants could also contaminate fresh groundwater.

4.3.2 Water quality

4.3.2.1 Surface water

All accidents potentially damaging to area water quality involve spills of fluids of one kind or another. Since all spills and leaks short of a major blowout would be contained within the ring dike surrounding the project, this section will confine discussion to the impacts of the only accident capable of adversely affecting local surface water: a major blowout of hot brine.

The degree of impact of a blowout on both aquatic and terrestrial systems is dependent on the flow rate and total volume of hot brine released, the total salinity, chemical composition, and temperature as well as the characteristics of the specific receiving systems.

Accurate prediction of flow rates in the event of a blowout is not possible. However, a maximum flow rate of 6360 m^3/d (40,000 bbl/d) from a major blowout is plausible. At this flow rate, a typical ring dike measuring 91 x 213 m (299 x 699 ft) would be able to contain the brine for 3 days. If the blowout continued beyond this period, the hot brine would overflow the dike and enter existing drainage systems until the blowout exhausted itself or a relief well were drilled. Blowout control would require several weeks using either approach.

Aside from the obvious differences between formation waters and surface waters in temperature and total salinity, the geopressured brines also differ dramatically in concentration of several potentially toxic elements and compounds. Table 4.2 shows ranges of concentrations of chemical constituents of geopressured brines of wells along the Louisiana and Texas coasts. It is evident from these data that some geopressured chemical constituents occur at concentrations potentially harmful to plants, animals, and, perhaps, man. Among these toxic substances, NH_3, H_2S, B, Pb, Zn, and Fe occur at high concentrations relative to uncontaminated surface waters and to EPA water-quality criteria for aquatic life, irrigation, or domestic use (EPA 1976). Radioisotopes of Rn, Ra, Cs, and U were also detected in the Tigre Lagoon sample at levels higher than those generally found in groundwaters or surface waters. The possible occurrence of toxic hydrocarbons also cannot be entirely dismissed.

Besides the obvious effects of dilution, several other factors may serve to modify considerably brine chemistry and physical characteristics as the brine interacts with the environment. For example, the enormous pressures responsible for the blowout in the first place may force the brine up several meters into the air where cooling and aeration will promote rapid gas and heat exchange. Hydrogen sulfide will likely flash off with steam, greatly reducing the levels of this highly toxic gas. Turbulent aeration in the exit spout drainage ditches, cooling, and mixing with freshwater and seawater will similarly enhance (1) evolution of NH_3 from the brine; (2) uptake of O; (3) precipitation of carbonates and sulfates of Ca, Sr, and Ba; (4) oxyhydroxides of Fe and Mn; and (5) coprecipitation of heavy metals (Kharaka et al. 1979). Because of its greater density with respect to freshwater, the brine can be expected to sink to the bottom of waterways, where mixing and dilution may be slowed until the brine finally meets open bay waters.

The biological implications of a major blowout at the project are addressed in Sect. 4.3.6. More detailed reviews and discussions of geopressured brines and their physics, chemistry, and toxicity can be found [T. C. Gustavson et al. 1978; J. S. Wilson et al. 1979; Y. K. Kharaka et al. 1979; DOE 1978a; R. M. Cushman, D. W. Barnes, and R. B. Craig (submitted); and EPA 1976].

4.3.2.2 Groundwater

Contamination of fresh groundwater could result from a casing failure, a subsurface blowout, or the infiltration of contaminating substances from the surface. The amount of contamination would be directly proportional to the magnitude and duration of the accident. As a worst case, groundwater could become unacceptable for irrigation and domestic purposes downgradient from an accident resulting from a casing failure or subsurface blowout. The duration of such an impact might last many years, but eventually dilution and flushing of the aquifer would restore the water quality to an acceptable level. Documented information on past experiences of groundwater contamination caused by accidents involving oil, gas, or geothermal operations is unavailable.

Because of the extreme difficulty of mitigating groundwater contamination, monitoring is especially important. Hence, the Environmental Monitoring Program for these projects includes drilling of observation wells into freshwater aquifer and sampling of well water for chemical analysis no less than once a month. Observation wells will be located as near as is practical to the production and disposal wells. Any wells supplying fresh water for domestic purposes will also be monitored. If there are any indications that groundwater contamination might be taking place, samples will be analyzed more frequently. If samples do identify contamination, drilling or production will stop as soon as possible, the source of contamination will be determined, and appropriate actions will be undertaken to prevent further contamination.

4.3.3 Air quality

Accidents involving the release of geopressured brines could produce minor impacts on air quality. The most serious problem would be the release of H_2S, which is oxidized slowly to SO_2 in the atmosphere. Estimates based on the blowout of the Edna Delcambre No. 4 gas well in 1971 (DOE 1978a) suggest that the H_2S released in a blowout could cause odor problems within about 3 km (2 miles) of the site but that the resulting maximum concentration of SO_2 would be well below national standards.

4.3.4 Noise

The loudest accidental noise from a design well site would be unmuffled venting of the well. In such an event, noise levels may reach 120 dBA at 31 m (100 ft) from the vent. Noise levels at residences closer than 300 m (1000 ft) would probably exceed EPA criteria for interference and annoyance and might exceed the 70-dBA criteria (EPA 1974) for hearing protection. In the unlikely event of prolonged unmuffled venting of a well, nearby residents might have to evacuate their homes temporarily.

4.3.5 Land use

If an accident occurs during drilling or testing, hypersaline geopressured fluids may be released to the surrounding wetlands, forests, or agricultural land. Prolonged release could hinder productivity for an indefinite, though possibly lengthy, time. Salinization of the soil has marked effects on its chemistry and can affect plants by reducing the availability of water and nutrients and by destroying important soil organisms. Dissolved solids and metals in geopressured brines may further lessen plant productivity. The potential for long-term damage is demonstrated by the present barren condition of the Saratoga Oil Field in Hardin County, Texas, 30-80 years after large-scale brine spills (Gustavson et al. 1977). Brine fallout from a single well as a result of blowout and wind action has been recorded up to 1830 m (6000 ft) from a site (Castle 1975). For this reason, nearby residences would be evacuated in the unlikely event of a major blowout.

4.3.6 Ecological impacts of accidents

Minor leaks and spills will be retained within the ring dike surrounding well sites. Consequently, adverse effects of leaked or spilled brine, oils, and other toxic fluids should be limited to the injury or death of a few of the small number of plants and animals remaining in the less disturbed areas within the dike.

A major blowout, on the other hand, would overtop the retention dike within 3 days if the worst-case conditions described in Sect. 4.3.2.1 were realized. Effects on terrestrial and aquatic systems are considered separately.

4.3.6.1 Terrestrial

The effects of a sufficiently large geopressured brine spill on natural or agricultural terrestrial communities would probably be severe and possibly long term (Gustavson et al. 1977). Salinization of the soil has marked effects on its chemistry and can affect plants by reducing the availability of water and nutrients and by destroying important soil organisms. In addition, there are many constituents of geopressured brines with possible detrimental effects on terrestrial organisms, including dissolved solids, trace metals, and heavy metals. Both the composition and toxicity of the brine and the magnitude of the spill influence the severity of impacts.

Impacts will also depend on the particular terrestrial ecosystem involved. There is very little information on the effects of geopressured brines on various habitats, and more research is needed in this area. The potential for long-term damage, however, is strikingly demonstrated by the present barren condition of the Saratoga Oil Field in Hardin County, Texas, 30-80 years after large-scale brine spills (Gustavson et al. 1977). In the event of an accidental release or brine, any fluids reaching streams or rivers could damage riparian habitats outside the immediate vicinity. Impacts would be more severe if spills or blowouts occurred on prime or unique farmland or in bottomlands, wetlands, woodlands, or native prairie. Intermediate marshes and rice lands are probably the most sensitive to heavy-metal pollution (DOE 1978a). On the other hand, forests or woods would require many years to recover from damage. The plains of south Texas, which receive windblown salt from the Gulf and little rain, would probably be less strongly affected since the biota are adapted to high salt concentrations. Fire at the well site, if not contained, could seriously alter land use or natural habitats and threaten lives and property. Most natural terrestrial communities in the study region are, to some degree, adapted to fire, but recovery to their original condition may require long periods. Forests may require centuries to regenerate.

4.3.6.2 Aquatic

The effects of a spill of geopressured fluid on aquatic ecosystems will likewise depend upon the fluid composition, the magnitude of the spill, and the type of aquatic habitat that receives the release. The consequences of a release into an aquatic system could be severe and would be different in coastal or brackish water systems than in freshwater systems. In addition, chemistry of fluids from the Frio formation is known only in a general way; the Wilcox and Tusculoosa could vary considerably. Therefore, the effects of a release of fluid on the aquatic biota may only be discussed generically. To this end, Appendix B contains a discussion of biological toxicities of the major constituents of geopressured fluid and a generic treatment of impacts as they would vary for coastal and freshwater aquatic systems.

4.3.7 Socioeconomics

In the event of a major prolonged blowout or a serious fire, nearby residents would be forced to evacuate. Damage to forest or agricultural land could adversely affect the economic situation for one or more families. No other impacts to socioeconomics are anticipated.

4.3.8 Cultural resources

Although very unlikely, archaeological remnants near a test site could be damaged or destroyed by a well blowout or fire. No other impacts to cultural resources are expected.

4.4 SUMMARY OF IMPACTS

The potential for impacts on land use, terrestrial ecology, and cultural resources in the prime prospect areas of the Wilcox is summarized in Table 4.3. The table presents the best generalizations possible with the information at hand and indicates areas where more data are clearly needed. Some impacts, such as prime farmland and archaeological sites, inherently require a site-specific survey prior to drilling. Others, such as endangered species, will require updating and consultation with federal and state officials to satisfy regulatory requirements. It appears that siting, based only on the impacts in the table and on the regional nature of the information, would be best in the southwest Texas part of the corridor. A comparison of impacts in the Wilcox with those in the Frio (DOE 1978a) shows further that, in general, drilling in inland areas (Wilcox) would produce fewer and less severe impacts than in the coastal zone (Frio).

The primary impact on aquatic ecosystems due to well-testing operations would result from the release of geopressured fluids into the environment. The magnitude of geopressured fluid releases into the environment could vary from small leaks to blowouts and could occur because of spills, equipment failure, dike breaching, or human error.

Geopressured fluids are characterized by high temperatures (150-260°C) and total dissolved solids (TDS) concentrations over twice that of seawater. Furthermore, the ionic ratio of these fluids are different from seawater and contain several biologically toxic chemicals that occur in much higher concentrations that the maximum safe levels recommended by EPA (EPA 1976). The principal toxic chemicals in geopressured fluids are NH_3, H_2S, B, and other trace elements. The biological toxicity of these elements will vary depending on the chemical, physical, and biological nature of the aquatic system affected. Temperature and pH of the aquatic system largely dictate how ammonia, hydrogen sulfide, and trace elements will speciate and behave in the aquatic system. Ammonia, for example, is more toxic (more goes into un-ionized form) at high pH than at low pH, while the opposite is true for hydrogen sulfide. In general, therefore, ammonia will be more toxic and hydrogen sulfide less toxic in saline ecosystems.

The hydrologic characteristics of the aquatic ecosystem receiving geopressured effluents will also have a large effect on the magnitude of the ecological impact sustained by that system. Systems with rapid and efficient mixing and dilution properties will dissipate and dilute the geopressured fluids rapidly, therefore minimizing biological effects. The toxicity of geopressured effluents to aquatic systems will also depend on the nature of the geopressured fluids, which will vary from site to site and from well to well. The types of organisms affected, the response of these organisms, and the overall effect of geopressured fluid release on an ecosystem will vary from site to site depending on the structural and functional organization of the ecosystem involved.

Assessment of the effects of geopressured fluid releases on aquatic ecosystems depends, therefore, on site-specific characteristics. The principle characteristics of an aquatic system to be considered in site-specific assessments and monitoring programs are:

1. biological characteristics — the structural and functional organization of the affected aquatic ecosystems;

2. chemical characteristics — pH, alkalinity, dissolved oxygen, and salinity;

Table 4.3. Summary of potential impacts in geopressured fairways of the Wilcox in Texas and Tuscaloosa in Louisiana

Potential impact	Geopressure fairway										
	Zapata	Webb	Duval	Live Oak	De Witt	Colorado	Harris	Liberty	Beauregard	Allen	Baton Rouge
Prime farmland (>50% in county)	*a*	*a*	*a*	*b*	*a*	*a*	*b*	*a*	*b*	*a*	*b*
Rare plants	*b*	*b*	*c*	*c*	*b*	*c*	*b*	*c*	*b*	*b*	*b*
Federally listed threatened or endangered animals	*b*	*c*	*c*	*c*	*c*	*d*	*b*	*b*	*b*	*b*	*b*
Waterfowl breeding	*c*	*c*	*c*	*c*	*c*	*d*	*d*	*d*	*a*	*a*	*a*
Recognized natural areas	*c*	*c*	*c*	*c*	*c*	*c*	*d*	*d*	*c*	*b*	*d*
Recognized historical sites	*c*	*c*	*c*	*c*	*d*	*c*	*d*	*c*	*c*	*c*	*d*
Archaeological sites	*a*	*a*	*a*	*a*	*b*	*d*	*d*	*a*	*d*	*a*	*d*

[a] More information needed.
[b] May be present in the fairway.
[c] Not known in fairway at present time.
[d] Known to be present within the fairway.

3. physical characteristics — temperature and hydrologic mechanisms such as dilution and mixing properties; and

4. effluent characterization — total dissolved solids, ammonia, hydrogen sulfide, pH, temperature, and trace elements.

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5. MITIGATION AND MONITORING

5.1 INTRODUCTION

This section summarizes recommended mitigation measures and outlines a sample monitoring program. The sample monitoring program has been used in conjunction with other geopressured test wells which have already been drilled. Future wells will employ a similar program, modified to respond to findings of previous monitoring and to suit the particular conditions of the site and test. A Department of Energy contractor will manage environmental baseline and monitoring studies for geopressured test wells.

5.2 MITIGATING MEASURES

Procedures for minimizing impacts which do occur are summarized below.

5.2.1 Land use

Impacts to land use can be minimized by siting the facility away from populated areas, residences, or prime agricultural land. Careful planning and drilling of reinjection wells and early provision for any water treatment facilities will prevent the unnecessary use of land.

5.2.2 Air quality

Impacts to air quality are expected to be slight, and special measures usually will not be required. In some cases, an H_2S removal system may be needed to prevent objectionable odors near the site.

5.2.3 Terrestrial and aquatic biota

Impacts to terrestrial and aquatic environments can be minimized by siting the test well away from recognized natural areas, state or Federal protected lands, or habitats for rare or endangered species. Further protection can be achieved by sprinkling to reduce dust and using shell or gravel to minimize erosion. Adequate mud pits and reserve ponds should be provided for storage of materials prior to reinjection. State-of-the-art well completion practice, use of blowout preventers, and periodic inspection of surface pipelines, holding tanks, and dikes will reduce the potential for accidental spills. If reinjection facilities prove to be adequate, the production well should be shut-in or operated at a reduced flow rate until reinjection capacity is increased. Following testing, natural contours should be reestablished as much as possible and native vegetation planted on natural sites. Recommendations for restoration of natural environments have been documented (Gustavson et al. 1977).

5.3 SAMPLE MONITORING PLAN

5.3.1 Environmental baseline and monitoring studies

The purpose of collecting environmental baseline data is to provide a description of selected physical, chemical, and biological conditions against which later environmental monitoring data can be compared. This comparison will provide a basis for determining the net environmental change attributable to test well operations at any subsequent time.

The following data shall be collected to establish the baseline of ambient conditions prior to fluid production:

Air quality

- existing air quality conditions
- local meteorological characteristics

Water quality (surface and subsurface)

- existing water quality conditions
- water resource usage
- hydrologic patterns, surface and groundwater levels

Subsidence

- subsidence history
- leveling surveys

Seismicity

- microseismic surveys

Ecosystem quality

- biological surveys

To avoid duplication, information presented in this EA and in documents referred to herein will be incorporated wherever possible into the environmental baseline evaluation. For example, very little additional work may be required to establish existing ecosystem quality.

An environmental monitoring program designed to provide comparative data during drilling and production phases will include the studies listed below.

Air quality

- air quality monitoring
- pollutant dispersion modeling
- continuous wind speed, wind direction, temperature and precipitation

Water quality (surface and subsurface)

- water quality monitoring
- water level monitoring

Subsidence

- repeated leveling surveys

Seismicity

- continuous microseismic surveys

Ecosystem quality

- biological surveys
- bioassays

Monitoring studies may be increased if environmental conditions, either natural or those resulting from test well activities and geopressured fluid analysis, require such adjustment.

The combined scope of environmental baseline and monitoring studies which are planned during the first year include the air quality, water quality, subsidence, and seismic and ecological studies described below.

5.3.1.1 Air quality

Air quality baseline studies will be performed to (1) determine ambient air quality prior to possible disturbance from test well activities; (2) identify any substance potentially derived from the geopressured fluid that may have an adverse effect on the environment and establish baseline concentrations for these substances; (3) collect locally available meteorological data necessary for understanding dispersion and conversion patterns; and (4) provide baseline data compatible with later measurements needed to ensure compliance with state and Federal air quality standards.

Air quality monitoring will be performed to determine changes in air quality which may be related to well testing activities. Sampling and analysis for hazardous substances will be from a fixed automated monitoring unit located approximately 1 mile downwind from the test site. Analyses will include continuous measurement of sulfur dioxide, hydrogen sulfide, total hydrocarbons, and methane. Meteorological data from continuous recorders shall include wind speed, wind direction, temperature, and precipitation. In the event of significant atmospheric pollutant emission, dispersion characteristics will be determined.

Analytical procedures for air quality monitoring will be consistent with designated methods published by the EPA (1978). Analyzer performance shall conform to specifications for automated methods as described in 40 CFR, Parts 50 and 53.

5.3.1.2 Water quality

Water quality baseline studies will be conducted to determine (1) ambient water quality conditions in local bayous and canals and in shallow groundwater prior to possible disturbance from test well activities; (2) baseline conditions for substances potentially present in the geopressured fluids; and (3) water resource usage and baseline concentrations for substances and physical properties for which state standards have been established.

Water quality monitoring studies will be performed so that changes in chemical and physical properties of surface water and groundwater can be determined. Surface-water samples will be collected monthly; surface-water levels will be recorded at the time of sample collection. Laboratory analyses to be conducted for each sample will include Na, K, NH_3, SO_4, Cd, Mn, Ca, Cl, Ba, Pb, As, B, Hg, total hardness (calculated), and total organic carbon. Field measurements shall include pH, specific conductance, turbidity, temperature, and dissolved oxygen.

Two observation wells will be drilled into the zone of fresh groundwater. Groundwater samples will be collected each month. Field and laboratory analyses to be performed on groundwater samples will be the same as for surface waters. Water levels in the observation wells will be reported monthly.

Groundwater and surface-water sample collection, handling, preservation and analysis will be consistent with methods published by the EPA (1974) and USGS (1977).

5.3.1.3 Subsidence

Subsidence baseline studies will include an initial leveling survey to establish relative surface elevations, and an examination of historic leveling data and topographic maps to determine subsidence history in the vicinity of the test well.

The initial leveling survey shall consist of approximately 26.6 km (16.5 miles) of first-order precise leveling. Leveling profiles will be tied to National Oceanic and Atmospheric Administration (NOAA) elevation benchmarks, which are located beyond the area of potential subsidence impact. Procedures to be used in establishing benchmarks in the vicinity of the test well will be in accordance with guidelines provided by the NOAA (1978).

Subsidence monitoring will consist of first-order releveling surveys which will be conducted at 12-month intervals during production to document the occurrence of land-surface subsidence, if any, near the well site or of differential surface movement along reactivated faults. First-order releveling is planned during the second-year environmental monitoring program and is not considered in the base scope of work for this proposal.

5.3.1.4 Seismicity

Microseismic surveys will be performed (1) to determine background microseismic activity prior to disturbance from fluid production and (2) to monitor microseismic activity during fluid production. Baseline microseismic studies will include an initial reconnaissance survey to determine sources and levels of background microseismic activity. Data from this survey will be used to identify locations for permanent monitoring installations which will be least influenced by natural and cultural background noise.

Continuous microseismic monitoring will be performed using seismometers emplaced in sealed boreholes about 1.2 m (4.0 ft) below ground surface. Microseismic monitoring studies will provide the origin time of local seismic events, their estimated locations, and their relative magnitudes. The microseismic monitoring net will be operative approximately six months prior to fluid production.

5.3.1.5 Ecosystem quality

Baseline ecological studies will rely on existing published and unpublished data to establish ranges and populations of plant and animal species in the vicinity of the test well. Additional biological surveys will be conducted in the event of significant impacts to plant or animal life but are not considered as part of the base scope of this work.

5.3.2 Environmental program management

The management of environmental monitoring will include ensuring that data collected are compiled, analyzed, and reported to DOE on a quarterly basis, or more frequently, if necessary. The DOE contractor will provide for contractual arrangements with firms for performance or selected field and laboratory studies. Overall data interpretation and impact assessment will be performed by the DOE contractor. The DOE contractor will also be responsible for determining whether Federal, state, and local environmental quality standards are being met and will inform DOE in the event of noncompliance as well as when an increase or decrease in baseline monitoring studies are required, justifying such changes in scope as they occur.

This Environmental Monitoring Plan outlines a one-year program of combined environmental monitoring and baseline studies. The DOE contractor will prepare a quarterly status reports, including data summaries, and an annual report summarizing the results obtained during the first year. Based on analysis of the data, on the development of the test well, and on Federal, state, and local regulations, DOE will develop a second-year plan for continuing air quality, water quality, subsidence and microseismic monitoring studies.

REFERENCES FOR SECTION 5

EPA. 1974. *Methods for Chemical Analysis of Water and Wastes*, EPA 625/6-74-003A, Environmental Monitoring and Support Laboratory, Environmental Research Center.

EPA. 1978. *Reference or Equivalent Methods for Air Quality Monitoring U.S. Environmental Protection Agency, Monitoring and Research Laboratory*, Research Triangle Park, North Carolina.

Gustavson, T. C. et al. 1977. *Ecological Implications of Geopressured-Geothermal Energy Development Texas-Louisiana Gulf Coast Region*, FWS 10 BS-78/60, U.S. Fish and Wildlife Service, U.S. Department of the Interior.

NOAA. 1978. *Specifications to Support Classification, Standards of Accuracy, and General Specifications of Geodetic Control Surveys*, National Oceanic and Atmospheric Administration, Washington, D.C.

USGS. 1977. *Recommended Methods for Water Data Aquisition*, U.S. Geological Survey Department of Interior, Washington, D.C.

6. COORDINATION WITH STATE, LOCAL, AND REGIONAL GOVERNMENTS

6.1 FEDERAL REGULATION AND PERMITTING REQUIREMENTS

Oil and gas operations, as well as geothermal activities, are subject to regulations at the Federal and state levels of government. A summary of existing policies, regulations, and permitting requirements at Federal, state, and local levels is presented in DOE/EA-0023, Appendix C (DOE 1978).

6.1.1 Geothermal leasing on Federal lands

The following Federal lands are removed from geothermal leasing by Congress: national parks, national recreation areas, fish hatcheries, wildlife refuges, wildlife ranges, game ranges, wildlife management areas, waterfowl production areas, land acquired or reserved for the protection and conservation of fish and wildlife that are endangered, and tribally or individually owned Indian trust or restricted lands, within or outside the boundaries of Indian reservations (DOE 1978).

The Bureau of Land Management is the agency responsible for the leasing of mineral resources in the states of Texas and Louisiana.

6.1.2 Degradation of the environment

Several existing Federal programs regulate some aspect of activities which have the potential to adversely affect the environment (Table 6.1). Discharging effluents into U.S. waters and releasing pollutants into the air require a permit from the EPA. Under the Safe Water Drinking Act (SWDA), EPA also has regulatory jurisdiction over injection wells. There are also Federal land use programs which regulate and control impacts to park and recreation areas in the vicinity of oil, gas, and geothermal activities.

6.1.3 Activities on navigable waters

Any development activities in areas under the definition of navigable waters and unprotected flood areas require a permit from the U.S. Army Corps of Engineers. The Coast Guard also requires permits for certain construction developments over navigable waters and tidal wetlands (DOE 1978).

Several Federal programs control geothermal resource development activities such as the Non-Nuclear Energy Research and Development Act of 1974 (Public Law 93-557, 88 Stat. 1878) and the Geothermal Energy Research Development and Demonstration Act of 1974 (Public Law 93-410, 88 Stat. 1079).

There are several Federal acts and programs which provide for the protection of historic and prehistoric sites, buildings, and monuments which might be adversely affected by a proposed development activity. Federal guidelines and procedures should be taken into account when undertaking federally required cultural resource surveys.

6.2 STATE PLANS AND POLICIES

Regulations and permitting procedures in the states of Louisiana and Texas regarding oil, gas, and geothermal resources development are briefly outlined in Table 6.2.

6.2.1 State land use plans

In Louisiana, the Register of State Lands may lease any public lands belonging to the state. Leases from school board lands can be obtained from the appropriate agency.

Table 6.1. Matrix of Federal actions on geopressure-geothermal well testing activities and related oil activities

Federal agency	Coastal construction activities	Navigable waters	Mineral leasing on public lands, O.C.S.	Oil, gas, other mining leases, permits, and other activities management programs	Dredging and filling Disposal of dredge material	Activities on marine sanctuary-coastal zones	Noise and air emissions	Effluent discharge, water quality, and water resources	Oil pipelines (interstate)	Fish and wildlife resources	EIS review	Historic sites buildings and objects national register
Bureau of Land Management (Department of the Interior)			*a*	*b*							*c*	
Bureau of Outdoor Recreation (Department of the Interior)											*c*	
U.S. Army Corps of Engineers	*a,b*	*a,b*			*a b*				*a,b*		*c*	
Department of Commerce Coast and Geodetic Survey, NOAA	*a,b*					*a,b*					*c*	
Environmental Protection Agency		*a,b*			*a b*		*a,b*	*a,b*			*c*	
Federal Power Commission									*a,b*			
Geological Survey			*a*	*b*							*c*	
Interstate Commerce Commission									*a,b*			
U.S. Coast Guard	*a,b*	*a,b*								*b*	*c*	
U.S. Fish and Wildlife Service (Department of the Interior)				*b*	*b*					*a,b*	*c*	
Water Resources Council								*b*			*c*	
Department of Energy			*a*	*b*							*c*	
Advisory Council on Historic Preservation											*c*	*a,b*

[a] Agency requires permits.
[b] Agency has rules and regulations applying to action.
[c] Agency reviews EIS and EA or reviews applications.

Table 6.2. Matrix of state actions on geopressure-geothermal well testing activities and related oil activities

State agency	Coastal activities (CZMP)	Mineral leasing of state public lands	Geothermal leasing of state public lands	Public land rights-of-way	Activities on scenic rivers and streams	Oil, gas, and geothermal regulations Geological or geophysical exploration	Effluents discharge (oil, gas, and geothermal) Water quality	Air emissions	Brine disposal	Fish and wildlife resources	Dredging and filling activities	Activities in, on, or around archaeological landmarks and cultural resources	Permit reviews and/or EIS review
Louisiana													
State Land Office		*a,b*	*a,b*	*a,b*							*a,b*		
Louisiana Wildlife and Fisheries Commission		*b*			*a,b*		*a b*						*c*
Louisiana Stream Control Commission							*a b*		*b*		*b*		*c*
Louisiana State Planning Office Coastal Zone Management Program	*b*												
Department of Conservation						*a b*			*a,b*		*b*		
Louisiana Archaeological Survey and Antiquities Commission												*a,b*	*c*
Louisiana Air Control Commission								*a,b*					*c*
Louisiana Department of Health							*a b*	*a,b*					
State Mineral Board		*a,b*	*a,b*			*a b*							
Department of Urban and Community Affairs													*c*
Texas													
Texas General Land Office	*b*	*a,b*		*a,b*									
School Land Board	*a,b*		*a*	*a,b*									
Texas Park and Wildlife Department	*b*				*b*		*b*		*b*		*a,b*	*c*	
Texas Railroad Commission						*a b*	*a b*		*a,b*				

Table 6.2 (continued)

State agency	Coastal activities (CZMP)	Mineral leasing of state public lands	Geothermal leasing of state public lands	Public land rights-of-way	Activities on scenic rivers and streams	Oil, gas, and geothermal regulations Geological or geophysical exploration	Effluents discharge (oil, gas, and geothermal) Water quality	Air emissions	Brine disposal	Fish and wildlife resources	Dredging and filling activities	Activities in, on, or around archaeological landmarks and cultural resources	Permit reviews and/or EIS review
Texas Water Quality Board[d]							a b		b			c	
Texas Water Development Board[d]							b		b			c	
State Department of Health Resources							b		b			c	
Texas Antiquities Committee												c	a,b
Texas Air Control Board								a,b				c	
Office of the Governor												c	
Texas Water-Well Drillers Board											a,b	c	

[a]Agency requires permits.
[b]Agency has rules and regulations applying to action.
[c]Agency reviews EIS and EA or reviews applications.
[d]These two agencies plus the Texas Water Rights Commission have become the Texas Department of Water Resources.

In the state of Texas, the General Land Office and the School Land Board regulate activities which take place on the public free school lands of Texas, including coastal public lands.

6.2.2 Coastal zone management plans

Neither the state of Texas nor the state of Louisiana has instituted a Coastal Zone Management Program (CZMP) approved by the Secretary of Commerce.

6.2.3 State well-drilling procedures

In the state of Texas, the Texas Railroad Commission is the agency which regulates and issues permits regarding oil, gas, and geothermal energy developments. Coordinating agencies are the Texas Department of Water Resources, the Texas Parks and Wildlife Department, and the State Health Department.

In the state of Louisiana, the Department of Conservation, Louisiana Geological Survey, is the main regulatory agency for activities concerning oil and gas developments.

6.2.4 State archaeological and historic survey requirements

Both Texas and Louisiana have set standards for cultural resources surveying in compliance with Federal regulations.

6.2.5 State environmental requirements — waste fluid disposal

6.2.5.1 Surface and subsurface permitting procedures at the state level

In the state of Texas, the Texas Department of Water Resources and the Texas Railroad Commission (TRRC) regulate and issue permits regarding waste fluid disposal in association with geothermal resources and with the production of oil and gas. The Environmental Protection Agency regulates and issues permits at the Federal level. Brine disposal associated with oil, gas, and geothermal activities requires a permit from the TRRC, Oil and Gas Division, which also grants permits for fluid injection into a productive oil, gas, or geothermal reservoir.

In Louisiana, the agency regulating brine disposal is the Department of Conservation, Louisiana Geological Survey, Oil and Gas Division.

6.2.5.2 Air emission regulatory and permitting procedures at the state level

The primary regulatory agency in the state of Texas is the Texas Air Control Board (TACB). In the state of Louisiana, the Louisiana Air Control Commission administers regulations concerning air emissions.

6.3 REGIONAL AND LOCAL PLANS AND POLICIES

Regional planning commissions in the states of Texas and Louisiana, as well as local planning bodies, exercise controls and have rules and regulations which apply to their particular regional or local area.

For more detail on the subject and for a list of regional and local agencies contacted and their views and comments, see DOE document DOE/EA-0023, Appendix C (DOE 1978).

REFERENCES FOR SECTION 6

DOE. 1978. *Environmental Assessment Geothermal Energy Geopressure Subprogram, Gulf Coast Well Testing Activity, Frio Formation, Texas and Louisiana*, DOE/EA-0023, Vols 1 and 2.

Appendix A

RARE AND ENDANGERED PLANTS AND ANIMALS IN TEXAS AND LOUISIANA WHICH MAY OCCUR IN THE WILCOX GEOPRESSURED ZONE

Table A.1. Rare and endangered plants native to Texas that may occur in the Wilcox geopressured corridor

Species (genera)	Common name	Known habitat	County distribution in Texas
Atriplex klebergorum (Chenopodiaceae)	Kelbert's saltbrush	Saline flats; clay soil	Webb, Kleberg
Bartonia texana (Gentianaceae)	Texas screwstem	Forested hills on sphagnum moss along stream	Tyler
Calliandra biflora (Fabaceae)		Pasture; brackish soil in sand along fences; prairie	De Witt, Goliad
Dyssodia tephroleuca (Asteraceae)		Sandy soil; grass-brushland	Starr, Zapata
Eriocaulon kornickianum (Eriocaulaceae)	Pipewort	Sphagnum bog; wet, sandy areas in open woods	Hardin, Tyler, Brazos
Frankenia johnstonii (Frankeniaceae)		Saline flats and rocky gypseous hills	Starr, Zapata
Grindelia oolepsis (Asteraceae)	Gumweed	Clay, clay-loam, low black clay	Bee, Cameron, Nueces, San Patricio
Hymenoxys texana[a] (Asteraceae)	Texas bitterweed	Sandy soils	Harris
Machaeranthera aurea[b] (Asteraceae)		Low prairies	Harris
Opuntia strigil var *flexospina* (Cactaceae)	Prickly pear	Dry, gravelly hills; limestone soils	Webb
Paronychia congesta (Caryophyllaceae)	Whitlow-wort	Rocky slopes of breaks	Jim Hogg
Paronychia maccarti (Caryophyllaceae)	McCart's Whitlow-wort	Hard packed, brick-red sand	Webb
Phlox nivalis subsp. *texensis* (Polemoniaceae)	Phlox	Pinelands	Hardin, Polk, Tyler
Physostegia correllii (Lamiaceae)	Correll's false dragonhead	Sandy silt along streams	Zapata, Val Verde
Schoenolirion texanum (Liliaceae)	Sunnybell	Moist prairies	Austin, Hardin, Walker, Waller, Brazos
Sedum texanum (Crassulaceae)	Stonecrop	Clay soils, dry soils; marsh; sand flats	Cameron, Nueces, Webb, Kleberg, Starr

[a]Probably extinct.
[b]May be extinct.
Source: Rare Plant Study Center, Austin, Tex.

Table A.2. Rare and endangered animals in Texas that may occur in the Wilcox geopressured zone

Name	TOES[a]	TPWD[b]	USFWS	Range in Texas	Preferred habitat	Reasons for status
				Amphibians		
Rio Grande siren (*Siren intermedia texana*)	T[d]	T	NL[e]	South Texas	Ponds, canals, swamps	Drainage, clearing, pollution
Mole salamander (*Ambystoma talpoideum*)	P[f]	T	NL	Central east Texas	Lowland burrows in woodlands	Lumbering, drainage, urbanization
Black-spotted newt (*Notophthalmus m. meridionalis*)	P	T	NL	South Texas	Ponds, lagoons, swamps	Drainage, clearing, pollution
Mexican burrowing toad (*Rhinophrynus dorsalis*)	P	T	NL	Starr and Zapata counties	Moist, loose-soil burrows	Restricted range, clearing, drainage
Houston toad (*Bufo houstonensis*)	E[g]	E	E	Southeast Texas (endemic)	Sandy soil, loblolly pine woodlands	Urbanization, lumbering, hybridization
Giant toad (*Bufo marinus*)	P	T	NL	Hidalgo, Starr, and Zapata counties	Riparian areas, resacas	Drainage, clearing
				Reptiles		
American alligator (*Alligator mississipiensis*)	T	E	E, T	Southeast third, coast	Marshes, swamps, rivers, lakes	Habitat destruction, commercial exploitation
Texas tortoise (*Gopherus berlandieri*)	T	T	NL	South Texas	Brush country, native rangeland	Habitat destruction, commercial exploitation
Reticulate collared lizard (*Crotaphytus reticulatus*)	T	T	NL	Western south Texas	Brush country	Habitat destruction, moderate collecting pressure
Texas horned lizard (*Phrynosoma cornutum*)	T	T	NL	Statewide	Open, flat terrain with sparse, scattered vegetation	Heavy pesticide use, commercial exploitation
Texas indigo snake (*Drymarchon corais erebennus*)	P	T	NL	South Texas	Brush country, native rangeland	Habitat destruction, commercial exploitation
Mexican milk snake (*Lampropeltis triangulum annulata*)	T	T	NL	Central and south Texas	Brush country, native rangeland	Brush clearing, commercial exploitation
Louisiana milk snake (*Lampropeltis triangulum amaura*)	T	T	NL	East Texas	Loose soils	Habitat destruction, commercial exploitation
Northern cat-eyed snake (*Leptodeira s. septentrionalis*)	P	T	NL	South Texas	Subtropical woodlands, brush country	Pesticide use, clearing, overcollection

Table A.2 (continued)

Name	TOES[a]	TPWD[b]	F&WS[c]	Range in Texas	Preferred habitat	Reasons for status
				Birds		
Swallow-tailed kite (*Elanoides forficatus*)	T	T	NL	Eastern half of state	Open woodlands	Indiscriminate shooting, lumbering
Bald eagle (*Haliaeetus leucocephalus*)	E	E	E	Statewide	Lakes, reservoirs, large rivers	Pesticides, indiscriminate shooting
Golden eagle (*Aquila chrysaetos*)	T	NL	NL	Statewide	Mountains, hilly country	Indiscriminate shooting
Peregrine falcon (*Falco peregrinus*)	E	E	E	Statewide	Coastal zone, lakes, mountains	Pesticides, nest robbing by falconers
Prairie falcon (*Falco mexicanus*)	T	NL	NL	Statewide, except extreme east	Open country of arid areas	Pesticides, nest robbing by falconers
Merlin (*Falco columbarius*)	T	NL	NL	Statewide	Open country	Pesticides
Attwater's prairie chicken (*Tympanuchus cupido*)	E	E	E	Coastal zone	Coastal prairies	Overgrazing, agriculture
Red-cockaded woodpecker (*Dendrocopus borealis*)	E	E	E	East of Trinity River	Mature open pine forest	Lumbering
Ivory-billed woodpecker (*Campephilus principalis*)	E	E	E	Big Thicket region	Mature hardwood river-bottom forests	Lumbering
				Mammals		
Black bear (*Ursus americanus*)	T	NL	NL	Big Bend, Guadalupe Mountains, southern Texas	Montane, broken country, woods, brush, forest habitat	Habitat destruction, predator control, hunting
River otter (*Lutra canadensis*)	T	NL	NL	Trinity River and eastward	Marshes, rivers, or streams	Trapping pressure, habitat destruction, drowning in fish traps
Ocelot (*Felix pardalis*)	E	E	E	Lower Rio Grande Valley	Subtropical woodland	Habitat destruction, predator control, hunting, trapping

[a]TOES – Texas Organization for Endangered Species.
[b]TPWD – Texas Parks and Wildlife Department.
[c]USFWS – U.S. Fish and Wildlife Service.
[d]T – Threatened.
[e]NL – Not listed.
[f]P – Peripheral, that is, endangered or threatened in the United States especially in Texas, although not in its range as a whole.
[g]E – Endangered.
Source: Texas Organization for Endangered Species, 1979.

Table A.3. Rare and endangered animals in Louisiana that may occur in the Wilcox geopressured zone

Name	Federal status	Range/habitat
	Reptiles	
American alligator (*Alligator mississippiensis*)	Threatened	Entire state, threatened (similarity of appearance) in Cameron, Vermilion, and Calcasieu parishes
	Birds	
Bald eagle (*Haliaeetus leucocephalus*)	Endangered	Entire state, especially Morgan City and Toledo Bend area
Peregrine falcon (*Falco peregrinus tundrius*)	Endangered	Near gulf; migrants
Bachman's warbler (*Vermivora bachmanii*)	Endangered	Swampy areas; very rare
Ivory-billed woodpecker (*Campephilus principalis*)	Endangered	Virgin hardwood forests, swamps; probably extinct
Red-cockaded woodpecker (*Dendrocopus borealis*)	Endangered	Entire state, in longleaf and other pines
	Mammals	
Eastern cougar (*Felis concolor cougar*)	Endangered	Entire state, forested areas; associated with deer populations
Red wolf (*Canis rufus*)	Endangered	Cameron and Calcasieu parishes; marsh

Table A.4. Threatened, endangered, or possibly extinct vascular plants in the Wilcox geopressured zone of Louisiana

Taxa	Common names	Distribution	Comments
Lindera melissifolia (Lauraceae)	Spicebush, Jove's fruit	Statewide; swamps, pond margins	A possible species interpretation of limited acceptance
Habenaria leucophaea (Orchidaceae)	Prairie orchid, Prairie white-fringed orchid	Statewide (?); wet prairie, open swamps, wet pine flatlands	Local, sporadic, rare; flowers very fragrant
Habenaria integra (Orchidaceae)	Southern yellow orchid	West and southwest Louisiana; savannas, wet pine flatlands, barrens, prairies	Very rare, nearly extinct
Sarracenia psittacina (Sarraceniaceae)	Parrot's pitcher	St. Tammany Parish	Threatened, habitat endangered by human encroachment
Coreopsis intermedia (Compositae)	Tickseed	Statewide; rich hardwood lands, open woods and borders, sandy prairies, dry slopes, low ground	A compositae, ray flowers, mostly yellow or particolored, rarely purple

Source: Louisiana Department of Natural Resources, Office of Forestry.

Appendix B

BIOLOGICAL TOXICITY OF EFFLUENTS

Appendix B

BIOLOGICAL TOXICITY OF EFFLUENTS

B.1 TOTAL DISSOLVED SOLIDS

The high concentration of total dissolved solids (TDS) combined with the high temperatures (150-260°C) of geopressured fluids has the potential to affect organisms adversely. The most obvious detrimental effect on aquatic organisms exposed to high concentrations of dissolved solids is impairment of osmoregulatory functions. Direct effects would be manifested as death to the organism, and indirect effects could occur through increased metabolic activity and decreased growth.

Most estuarine organisms are euryhaline and, if adapted slowly, can withstand high salinities (kinne 1967). The rate at which salinity fluctuations occur is, therefore, an important factor influencing the magnitude of biological effects related to effluent releases. Eggs and larvae of teleost fish are more susceptible to salinity variations than are adults because of the absence of fully developed osmoregulatory organs such as gills and kidneys (Gustavson et al. 1977). Since high salinities (>35 ppt) are detrimental to the eggs of most teleost fish, large salinity changes could have drastic effects in areas where nurseries are located (May 1975; Lasker, Tenaza, and Chamberlain 1972; Gustavson et al. 1977). In addition, the spatial distribution of salinity within estuaries is an important factor in the early life history of many estuarine species. Van Sickle et al. (1976) found that increased salinities in Barataria Basin, Louisiana, have provided for inland movement of oyster populations. This movemenet could be detrimental as encroaching levels of pollution intrude seaward (Gustavson et al. 1977). Hoese (1967) reported that in Texas bays the young of blue crab and white shrimp populations require low salinities for normal development. Oysters require low salinities for the exclusion of predators, such as the oyster drill, which occur in higher salinity habitats. The salinity tolerances and preferences for some estuarine and marine species common to the coastal Frio areas of Texas and Louisiana are given in Table B.1. The salinities at which these tolerances and preferences occur are lower than the salinity (TDS = 74,000 ppm) of geopressured fluids.

Another important factor to consider in relation to the ecological effects of high TDS is the synergistic interaction of salinity and temperature. The effect on organisms of salinity and temperature acting together may be different from the additive effects of temperature and salinity, separately. The percent mortality of young estuarine crabs exposed to varying concentrations of temperature and salinity is shown in Fig. B.1. Mortality is highest at the lower salinities and higher temperatures; these mortality patterns would probably be different if the effects of temperature and salinity were examined separately. May (1975) also demonstrated the synergistic effects of temperature and salinity on the eggs and larvae of the Gulf Croaker (*Bairdiella icistia*).

The magnitude of impacts resulting from high salinities (TDS) could be greater in freshwater than estuarine ecosystems because freshwater organisms are generally not adapted to high and varying salinity regimes. However, the magnitude of impacts resulting from large TDS releases could be greater for estuarine systems because of the large number of young fish and shellfish that inhabit estuarine systems. As mentioned previously, these young are not functionally adapted to cope with unnatural extremes in salinity variations. Effluents released to aquatic systems would tend to sink, therefore affecting benthic organisms. Effects on mobile organisms, such as fish and crabs, would be less severe since these organisms could avoid affected areas.

B.2 BORON

Boron levels in geopressured fluids can occur at up to 100 times the maximum concentration suggested by EPA (1976) for irrigation of sensitive crops (see Table 1.3). Although essential to plant growth, boron can be toxic at concentrations slightly above optimum. Concentrations not exceeding 1 and 3 ppm are recommended for irrigating boron-sensitive and boron-tolerant crops, respectively (White, McGraw, and Gustavson 1978). Boron in solution at concentrations greater than 1.5 ppm is toxic to plants, although 3- and 5-day LC_{50} values for fish range from 3.16 to 52 ppm, respectively (Thurston and Russo 1975). A boron concentration of about 400 ppm

Table B.1. Salinity ranges at which some common coastal animals of Texas and Louisiana occur and their preferences

Species	Common name	Salinity range (ppm)		
		Low	High	Preference
Menippe mercenaria	Stone crab		35,000	
Rangia cuneata	Marsh clam	0	24,900	
Crassostrea virginica	American oyster	10,000	30,000	
Thais haemastoma	Oyster drill	1,700	25,900	>15,000
Panaeus setiferus	White shrimp	25,000	45,000	<45,000
		0	30,000	
		15,000	30,000	
Penaeus duorarum	Pink shrimp		69,000	
		15,000	25,000	
Penaeus aztecus	Brown shrimp	0	69,000	
		15,000	28,000	
Palaeomonetes vulgaris	Grass shrimp	25,000	45,000	<45,000
Palaeomonetes pugio	Grass shrimp	25,000	45,000	
Palaeomonetes intermedius	Grass shrimp	20,000	60,000	
Callinectes sapidus	Blue crab	20,000	60,000	
Brevoortia patronus	Large-scale menhaden	20,000	60,000	
		500	54,300	
Dorosoma cepedianum	Gizzard shad	100	41,300	
Anchoa mitchelli	Bay anchovy		80,000	<50,000
		6,000	30,000	
Cyprinodon variegatus	Sheepshead minnow	5,000	75,000	
		5,000	28,000	
Cynoscion arenarius	Sand trout		45,000	<45,000
		15,000	26,000	
Cynoscion nebulosus	Spotted sea trout	25,000	75,000	<60,000
		19,000	27,000	(young)
Leiostomus xanthurus	Spot		60,000	<50,000
		8,000	27,000	
Micropogon undulatus	Atlantic croaker		70,000	
		15,000	30,000	
Mugil cephalus	Striped mullet	1,400	75,000	<45,000
		15,000	27,000	(spawn)
Mugil curema	White mullet	25,000	50,000	<40,000
		25,000	30,000	

Source: Gustavson et al., *Ecological Implications of Geopressured-Geothermal Energy Development, Texas–Louisiana Gulf Coast Region*, U.S. Fish and Wildlife Service, Office of Biological Services, FWS/OBS-78/60, 1977.

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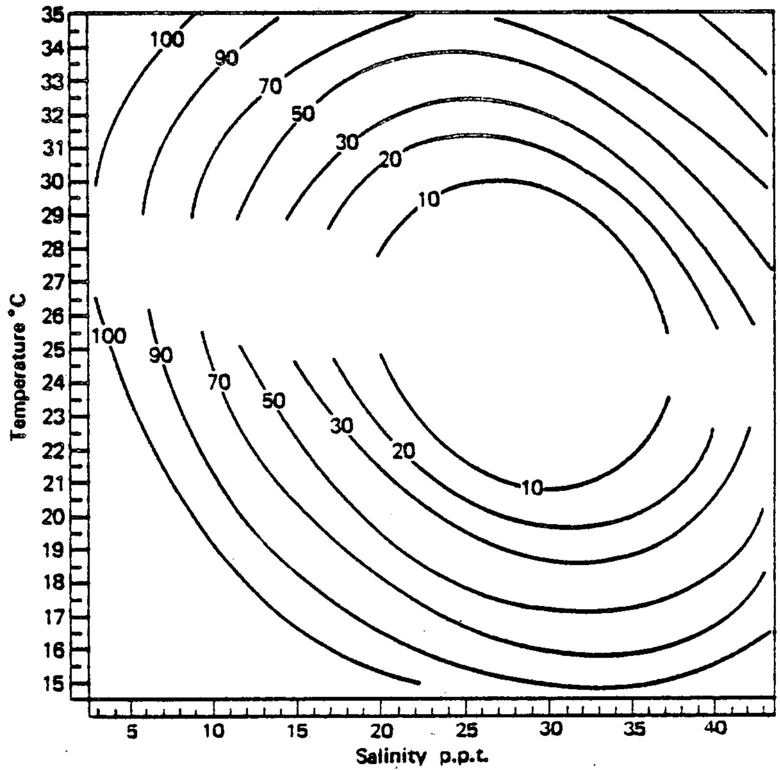

Fig. B.1. Estimate of percent mortality of first stage zoeae of *Sesarma cinereum* based on fitted response surface to observed mortality determined at 12 temperature-salinity combinations. Source: J. D. Costlow, C. G. Bockout, and R. Monroe, "The Effect of Salinity and Temperature on Larval Development of *Sesarma Cinereum* (Bosc) Reared in the Laboratory," *Bio. Bull.* 118: 183-202 (1960).

has been reported as the 48-h LC_{50} for rainbow trout (Cushman et al. 1977). Some data indicate the occurrence of chronic effects on aquatic plants and invertebrates at boron concentrations of <100 ppm (Cushman et al. 1977). Some effects on aquatic organisms, therefore, may occur within the range of boron concentrations (1-91 ppm) reported for geopressured fluids (Table 1.3).

The effects of boron on freshwater ecosystems (Wilcox area) should be greater than on coastal ecosystems (Frio area) because of the lower concentrations of boron in natural freshwater systems. According to Becker and Thatcher (1973), however, pH should not have an effect on boron toxicity.

B.3 AMMONIA

Ammonia is potentially the most biologically toxic substance in geopressured fluids. Kharaka, Callender, and Wallace (1977) found ammonia (NH_3) in geopressured fluids to range from 5.6 to 26 ppm. The minimum value of un-ionized ammonia considered toxic by the EPA (1976) is 0.2 ppm; the concentration recommended for protection of freshwater organisms is 0.02 ppm.

Ammonia exists in water in either the ionized (NH_4^+) or the biologically toxic un-ionized form. The toxicity of a given amount of total ammonia to aquatic animals depends on pH, oxygen, CO_2, and temperature (Burkhalter and Kaya 1977, Emerson et al. 1975). For each unit increase in pH, if total ammonia remains constant, the fraction of un-ionized ammonia increases by a factor of 10 (Burkhalter and Kaya 1977). Various physiochemical characteristics of geopressured effluents may influence the biological toxicity of ammonia when it is released into surface waters. The pH of effluents tested by Kharaka, Callendar, and Wallace (1977) ranged from 5.2 to 6.8. Most freshwater systems are generally neutral or slightly acid, and estuarine or seawater systems are slightly alkaline, ranging from pH 7.0 to 8.0. When effluents are discharged into alkaline surface waters, therefore, the relative fraction of un-ionized ammonia in solution will increase. Less un-ionized ammonia will be formed with the discharge into freshwater systems because of the lower pH. For example, at 20°C, the amount of NH_3 in aqueous solution at a pH of 6.0 (freshwater system) is 0.04%; at a pH of 7.5 (estuarine system) the percentage is 1.24% (Emerson et al. 1975).

Temperature also has a slight effect on the percent of un-ionized NH_3 in solution. As temperatures increase, the percent of NH_3 in solution increases. The significance of this is especially pertinent because of the high temperatures of geopressured effluents.

Ammonia (NH_3) in relatively low concentrations has been found to be toxic to aquatic organisms. Burkhalter and Kaya (1977) found that NH_3 levels of 0.05 ppm affected early growth of trout fry, although the incipient lethal level for fry was 0.25 ppm. For larger trout, Becker and Thatcher (1973) reported that the lowest 48-h LC_{50} was 0.4 ppm. Most lethal threshold concentrations reported have been in the range of 0.2-4 ppm (Burkhalter and Kaya 1977).

In conclusion, the levels of ammonia (NH_3) found in geopressured fluids (1-25 ppm) are not only higher than EPA standards but range up to 130 times the lower lethal threshold concentrations reported for fish. Effects of ammonia may be of special concern when effluents are discharged into high pH coastal waters. In addition, the high temperatures associated with geopressured fluids may contribute to ammonia toxicity.

For ammonia (and the other potentially toxic constituents of geopressured fluids), the impact on aquatic ecosystems will depend primarily on the mixing and dilution rates of the aquatic system and is therefore a site-specific consideration.

B.4 HYDROGEN SULFIDE (H_2S)

Hydrogen sulfide concentrations range from 1.0 to 3.5 ppm in geopressured fluids (Table 1.3). A criterion of 0.002 ppm undissociated H_2S is recommended by the EPA (1976) for protection of aquatic organisms. Smith and Oseid (1972) found that the survival of Walleye fry decreased from 86% at 0.012 ppm H_2S to 10% at 0.059 ppm H_2S.

The toxicity of H_2S to organisms increases with decreasing pH; therefore, the relative impacts of H_2S to aquatic fauna should be greater in freshwater systems, which generally have lower pH than estuarine systems.

Because of the initially high temperature of geopressured fluids, however, dissolved H_2S is likely to be flashed off with steam and may not enter aquatic systems except under spill situations.

B.5 TRACE ELEMENTS

Many dissolved trace elements in geothermal fluids are potentially hazardous to aquatic life (Cushman et al. 1977). Copper, zinc, lead, magnesium, and manganese are usually found in geopressured fluids (Table 1.3). Cushman, Barnes, and Craig (submitted) have presented a detailed discussion on the environmental effects of these and other trace elements. Besides being directly toxic to aquatic life, these elements may accumulate in sediments and in the food chain. As with other constituents of geopressured fluids, the concentrations of elements present in fluids vary greatly, and the nature and magnitude of aquatic impacts will also vary according to the chemical, physical, and ecological characteristics of the aquatic system receiving the effluents.

B.6 HYDROLOGIC CONSIDERATIONS

Ultimately, the magnitude of the impacts incurred by an aquatic system from released geopressured fluids into the environment depends primarily on the hydrologic nature of the system and, in particular, on the mixing and dilution rates of the geopressured fluids. Mixing and dilution rates will vary from system to system. An estuarine marsh ecosystem at the upper reaches of tidal influence and subject to low freshwater inflows will have much lower dilution rates than large, fast flowing rivers.

In order to predict the distribution and ultimate fate of geopressured effluents released into the environment from a point source, hydrodynamic and pollutant transport modeling should be undertaken on a site-specific basis. The final product of the hydrodynamic and transport modeling for each system should be the construction of a concentration-frequency of occurrence curve (probability curve) that predicts the probability (percentage of the total time) of occurrence of various concentrations of effluents in various areas of the aquatic system. Such a curve is generated from combinations of water flushing, freshwater inflows into the system, and effluent quantity releases. For example, in coastal marsh and estuarine habitats, the worst-case condition would occur during a major blowout and when freshwater inflow and tidal flushing are minimal. Conditions would be far less dangerous if small pipe leaks or small amounts of effluents escaped into the environment during maximum freshwater inflow and tidal flushing.

Information on the hydrodynamic flow regimes and construction of the concentration-probability curves is needed in order to (1) predict the spatial-temporal distribution of the effluent in the receiving system, (2) indicate the realistic ranges of toxicants that may occur in the receiving ecosystem so that these concentrations or ranges of concentrations can be tested in bioassay and experimental field studies, (3) indicate particular areas of the aquatic environment or ecological communities that have the greatest potential to be affected by effluent release, and (4) aid in management decisions concerning acceptable levels of effluent that may be released into the environment.

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Appendix C

SITE-SPECIFIC ENVIRONMENTAL INFORMATION CHECKLIST
GEOPRESSURED-GEOTHERMAL WELL TEST PROGRAM

APPENDIX C

SITE-SPECIFIC ENVIRONMENTAL INFORMATION CHECKLIST
GEOPRESSURED-GEOTHERMAL WELL TEST PROGRAM

A. GENERAL

1. Is the proposed site located in the area covered by the "Gulf Coast Programmatic Environmental Assessment, Geothermal Well Drilling and Testing, the Frio, Wilcox, and Tuscaloosa Formations of Texas and Louisiana," July 1979? Yes ____ No ____ If no, explain.
2. Is the well site safely removed from any populated areas that could be threatened by a blowout? Yes ____ No ____ If no, explain.
3. Has a Federal, state, and/or local environmental assessment been conducted previously for the proposed test well or other wells in the area? Yes ____ No ____ If yes, provide a copy, if available.
4. Have all required permits, licenses, and/or agreements for proposed project been obtained? Yes ____ No ____ If no, explain.
5. Does the project site fall within the habitat of state or federally designated rare, threatened, or endangered species? Yes ____ No ____ If yes, explain.
6. Has an archaeological survey been conducted? Yes ____ No ____
7. Are known archaeological sites, historic sites, or natural landmarks within or visible from the site area? Yes ____ No ____ If yes, explain.
8. Is the site on or adjacent to:

   ____ a) State, national park, forest or recreational area?
   ____ b) State or national wildlife management area or refuge?
   ____ c) A sensitive wildlife habitat such as estuary, spawning areas, forested bottomlands, or native prairie?
9. Is the site on or adjacent to land classified as prime or unique farmland? Yes ____ No ____ If yes, describe.
10. Will expected continuous noise levels from site operations be 65 dBA or less at the nearest residence? Yes ____ No ____ If no, explain.

B. SITE CONSTRUCTION OR PROJECT DETAILS

1. Will any existing facilities be utilized for the test well (e.g., drill pad, roads, mud reserve pits, pipeline)? Yes ____ No ____ If yes, describe.
2. Will any existing facilities be utilized for the disposal well(s) (e.g., drill pad, reserve pits, utilities, roads, pipeline)? Yes ____ No ____ If yes, describe.
3. Will the site and related roads be treated to minimize dust? Yes ____ No ____ If no, explain.
4. Are portable sanitary facilities or an approved septic system to be used at the site? Yes ____ No ____ If no, explain.
5. Will liquid and solid wastes be disposed of in accordance with local regulations? Yes ____ No ____ If no, explain.
6. Will a ring dike be constructed to contain all potential spills (excluding blowout) on site? Yes ____ No ____ If no, explain.
7. Will erosion control be practiced for excavated areas? Yes ____ No ____ If yes, describe; if no, explain.
8. Will there be dredging, and, if so, will dredge spoil be deposited in swamp, forest, or marshland? Yes ____ No ____ If yes, explain.

9. Upon completion of proposed test program, will the site be restored to as natural a condition as possible by regrading, filling, and reseeding? Yes ____ No ____ If no, explain.

C. WELL TESTING AND SAFETY

1. Will all wells be pressure tested before being placed in service? Yes ____ No ____ If no, explain.
2. Is the temperature of produced geopressured fluid expected to be 260°C or less? Yes ____ No ____ If no, explain.
3. Will the gas content of the produced fluid be flared? Yes ____ No ____ If no, explain.
4. Will blowout preventers rated to at least 10,000 psi be used? Yes ____ No ____ If no, explain.
5. Will production tubing rated to at least 20,000 psi be used? Yes ____ No ____ If no, explain.
6. Can safety valves be operated from remote locations? Yes ____ No ____ If no, explain.
7. Will the test tree be rated to at least 10,000 psi? Yes ____ No ____ If no, explain.
8. Will a test well directional survey be conducted? Yes ____ No ____ If yes, at what interval? ____ feet. If no, explain.
9. Will a lined pond or other storage reservoir be used to hold all liquid effluents and production fluids that are not injected? Yes ____ No ____ If no, explain.
10. Has an injection permit been obtained? Yes ____ No ____ If no, explain.
11. Will injection pressure be kept below 0.75 psi/ft of injection depth? Yes ____ No ____ If no, explain.
12. Will production fluid be pretreated prior to reinjection? Yes ____ No ____ If yes, explain.
13. Will H_2S monitors be located onsite? Yes ____ No ____ If no, explain.
14. Will fire extinguishers be located onsite? Yes ____ No ____ If no, explain.
15. Do contingency plans exist for evacuating personnel should a blowout occur or high levels of H_2S be detected? Yes ____ No ____ If no, explain.
16. Will high-pressure engineering and mud-logging personnel be onsite during production well drilling operations? Yes ____ No ____ If no, explain.

D. INFORMATION NEEDS FOR SITE-SPECIFIC ENVIRONMENTAL EVALUATIONS

Listed below is the information required to evaluate environmental impacts for all specific well drilling and testing projects carried out in this program. Some individual projects may require additional information not listed here.

1. Name of prospect and well
2. Location
3. Subsurface characteristics
   a. Producing formation
      (1) Name
      (2) Depth
      (3) Sand thickness
      (4) Temperature, pressure, salinity, permeability, gas/water ratio, H_2S content, if known.
   b. Disposal formation(s)
      (1) Name
      (2) Depth
      (3) Sand thickness
4. Surface characteristics
   a. General land use and vegetation, location of waterways in the area.
   b. Current land use and condition of the site(s).

c. Proximity to residence that might be affected by a blowout.

d. Location of all occupied dwellings within 300 m; location of other structures (e.g., schools, hospitals) which may be affected by project-related noise.

e. Proximity to state or national parks, forests, wildlife management areas or refuges.

f. Location, nature, and extent of any nearby sensitive ecological areas or valuable wildlife habitat such as estuaries, wetlands, floodplains, forested bottomlands, native prairies of spawning, breeding or nesting areas.

g. Location, nature, and extent of nearby land classified as prime or unique farmland by the U.S. Soil Conservation Service.

h. Location, nature, and extent of any archeological sites, historic sites, natural landmarks or unique geological features, within or visible from the site area.

5. Construction

a. Dimensions of well pad, pits, roads, pipelines and ring levees to be constructed.

b. Location and description of any dredging; volume of spoil to be generated; location of spoil disposal site.

c. Erosion control plan.

6. Operation

a. Disposal plan for wastes, including:
   (1) H_2S if necessary,
   (2) methane,
   (3) temporary storage and final disposal of non-injectable liquid and solid wastes,

b. Site restoration plan including revegetation.

c. Contingency plans for blowout.

7. Permits: all required permits planned, applied for, or obtained.