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ANALYSIS OF ENVIRONMENTAL CONSTRAINTS ON EXPANDING RESERVES IN CURRENT AND FUTURE RESERVOIRS IN WETLANDS

Final Report

By
Brian J. Harder

March 1995

Performed Under Contract No. DE-FG22-91MT91004

Louisiana State University
Baton Rouge, Louisiana

Bartlesville Project Office
U. S. DEPARTMENT OF ENERGY
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ABSTRACT

Louisiana wetlands require careful management to allow exploitation of non-renewable resources without destroying renewable resources. Current regulatory requirements have been moderately successful in meeting this goal by restricting development in wetland habitats. Continuing public emphasis on reducing environmental impacts of resource development is causing regulators to reassess their regulations and operators to rethink their compliance strategies. We examined the regulatory system and found that reducing the number of applications required by going to a single application process and having a coherent map of the steps required for operations in wetland areas would reduce regulatory burdens. Incremental changes can be made to regulations to allow one agency to be the lead for wetland permitting at minimal cost to operators. Operators need cost effective means of access that will reduce environmental impacts, decrease permitting time, and limit future liability. Regulators and industry must partner to develop incentive based regulations that can provide significant environmental impact reduction for minimal economic cost.

In addition regulators need forecasts of future E&P trends to estimate the impact of future regulations. To determine future activity we attempted to survey potential operators when this approach was unsuccessful we created two econometric models of north and south Louisiana relating drilling activity, success ratio, and price to predict future wetland activity. Results of the econometric models indicate that environmental regulations have a small but statistically significant effect on drilling operations in wetland areas of Louisiana.

We examined current wetland practices and evaluated those practices comparing environmental versus economic costs and created a method for ranking the practices.

We examined the possible alternative access methods for wetland access and found that while currently cost prohibitive, these methods would provide significant environmental benefits. In the interim, careful planning to account for environmental impacts in all stages of the exploration process can reduce environmental costs for operators. Operator emphasis should be on avoidance rather than mitigation. Future technological innovations such as waste minimization strategies, horizontal drilling, and coiled tubing will lead to reduced environmental impacts and operators' costs.

EXECUTIVE SUMMARY

This report focuses on the regulatory procedures designed to reduce the environmental impacts on the oil and gas industry. Current and proposed regulatory requirements for access to wetland locations in Louisiana are detailed. Ten fields were selected for study that included their geologic and engineering appraisal. Three of the ten were used as case studies to examine wetland impacts from oil and gas operations. Aerial photography and computer-generated mapping were used to create possible scenarios to describe how these fields would be developed in accordance with present regulatory requirements. Estimates of potential future activity occuring in wetlands are developed using econometric methods. Impact avoidance technologies and mitigative methods for reducing wetland impacts along with alternative mitigation options are presented.

Louisiana's wetlands have been the primary area for the development of oil and gas resources in the state. Activity has been concentrated in south Louisiana, but all wetland habitats in the state have been affected by exploration, development, production, and petroleum transportation. This growth has impacted the vast, undisturbed wetland environments and habitats of Louisiana. Wetlands are a very valuable natural and economic resource for the state of Louisiana. Louisiana's economy and culture rely heavily on renewable resources of the coastal zone such as finfish, shellfish, and fur. Louisiana's coastal wetlands produce 33% of the nation's seafood and provide habitats for commercial and sport fisheries. These areas provide significant waterfowl habitat, supporting over five million ducks and geese. Eleven federally listed endangered or threatened species are found in coastal Louisiana wetlands (Lindstedt 1991). Wetland loss is a serious problem in Louisiana, where the natural process of subsidence of deltaic sedimentary deposits coupled with human development activities have caused average loss rates of 30–40 mi^2 (78–104 sq. km) a year between 1956 and 1978 (Gagliano et al. 1979).

Louisiana's intensive petroleum development is concentrated in the coastal areas, and potential deep future discoveries also underlie these areas. The success of this petroleum activity is due to Louisiana's unique geologic, history which is characterized by optimal geological conditions for the formation and trapping of petroleum resources. Gas production from the state totaled 1.527 TCF with an additional 3.3 TCF from federal waters (Energy Information Administration 1992) . These totals represent 9% and 18% of the nation's total gas production, respectively. Estimated reserves for Louisiana in 1991 excluding offshore federal waters are 679 million bbl of crude and 10.9 TCF of gas (Energy Information Administration 1992). Technological advances in three dimensional (3-D) seismic may significantly add to these totals in the coming years.

Over 187,000 wells have been drilled in Louisiana since the Louisiana Department of Conservation began regulating oil and gas activity. This activity has changed the landscape of Louisiana. Future exploration trends will continue to alter the coastal landscape as more wells are drilled in wetland areas of south Louisiana, and

deeper wells in untested areas are attempted. Increased access to these geologically untested and environmentally undisturbed areas of the state will be by-products of this search for additional reserves.

The state developed regulations to prevent waste and later to reduce environmental impacts caused by oil and gas operations. Early regulations were developed to protect drinking water aquifers, to prevent wasteful drilling and production practices, and to conserve resources through a unitization process. In the 1970s the federal government created environmental regulations that were passed through and administered by the state. Since that time the number of permits and permissions (letters of no objection) needed to explore and produce oil and gas in Louisiana has and continues to increase.

New regulations on NOW (non-hazardous waste pits), cuttings disposal, pit closure, NOW commercial disposal sites, produced waters from drilling and production operations and NORM have been promulgated since 1978 in Louisiana. These regulations have added to the compliance burden companies face. Wetland regulation during this time evolved with the creation of the Louisiana coastal zone and resulting agency to oversee operations in this zone. Increased pressure from the Environmental Protection Agency (EPA) requiring more stringent review in the 404 permit process controlled by the U.S. Army Corps of Engineers, and the creation of Nation Pollution Discharge Elimination System (NPDES discharge permit) permitting in the Department of Environmental Quality funded by the federal government, have increased the compliance costs for companies operating in wetland areas of the state. Local governments have attempted to form their own permitting entities to limit development and collect fees from operators; even though, oil and gas operations have been exempted from local control by the Louisiana Legislature.

The permitting process in Louisiana for drilling and production in wetland areas is complex and in this report, a simplified road map for navigation through this system has been provided. This road map shows the major permits required and how the various state and federal agencies interrelate with each other. This road map does not include local permits needed for operations (if they exist) such as occupational licenses or zoning plans, or local waste permits unrelated to oil and gas that may be required by parish or city governments. Parish governments in parishes highly impacted by oil and gas development, including Terrebonne, Lafourche, Plaquemines, and Jefferson parishes, are more likely to require local permits. In addition to the road map, an attempt has been made to quantify the additional economic cost incurred by operators in meeting the existing wetland permitting rules. We found that the minimum additional cost for the first acre permitted in wetlands is $4,745 and that costs could be up to $54,549 for the first acre. Additional costs per acre for mitigation are $300 for processing and from $397 to $14,048 (depending on habitat) for mitigation under the states new proposed mitigation fee schedule. Because a general permit for a land location impacts up to 4.55 acres (1.84 hectares) and a water location from 2.95 to 10.99 acres (1.19 to 4.449 hectares) the additional costs for wetland permitting are significant.

Additional regulations affecting oil and gas operations are currently being envisioned by the federal government. The EPA is developing costly new rules under the Underground Injection Control program for 23 cases (from 1972 to 1989) of aquifer contamination out of 2.4 million wells. New regulatory burdens for this type are unwarranted and unnecessary, and if implemented will reduce overall drilling rates slightly. Another problem exists in how the Minerals Management Service (MMS) created the new rules for complying with the Oil Pollution Act of 1990. The definitions used by MMS in the new rules are so broad that all current and future operations in Louisiana wetlands would be required to have a $150 million certificate of financial responsibility. This is unattainable for all but the largest companies operating in Louisiana. This change could eliminate most oil and gas operations in the state with the resulting catastrophic economic and job losses. State regulators are examining mercury contamination from the manometers used in gas meters. Preliminary studies are underway to define the scope of this problem and if the problem is determined to be significant this could have a further detrimental impact on future operations in wetland areas. Continued refinement and redefinition of existing regulations now cause large increases in compliance cost for little environmental benefit. The Department of the Interior would like to eliminate tax write-offs for intangible drilling expenses in wetlands because of the damage caused by canal dredging. Instead of eliminating the write-off making south Louisiana uncompetitive, they should consider limiting the write-off to technologies that allow access while being less damaging to the environment. This would be an example of incentive-based regulation instead of the current command and control regulations.

Access to wetland areas is the greatest problem faced by companies operating in wetland areas. Access is required for preliminary evaluation activities such as seismic data acquisition and exploratory drilling followed by production and pipeline operations. Current access practices are different for each phase of operations. Marsh buggy (a tracked vehicle) and air boats are used to access wetland areas for seismic work. The environmental impact of this access is significant; although, current regulatory programs have been successful in reducing these impacts while still allowing access. Exploration and production activities impact wetlands by dredging canals forming open water. Dredge and fill activities for board road dumps in marsh areas create uplands. Both means of access significantly damage the current existing ecosystem directly and indirectly; the major impacts include loss of habitat, noise during construction, introduction of toxins to system, changes in plant type and growth, interrupted breeding cycles, decreased water quality, alteration in hydrology, saltwater intrusion, increased flooding, changes in sediment distribution, habitats, soil chemistry and loss of plant material reducing vertical accretion in some areas.

To reduce adverse impacts of a proposed activity mitigative techniques may be employed. Mitigation does not mean restoration or creation of new habitat; although, these activities could be part of a mitigation plan. Mitigation can best be described as a series of steps to a goal with the steps being avoid, minimize and compensate. Avoid the impact if possible, minimize unavoidable impacts and then if necessary compensate for those impacts.

To avoid impacts the most important cost effective tool is to create a site access plan incorporating environmental and cost factors. Then discuss this plan in the preliminary stages with various regulatory and commenting agencies to find areas of concern and areas of acceptance by the various agencies. Review the plan and make the changes requested if feasible or look at alternatives and then submit an application for a permit. This type of planning will reduce the additional cost of wetlands permitting to the minimum possible in most cases. The largest cost savings are achieved by designing operations that completely avoid the need for a wetland permit. If that is impractical, then attempting to qualify for general permit that has set allowed impacts previously reviewed and accepted by the permitting agencies will allow cost savings compared to an individual permit. The present regulatory structure in Louisiana provides incentive for proper planning by requiring the geologic review process which has reduced site size through moving locations and by directional drilling. This process examines lease, geologic and drilling information to determine the least damaging alternative for a proposed location. Another way to reduce costs is a formal internal review and if necessary a pre-application meeting with the regulatory agencies before submission of all applications to highlight problem and areas where additional information is needed. Going through this process is useful before any type of operation is undertaken in wetlands.

Innovation is the key to solving the access problem and for reducing the environmental footprint of operations. Closed-loop systems have already reduced site size and lowered drilling costs in Louisiana. Other managed reserve pit designs have reduced cost where they have been used. Our findings are that adoption of bulk mud transport and storage will in the future reduce costs for the industry and reduce site size needs, thereby reducing environmental impacts.

Directional, horizontal, slim-hole, slant well and coiled tubing drilling are all environmentally less damaging in most cases because the well sites can be outside of critical wetland areas or the footprint needed for operations is substantially less than a conventional drilling operation. Operators should plan to drill a directional well or a horizontal well to avoid disturbing wetland areas and thereby not require a wetland permit. Slimhole reentry and horizontal kick from an existing well site is a cost-effective method of access where permitting and access costs are high. Limited use of slant well rigs to drill extended reach horizontal wells in critical areas might be cost effective, depending on the length of canal needed for access and the type of habitat. Coiled tubing drilling if fully developed will allow wells to be drilled from pads as small as 7,800 ft^2 (0.18 acres or 0.07 hectare) compared to 2.06 acres (0.80 hectare) for a normal ring levee site thereby reducing the cost of compensating for the environmental impacts. The development of coiled tubing operations in the future will potentially be cost effective but, at present, it is almost double the cost of a well compared to conventional drilling.

Three alternative access methods including helicopters, cyclocraft, and hovercraft were evaluated in this study. All methods would significantly reduce the impacts of access to oil and gas sites in wetlands. From a strictly environmental view the least-damaging method was the use of helicopters, followed by cyclocraft and then slightly more damaging was the hovercraft. From our analysis the conclusion reached was that helicopters are technically feasible to use for site access but are not readily available for use. Further, they are economically unfeasible for use in Louisiana costing $168 per ton/per hour when they are in use. The cyclocraft, although significant design work has been completed, has not been tested. Potentially it would be technically feasible to use cyclocraft to transport a drilling rig for access. The economic cost calculated to $70 per ton/per hour. Hovercraft are technically feasible for use as an alternative access method. The economic cost for hovercraft was calculated to be $40 per ton/per hour, which is significantly more expensive than current access using trucks at $2.00 per hour/per ton or barges at $1.00 per hour/per ton. When total well economics including reduced construction costs, no directional drilling, reduced liability, and lower compensation costs are included, a solid case for testing the use of hovercraft as suitable transport emerges. To accurately measure these economic cost savings a hovercraft operation needs to be tried in the field. The environmental benefits of using this system are significant enough to justify this type of field testing.

Various mitigation options were contrasted and ranked by creating a matrix and placing the various options into the matrix. It is suggested that operators and regulators use the matrix to evaluate new and existing methods and strive for techniques that avoid environmental impacts and allow access at minimal economic cost. The final sequence of mitigation is compensation and the new tool is "mitigation banking". Mitigation banking operates like a bank in which money is deposited. The mitigation bank uses the funds to buy wetland areas or to attempt to create new wetlands. For your deposit you receive habitat credits to be used towards compensation for the unavoidable impacts of the project. Mitigation banks that buy additional wetlands appear to be better than banks that attempt to create wetlands. Wetland creation is still a fledgling science and has at present not yielded credible results. Wetland mitigation banking can only be successful, if its role for meeting wetland protection objectives is clearly defined, and if it can serve ecological and economic goals successfully as long as the regulatory climate remains in favor of it. In general mitigation banking as the best method to allow access to wetlands does not appear to be a well-thought-out strategy for either regulators or industry.

In evaluating the possible environmental effects of future enhanced oil recovery activities on the ten fields selected for this study, it was found that in existing fields enough areas have been previously impacted to allow all types of enhanced recovery except South Black Bayou, which is the latest study field discovered. The structure of the field consists of a series of discontinuous small reservoirs trending west to east along the coast, thereby making it an unsuitable candidate for enhanced recovery. After discussions with the technical review committee members it was decided to examine the impacts of three fields and to illustrate how the fields would be developed using existing regulations The fields examined were in this way were Bayou Bleu in Iberia Parish, Jeanerette in St.Mary Parish, Laffite in Jefferson Parish and Paradis in St. Charles Parish.

Using digitized aerial photography and a geographic information system (GIS) we found that in the Bayou Bleu field 147,558 m^2 of wetlands were directly impacted by industry in 1952 along with 2,299,444 m^2 of vegetation that was altered by this direct activity and 280,739 m^2 of human-made waterways. The total human-induced oil and gas impacted area was 2,727,741 m^2 or 3.37% of the total area studied. Other classifications included agriculture 0.27% , undisturbed wetlands 95.09%, and natural open water 2.27% of the total area. By 1990 oil and gas operations impacted 5.32 % of the total area. Agriculture impacted 1.63%, undisturbed wetlands 90.67%, and open water 2.28 % of the total area. Direct impacts from water operations in the southern parts of the field increased significantly in this time period. If development of this field occurred today, directional drilling would be required by the geologic review process, which would have significantly reduced the direct and indirect impacts of the Bayou Bleu field development.

In examining the aerial photography of Jeanerette field, it was found that oil and gas operations in 1956 impacted a total of 310,509 m^2. These impacts are categorized as follows: direct land impacts 33,032 m^2, human-made waterways 128,680 m^2, and altered vegetation 148,797 m^2. The total area studied in Jeanerette field was 183,270,000 m^2 with oil and gas operations impacting 0.17% and agriculture impacting 60.39% of the total area. The rest of the area is represented by remaining undisturbed wetlands 28.77% and natural open water 10.67%. By 1989 these percentages had changed to 0.74% impacted by operations, 63.91% impacted by agriculture, 24.68% undisturbed wetlands, and 10.67% natural open water. Additional wetland losses were caused mostly by conversion to agriculture and not by oil and gas operations in this area. Jeanerette field as was Bayou Bleu, is predominately a land-based operation. Board road impacts on a broad scale did not significantly alter the landscape when compared with other development activities. This field could have been developed using directional wells to minimize wetland impacts. Impacts could have also been reduced by using centrally located multi-well pad locations in wetland areas and through better and more careful planning to avoid those areas.

Lafitte field is not a land-based field and the impacts of its canal infrastructure are much more significant than was seen in the other fields. From aerial photography 57,480,000 m^2 in and surrounding the field was evaluated. It was found that 1956 oil and gas operations impacted 3,590,786 m^2 or 6.25%, agriculture impacted 0.23%, undisturbed fresh marsh occupied 80.97%, and natural open water 10.10%. By 1978 of the total area studied oil and gas operations impacted 22.49%, agriculture impacted 0.42%, all fresh marsh wetlands had disappeared were replaced by brackish marsh occupying 51.41% and natural open water areas expanded to 24.32% of the area. Oil and gas operations severely impacted this area allowing saltwater intrusion destroying over 46 million m^2 of fresh marsh and replacing it with less biologically diverse or productive brackish marsh. No technology is currently available that would allow this type of field to be developed in a manner that does not affect the environment. However, planning to prevent saltwater intrusion, by site access using natural waterways, discontinuous and disconnected canals, and canal networks, using parallel slips and directional drilling used for environmental reasons could have greatly reduced the impact of these operations. Lafitte is an excellent example of a field that needed alternative access methods if it was to be developed in an environmentally non-destructive way.

The major conclusions from the field studies show that environmentally conscious planning is extremely important for wetland preservation. Board road direct impacts are less than canal direct impacts, but both have indirect impacts many times their direct impacts. Alternative access methods would prevent major impacts like those seen in the Lafitte field, if cost-effective methods could be used. Future activity involving enhanced recovery should not greatly impact any of the ten fields examined because previously impacted areas can be used for development in most cases. Directional, horizontal, and coiled tubing extended reach drilling should allow all types of enhanced recovery operations with minimal impact on the environment. Any additional production or processing equipment can be moved to non-wet areas or to previously disturbed sites.

To predict future activity and field size we attempted to survey the independent community to determine future plans with a questionnaire that was mailed out to oil and gas operators. Only a 3% response to the survey was received. A second trial at the Louisiana Independent Oil and Gas Association meeting solicited no responses. As a consequence two econometric models were created by our economist to explain and predict exploratory drilling and to estimate the number and size of future fields that may be found. The state was divided into two regions north and south Louisiana and ranges of estimates were created for varying economic scenarios. For the low price scenario the estimated total number of well locations in south Louisiana would be approximately from 392 to 415 with 80% of these locations being in wetland areas. From 5 to 7 new fields will be found and average field size will be 251,000 bbl of oil equivalent (BOE) assuming an 8% success ratio. The estimated range of total locations for north Louisiana was found to be approximately from 832 to 939 locations with 35% being in areas considered as wetlands.

Our analysis found that the expected future price on a BOE basis is the most significant factor in determining future activity. Another important finding is that the effects of possible new regulations on future drilling expectations is significant but small compared to the possible effects of product price fluctuations. The models indicate that if prices rise in real terms significantly and the cost of compliance rises at the same rate, represented by increased drilling costs, more wells will still be drilled in the future than during this year because the expected price is much more significant to operators than the increased environmental costs. If price rises slowly and compliance costs rise at much faster rate more wells will still be drilled in the future than the present. However, slightly fewer wells will be drilled than would have otherwise been drilled because of the increased environmental costs. Marginal wells will not be drilled where the slight additional drilling costs will reduce the rate of return or increase the risk to unprofitable or uneconomic levels.

Environmental regulations that change drilling costs do not affect current exploratory and development drilling underway when the regulations are changed. Wells are generally planned using an expected future price for product and once begun the time frame to completion is so short that the well will finish drilling unless the regulation prohibits the activity. The effects of new regulation will occur on future planned wells. Well economics will be redone for planned wells and uneconomic prospects will be discarded or delayed until conditions change. Low prices for oil and gas will have a detrimental affect on future activity in wetland areas of Louisiana because of the high environmental costs. Wetland reserve additions cannot continue at the present rate without higher product prices or significantly lower drilling costs. Finding cost-effective means of access to wetland areas that reduce environmental impacts will reduce drilling costs allowing reserve additions to continue in spite of albeit the low price conditions now in place. To expand reserves, higher prices and lower drilling and environmental costs will be necessary. These cost savings may be achieved by using alternative means of access and directional or horizontal drilling rather than conventional drilling where applicable. Regulators must provide incentives to promote technological innovation that lowers costs and achieves their regulatory goals while increasing reserves. Operators must embrace new technology in all aspects of operations to reduce operating costs and increase environmental compliance at a lower cost.

INTRODUCTION

A. Objectives

The oil and gas industry has been an integral part of Louisiana's economy since the industry began. Industrial activity in all phases of petroleum exploration, recovery, refining, and marketing was promoted by state and local governments. The industry provided jobs and a stable tax base under which Louisiana prospered. This growth was not without costs, and one of the prime areas affected was the vast, undisturbed wetland environment. Louisiana's wetlands have been a primary area for development of oil and gas resources, and all wetland habitats in the state have been affected by exploration, development, production, and transportation of petroleum. The need to protect these habitats and attempt to mitigate or restore past damages has led to new constraints on the industry.

Louisiana's wetland areas produce about 66% of the oil and gas in the state. Production of these reserves is becoming increasingly limited as concern for wetland loss motivates more stringent environmental regulations. The nation needs the oil and gas and the wetland-based renewable resources present in south Louisiana and other wetland areas of the United States. This project will evaluate and analyze past, present, and possible future primary and enhanced methods for producing the remaining reserves in sensitive wetland habitats at minimal environmental cost. This analysis will focus on the physical and environmental constraints controlling reserve growth in existing and future fields.

With nearly 80% of Louisiana's remaining reserves (oil in place, gas in place, and undiscovered oil and gas resources) located in coastal wetland areas, it is important to evaluate and analyze the constraints placed on the operator and the potential loss of production by compliance with these environmental regulations and to propose alternate methods of complying with them with minimal environmental impact. Identification of the problems that exist for oil and gas operations in wetland areas and recognition of approaches that will minimize impacts will allow operators to make informed decisions on drilling, production, and enhanced recovery techniques.

B: Scope of Study

1. Formation of a Technical Review Committee to guide the research. This committee will consist of members of state and federal regulatory and commenting agencies and industry representatives. Consultations were held with the committee throughout the life of the grant.

2. Presentation of a brief overview of present access technology for wetland areas and an overview of present wetland permitting activity.

3. Estimate future activity and its environmental impact using statistical methods for new primary exploration and evaluate the environmental mitigation requirements for this activity.

4. Examine and evaluate new technologies and techniques that are or may be available to reduce impacts. Assess the relative estimated cost of these potential alternative options compared to current practices.

5. Select ten fields, three with existing enhanced recovery activities as controls, to evaluate possible surface effects of enhanced recovery activities.

6. Conduct an industry survey of future drilling, production, and EOR activity planned in south Louisiana.

7. Develop alternative management and mitigation options to moderate potential impacts of increased operations. This will consist of a ranking mechanism that will allow small independents to pursue new wells in wetland areas at minimal environmental and economic cost.

8. Present conclusions and results by publishing in an environmental or oil and gas journal and through

technology transfer at local and national conventions or meetings.

C. Methods and Approach

This report focuses attention on the regulatory procedures designed to reduce environmental impacts and their present and future effects on the oil and gas industry in Louisiana. Data were gathered on current and proposed regulatory requirements for access to wetland locations in Louisiana to allow the creation of diagrams to illustrate the present system. Permitting statistics were gathered from Louisiana Offices of Coastal Management and Conservation. Regulatory requirements were evaluated for federal, state, and local conditions. Impact avoidance technologies and mitigative methods for reducing wetland impacts along with alternative mitigation options were examined and evaluated. Using a matrix, we evaluated the existing potential and possible options on environmental and economic criteria.

Ten fields were selected and evaluated on engineering and geologic criteria to determine their past and possible future enhanced recovery potential specifically targeting the potential surface effects of enhanced recovery or in-fill drilling activity. Data were obtained from the Louisiana Department of Natural Resources files, computer data bases and other public information sources. Company cooperation was solicited, but no field data were made available. Data obtained were loaded into Geographix a commercial geographic information system (GIS). After discussions with project advisors, surface maps and possible scenarios were created to describe how these fields would have been developed using present regulatory requirements.

Four fields were evaluated in greater detail using aerial photography. Aerial photography, obtained from NASA, was digitized to create surface maps. Using this information and an Intergraph GIS, estimates of areas impacted by oil and gas operations through time were created.

An industry survey was prepared and evaluated by our economist. A test mailing of 30 received one response that was from a member of the technical review committee. We then created econometric models for estimating of future activity and reserves that are in wetlands areas of the state.

D. Organization

The report is organized with background information on wetlands then oil and gas production patterns. The permitting process is evaluated and several flow charts were created to describe routes through the process and the economic cost of navigating this process. Background information on current access practices is presented and its environmental impact on Louisiana. Mitigation is then detailed and possible alternative access methods, drilling techniques, technological innovations, and planning techniques are presented. Mitigation banking is examined along with an evaluation of the mitigation strategies.

Then data and results on the ten fields are presented including surface maps, possible scenarios and past surface impacts. Future impacts are then projected for north and south Louisiana with estimates of the number of new locations needed for future drilling operations.

WETLAND HABITATS IN LOUISIANA

Wetlands are land areas that have features unique from upland habitats. The distinguishing features of a wetland are the presence of standing water, certain wetland soils, and vegetation adapted to or tolerant of saturated soils (Mitsch and Gosselink 1986). Wetlands include marshes, swamps, bogs, wet meadows, potholes, sloughs, and river outflow lands.

Wetlands vary in depth and duration of flooding, size (from small potholes to several hundred square kilometers), and location (coastal to inland). Because they are transitional areas between deepwater and terrestrial upland systems, they are influenced by these disparate systems. Human influence on wetlands varies in each region as well.

The legal definition of a wetland is extremely important for management purposes. The U.S. Army Corps of

Engineers (USACE) and EPA use the definition under Section 404 of the Clean Water Act, which defines wetlands as:

"those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, fens, and similar areas." (33CFR 323.2C 1984).

For research as well as management purposes the U.S. Fish and Wildlife Service and Louisiana Coastal Management Division (CMD) use the definition described by Cowardin et al. (1979):

"wetlands are transitional areas between terrestrial and aquatic systems where the water table is usually at or near the surface, or the land is covered by shallow water.
Wetlands must have one or more of the following attributes: 1) at least periodically, the land supports predominantly hydrophytes, 2) the substrate is predominantly undrained hydric soil, and 3) the substrate is nonsoil and is saturated with water or covered by shallow water at some time during the growing season of each year."

While CMD uses the Cowardin definition of wetlands, the definition described in Louisiana Coastal Resources Program Final Impact statement (1980) is as follows:

"Wetlands are open water areas or areas that are inundated or saturated by surface or ground-water at a frequency and duration sufficient to support a prevalence of vegetation typically adapted for life under saturated conditions."

While these working definitions are very similar, there are cases in the coastal zone where USACE may not require a permit under Section 404 but CMD would.

Louisiana's coastal land contains approximately 40% of our nation's wetlands. The entire coast of Louisiana is fringed with wetlands, some of which extend up to 50 miles (80 kilometers) inland. Louisiana's coastal zone consists of 9.5 million acres (3.8 million hectares) of which 5.2 million acres (2.1 million hectares) are water. Within this wide band of wetlands, several distinct wetland habitats exist. These habitats have variable environmental conditions and variable flooding, tidal regime, and salinity as well as diverse plant communities. The Natural Heritage Program has identified several distinct marine, estuarine, lacustrine, palustrine, riverine, and terrestrial communities found in the coastal zone (table 1).

Louisiana's coast contains marshes and swamps that make up about 75 % of the habitat in the coastal zone. The remaining 25% of the land area is mostly classified as developed or agricultural/pasture land. Major marsh habitat types and their areal extent include fresh, intermediate, brackish, and salt marshes that are divided depending on salinity and dominant plant communities. These marsh types succeed from salt to brackish, to intermediate, to fresh marsh habitat from the shoreline inland.

Forested wetlands include cypress-tupelo swamps, mangroves and bottomland hardwoods. Other habitats such as natural and spoil shrub/scrub communities and submerged and aquatic vegetation are not described here.

Table 1. Natural Communities in Louisiana from Lester (1988).

Marine		
	Marine Subtidal Open Water	
		Deepwater
		Shallow Water
	Marine Intertidal Beach/Bar	
		Intertidal Sand/Mud/Shell Beach/Bar
	Marine Aquatic Bed	
		Submergent Algal Vegetation
		Submergent Vascular Vegetation
Estuarine		
	Intertidal Emergent Vegetation	
		Salt Marsh
		Brackish Marsh
		Intermediate Marsh
	Subtidal Aquatic Bed	
		Submergent Vascular Vegetation
		Submergent Algal Vegetation
	Intertidal Flat	
		Intertidal Sand/Shell Flat
		Intertidal Mud/Organic Flat
		Vegetated Pioneer Emerging Delta
		Intertidal Mollusk Reef
		Intertidal Saltwater Swamp
	Subtidal Open Water	
		Bay
		Tidal Channel/Creek
		Tidal Pass
Lacustrine		
	Littoral Open Water	
		Marsh Lake
		Swamp Lake
Palustrine		
	Emergent Vegetation	
		Freshwater Marsh
		Herbaceous Bog (Flatwood bog)
	Aquatic Bed	
		Submerged Algal Vegetation
		Submerged/Floating Vascular Vegetation
	Scrub/Shrub Wetland Vegetation	
		Scrub/Shrub Swamp
		Shrub Swamp

Table 1. Natural Communities in Louisiana from Lester (1988) continued.

Forested Wetland

- Cypress-Tupelo Swamp
- Cypress Swamp
- Tupelo-Blackgum Swamp
- Batture (Riverfront pioneer)
- Bottomland forest
    - Overcup Oak-Water Hickory
    - Hackberry-American Elm-Green Ash
    - Sycamore-Sweet Gum-American Elm
    - Sweet Gum-Water Oak
    - Forested Canebrake
    - Live Oak Forest
- Bayhead Swamp
- Slash Pine-Cypress/Hardwood Forest
- Riparian Sandy Branch Bottom
- Riparian Forest (Small stream floodplain forest)

Riverine

- Riverine Subtidal Channel
    - Tidal Mud Flat
    - Subtidal Open Water
- Riverine Lower Perennial Channel
    - Sand/Gravel Beach/Bar
    - Mud Bar
    - Lower Perennial Open Water
- Aquatic Bed
    - Submerged/Floating Vascular Vegetation

Terrestrial

- Tallgrass Grasslands
    - Coastal Dune Grassland
    - Coastal Prairie
- Shrub Thicket
    - Coastal Dune Shrub Thicket
- Deciduous Forests
    - Coastal Live Oak-Hackberry Forest (Chenier maritime forest)
    - Beech/Magnolia Forest (Hardwood slope forest)
- Mixed Evergreen/Deciduous Forests
    - Mixed Hardwood-Loblolly Forest
    - Pine Flatwoods
    - Slash Pine/Post Oak Forest
    - Pine Savannah
    - Live Oak-Pine-Magnolia Forest

IMPORTANCE OF LOUISIANA WETLANDS

Generally wetlands are important for a variety of reasons. They provide flood damage protection, protection from storm and wave damage, water quality improvement, and they recharge aquifers. They also provide critical habitat for all or part of life stages of plants, fish, shellfish, and wildlife.

The Louisiana coastal zone contains over 8 million acres (3.24 million hectares) of swamps, marsh, cheniers, barrier islands, open bays, bayous, and other water bodies. These habitats are important to the state because of their recreational, aesthetic, and commercial value. They provide habitat and food for numerous fish, shellfish, birds, mammals, and other wildlife. Wetlands provide nutrients for plants to grow and buffer zones that protect populated areas from storms and hurricanes.

Louisiana has some of the richest wetlands in the world. They produce 33% of U.S. seafood, 40% of its fur harvest, and 40% of its alligators (Lindstedt 1989). Many commercially and recreationally important species spend all or part of their life cycle in the Louisiana wetlands. It has been estimated that as much as two-thirds of all commercial fishery species rely on coastal marsh habitat during some or all of their life cycles.

As of 1990 Louisiana marshes supported over five million migrating ducks and geese. Eleven federally listed endangered and three threatened species were found in coastal Louisiana. These include bald eagles, brown pelicans, and several species of sea turtles and whales. Forty-five eagles' nests were found in coastal Louisiana along with over 150 water bird colonies.

Because Louisiana wetlands were formed through recent sedimentation of the Mississippi River, oil and gas deposits are common in the coastal area. Louisiana's coastal area has been more extensively developed for oil and gas production than any other place in the country. One-half of Louisiana's oil and gas production occurs in coastal marshes, where over 10 billion bl of oil and 65 trillion cubic feet (TCF) of gas already have been produced (Lindstedt et al. 1991).

Wetland loss has become a serious problem in south Louisiana where the natural process of subsidence of deltaic deposits coupled with human activity has caused high land loss rates. Causes of land loss include regional and local subsidence, sea level rise, leveeing of the Mississippi River, saltwater intrusion, and drainage of wetlands. As a result of natural and human-induced alterations, Louisiana has lost about 30–40 mi^2 (78–104 km^2) of wetlands a year between 1956 and 1978 (Gagliano et al. 1979, Gagliano 1973, Scaife et al. 1983, Turner and Cahoon 1988, Britsch and Kemp 1990, Dunbar et al. 1990). Recent studies (Dunbar et al. 1990, Britsch and Kemp 1990) show an increase of land loss rates during the 1970s, and a decrease in loss rates in the 1980s (about 30 mi^2/yr. (78 km^2/yr.)) down from estimates of 39–42 mi^2(101–109 km^2) in the 1970s.

Marshes

Salt Marsh

Salt marshes are the habitat closest to the Gulf of Mexico and may range from 1 to 15 miles wide in coastal Louisiana (Lester 1988). Salt marshes covered 455,044 acres (184,228 hectares) of the coastal zone in 1978 (Mossa et al. 1990). Because of the proximity to the Gulf and regular tidal cycles, the salinity level varies from almost fresh to hypersaline (0.6 to 52 parts per thousand). However, the mean salinity for salt marshes is about 16 ppt and generally ranges from 11 to 19 (Lester 1988, Chabreck 1972).

Salt marshes are often monospecific with smooth cord grass *(Spartina alterniflora)* as the dominant plant. This prolific, salt- and flood-tolerant plant can be found in pure stands or intermixed with the other 16 species of plants found in Louisiana salt marshes. Some other common species that may occur include black needle rush *(Juncus roemerianus)*, salt grass *(Distichlis spicata)*, and wire grass *(Spartina patens)* (table 2). In areas where elevations and soil salinity are slightly higher, species such as sea oxeye *(Borrichia frutescens)* and saltwort *(Batis maritima)* are more frequently found.

Table 2. Common plants of wetland habitats in Louisiana.

Salt Marsh	
Black needle rush	*Juncus roemerianus*
Salt grass	*Distichlis spicata*
Saltwort	*Batis maritima*
Sea oxeye	*Borrichia frutescens*
Smooth cord grass	*Spartina alterniflora**
Wire grass	*Spartina patens*

seventeen species of plants have been found in the salt marshes of Louisiana.

Brackish Marsh	
Big cord grass	*Spartina cynosuroides*
Black needle rush	*Juncus roemerianus**
Bulrush	*Scirpus robustus*
Dwarf spikerush	*Eleocharis parvula*
Salt grass	*Distichlis spicata**
Seashore paspalum	*Paspalum vaginatum*
Smooth cordgrass	*Spartina alterniflora*
Three cornered grass	*Scirpus olneyi*
Water hyssop	*Bacopa monnieri*
Widgeon grass	*Ruppia maritima*
Wire grass	*Spartina patens**

sixty-one species of plants have been found in the brackish marshes of Louisiana.

Intermediate Marsh	
Alligator weed	*Alternanthera philoxeroides*
Bulltongue	*Sagittaria falcata**
Common three square	*Scirpus americanus*
Cow pea	*Vigna repens*
Deer pea	*Vigna luteola*
Giant Bulrush	*Scirpus californicus*
Roseau cane	*Phragmites australis**
Seashore paspalum	*Paspalum vaginatum*
Spikerush	*Eleocharis spp.*
Switch grass	*Panicum virgatum*
Three cornered grass	*Scirpus olneyi*
Water hyssop	*Bacopa monnieri*
Wire grass	*Spartina patens**

fifty-four species of plants have been found in the intermediate marshes of Louisiana.

Table 2. Common plants of wetland habitats in Louisiana continued.

Fresh Marsh	
Alligator weed	*Alternanthera philoxeroides*
Arrowhead, Duck potato	*Sagittaria latifolia**
Bladderwort	*Utricularia spp.*
Bulltongue	*Sagittaria falcata*
Cattail	*Typha latifolia**
Giant cutgrass	*Zizaniopsis miliacea*
Grass	*Eleocharis spp.*
Maidencane	*Panicum hemitomon**†
Marsh fern	*Thelypteris palustris*†
Pickerel-weed	*Pontederia cordata*
Roseau cane	*Phragmites australis**
Royal fern	*Osmunda regalist*
Southern wildrice	*Zizaniopsis Miliacea*
Spike sedge	*Eleocharis spp.*
Tear thumb	*Polygonum sagittatum*
Vine	*Vigna luteola*

93 species of plants have been found in the fresh marshes of Louisiana.

Swamp	
American snowbell	*Styrax americana*
Ash	*Fraxinus tomentosa*
Bald cypress	*Taxodium distichum**
Black willow	*Salix nigra*
Buttonbush	*Cephalanthus occidentalis*
Green ash	*Fraxinus pennsylvanica*
Pumpkin ash	*Fraxinus profunda*
Red maple	*Acer rubrum var. drummondi*
Swamp blackgum	*Nyssa sylvatica*
Virginia willow	*Itea virginica*
Water elm	*Planera aquatica*
Water locus	*Gleditsia aquatica*
Water tupelo	*Nyssa aquatica**

143 species of plants have been found in swamps in Louisiana.

Table 2. Common plants of wetland habitats in Louisiana continued.

Bottomland Hardwood Forest	
American elm	*Ulmus americana**
Boxelder	*Acer negundo**
Hackberry	*Celtis laevigata**
Peppervine	*Ampelopsis arborea*
Poison ivy	*Rhus radicans*
Red maple	*Acer rubrum var. drummondi*
Sweet gum	*Liquidambar styraciflua**
Vines	*Smilax spp.*
Virginia creeper	*Parthenocissus quinquefolia*

149 species of plants have been found in bottomland hardwood forests in Louisiana.

* Dominant plant of that habitat
t Common to floating marsh habitat
For a complete list of species in each habitat see Lindstedt (1990a).

Salt marshes support 99 species of birds, 7 species of mammals, 5 species of reptiles, and no amphibians (Lindstedt 1990a). Raccoons *(Procyon lotor)* are probably the most common mammal found in Louisiana salt marshes. Abernethy (1987) and Chabreck (1988) state that the most common birds that live in the salt marsh are the clapper rail *(Rallus longirostris)*, seaside sparrow *(Ammodramous maritimus)*, night heron *(Nycticorax sp.)*, laughing gull *(Larus atricilla)*, Foster's tern *(Sternaforsteri)*, royal tern *(7halasseus maximus)* and caspian tern *(Hydroprogne caspia)*.

Brackish Marsh

Brackish marshes are generally found between salt and intermediate marshes where salinity averages 8 ppt (Lester 1988) but can reach 28 ppt (Chabreck 1972). However, salinity usually ranges from 4 to 12 ppt (Chabreck 1972). Brackish marshes are irregularly tidally flooded and dominated by salt-tolerant plants. Plant diversity and organic matter in the soil are higher than in the salt marsh but lower than fresh and intermediate marsh. The brackish marsh community covered 909,481 acres (368,211 hectares) of the coastal zone in 1978 (Mossa et al. 1990).

Because many species overlap brackish and intermediate marshes, these two habitats are often combined in the literature as brackish (Conner et al. 1986). Approximately 61 plant species have been found by various authors in the brackish marshes of Louisiana (Lindstedt 1990a). The dominant species of the brackish marsh is wire grass, *(Spartina patens)*, which is extremely productive and is the basis of the brackish marsh food web. Other common species include salt grass *(Distichlis spicata)*, black needle rush *(Juncus roemerianus)*, three-cornered grass *(Scirpus olneyi)*, dwarf spikesedge *(Eleocharis parvula)*, bulrush *(Scirpus robustus)*, widgeon grass *(Ruppia maritima)*, seashore paspalum *(Paspalum vaginatum)*, water hyssop *(Bacopa monnieri)*, smooth cordgrass *(Spartina alterniflora)*, and big cordgrass *(S. cynosuroides)* (table 2, Conner et al. 1986, Chabreck 1972, Lester 1988).

Brackish marshes support 101 species of birds, 17 species of reptiles, 10 species of mammals, and 5 species of amphibians; Lindstedt (1990a) provides a list of these species. Common mammals in brackish marshes include the muskrat *(Ondatra zibethicus)*, raccoon *(Procyon lotor)*, mink *(Mustela vison)*, and otter *(Lutra canadensis)* (Conner and Day 1987, Chabreck 1988).

Loons, grebes, and cormorants often winter in brackish marshes. Common ducks are gadwall *(Anas strepera)* and mottled duck *(.fulvigula)*. Other birds such as the great egret *(Casmerodius albus)*, great blue heron *(Ardea herodias)*, marsh hawk *(Circus cyaneus)*, night heron *(Nycticorax spp.)*, clapper rail *(Rallus longirostris)*, and seaside sparrow, *(Ammondramus maritimus)* frequent brackish marshes (Abernethy 1987, Chabreck 1988).

Intermediate Marsh

In Louisiana, intermediate marsh forms an extensive transition zone between brackish and fresh marshes. This oligohaline habitat where salinity averages about 3 ppt (Lester 1988), has been classified as brackish or fresh marsh in some studies. Mean salinity ranges from 2 to 5 ppt, but it has been recorded as high as 10 ppt (Chabreck 1972).

This marsh type covered 426,386 acres (172,626 hectares) of the coastal zone in 1978 (Mossa et al. 1990). The tidal regime is irregular, and the vegetation is composed mainly of narrow-leaved species. Plant diversity and organic content of the soil are not as high as fresh marsh but are higher than in the brackish and salt marsh.

Lindstedt (1990a) provides a list of the 97 plant species that have been found by several authors in intermediate marshes in Louisiana. Species that are common to fresh and brackish marshes may be found together in intermediate marshes. Broad-leaved plants and vines as well as grasses are common. The dominant plants are wire grass *(Spartina patens)*, roseau cane *(Phragmites australis)*, and bulltongue *(Sagittaria falcata)*. Other species commonly found in intermediate marshes, which are listed in 20, include the spikesedge *(Eleocharis spp.)*, water hyssop *(Bacopa monnieri)*, three-cornered grass *(Scirpus olneyi)*, giant bulrush *(S. californicus)*, common three square *(S. americanus)*, seashore paspalum *(Paspalum vaginatum)*, cow pea *(Vigna repens)*, deer pea *(V. luteola)*, switch grass *(Panicum virgatum)*, and alligator weed *(Alternanthera philoxeroides)* (table 2, Chabreck 1972, Lester 1988).

The intermediate marshes in Louisiana support 98 species of birds, 19 reptiles, 10 mammals, and 6 amphibians, all of which are listed in Lindstedt (1990a). Mammals common to intermediate marsh are the muskrat *(Ondatra zibethicus)*, raccoon *(Procyon lotor)*, mink (*Mustela vison*), and otter *(Lutra canadensis)*. White-tailed deer *(Odocoileus virginianus)* also are found in intermediate marshes, especially along ridges and levees (Conner and Day 1987, Chabreck 1988).

Several ducks may be found in intermediate marshes, including the mottled duck *(Anas fuilvigula)*, which is a permanent resident, and migratory ducks such as the mallard *(.platyrhynchos)*, blue-winged teal *(.discors)*, and green-winged teal *(.crecca)*. Other birds include the great egret *(Casmerodius albus)*, great blue heron *(Ardea herodias)*, marsh hawk *(Circus cyaneus)*, and common snipe *(Capella gallinago)*.

Fresh Marsh

Fresh marshes occupy the northernmost extent of coastal marshes in Louisiana. In 1978, 653,636 acres (264,630 hectares) of fresh marsh covered the coastal zone (Mossa et al. 1990). In Louisiana, fresh marshes are located adjacent to intermediate marshes and swamps or at the mouths of major rivers such as the Atchafalaya and Mississippi. Frequency and duration of flooding and salinity are the primary factors governing species distribution. Secondary factors such as substrate, current flow, and competition affect species distribution as well. Fresh marsh has the greatest plant diversity and the highest soil organic content of all the marsh types. Salinity in fresh marshes is usually less than 2 ppt (Smith 1988) but may reach 7 ppt (Chabreck 1972).

Species composition in fresh marshes is extremely diverse and is dominated by broadleaved, flowering plants, grasses, reeds, and sedges. Lindstedt (1990a) compiled a listing of 150 plant species that have been found in the fresh marshes of Louisiana by several authors (Gosselink 1984, Gosselink et al. 1979, Peterson et al. 1987, Chabreck 1972, Lester 1988, Montz 1977).

Two types of fresh marshes may be found in Louisiana—emergent and flotant. Emergent and flotant marshes have many of the same species, but these communities are anchored differently. Emergent marshes are anchored in the sediment whereas flotant marshes are anchored in a dense mat of roots, sediment, and detritus that floats on a layer of water and moves with the tides and water level.

The dominant plants in emergent fresh marsh communities are broad-leaved plants such as arrowhead *(Sagittaria latifolia)* and bultongue *(S. falcata),* and grasses such as maiden cane *(Panicum hemitomon),* roseau cane *(Phragmites australis* formerly *P. communis),* and cattail *(Typha latifolia)* (Conner et al. 1986, Chabreck 1972, Lester 1988, Smith 1988). Table 2 lists other common species.

Flotant marsh is dominated by maidencane *(Panicum liemitomon),* a grass that grows on the floating but firm organic substrate. The plant community is diverse and capable of supporting vegetation that is less flood tolerant than other marsh vegetation because water does flood the vegetation. These species such as the marsh fern *(Thelypteris palustris)* and the royal fern*(Osmunda regalis)* are unique to flotant marshes. Other plants common to this community include the vine *(Vigna luteola),* a grass *(Eleocharis spp.),* and tear thumb *(Polygonum sagittatum,* Conner et al. 1986, Chabreck 1972).

Fresh marshes support 90 bird species, 33 reptile species, 19 amphibian species, and 14 mammal species (Lindstedt 1990a). The muskrat *(Ondatra zibethicus)* and nutria *(Myocastor coypus)* are common commercial fur bearers in fresh marsh. Other mammals, such as the raccoon *(Procyon lotor),* mink *(Mustela vison),* otter *(Lutra canadensis),* White-tailed deer *(Odocoileus virginianus),* and harvest mouse *(Reithrodontomys fiilvescens)* also live in fresh marshes.

Common birds in fresh marshes include loons, grebes, and cormorants. Other common species include anhingas *(Anhinga anhinga),* gallinules *(Porphyrula maritinica, Galliunula chloropus),* and king rails *(Rallus elegans).* Bald eagles *(Haliaeetus leucocephalus),* which are on the federal endangered species, nest in trees in and around fresh marshes. The mottled duck *(Anas fulvigula)* is a permanent resident while other ducks such as mallards *(.platyrhynchos),* blue-winged teal *(.discors),* and green winged teal *(.crecca)* are common migratory waterfowl. Wading birds, such as the great egret *(Casmerodius albus)* and great blue heron *(Ardea herodias),* are the most common birds found in fresh marshes.

Forested Wetlands

Wetland forests in Louisiana are primarily composed of two types: freshwater and saltwater swamps. Freshwater swamps include the deepwater or cypress-tupelo swamp and bottomland hardwood forests. The difference between these forested areas is the tree species and how often they are flooded and how long the flooding lasts. The cypress-tupelo swamp mainly consists of cypress, water tupelo, and maple trees, while bottomland hardwoods contain a variety of species of trees, including elms, sweet gum, and maple. Mangrove swamps are the forested wetlands in the saltwater environment.

Mangrove Swamp

Mangroves or saltwater swamps in Louisiana occur mostly behind barrier islands or on slightly elevated stream edges. The black mangrove *(Avicennia germinans)* is the only mangrove species found in Louisiana. They are mainly located along the bayou edge of *S. alterniflora* marshes where marsh elevation is slightly higher. In Louisiana, mangroves do not always form a thick swamp but are often found as a marsh in association with *S. alterniflora.* Because Louisiana is in the northern edge of its range, freezes cause diebacks of this plant. This prevents large established stands here, and therefore these plants seldom exceed 1.5 m tall (Bahr and Hebrard 1976). The brown pelican *(Pelecanus occidentalis)* and white-faced ibis *(Plegadis chihi)* nest in this habitat (Abernethy 1987, Chabreck 1988).

Bottomland Hardwood Forest

Bottomland hardwood forests flank rivers and bayous and serve as a transition zone from swamps and marshes to drier upland areas. In the classification of habitats in the Louisiana coastal zone, forests occupy 199,577 acres (80,800 hectares) and bottomland hardwoods occupy most of this area (Mossa et al. 1990). This habitat type has the least-flooded, best-drained soils in wetland areas. These areas were once natural levees that were dominated by upland hardwood trees; they have since subsided and now are dominated by flood-tolerant species. Because many of these areas are so well drained, they have been cleared and used for residential areas, roads, industry, and agriculture. The lower portions of the natural levee are less well drained and are usually the sites of the bottomland hardwoods that grade into cypress-tupelo swamps.

Bottomland hardwoods are flooded each year for several weeks to a few months, usually in the winter and early spring. During the rest of the year the water table is near or just below the soil surface. Salinity is virtually zero in these areas. They are important natural communities for maintaining water quality and for providing habitat for a variety of fish and wildlife.

Bottomland hardwoods are dominated by hardwood trees and woody shrubs in which 149 plant species have been reported (Conner et al. 1975, Wharton et al. 1982, Conner et al. 1986). Lindstedt (1990a) compiled a list of these species. The most common species are the American elm *(Ulmus americana),* sweet gum *(Liquidambar styraciflua),* hackberry *(Celtis laevigata),* and red maple *(Acer rubrum var. drummondi).* The woody understory is composed mainly of red maple *(A. rubrum var. drummondi)* and box elder *(A. negundo)* saplings (table 2).

A variety of herbaceous plants are found in bottomland hardwood forests as well, especially along the edges and in open areas. The most common herbaceous plants and vines found in Louisiana bottomland hardwoods are poison ivy *(Rhus radicans)* and other vines such as *Smilax spp.*, pepper vine *(Ampelopsis arborea),* and Virginia creeper *(Parthenocissus quinquefolia)* (Lester 1988, Smith 1988, Conner et al. 1975).

Swamp

Cypress-tupelo swamps are the primary forested wetlands in fresh, poorly drained areas where the soil is saturated or covered with water for at least one month during the growing season (Penfound 1952). Cypress-tupelo swamps covered 342,425 acres (138,634 hectare) of the coastal zone in 1978. The dominant species found in the swamp are the bald cypress *(Taxodium distichum)* and the water tupelo *(Nyssa aquatica).* Often swamps are composed of pure strands of one of these species or a mixture of the two trees. Conner et al. (1986) found 146 species of plants in Louisiana swamps. Other trees that may be commonly found in the swamp are ash *(Fraxinus tomentosa),* green ash *(F. pennsylvanica),* pumpkin ash *(F. profunda),* black willow *(Salix nigra),* water elm *(Planera aquatica),* water locust *(Gleditsia aquatica),* swamp blackgum *(Nyssa sylvatica),* and the red maple *(Acer rubrum var. drummondi).* Common species found in the woody understory include saplings of the red maple *(A. rubrum var. drummondi),* Virginia willow *(Itea virginica),* buttonbush *(Cephalanthus occidentalis)*, and American snowbell *(Styrax americana)* (Lester 1988, Smith 1988, Conner et al. 1986).

Tupelo-blackgum swamps are also forested wetlands where the dominant overstory is composed of gums *(Nyssa spp.).* Common species associated with these communities are similar to cypress and cypress-tupelo swamps (Lester 1988, Smith 1988).

Other common plants in swamp habitat are floating aquatic and emergent plants. The most common floating aquatics include duckweed *(Lemna minor),* water hyacinth, *(Eichhornia crassipes),* water fern *(Azolla caroliniana),* and American frogbit *(Limnobium spongia).* The most common emergent plants include lizard tail *(Saururus cernuus)* and smart weed *(Polygonum punctatum).*

Common mammals found in Louisiana swamps are the opossum *(Didelphis virginiana),* bobcat *(Lynx rufus),* fox squirrels *(Sciurus carolinensis, S. niger),* cottontails and swamp rabbits *(Sylvilagusfloridans, S. aquaticus),* nutria (*Myocastor coypus),* and white-tailed deer *(Odocoileus virginianus).*

Birds common to the swamp are anhingas *(Anhinga anhinga)*, gallinules *(Porphyrula maritinica, Galliunula chloropus)*, wood duck *(Aix sponsa)*, red shouldered hawk *(Buteo lineatus)*, barn owl *(Tyto alba)*, great horned owl *(Bubo virginianus)*, barred owl *(Strix varia)*, black vulture *(Coragyps atratus)*, and turkey vulture *(Cathartes aura)*. The endangered bald eagle *(Haliaeetus leucocephalus)* nests in the swamps of Louisiana.

Amphibians and reptiles are especially common in swamp forest communities, particularly the alligator *(Alligator mississippiensis)* and cottonmouth snake *(Agkistrodon piscivorus)* (Abernethy 1987).

Other Wetland Forest Communities

There are several less-known forest communities where soils are inundated or saturated part of the year and could be classified as wetland habitat. These areas occur in the coastal zone of Louisiana and are under jurisdiction of the Coastal Zone Management Act. These communities are the overcup oak-water hickory community, the hackberry–American elm–green ash community, the sycamore–sweet gum–American elm community, and the sweet gum–water oak community. These communities are dominated by the species for which they are named and are found along low ridges and along banks of rivers and streams, and on the flood plain. Lester (1988) and Smith (1988) describe these communities in detail.

Endangered Species

There are 10 federally listed endangered and 4 threatened species in Louisiana's coastal zone. Three of the endangered and 2 of the threatened species are sea turtles, and 3 are endangered whales that do not frequent inland wetlands of the state. Those endangered species that do inhabit Louisiana marshes and swamps are the piping plover *(Charadrius melodus)*, brown pelican *(Pelecanus occidentalis)*, red-cockaded woodpecker *(Picoides borealis)*, Florida panther *(Felis concolor coryi)*, and the west Indian manatee *(Trichechus manatus)*. There were 45 bald eagle nests in the coastal zone in 1989. More detailed information on endangered and threatened species may be found in Lindstedt (1990b) and Lester (1988).

In addition, the Natural Heritage Program, with the Louisiana Department of Wildlife and Fisheries maintains a list and a data base of state threatened and endangered species. There are 50 plants, 15 birds, 11 reptiles, 2 amphibians, 3 fish, and 16 mammals on this list. Lester (1988) provides additional information on these species of special concern in Louisiana.

LOUISIANA OIL AND GAS PRODUCTION PATTERNS

Louisiana was the nation's 4th largest oil-producing and the 3rd largest gas-producing state in 1991. Production figures from the Energy Information Agency show state crude and condensate production totaling 113 million bbl including state waters. Offshore areas in federal waters produced an additional 240 million bbl of production that was piped onshore to Louisiana. Gas production from the state totaled 1.527 TCF with an additional 3.3 TCF from federal waters (Energy Information Administration 1992). These totals represent 9% and 18% of the nation's total gas production respectively. Extensive production occurs in the wetland areas of the state primarily in the southern portions of the state. In a study on oil and gas development in Louisiana's coastal zone, Lindstedt et al. (1991) found that 55% of the oil production and 47% of the gas production has occurred in fields in the coastal zone.

The state (excluding the federal offshore) now has a total of 1,620 oil and gas fields. The first well was drilled in the state in southwest Louisiana around 1868 and the first successful well was drilled in Jennings, Louisiana in 1901. Early exploration was concentrated in northern Louisiana where giant gas fields were discovered at Caddo and Monroe in 1905 and 1916, respectively. These fields were primarily located in upland areas, except for parts in flood plains.

Interest was stimulated in south Louisiana after the success of Spindletop in Texas marshes in 1901. The Hackberry Dome in Cameron Parish was discovered in 1902. South Louisiana production was concentrated around salt domes until 1926 when the Sweetlake field in Cameron Parish was completed. Rotary drilling rigs were used from existing road networks and new board roads were built to access marsh and wetland locations and to allow transportation of supplies to the rig site. In some marsh and water areas, wooden platforms were built at the drilling site and a drilling rig was placed on the platform.

The marsh buggy, a vehicle with hollow wheels, was developed for seismographic crews to access previously inaccessible wetland areas. With the invention of refined seismologic techniques major field discoveries occurred in the wetlands in the early 1930s (Lindstedt et al. 1991).

As discoveries and field development proceeded the demand for access to wetland areas that were inaccessible to board roads increased. The development of the semi-submersible drilling rig in 1932 allowed cost effective exploitation of inaccessible wetland areas. Improved and efficient dredging technology allowed canals to provide access for seismic exploration and later for drill sites. Economic factors caused canal access to become the preferred method of access in most areas of south Louisiana.

Miles of canals for exploration, navigation, and later extraction through pipelines interlace south Louisiana. These canals cover over 200,000 acres (80,972 hectares) and are cited as one the major contributing factor in Louisiana's extensive coastal land loss. These canals have directly and indirectly contributed to the staggering 40–50 mi^2 (104–130 km^2) loss of wetlands from 1956 to 1978 found by various researchers (Gagliano et al. 1981, Turner and Cahoon 1988). These impacts have been calculated to have caused from 20% to 90% of the land loss rate, depending on the location and the period studied (Craig et al 1979, Gagliano 1972, Scaife et al. 1983, Turner and Cahoon 1988). These patterns remained constant until the creation of the Louisiana Coastal Zone in 1978.

As discoveries moved farther south into more inaccessible areas and open water, overwater drilling structures were developed. Overwater structures were first used in this country in Caddo Lake in 1910. Platforms were placed in the lake off roads built on pilings to allow access. This success made possible the first unprotected offshore drilling structure in the Gulf of Mexico near Creole, Louisiana in 1938. In 1939, the first offshore field was discovered—the Creole field—and freestanding platforms proved successful. In 1947, Kerr-McGee completed the first successful well out of sight of land, marking the beginning of OCS development. Since that day the oil and gas industry has rapidly developed in the coastal zone and offshore Louisiana. Technological developments, including steel pilings, the submersible drilling rig, and tender equipment, have made drilling offshore physically possible. As production increased additional canals were dredged to lay pipelines to transport the crude to local refineries. The need for pipelines to carry crude and refined products increased dramatically in the late 1940s. In 1951, the first large-diameter, concrete-coated pipeline was laid offshore in the Gulf of Mexico (Lindstedt et al. 1991). Over 140 pipelines originating in federal waters and over 85 pipelines originating in state waters make landfall in coastal wetland areas of south Louisiana (Lindstedt 1991, Minerals Management Service 1984). By December 1990, there were 17,727 mi (28,523 km) of pipelines offshore Louisiana alone (Minerals Management Service 1992) and about 12,000 mi (19,300 km) in onshore Louisiana.

Offshore support activities also increased dramatically at this time. Seaplanes and helicopters as well as boats and barges became extremely important in servicing crews and platforms in the 1950s. By 1955 more than 40 platforms were operating offshore (Havran and Collins 1980). As offshore production increased in the 1960s and the demand for natural gas began to rise for heating in the northeast United States, new infrastructure and field development occurred in south Louisiana. This increased demand for natural gas along with the Arab oil embargo of 1973 led to increased exploration for oil and gas throughout the 1970s an into the middle 1980s. In 1984, 11 ports, 44 shipyards, 18 platform fabrication yards, 23 supply bases, 82 processing plants and 28 refineries each covering from 1 to 1000 acres supported offshore activities (Minerals Management Service 1984, Lynch and Risotto 1985).

Louisiana is one the nation's leading petroleum- and natural gas- producing states. Over 187,000 wells have been drilled in Louisiana since the Louisiana Department of Conservation began regulating oil and gas activity.

This activity has changed the landscape of Louisiana. Future exploration trends will continue to alter the landscape as more wells are drilled in wetland areas of south Louisiana and deeper wells in untested areas of northern parts are attempted primarily in the Smackover and Austin Chalk formations. As in the past, technological innovation creates increased demand. Estimated reserves for Louisiana in 1991 excluding offshore federal waters are 679 million bbl of crude and 10.9 TCF of gas (Energy Information Administration 1992). Technological advances in three-dimensional seismic may significantly add to these totals in the coming years. Increased access to geologically untested and environmentally undisturbed areas of the state will be by-products of this search for additional reserves.

LOUISIANA PERMITTING PROCESS

History

From its beginning in 1901, the oil and gas industry grew rapidly and the need for regulatory guidelines and regulations became apparent as careless and wasteful drilling practices developed. During the early period of oil and gas production, Louisiana wasted more of these resources than any other state (Chisholm 1938, Conservation Commission 1914). For example, the Caddo field in north Louisiana had a wild gas well burn for five years wasting at least 27 BCF of gas (Conservation Commission 1914).

Act 71 of 1906, which prohibits waste, was the first oil and gas legislation to be passed in Louisiana. In 1912, Act 127 created the Conservation Commission to administer oil and gas operations within the state. Several acts followed that provided regulations for waste practices, taxing, well spacing, and unitization. In addition, the Conservation Commission issued rules governing practices of extraction, escape of oil and gas, and sealing and plugging of wells. However, many of these acts and rules only applied to specific areas or fields and were not observed statewide.

Inconsistent administration practices and corruption led to the need for broader regulations and resulted in passage of the Oil and Gas Conservation Law of Louisiana (Act 157) in 1940. It was the first statewide comprehensive oil and gas conservation statute in the nation (Sutton 1978). It regulates the use and conservation of natural resources within the state and mandated the Commissioner of Conservation to regulate oil and gas exploration, development, and production. Title 30 R.S. 1950 contains the mandates of the Office of Conservation and the rules now governing mineral resources. Statewide Order 29-B first issued in 1942 consisted of rules and regulations pertaining to the production and conservation of oil and gas resources.

Since 1950, the Office of Conservation has created new rules and regulations to adapt to a changing regulatory environment. The office has been granted primacy for all classes of Underground Injection Control (UIC) wells under Clean Water Act 1972. In 1974, Order 29-B was amended to incorporate all oil and gas regulations into one document. At this time the first environmental regulations were incorporated into the Act to comply with the federal Clean Water Act of 1972. The specific provisions were designed to prohibit discharges in freshwater streams, rivers, and lakes and to establish standards for underground injection of produced waters. Other sections established bonding authority and plugging requirements for existing and new wells. Specific requirements were established to allow wells to be plugged and abandoned safely.

Major amendments and readjustments to Order 29-B occurred throughout the 1980s. In response to the Safe Water Drinking Act, Order 29-B was amended to create regulations for all types of injection wells including disposal, enhanced oil recovery, and liquid or gas storage wells. The Department of Natural Resources/Office of Conservation created a new sub-office called Underground Injection Control (UIC) to control permitting, construction, logging, testing, monitoring, and reporting for these wells (Louisiana Department of Natural Resources/Office of Conservation Order 29-B 1982) .

In 1986, Order 29-B was extensively amended to incorporate the regulation of Non-hazardous Oilfield Waste (NOW) generated from oil and gas activities. Oilfield pit construction, waste analysis, tracking of the waste, and pit closure requirements were incorporated into the act. The amendment provided for the permitting of off-site disposal sites and increased monitoring of injection wells (Louisiana Department of Natural Resources/Office of Conservation Order 29-B 1986). These incremental changes continued with another amendment to Order 29-B in 1990. Coastal, wetland, and upland areas were defined for the state and the pit regulations were amended to establish specific requirements for each of the defined areas. Pit liner requirements were established and more detailed operating and monitoring requirements were incorporated into the act (Louisiana Department of Natural Resources/Office of Conservation Order 29-B 1990).

Although the Louisiana Department of Natural Resources/Office of Conservation (DNR/OC) has regulatory control in all areas pertaining to oil and gas exploration, extraction and transportation, other agencies also are involved in oil and gas regulation in the state. The Louisiana Department of Environmental Quality (DEQ) was created in 1983 to control surface discharges, air quality, water quality and solid waste regulations. The Public Service Commission (PSC) licenses waste haulers in the state including oilfield waste. DEQ in 1992 increased its regulation of oil and gas operations through the creation of regulations pertaining to Naturally Occurring Radioactive Material (NORM).

Current Permitting Requirements

Classification of Exploration and Production Wastes

Louisiana requirements use the same definitions and classifications of oil and gas exploration and production (E&P) wastes as those specified under Resource Conservation and Recovery Act (RCRA). Under RCRA the vast majority of exploration and production wastes are exempt from hazardous waste regulation. Louisiana requires testing of waste to determine various levels of contaminants present that may affect the disposal options available.

Operating Permits

Permit requirements for oil and gas wells have been in place since 1914 and have evolved over time (Conservation Commission 1914). Applications for a permit to drill any well must be made on Form MD-1-OR and must include a location plat conforming to the guidelines adopted by the Commissioner of Conservation (Louisiana Department of Natural Resources/Office of Conservation, Order 29-B 1974). The fee for each well will be $100 for depths of less than 3,000 ft (914 m), $500 for wells 3,001–10,000 ft (914–3281 m), and $1,000 for depths of greater than 10,000 ft (3,281 m). Oilfield noncommercial injection well permits cost $200. (Louisiana Department Of Natural Resources/Office of Conservation Order 29 [Q-1]).

Under Chapter 1, Title 30, R.S. 1950, the Commissioner of Conservation has the authority to require bonds before wells are permitted to assure proper plugging and abandoning of wells. At this time no bonds are required, but this matter is currently under review by DNR/OC. Commercial injection facilities and waste disposal firms are presently required to post closure bonds or provide other insurance or financial guarantees to assure proper site closure. (Louisiana Department of Natural Resources/Office of Conservation, Order 29-B 1990)

Casing requirements to protect drinking water aquifers is regulated by DNR/OC with specific requirements set on a well by well basis. Minimum requirements are to set casing 200 ft (61.4 m) below the nearest underground source of drinking water. Pit construction at well sites and facilities is regulated through DNR/OC. Operators must notify the DNR/OC at least ten days prior to pit construction, to allow DNR/OC representatives the opportunity to inspect the site (Louisiana Department of Natural Resources/Office of Conservation, Order 29-B 1990).

Approval from DNR/OC must be obtained before injecting drilling wastes or produced waters. Application for approval to inject drilling wastes must include a schematic diagram, operation data, and all required logs that have been run. Within six months of completion, operators must report the amount of waste generated, the manner of disposal, and certify that such disposal occurs according to DNR/OC regulations (Louisiana Department of Natural Resources/Office of Conservation, Order 29-B 1990).

A valid Louisiana Water Discharge Point Source (LWDPS) permit obtained from DEQ's Office of Water Resources is required for all produced water discharges (Department of Environmental Quality/Office of Water Resources, Title 33, Part IX 1991).

Waste haulers are licensed by the Louisiana Public Service Commission (PSC). The PSC provides a common carrier's certificate on application and after a comment period. All motor carriers also must apply for and receive a PSC registration permit and pay an annual fee of $10 per vehicle. Oilfield operators who haul their own wastes are exempt from these requirements (Public Service Commission, Title 45, Chapter 4, Motor Carriers).

Rules and Regulations

Louisiana Statewide Order 29-E regulates spacing requirements for wells throughout the state. Wells drilled to less than 3,000 ft (914 m) are exempt from spacing requirements until such time that sufficient geologic and engineering information is available for the Commissioner of Conservation to promulgate rules to conserve the resources and pools found. Oil wells drilled deeper than 3,000 ft (914 m) must not be located closer than 330 ft (101 m) to any property line or within 900 ft (274 m) of another well drilling for the same formations. Gas wells drilled deeper than 3,000 ft (914 m) shall not be located within 330 ft (101 m) of a property line or within 2,000 ft (610 m) of a well drilling for the same formation. Exemptions may be granted by the Commissioner of Conservation for a variety of reasons including but not limited to special offsets, prior completion, complex faulting, to prevent waste, and at the request of other state or federal regulatory agencies. After petitioning the Commissioner a public hearing may or may not be deemed necessary and the exemption will be allowed or disallowed at the discretion of the Commissioner of Conservation (Department of Natural Resources/Office of Conservation, Statewide Order 29-E 1957). Statewide order 29-B regulates pit construction, waste disposal, casing set points and monitoring requirements. This order creates three classifications for pit construction requirements: Coastal, wetland and upland. The construction of new pits has been prohibited unless strict guidelines are followed. Existing pits must be lined unless the pit is subject to an approved LWDPS permit or is located within an 'A' or upland zone (area subject to a hundred-year flood) and contains only produced water. New pits must have 3 continuous ft (1 m) of clay (or the synthetic equivalent) lining all surfaces. Pits must be protected from surface waters by levees, walls, or drainage ditches and 2 ft (0.6 m) of freeboard must be maintained. Pits must be closed within six months of abandonment (Louisiana Department of Natural Resources/Office of Conservation, Order 29-B 1990).

Production pits located in coastal areas unless granted an exemption were required to be closed by January 1, 1993. There are exceptions to this rule if the pit is defined as an "exempt pit" (i.e., compressor station, gas processing plant, emergency, and salt dome cavern storage pits). Additional exemptions are granted for pits constructed after June 30, 1989, that have obtained a valid discharge permit (LWDPS) from the DEQ. These pits may remain open until January 1, 1995, or until the permit expires. Unless exempted, new pits have been forbidden in coastal areas since June 30, 1989 (Louisiana Department of Natural Resources/Office of Conservation, Order 29-B 1990).

Order 29-B allows drilling waste disposal through onsite land treatment, burial, solidification, or other techniques if the waste is measured and tested and meets the criteria in the order. Pit contents must be analyzed for pH, metals content, oil and grease, salts, and radioisotopes before closure. Waste standards are stringent for land treatment and less stringent for burial where the waste will be covered by 5 ft (1.5 m) of native soil. In limited cases, passive closure is allowed only if the pit can be used as wildlife habitat/agricultural (aquaculture) or where closure could cause greater environmental damage than leaving the pit open. Annular injection of wastes generated onsite may be granted with the appropriate approval of the Commissioner of Conservation.

Oil-based drilling fluids may not be discharged but may be annularly injected. Freshwater muds and drill cuttings may be discharged with a valid discharge permit (LWDPS) from the Department of Environmental Quality (DEQ). Discharge in freshwater and intermediate or brackish water areas is limited to freshwater drill cuttings and fluids (Department of Environmental Quality/Office of Water Resources, Title 33, Part IX 1991).

Produced waters are regulated by the National Pollutant Discharge Elimination System (NPDES). This program is administered by EPA or by states through programs delegated by EPA. Louisiana has a delegated program run by DEQ/Office of Water Resources (OWR). NPDES permits establish effluent limits and monitoring requirements for discharges. Effluent limits are established for best available technology and the levels necessary to meet EPA approved state water quality standards (Interstate Oil Compact Commission, Section 2.3 1991).

With a valid discharge permit issued under the state LWDPS program or the federal NPDES program, produced water can be injected into nonproductive formations, discharged or transported offsite for disposal at a state-approved disposal site or injection well. Injection wells must be permitted, pretested, and then approved by DNR/OC. If the well is used for outside party injection or as a commercial enterprise a fluid volume recorder must be installed. Reporting of injected volumes is required by DNR/OC.

Produced water may not be disposed directly in any freshwater or upland area. Discharges authorized in marsh areas must be directly connected to the Mississippi or Atchafalaya rivers or the open bays of the Northern Gulf of Mexico (Department of Environmental Quality/Office of Water Resources, Title 33, Part IX 1991). Where discharge is permitted a 72-mg/L limit for oil and grease exists with monthly samples required. Surface disposal of less than one barrel per day of produced water, as long as no visible sheen is left, may be authorized on a case-by-case basis by DEQ. Disposal to the state's territorial waters in the Gulf of Mexico also may be authorized on a case-by-case basis, subject to the provisions of the LWDPS permit authorizing the discharge (Department of Environmental Quality/Office of Water Resources, Title 33, Part IX 1991).

By January 1, 1995, discharge in brackish and saline water areas will be eliminated unless strict effluent limitations are met. These limitations are stringent enough that operators are completely eliminating discharges in most cases. The limits required are shown in table 3. Operators were required to file compliance schedules by November 20, 1991. Various exceptions to this rule have been granted for different size operations, but all operations must comply by January 1, 1996, or file to completely phase out operations by requesting an extension of the compliance period until January 1, 1997. Exceptions will be considered if the operator establishes that surface discharge is the only immediately available and economically feasible alternative and that continued discharge does not present potential environmental degradation.

Operators discharging into open water areas at least one mile from shore in the major bays of south Louisiana have two years from the effective date of these regulations or one year after the completion of the U.S. Department of Energy (DOE) study concerning Louisiana coastal bays whichever comes first, to show on a case-by-case basis that their particular discharge should be exempt from these regulations, if the DOE study after peer review, shows minimal acceptable environmental impacts (Department of Environmental Quality/Office of Water Resources, Title 33, Part IX 1991). Since this state regulation was instituted, DOE has decided not to fund or endorse this study.

Louisiana's NORM regulations apply to all oilfield waste, equipment or facilities, except produced water. The regulations control the receipt, possession, use, processing, distribution, and disposal of NORM wastes. Radiation limits for NORM waste are a maximum radiation exposure level of 50 microroentgens per hour.

A general license is issued to mine, extract, receive, possess, own, use, and process NORM, without regard to quantity. An initial and annual license fee of $100 is required for each location subject to the general license provisions. The decontamination, remediation, or maintenance of facilities and equipment contaminated with NORM may only be performed by a general licensee, persons specifically authorized by the Nuclear Energy Division, or by another licensing state. Licensees are required to file a report showing the facility owner and any location where NORM exists with the Radiation Protection Division of DEQ (Department of Environmental Quality/ Energy Division, Title 33, Part XV, Chapter 14).

Currently approved options for NORM disposal include disposal at an approved 29-B commercial facility and placement in a plugged and abandoned well owned by the operator. The Office of Conservation has issued NORM disposal guidelines concerning downhole disposal. These guidelines outline the proper plugging and abandonment procedures for wells utilized for the downhole disposal of NORM solids and/or NORM contaminated tubing.

(Louisiana Department of Natural Resources/Office of Conservation, Order 29-B 1990). New disposal regulations are currently under review and changes will be promulgated in the near future.

Regulations on plugging and abandonment and annular disposal of drilling waste or NORM waste are promulgated by the Office of Conservation. At the completion of operations of producing wells or after a determination of a "dry" hole wells are plugged. Dry holes must be plugged within 90 days of the determination that the well is dry and drilling or workover operations cease. If requested by the landowner wells may be converted to freshwater use. However, all producing formations must be protected to prevent communication with surface or other formations. The DNR/OC must be notified of intent to plug; on receiving a permit, operators must notify the DNR/OC District Manager at least 12 hours before plugging operations commence. When a well is plugged, cement plugs of at least 100 ft (30.5 m) long must be placed immediately above the uppermost perforated interval, 50 ft (15 m) above and below the casing, and 100 ft (30.5 m) below and 150 ft (45.7 m) above any freshwater-bearing sand; a plug of at least 30 ft (9.1 m) long also must be placed at the top of the well. All portions

Table 3. Discharge limits.

Pollutant or Pollutant Property	Discharge Limitation	
Benzene	0.0125	mg/L daily maximum
Ethylbenzene	4.380	mg/L daily maximum
Toulene	0.475	mg/L daily maximum
Oil and Grease	15	mg/L daily maximum
Total Organic Carbon	50	mg/L daily maximum
pH	6–9	standard units
Temperature	(as per LAC 33:IX.1113.C.4)	
Total Suspended Solids	45	mg/L daily maximum
Chlorides	10:1 Dilution required (ambient water: produced water. All other parameters must be within limits prior to dilution	
Dissolved Oxygen	4.0	mg/L daily maximum
Toxicity (Acute and Chronic)	1	Toxicity unit
Soluble Radium	60	picocuries/L
Visible Sheen	No Presence	

Source:Department of Environmental Quality/Office of Water Resources, Title 33, Part IX. Chapter 7. S708.C.2.vii.1991.

of the well not filled with cement must be filled by a mud of not less than 9 pounds per gallon (1.08 grams per cubic centimeter). After placing the top plug the casing must be cut below plow depth on land and 10 ft (approx. 3 m) below the mud surface in marsh and water locations. If the well may be re-entered or used for disposal at a future date an exemption to this rule may be issued. After completion of plugging, a subsequent report must be filed within 20 days detailing the location of the plugs and the cement placed in the well (Louisiana Department of Natural Resources/Office of Conservation, Order 29-P 1978 and 29-B 1990).

Within six months of ceasing production, temporarily abandoned wells must be reported on the semiannual Inactive Well Report Form and classified as to future utility. Those wells with no future utility must be plugged within 90 days unless listed on a separate Schedule of Abandonment approved by the DNR/OC. Wells classified as having future utility shall be reviewed every six months by the District Supervisor (Louisiana Department of Natural Resources/Office of Conservation, Order 29-P 1978).

The transport of oilfield waste by operators is covered by the DNR/OC. Offsite disposal facilities (including disposal wells) must be approved by the DNR/OC. Thirty days before applying for such approval, operators must publish a public notice of intent. Applications must include a $500 filing fee, a $600 hearing fee, names and addresses of corporate officials, names, and addresses of property owners within one-quarter mile of the proposed site, property title for the site, parish map showing location, statement of proposed operating procedures, and proof of insurance. Offsite disposal facilities may not be located within 500 ft (152 m) of any building not associated with the operation or over permeable ground. Levees are required in flood zone areas. Spill containment systems are required at the unloading area. Vent lines must be installed on all storage tanks containing nonhazardous oilfield waste and must extend outside of tank battery fire walls. Access must be limited through use of a locked gate. A 6- ft (2 m) -high chain link fence around the facility's perimeter may be required on DNR/OC inspection (Louisiana Department of Natural Resources/Office of Conservation, Order 29-B 1990).

The state deems waste generators to be responsible for the waste until it reaches its final destination. Manifests are required for each shipment of oilfield waste transported into a commercial facility. Part I of the manifest must be completed and signed by the generator, Part II by the transporter, and Part III by the commercial facility operator. The generator, transporter, and commercial facility operator must keep copies of the filed manifests for three years. Manifests are also kept on file at the DNR/OC for a period of two years after being filed. The DNR/OC enters the information into their computerized Oilfield Waste Tracking System. Types, volumes, and generators of oilfield waste received by offsite commercial disposal facilities are required to be reported monthly to the DNR/OC (Louisiana Department of Natural Resources/Office of Conservation, Order 29-B 1990).

The above rules and regulations apply to all wells drilled in Louisiana. Wells drilled in wetland or environmentally sensitive areas have numerous additional regulatory and statutory requirements that must be met.

Wetland Permitting Requirements

Wetland permitting requirements are administered and overseen by the federal government. The three main agencies in charge of wetland and coastal permitting are the U.S. Army Corps of Engineers (USACE), the Environmental Protection Agency (EPA) and the U.S. Department of Commerce, National Oceanographic and Atmospheric Agency (NOAA). USACE actively permits wetland activity, while the EPA has oversight responsibility for all wetland programs. NOAA is delegated the responsibility to approve, fund, and oversee state coastal management programs to protect coastal resources and habitat.

USACE permits dredge and fill operations, spoil disposal, and activities that obstruct or alter waterways. These permits are issued to comply with Section 404 of the Clean Water Act (1972) and Section 10 of the Rivers and Harbors Act 1899. Under provisions of the Clean Water Act (1972), USACE was delegated the authority to regulate navigable waters including their tributaries and watershed. Using the reasoning that to promote water quality wetland areas needed to be regulated and protected USACE began a permitting process to regulate activity in wetland areas under their jurisdiction. The goal of the program was to "control" the impact of "pollutants" such

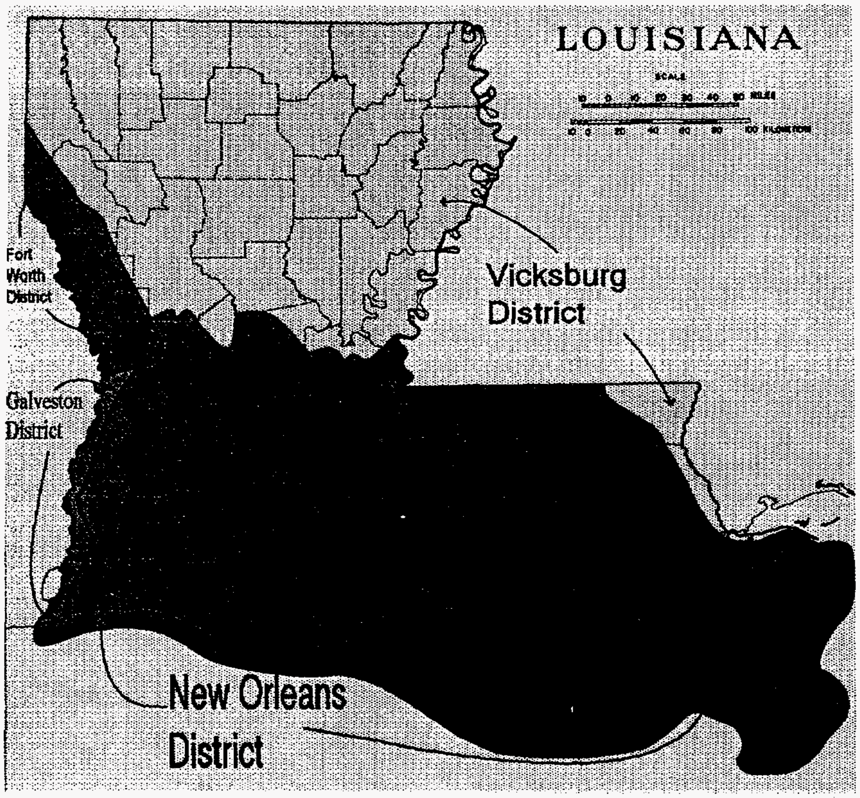

Figure 1. Approximate boundaries of the four Corps of Engineers Districts in Louisiana.

as dredge and fill material on waters of the United States. The 404/10 permit is issued by each separate Corps district for all areas meeting the USACE definition (**Wetland Habitats in Louisiana** page 14) of wetlands in the respective districts in the state (American Petroleum Institute 1990). All other "pollutants" are controlled by EPA under section 402 of the Clean Water Act 1972.

Section 404/10 permits are either general or individual. General permits are for actions that are limited in scope and can be specifically covered by a general permit. General permits can be nationwide or regional and undergo a lengthy approval process before acceptance. Nationwide general permits can be found in 33 Code of Federal Regulations (CFR) part 330.5 (American Petroleum Institute 1990). There are currently 40 nationwide general permits in effect, covering such routine things as maintenance, bank stabilization, and repairs to existing structures. Regional general permits can be developed by the 36 USACE district offices.

Individual permits are required for all other activities that will not comply with one of the general permits. Louisiana is unique in that four of the 36 USACE districts claim jurisdiction over the various wetland areas in the state (figure 1).

The New Orleans district is the largest covering all of south Louisiana except the extreme western portion. That area is part of Sabine River watershed and is controlled by the Galveston, Texas district. The Vicksburg district covers all of north Louisiana west to northern Sabine River watershed where jurisdiction changes to the Fort Worth district. Vicksburg district also has the extreme eastern portion of the state in the Pearl River watershed. This type of district boundary delineation causes many problems for companies operating in Louisiana as different sets of criteria are used by the four districts in wetland permitting matters.

In addition to a 404/10 permit wells drilled in south Louisiana in the Coastal Zone (figure 2) will require a permit from the Louisiana Department of Natural Resources, Coastal Management Division (DNR/CMD). Under the federal Coastal Zone Management Act 1972 and the State and Local Coastal Resources Management Act 1978,

Figure 2. Coastal Zone of Louisiana.

NOAA was delegated the responsibility to approve, fund, and oversee state coastal management programs to protect coastal resources and habitat. The Louisiana Coastal Resources Program (LCRP) was federally approved in 1980 and began issuing Coastal Use Permits (CUP) for oil and gas operations in October of that year. (Lindstedt et al. 1991).

The Louisiana Coastal Use Permit is only issued in the coastal wetland areas of south Louisiana contained in the coastal zone of Louisiana. Since 1980, when the LCRP was approved, a CUP has been required for any petroleum-related activity within the coastal zone. Like the USACE, DNR/CMD has general and individual permits for activities in the coastal zone.

Before 1983, to obtain the CUP and USACE permits, applicants filed separately with the USACE and the DNR/CMD. The USACE used a standard application form (ENG Form 4345, Application for Department of the Army Permit) that required the name and address of the applicant and the location, nature, purpose, and description of the proposed activity. Three types of drawings of the proposed activity were required: a vicinity map, a plan view, and an elevation or cross-sectional view (Lindstedt et al. 1991).

A CUP application requires the same information as the USACE permit plus (1) project drawings, including existing drainage patterns; (2) a list of applicable coastal use guidelines; (3) alternate routes or methods; (4) economic justification for the project; (5) coastal water dependency; (6) secondary and cumulative impacts; and (7) impacts to historical, recreational, or cultural resources.

Between 1980 and 1983 each agency separately issued public notices of the proposed activity and accepted comments from interested citizens and other state and federal agencies. In 1983 the USACE and CMD coordinated their public notice procedures and began issuing a Joint Public Notice (JPN) for certain projects within the geographical area common to their jurisdictions. JPN handles all permits where joint jurisdiction exists. Each agency still has its own public notice and review process and issues separate permits for locations outside joint jurisdiction. These two permits and a water quality certification from DEQ are the only permits required to operate specifically in wetland areas. However, the USACE requires that an applicant obtain all relevant permits from all other local, state, and federal agencies, including discharge and drilling permits, before a 404/10 permit will be issued. Compliance with all applicable DNR/OC regulations on spacing and well, pit, and location construction is required by state and federal permits.

The permitting process for wetland locations is a complex highly orchestrated and easily misunderstood process to persons and companies indirectly involved with the process on a regular basis. This complexity has created the need for permit consultants to navigate the bureaucratic jungle involved in receiving a wetlands permit. To better understand the entire process and the web of permits and letters of no objection needed to obtain either an individual CUP and an individual 404/10 permit a flow chart of the application process to drill a well in a wetland area of south Louisiana was created (figure 3).

This flow chart shows the agencies and the required permitting steps. We have simplified this process to allow a basic understanding of how a permit for a wetland drilling location or production operation moves through the system. The R&C boxes present in the diagram represent internal review and the commenting period allowed for each permit. Individual reporting and communications lines represent highly complex communication between the various permitting and commenting agencies. Each individual request by a commenting agency must be processed by the permitting agency. Then the permitting agency requests the information from an applicant by telephone or through a letter. The applicant must then respond to the permitting agency who passes the information to the commenting agency. While these requests are processed the application is placed "on hold" delaying the application. If any of the permits are delayed the entire process slows down and in the case of denial of any one permit the total process stops; although, individual permits may continue to be pursued. Denial of a wetlands permit is rare, but long delays caused by requests from commenting or other permitting agencies can effectively stop a proposed operation. Most comments cause the proposed operations to be modified slightly in some way to prevent environmental damage. Some of the modifications routinely recommended include using the minimum area necessary, using board roads instead of canals, limiting dredging of wetlands by using existing open water access routes or picking an alternate route, and beneficial usage of dredged material and mitigation (on-site or off-site) of the damage incurred.

Each agency as shown except for CMD and the USACE which use the same form (Form 4345) have an independent application process. Independent offices in the same agencies require independent applications to each office. The applicant is required depending on the location of the proposed well to apply to the following agencies for the following permits and letters of no objection.

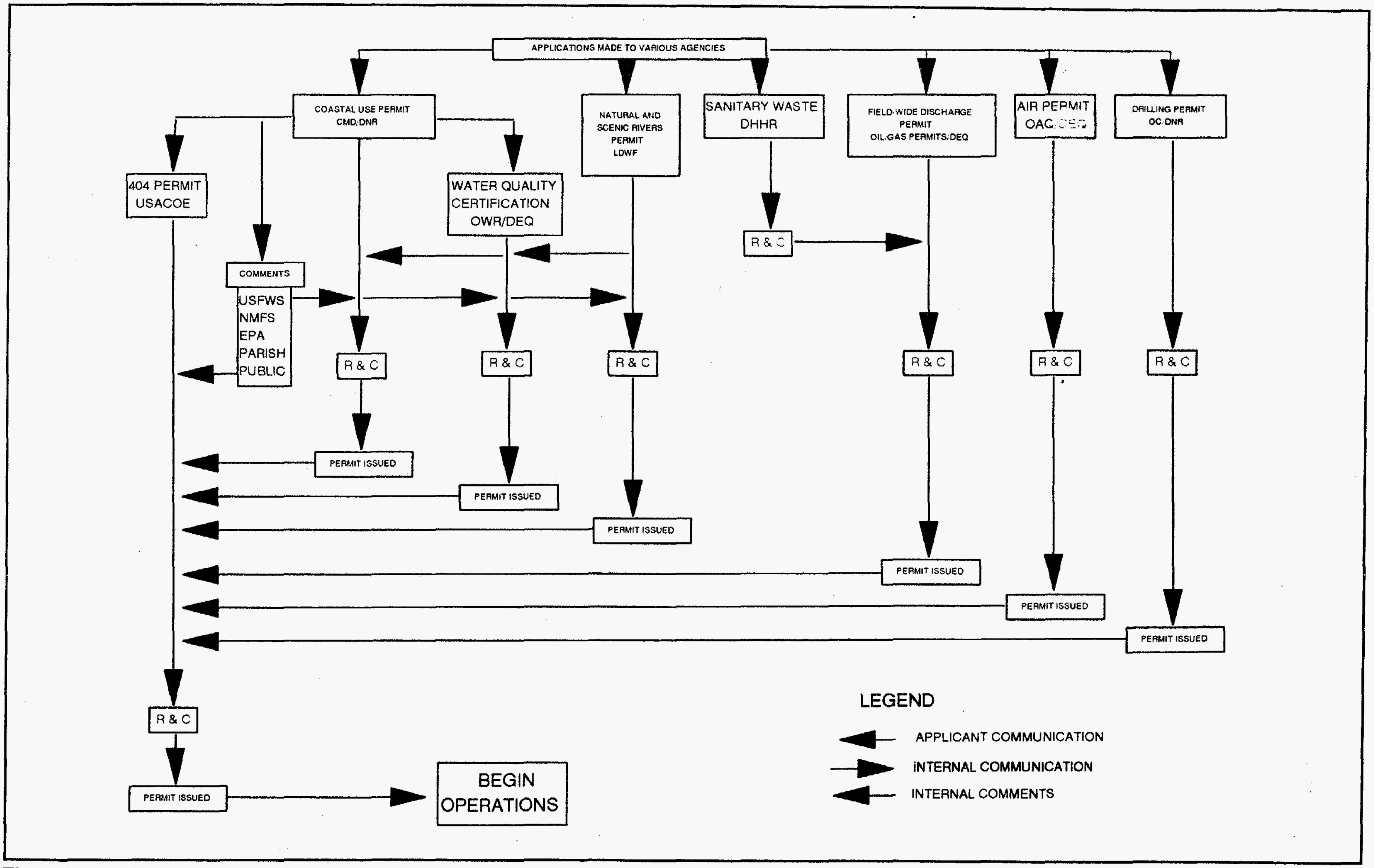

Figure 3. Simplified wetland permitting process flow chart before 1994. (R&C represents internal agency review and comment steps)

Starting from right to left in the figure is a drilling permit from DNR/OC. This permit is reviewed by the office before issuance. Second is DEQ for two different permits a Field-wide Discharge Permit from the Oil and Gas Division and if necessary a Air Quality permit from the Office of Air Quality (DEQ/OAQ) along with a Water Quality Certification from the Office of Water Resources, which is now included in the JPN. Air Quality permits are not usually required for drilling operations but in limited areas inside city boundaries and ozone non-attainment areas they may be required on a case-by-case basis. Large production facilities more frequently require Air Quality permits. Application by letter is required to obtain a Letter of No Objection from the Department of Health and Hospitals, waiving the requirement for a Sanitary Waste permit.

If the proposed location is on or adjacent to a water body covered by the Louisiana Natural and Scenic Rivers Program, a permit will be required from the Louisiana Department of Wildlife and Fisheries (LDWF). Direct application to the department for this permit is required.

Finally application must be made for a CUP or a 404 permit. Here the process has been simplified through the JPN procedure. The applicant applies to the Louisiana Department of Natural Resources, Coastal Management Division (DNR/CMD) for a CUP. Once the application has been reviewed and is complete with all information needed by the agency to make a decision the application is then sent by CMD to USACE as a 404 permit and to the Department of Environmental Quality/Office of Water Resources (DEQ/OWR) for a Water Quality Certification. These agencies begin processing the permit and ready the permit to be placed on public notice. Public notice of a proposed project is an integral part of the permitting process. After review CUP's are placed on public notice for 25 days and 404 permits for 30 days during which the public and various commenting agencies such as U.S. Fish and Wildlife Service (USFWS), National Marine Fisheries Service (NMFS), EPA, DEQ, LDWF, and local parishes can present written comments on the proposed activity.

For wells outside the coastal zone, applications must be made directly to USACE and DEQ Office of Water Quality Certification. USACE will notify the federal commenting agencies directly, but the applicant must request that USACE notify any state agencies.

The New Orleans district of USACE has created it own regional general permits to expedite and facilitate oil and gas operations in wetland areas. In 1985, two permits (NOD-13 covering board road length, construction, and well pad size and NOD-22 covering canal length, construction and slip size) were created to shorten permitting time for applicants. General permits shorten permitting time by waiving the required 30-day public notice and replacing it with an internal 10-day review process by the various agencies. If the proposed project meets all the general permit conditions permitting time is reduced. In response, CMD began issuing state general permits that conformed to the USACE permits to eliminate their 25-day public notice period. General permits have been highly successful in reducing permitting time for production and development wells where there is an existing access infrastructure.

One of the major problems encountered by independent oil and gas operators and others who operate in wetland areas is that the permitting process is constantly changing. Figure 3 was created in 1992 from what was then current information showing how the various agencies interacted. In early 1994 CMD issued new general permits that changed the permitting and notification process again. This change was beneficial in that the process has been simplified for the applicant. The new flow chart diagram (figure 4) shows the differences in the application process involving notification of the various state agencies who provide letters of no objection, in most cases, or comment in cases where the state's interest is affected directly. This expansion of the notification of the various agencies will simplify applications and reduce permitting time. For general permits the internal review process has been shortened to five days from ten days for the various agencies to respond to CMD.

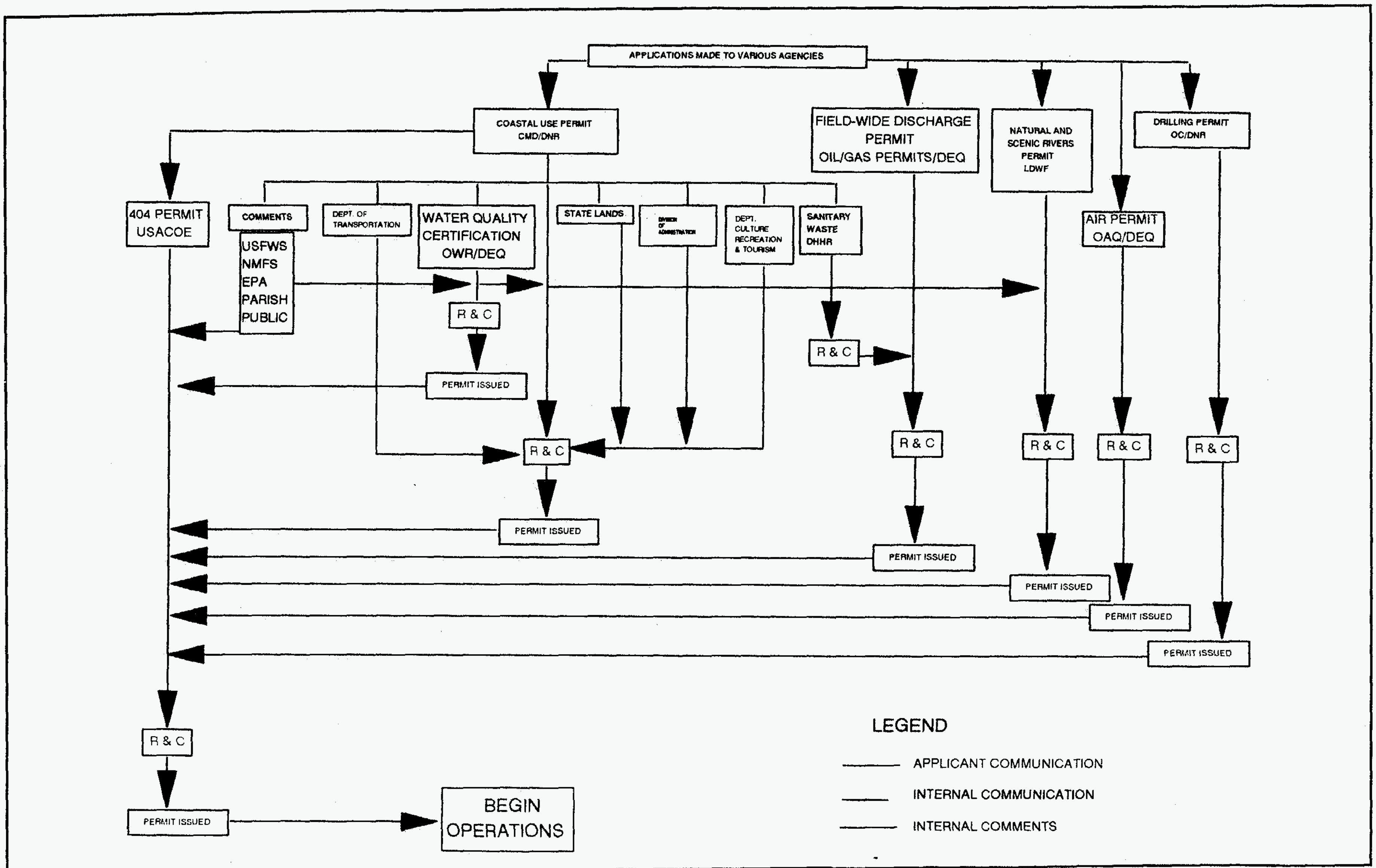

Figure 4. Simplified flow chart of current wetland permitting process in South Louisiana. (R&C represents internal agency review and comment.)

Although the notification process has been simplified the applicant still has to make separate applications to four other offices and agencies. To enhance the process and reduce permitting time, streamlining of the process can continue until one application would be needed for all agencies. Standardization of general permits for all four USACE districts would reduce permitting time for applicants who operate in all areas of the state.

The costs of obtaining a wetlands permit in Louisiana are summarized in table 4. This table represents additional costs for a well in wetlands compared to a well placed in a non-wet area. The additional cost of permitting ranges from $4,563 to $77,901 for a one-acre site and additional acreage will raise this cost. Indirect costs for permit consultants, oyster assessments, cost of surveying, and mitigation for damages can significantly increase this basic cost of the permit. Surveying companies that provide permit consultants can charge up to $2,000 (Ganzak 1993) for handling a simple project. Environmental problems (i.e., eagles' nests or oysters) can double or triple the cost of permitting a well—the larger the project, the larger the possible cost of surveying and consulting fees. Pipelines because of their large size and complex nature are more expensive to permit than a well location.

In most cases the price of restoration to pre-project conditions or the compensatory mitigation required to obtain a permit is the largest portion of the excess costs, except for very small projects impacting very little acreage. Mitigation costs can run up to $15,000 per acre ($37,000 per hectare) because the criteria under which compensatory mitigation has been permitted in the past is ambiguous. Mitigation may include simple replanting of the disturbed area and/or backfilling and plugging of the canals, which is an expensive type of restoration. Mitigation and alternative mitigation methods are discussed in detail in (see **Mitigation**).

Table 4. Wetland permits with approximate associated costs.

PERMITS/DEPARTMENTS	OFFICIAL COST	INDIRECT COSTS	RANGE
Drilling Permit Office of Conservation Dept. of Natural Resources	$100 0 - 3000 feet deep $500 3001-10,000 feet deep $1000 >10,000 feet deep	$200-400 plats	$300-1400
Coastal Use Permit Coastal Management Division Dept. of Natural Resources	$20 filing fee $0.04/cubic yard processing fee [1] ($2000 max.)	$200-400 plats $0-2000 consulting fee $0-8000 oyster assessment $0-1500 meeting travel costs $400-15,000/acre mitigation costs[2]	$600-56,285
Water Quality Certification Office of Water Quality Dept. of Environmental Quality	$265 processing fee		
404 Permit Army Corps of Engineers	$100 processing fee		
Natural & Scenic Rivers Permit Dept. of Wildlife and Fisheries	$150 processing fee	$0-15,000 consulting fee $50-400 publication costs[3]	$200-15,550
Field-wide Discharge Permit Oil and Gas Permits Dept. of Environmental Quality	$170.63/point (20 points per field)[4]	$50-400 publication costs	$3463-4666
Sanitary Waste Dept. of Health and Hospitals	No Cost Letter of No Objection		$0
Air Permit Office of Air Quality Dept. of Environmental Quality	No Cost Variance will be issued		$0
NPDES Permit Environmental Protection Agency	No Cost Application Required		$0

1. This fee is paid to Coastal Management and includes all publication cost for CUP, Water Quality Certification and 404 permit.
2. Average location sizes range from 2.3 acres and over.
3. Applicant must publish in state journal in the parish in which project will occur.
4. This is an annual fee. Five additional points per field may be assessed annually if discharge is within 50 miles downstream of a municipal water systems intake. Add. wells at no charge.

Because compensatory mitigation guidelines are not clearly defined and agreement by agencies on what constitutes compensatory mitigation can be different and site specific, the costs can vary widely making it impossible for oil companies to accurately plan for potential restoration and mitigation costs. This uncertainty can lead to wells not being drilled because the well economics that may be marginal may become uneconomic if mitigation costs are excessive. This is especially true with shallow wells in sensitive areas. To prevent this loss of potential revenue to the state, DNR has tried to promulgate rules that would clarify mitigation and set a standard cost per acre for different habitat types. In late 1993 the landowners, oil companies, and the state agencies agreed on a series of costs for different habitat types (table 5). The rules also require an additional processing fee that ranges from $300 to $6000 depending on the acreage impacted. These rules will help companies to more precisely estimate potential mitigation costs. However, problems still exist because USACOE does not yet accept these numbers and may require restoration in lieu of or in addition to any mitigation fee collected by the state. This would require companies to pay twice for the same benefit.

Table 5. Proposed mitigation fee per acre schedule February 1994.

Bottomland Hardwoods	$397-1588
Fresh Marsh	$1886 - $7542
Intermediate Marsh	$1996 - $7866
Brackish Marsh	$2081 - $8324
Saline Marsh	$2198 - $8793
Fresh Swamp	$3512 - $14048

Future Regulatory and Permitting Changes for Louisiana

Change in the permitting process is continuing, and trends are not favorable for operators trying to extract resources from under wetland areas. Since beginning this report in 1991, Congress attempted to reclassify oilfield waste under Resource Conservation and Recovery Act (RCRA). This attempt was defeated when the EPA concluded that oil and gas exploration and production waste is not hazardous as currently regulated.

EPA is considering an internal overhaul of its effluent discharge program under the Clean Water Act. EPA wants to consider total impacts on a particular watershed instead of the individual criteria now used. (American Oil and Gas Reporter 1994). The effects of this change will be mitigated as surface discharges are presently being phased out by 1997 (Burke 1992).

EPA is developing costly new underground injection well rules under its UIC program; although, only 23 cases of aquifer contamination have been reported and confirmed by the General Accounting Office (GAO) by 1989. At the time of this report, the United States had over 170,00 active injection wells and 2.2 million inactive or abandoned wells (Oil & Gas Journal 1993). At the present time the final rules have not been issued.

The biggest threat to operations in wetlands comes from an unlikely source. Under the Oil Pollution Act 1990

(OPA90) the Minerals Management Service (MMS) has been delegated the authority to create rules for compliance with the act. One of the provisions of the act is to require a certificate of financial responsibility (COFR) in the amount of a $150 million bond for all operations in on or under navigable waters of the United States. OPA90 was intended for offshore operations but the wording has extended the boundaries to cover all operations near almost any water body or wetland. This would mean that all operators in wetland areas would need to provide a COFR for their operations. This requirement is unattainable by all but the largest operators in Louisiana. Insurers will not issue insurance because of the language in OPA90 that permits direct action and litigation against the guarantor (insurer). Even if coverage was provided estimated costs of COFR range from $3–15 million per year with $20 million deductible. (Conner 1994).

If OPA90 stays in its present form, wholesale shut-down of producing facilities and the resulting loss of jobs will occur. The economy of Louisiana will be devastated as most of its production is in wetlands and controlled by operators who will be unable to obtain a COFR. (Beims 1994).

On the state level, changes in NORM regulations are expected to remove some ambiguous and confusing language to clarify the rules. Mercury contamination in North Louisiana from gas-metering activities is a future problem for the industry and regulators. The scope of the problem is currently under review, and no regulatory action has occurred in this area at this time (Durham 1993).

WETLAND ACCESS PRACTICES

Wetlands by nature are highly inaccessible in most cases. For this reason exploration and development of petroleum resources in wetlands pose severe logistical problems for operators. The means to transport equipment into a wetland drilling or production site are limited. Early access prior to the invention of the semi-submersible drilling barge was either by natural waterways, or roads built on adjacent uplands (Williams 1929). In areas where water access was feasible, drilling from platforms or floating barges was the normal mode of operation. In swamps and marsh wetlands and other shallow or unconnected open water environments, traditional access methods using roads and floating barges was not feasible. New technology and methods of access were required to proceed in these difficult areas. Canals and board roads are modifications of the then existing access methods for land or open water and are still widely used in wetland areas.

Wetland soils are highly organic in nature and this factor limits their ability to support heavy drilling equipment. The soil tends to compress and in many areas sink below the existing water table when loads are placed on them. This factor limits the use of roads as a means of access.

Canals

Because canal and road construction in wetlands is expensive and time consuming, roads on firmer marshes were used where possible and canals were built in areas that could not support roads. In areas accessed by canals, early drilling sites were either constructed on pilings similar to open water sites or on wooden mats that were placed on the marsh surface. By 1931 the floating barge rig was invented followed by the submersible drilling barge in 1934, which eventually proved to be cheaper and more efficient than the previous site preparation methods (Williams 1934a, b).

Once the submersible barge was in use, there was a need for a more efficient method of digging access canals through the marsh. By 1938, both barge-mounted bucket dredges and hydraulic dredges were used. Sometimes both type of dredges were used in combination because the bucket dredge was more efficient in removing the vegetative layer and the hydraulic dredge would remove the underlying substrate (Williams 1944). By the mid 1950s bucket dredge technology improved and they became more efficient than hydraulic dredges. By the early 1960s few hydraulic dredges were used, and today conventional bucket dredges are almost solely used (Cahoon and Holmes 1989). With advances in dredging technology from the 1930s to the 1950s, canals became the common access method to drilling sites in coastal Louisiana.

Typical canals (figure 5) are 8 ft (2.5 m) deep with the dredged spoil deposited along the sides of the newly created canal to form spoil banks. Permitted canal widths measured at the bottom vary from 65 to 80 ft (20 to 24 m) with 70 ft (21 m) across being the most widely permitted dimension. Surface canal width may vary from 65 to 100 ft (19.8 to 30.5 m) depending on the organic content and the stacking properties of the marsh substrate. To prevent the sides of the canal from collapsing the dredged spoil is placed about 25 ft (7.6 m) outside the edge of the canal. The stacked spoil or "spoil bank" as it is called is stacked up 4–5 ft (1.2–1.5 m) high and 50–75 ft (15–23 m) wide. Depending on the original canal width and soil conditions each canal can disturb a path from 220 to 300 ft (67.1 to 91.4 m) wide through the marsh.

Access canal size for a particular well is determined by the drilling barge and ancillary equipment needed to complete the well. Figure 6 shows an overhead view of a typical canal and slip configuration. Drilling barge size varies from 45 to 55 ft (14 to 17 m) wide and from 180 to 220 ft (54.9 to 67.1 m) long (Cahoon and Holmes 1989). Most drilling barges require 5.5 to 6.5 ft (1.7 to 2.0 m) of draft. Shallow draft drilling barges drawing 4.5 ft (1.4 m) of water exist, but only one is still in operation in Louisiana. At the terminus of the canal a "keyhole" or slip is dredged for the drilling barge and from 1 to 3 additional barges that will used in drilling and resupplying operations. This slip is usually from 150 to 180 ft (45.7 to 54.9 m) wide with 160 ft (48.8 m) being the standard permitted size. As with the canal itself the slip is surrounded by a continuous spoil bank. The long side of the keyhole can vary from 325 to 375 ft (99.1 to 114 m) with 345 ft (105.16 m) currently being the standard length. The depth of the slip is 8 ft (2.4 m) or the depth of the canal. Figure 7 shows an actual location with a barge mounted rig in action.

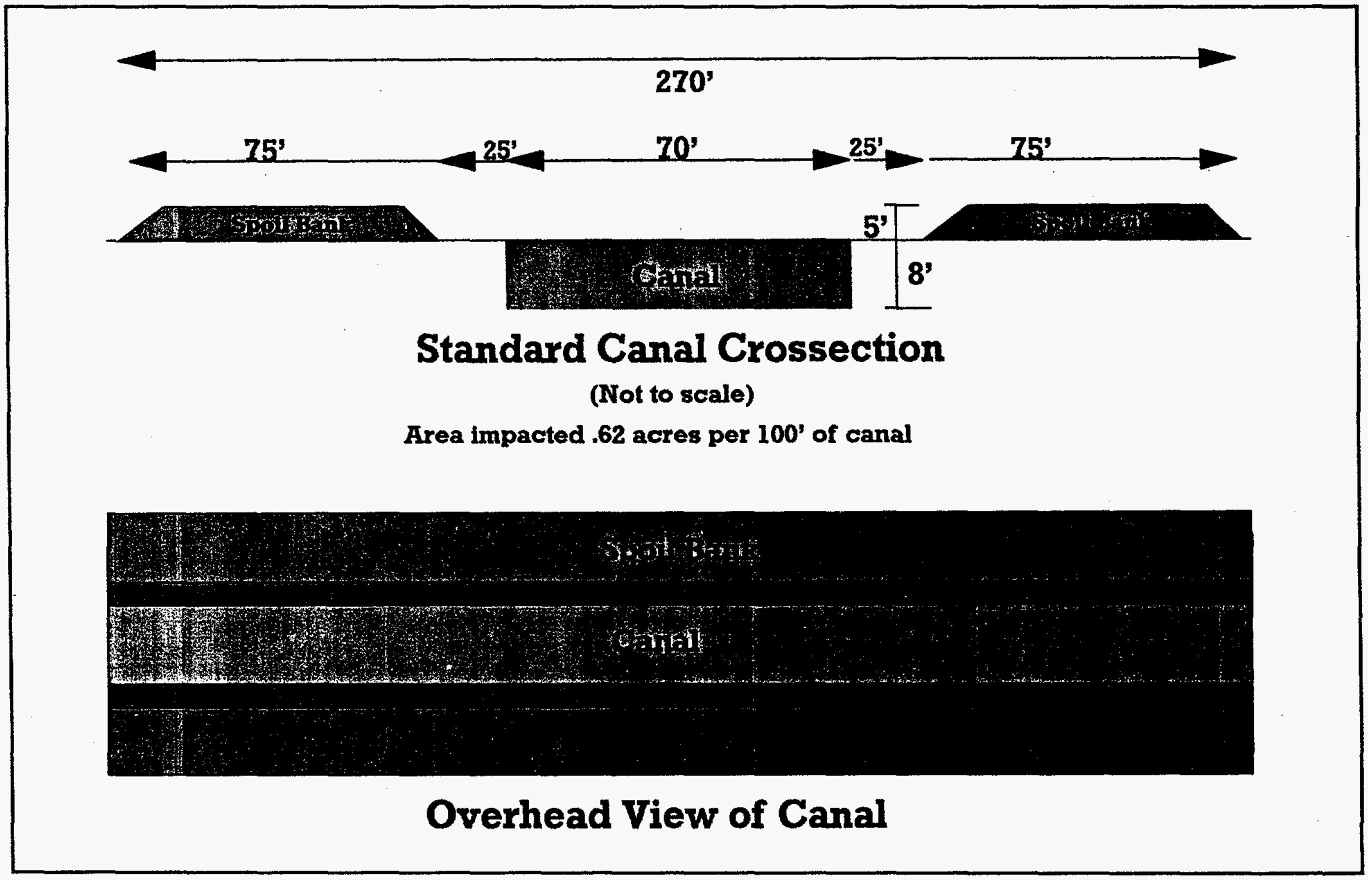

Figure 5. Cross-section and overhead view of a standard canal in South Louisiana.

Over time Louisiana has built a network of canals for oil and gas exploration. Canals were dredged to allow access by seismological crews and for pipelines to carry production to the refineries in addition to wells for drill site access.

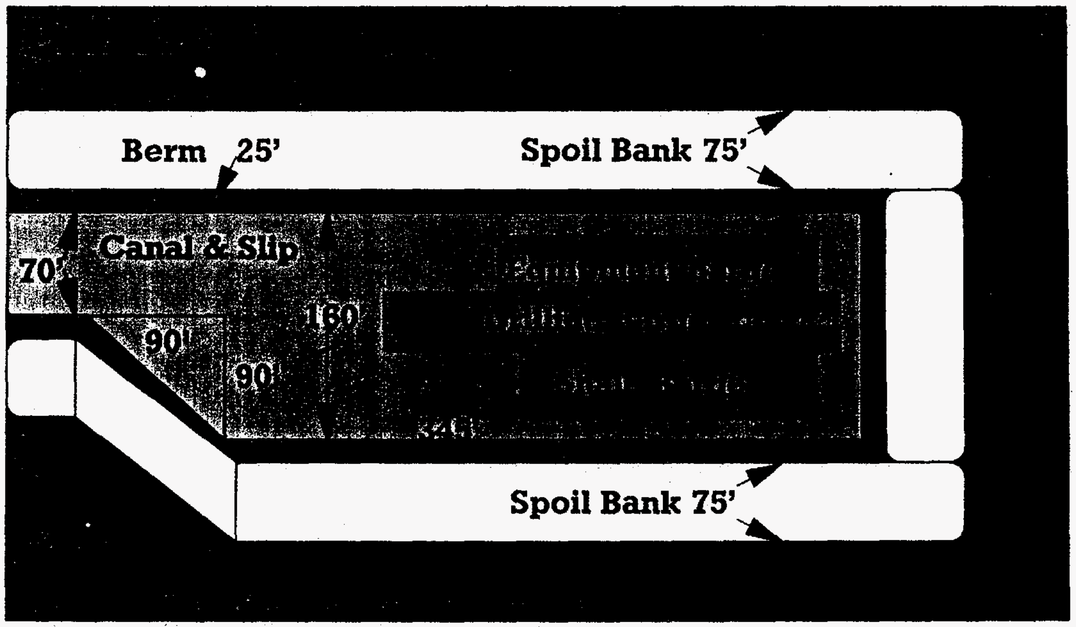

Figure 6. Overhead representation of a typical canal well site in Southern Louisiana.

Board Roads/Ring Levees

Board roads are roads formed by laying planks or boards along the ground to form a mat-like structure capable of supporting heavy loads. Early roads were created using shell and boards as materials. Road access is used exclusively in north Louisiana where no canal systems exist and extensively in south Louisiana because of lower costs. Another type of board road which was used is a piling-supported road to access sites in open water (Cahoon and Holmes 1989).

Current rig design allows the rigs to be broken down for transport along roads and highways. In marsh areas where access by water in not used, a road is constructed of dredged material "borrowed" from the adjacent marsh or swamp.

Cahoon and Holmes (1989) describe the standard construction procedure in detail. A brief summary of their work follows explaining the dimensions and construction techniques used to build board roads. Not all marsh areas are suitable for board roads. Cahoon and Holmes (1989) indicate that 1 out of 100 sites along the Texas and Louisiana coasts are not suitable for road dumps. This fact does not consider the economic cost of building some of these roads. Pleistocene terrace or Chenier plain subsoils may support board road technology at a reasonable cost but, a freshwater marsh or swamp board road might be so expensive that unless alternative means of access

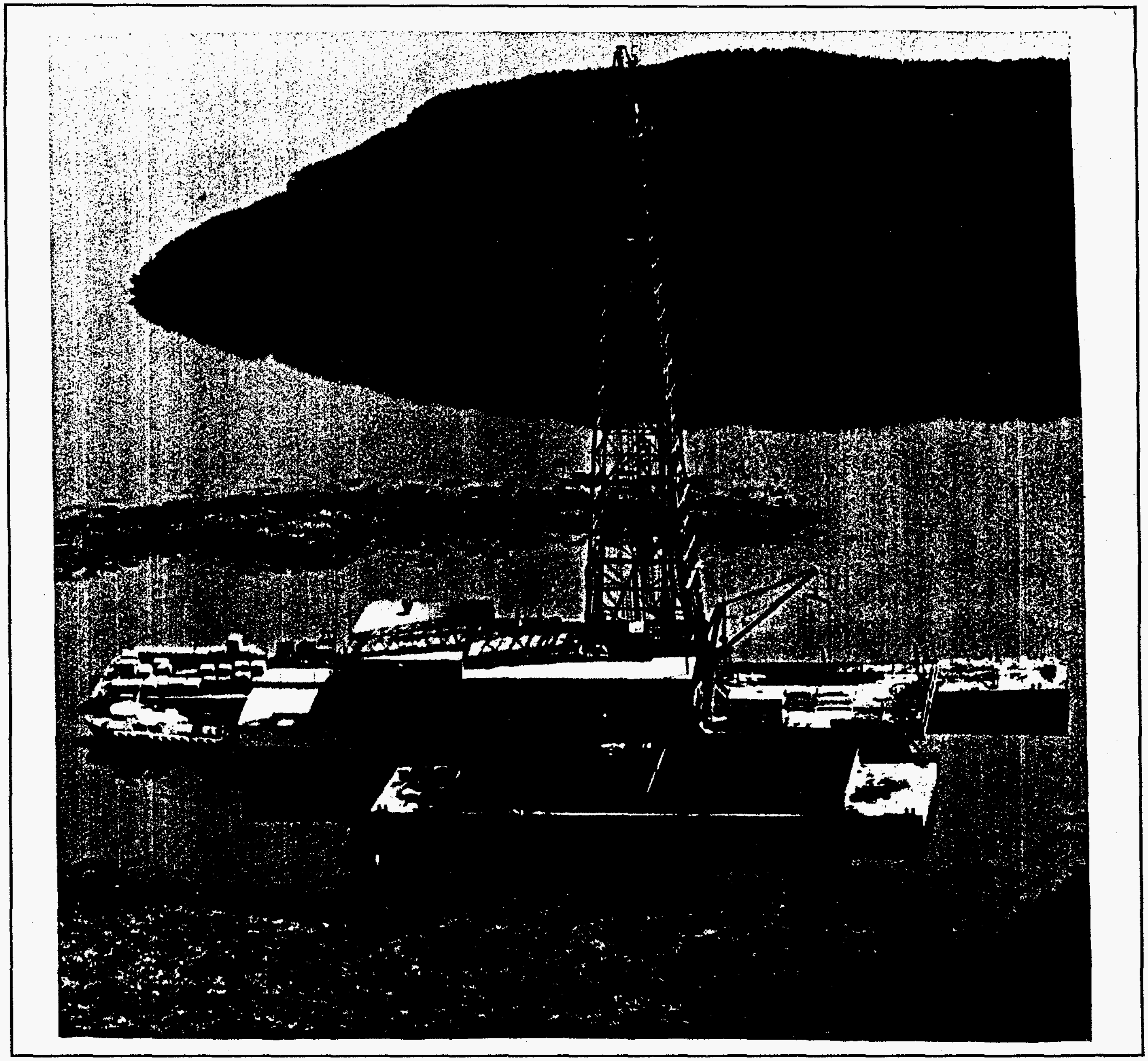

Figure 7. Aerial photograph of barge mounted drilling rig in action. (Courtesy Dean Shank Drilling Co.)

is found the well would not be drilled. For this reason the 1 out of 100 figure in reality is more like 40 out of 100 with the specific site conditions as the controlling factors. Depth to an underlying clay layer and percent organic matter determine the cost, size of the road, borrow ditch width and depth, and total disturbed area.

To begin, a dragline, which uses wooden mats as temporary supports is placed at the starting point of the road. The support mat consists of timbers about 1 by 16 ft (0.30 by 4.9 m) long wired together to form a mat 4–6 ft (1.2–1.8 m) wide and 16 ft (4.9 m) long. As the dragline progresses, it moves a series of mats forward and "walks" across the marsh. The dragline dredges marsh material from one side 5–8 ft (1.5–2.4 m) deep and deposits it on the other side to form a road dump. In the past, two draglines might have been used one on each side to get enough material to form the road dump. Permits today require alternating or staggered borrow pits eliminating the use of two draglines as an option. This lengthens the time required to construct board roads and adds to the costs. To allow roads to be completed in these areas, permits allow borrow pits to be up to 20 ft (6.1 m) deep if necessary.

The dredged material is piled up to create a surface 5 ft (1.5 m) above the marsh level. The typical road dump requires a 30 ft (9.1 m) wide road and a 30 ft (9.1m) wide borrow ditch, 5 ft (1.5 m) deep and 300 ft (91.4 m) (maximum) long, alternating on either side of the road (figure 8). The width and depth of the borrow ditches vary with the fill requirement of the road dump, but borrow ditches wider than 30 ft (9.1 m) are rare in today's regulatory environment. Less fill is required for soils with high clay content and more for soils with high water and organic content.

In forested wetlands construction varies somewhat because the access route must be cleared of trees before building the road dump. Stumps in the borrow ditch site also must be removed prior to dredging, but stumps on the road site are left in place to provide support.

In both habitats after the dredged spoil is deposited to form the road, a sediment filter cloth or plastic sheeting is placed on the fill to allow the material to de-water and solidify. After the material has formed a hard surface, the boards are placed on the elevated site. Several layers of boards 4 by 8 in. (10 by 20 cm) and 16 ft (4.9 m) long are hand placed at right angles to each other on the dumped material. The first layer of boards (mud boards) is laid directly on the fill material along the direction of travel. The next layer of boards is laid perpendicular to the first layer and nailed to the first layer. Each subsequent layer is laid perpendicular and nailed to the layer below it. Two to four layers of boards may be required, depending on the strength of the substrate. The top layer (running or tread boards) are nailed on top in the direction of travel. The running boards are positioned where truck tires will travel. The total number of board layers depends on the soil conditions and the size of the drilling rig and equipment at the site (Cahoon and Holmes 1989).

Board roads are a temporary means to access a site and are reusable. Because the road is designed to be removed if the site is unsuccessful, the boards are rented by the drilling company for 90–180 days depending on well depth. If the operation extends beyond 180 days before the site is abandoned, the road is considered permanent. When a site is successful, the road becomes permanent by removing the running boards and placing shell or limestone on top of the remaining boards.

Early board roads constructed prior to 1953 and now abandoned are clearly visible on aerial photographs (Cahoon and Holmes 1989) of southwestern Louisiana. Early board roads often used a continuous borrow ditch unlike the alternating ditch now required. These continuous borrow ditches have developed into boat routes for hunters and fishermen, and many of the leftover road dumps have revegetated and appear as an elevated anomaly

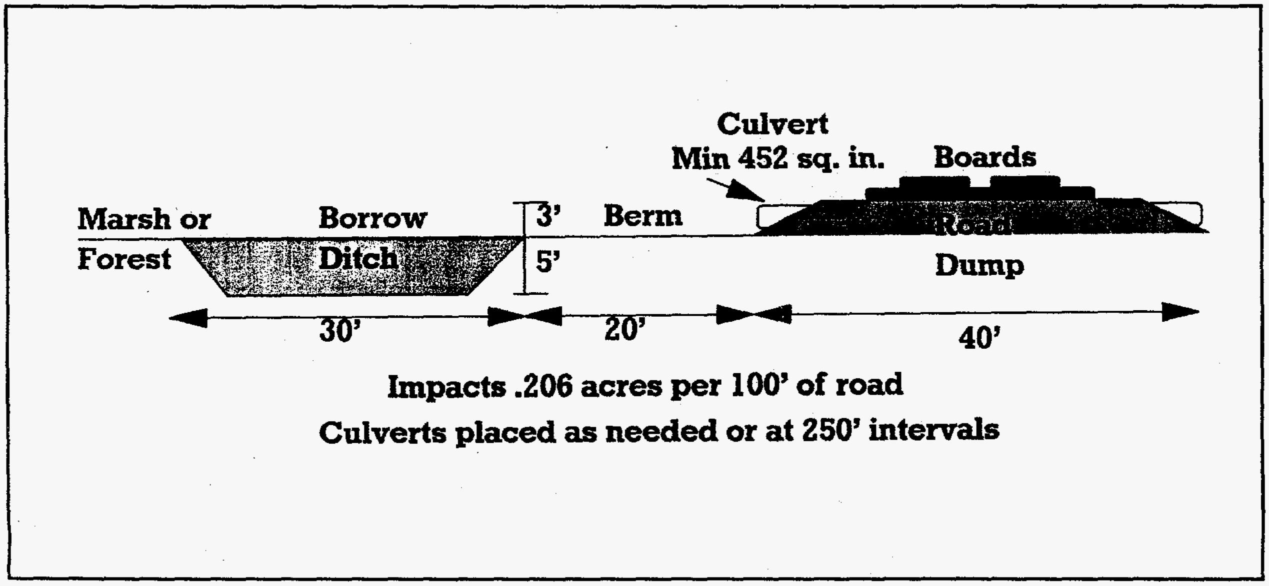

Figure 8. Cross-sectional view of board road construction technique.

(Cahoon and Holmes 1989) from the air.

At the end of the board road the well pad or ring levee will be constructed to allow drilling to proceed. Figure 9 shows an overhead and cross-sectional view of a typical board road and ring levee location used to access wetland areas. As with the board road, a ditch will be dug around the location to pile spoil up to 5 ft (1.5 m) high above marsh elevation. This pile of material that completely surrounds the location is called the ring levee. Ring levees serve an important function because they prevent water from entering the location from outside. They also contain any possible spill or contamination on a site within the ring levee preventing it from affecting the surrounding marsh habitat.

Current regulations allow maximum ring levee dimensions of 400 by 400 ft (122 by 122 m). However, after careful analysis of the actual needs of a standard size of 300 by 300 ft (91.4 by 91.4 m) or 90,000 ft² (8,400 m²) is used for wells drilled to less than 10,000 ft (3,050 m), 300 by 350 ft (91.4 by 107 m) for wells drilled 10,000–15,000 ft (3,050–4,570 m) and for deeper wells a location size of 400 by 350 ft (122 by 107 m) is standard.

Inside the ring levee, a reserve or drilling mud pit will be excavated 8–10 ft (2.4–3.0 m) deep below marsh elevation. The spoil will be used to raise the elevation of the drilling pad area by 1–2 ft (0.3–0.6 m) above marsh elevation. Piles will be driven under the area where the rig will be placed and a well crib 8–10 ft (2.4–3.0 m) deeper will be excavated. Four layers of alternating boards will be laid around the rig stand and three layers will be laid outside this area to allow operations to begin.

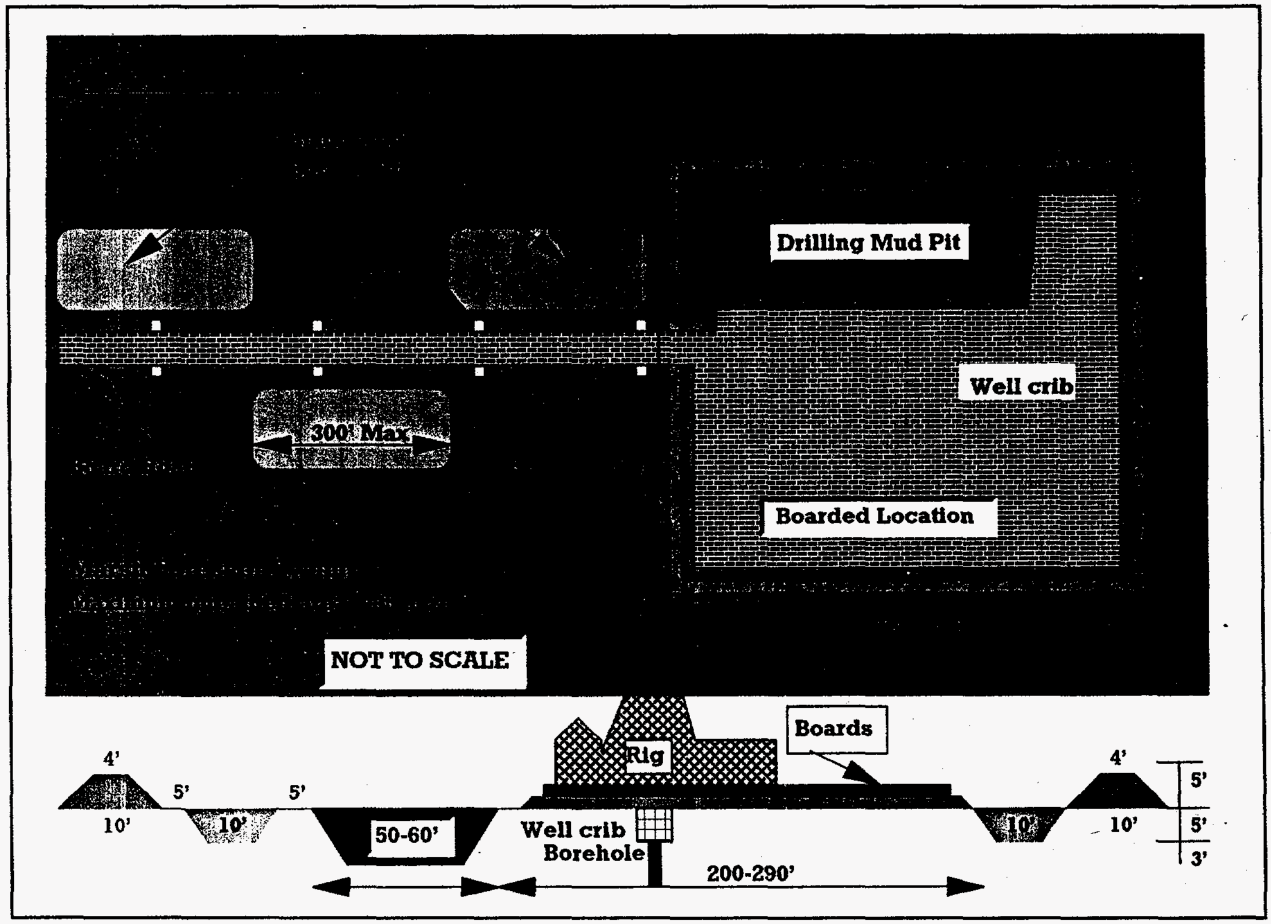

Figure 9. Overhead and cross-sectional view of a board road and ring levee used in wetland areas.

IMPACTS OF OIL AND GAS DEVELOPMENT

To understand why the current permitting system exists one needs to examine the underlying causes for the creation of such a system. The current permitting process began as individual actions by various agencies to correct specific problems. This has evolved into a regulatory process to control impacts of all types on wetland areas that were created by unrestricted access to the areas. Background understanding of these impacts is necessary for an objective examination of whether or not a given regulation or procedure is necessary, beneficial and cost effective.

The oil and gas industry has had and will continue to have long-term impacts on Louisiana's people, institutions, and environment. Beneficial and detrimental effects of the industry are evident in the state's economy and in wetland areas. Although the state's economic security has declined with declining production, the industry remains the most important one in the state today (Lindstedt et al. 1991). The effects on the wetlands of oil and gas activities are long term and will continue to alter natural processes long after the area is no longer actively producing oil and gas.

Since the beginning of exploration in Louisiana its wetland areas have been impacted by the activity. Early activity was constrained by the ability of the company to access a location. Early activity as described in (**Louisiana Oil and Gas Production Patterns**, page 32) was limited to building roads to access sites. Roads were built in much the same manner as today (**Wetland Access Practices**, page 60). Road access has changed little since early days, so we will examine its impacts first.

Since the 1950s, south Louisiana's population has grown steadily and shifted from remote rural areas in the marshes to more densely settled communities where employment with the petroleum industry has been available (Davis and Place 1983). The coastal parishes have grown quicker than the northern ones, but this concentration of petroleum activities in the coastal zone has required coastal communities to develop roads and other public services (Davis and Place 1983, Gramling 1984).

High, dry land suitable for residential, commercial, and community use is limited in south Louisiana and wetlands have been reclaimed for such activities. Support bases, supply yards, and related industries are located near the development and production areas. As a result, heavy concentrations of petroleum-related industries are found in the coastal parishes and surrounding areas. For example, in 1990 there were 26 service bases, 21 heliports, 9 pipe-coating yards, 14 platform-fabrication yards, 26 gas processing plants, 17 oil refineries, and 50 separation facilities in south Louisiana (Minerals Management Service 1992). These facilities require from 1 to over 1,000 acres (0.2 to 405 hectares) for construction and operation.

Board Roads/Ring Levees

Road dumps disrupt ecological processes and directly and indirectly cause wetland alteration or loss. Cahoon and Holmes (1989) provide an overview of the specific effects road dumps have on wetlands. They list environmental consequences such as habitat alteration (physical and ecological impact and altered physical processes) and impact on biota. Road dumps destroy habitat, create barriers to water movement, and alter the flooding regime and sediment distribution patterns. Borrow ditches, which connect different salinity regimes may promote saltwater intrusion. Alteration of wetland processes in turn reduces organic production and vertical accretion.

Road dump construction like canal construction (**Wetland Access Practices**, page 60) converts marsh into open water and spoil habitat. Each 100 ft (30.5 m) of board road using current techniques converts up to 0.21 acres (0.08 hectares) of marsh (table 6), including the berm area or 0.16 acres (0.06 hectare) if the berm is assumed to be undisturbed. Confusion exists in the literature; Cahoon and Holmes (1989) do not include the berm for board road locations in their calculations. However, when the canal calculations were made, they included the berm area in the total impacted area. To be consistent the berm area is included in our calculations of total impacted areas using the standard location dimensions found in NOD-13 and general permits 5 and 7 issued by CMD/DNR to calculate total impacted areas. Current USACE rules for the New Orleans District allow a maximum of 1,500 ft (457 m) of access road and ring levee under a general permit NOD-13. The maximum area altered by the road and ring levee/drill pad using a 400 by 400 ft (122 by 122 m) ring levee is approximately 5.95 acres (2.41 hectares) as

Table 6. Impacts of board road and ring levee combinations.

acres (hectares)	100' Road (30.48 m)	Maximum NOD-13	Standard NOD-13
With Berm	0.21 (0.08)	5.95 (2.41)	4.55 (1.84)
Without Berm	0.16 (0.06)	5.44 (2.20)	3.99 (1.61)

shown in table 6. However, the standard impacted area for most locations is 4.55 acres (1.84 hectares) as a 300 by 300 ft (91.4 by 91.4 m) ring levee is commonly used. Depending on the requirements of the drilling rig the total impacted area of a location will vary between these two numbers. Presently there are no quantitative data on the total area directly converted from wetlands to road dumps and borrow pits (Cahoon and Holmes 1989); however, as part of its regulatory program CMD/DNR is currently gathering data on this impact.

Board road dumps impact habitat directly and indirectly. Direct impacts include loss of marsh or forest habitat by conversion to open water or upland habitat, noise and commotion during construction, introduction of toxins to marsh surface, changes in plant growth and vertical accretion, changes in plant type and habitat, interrupted breeding cycles and decreased water quality (Cahoon and Holmes 1989). Indirect impacts include alterations to surface and subsurface drainage, saltwater intrusion, increased flooding, changes in sediment distributions, habitats, and soil chemistry, and loss of vertical accretion of plant material.

Board road and ring levee locations directly impact marsh or forested habitat by converting this habitat to biologically less-productive habitats. The dredging of borrow pits creates relatively deep ponds or open water habitat. The stacked road dump rises 3 ft (1 m) above the surrounding marsh or forested areas. In marsh environments, as little as 6-in. (15-cm) elevation changes can allow habitat alteration. The road dump is converted to more upland environment where plants more biologically proficient in that environment will dominate. This factor contributes to complete loss of wetland areas.

To understand wetland loss caused by oil and gas operations, it is essential to understand the regional environment. Coastal wetland areas constantly are fighting a battle between vertical accretion of biomass from plants and increase in sediment from flood events versus the regional subsidence of a riverine deltaic lobe. South Louisiana wetlands are undergoing subsidence as they are built up on deltaic sediment. People have created levees to prevent the sediment load carried by the river from spreading across the marsh like a giant sheet to nourish the habitat. Instead the sediment and nutrient-laden water is dumped over the edge of the continental shelf disturbing the natural process of wetland sedimentation. Because the marsh is not being re-nourished, vertical accretion of biomass is the only retardent on subsidence. Wetland species grow quickly creating a reservoir of biomass that is converted to soil over time as the plants die and decompose. When less-proficient species replace wetland plants the rate of vertical accretion decreases. If the rate is less than the subsidence rate the marsh habitat over time becomes open water.

Board road locations change surface and subsurface hydrology. This change in hydrology occurs when the stacked spoil of road dumps compresses the underlying sediment layers to create a reduced flow area. In marsh or forest areas this creates a barrier to surface and sub-surface sheet flow that nourishes the marsh. To mitigate the impacts caused by the road dump, regulators require the installation of culverts as required at periodic intervals (250 ft [76.2 m] maximum) to allow water movement across the marsh to reduce the impact of the road dump on the surrounding ecosystem. Culverts can alter the flow regime when water funnels to the culverts to create new surface channels. Impacts to hydrology are minimized but not eliminated.

Orientation of the road dump can be used to mitigate the impacts on hydrology. For example, if a road is perpendicular to the water movement, a hydrologic head may develop alternately on either side with the rising and falling tides (Cahoon and Holmes 1989). This flooding can cause plants to become stressed or may alter species composition. Proper planning and site assessment along with consultations with the wildlife agencies can prevent these impacts. Road design should be parallel to sheet flow and well locations should be chosen to minimize surface effects. Use of natural features to access the location such as ridges can prevent damage to natural hydrologic flow patterns.

Feeding and breeding habits of various species inhabiting the marsh may be disrupted by the creation of a road or ring levee location. Noise and commotion associated with construction of the dump can cause temporary disruption of life cycles. Over time the surrounding species will adjust by moving or ignoring the work performed.

Board road construction also can increase water turbidity, and water quality may decrease because of resuspension of toxic substances and nutrients during excavation and deposition of sediment at the construction site.

Board road impacts are significant, but the ring levee location itself directly contributes 75% of all impacts caused by a board and ring levee location. The problems associated with creation of a board road are magnified when creating a well location inside the ring levee. To build a ring levee a spoil bank that surrounds the well location is created. This levee causes the same effects as a board road, but culverts cannot be used to mitigate the impacts. Habitat is destroyed until operations end by preventing vertical accretion of biomass.

Canals

The most obvious and significant ecological impacts of the oil and gas industry in the coastal wetlands are related to dredging for well access, seismic activity, and pipeline construction. Miles of each type of canal along with major navigational channels interlace the coastal zone. They alter hydrology by changing an area's drainage patterns from numerous small, sinuous channels to one large, straight, deep channel. These channels are one cause of saltwater intrusion and subsequent loss of freshwater vegetation in the state (Gosselink 1984, Stallings 1984).

Canals and spoil banks affect wetlands in direct and indirect ways. Direct effects are the immediate loss of habitat, i.e., conversion of marshes to open water and to spoil bank (shrub/scrub) habitat. Indirect effects occur over an extended period of time and result in a change in ecological processes because of a physical change. Cahoon and Holmes (1989) summarize these changes and effects and illustrate the relationships between human activities and natural processes.

When canals and road dumps are constructed, marsh habitat is directly converted into either open water or spoil bank habitat. These new habitats alter the hydrological regime of the marsh. The total area impacted by a canal includes the channel itself and the associated spoil bank. The spoil bank on each side of the canal alters more than twice the area than the actual channel does (Monte 1978, Cahoon and Holmes 1989). This change in habitat is apparent and widespread when considering the data presented in Mossa et al. (1990). This study presents the area of spoil banks present in the coastal zone at 19,866 acres (8,043 hectares) in 1956 and increases to 93,973 acres (38,045 hectares) in 1978. In addition, habitat classified as artificial water, which includes canals, channels and impounded areas mostly used by industry, increased from 77,042 acres (31,191 hectares) in 1956 to 145,072 acres (58,734 hectares) in 1978.

Canal locations can alter almost twice as much area for the same length canal compared to a board road. A 1,500 ft (457 m) with a standard slip alters 10.99 acres (4.449 hectares) (table 7) of habitat compared to approximately 5.95 acres (2.41 hectares) for the largest board road location with same length. For longer canals and road dumps the difference in impact is greater because canals impact 0.65 acres (0.26 hectares) per 100 ft (30.5 m) compared to 0.21 acres (0.08 hectare) per 100 ft (30.5 m) for a board road. In addition, the open water created by the road construction is usually shallower than canals 5 vs. 8 ft (1.5 vs. 2.4 m) and disconnected preventing saltwater introduction.

Hydrologically, canals are more efficient and rapid than natural bayous. Faster runoff decreases the potential of the marsh to filter nutrients and pollutants effectively to decrease water quality lower in the estuary where eutrophication occurs more quickly. The increased runoff also causes rapid fluctuations in the water table and also lowers it to cause more frequent dry periods that affect soil/water chemistry and the ability of plants to respond to wider ranges of environmental conditions (Cahoon and Holmes 1989).

Finally, canals also provide more routes for salt water to move farther inland, thus changing marsh communities significantly. Increases in salinity cause change in marsh habitat and the distribution of oysters. Depending on the location, an increase in salinity causes different reactions. In freshwater swamps and flotant marshes the habitat is usually converted to open water and fresh and brackish marshes change into brackish and salt marshes respectively (Cahoon and Holmes 1989).

Once a canal is completed, the area it alters continues to change, with boat traffic that continuously erodes the sides of the canal. The canal widens and spoil and marsh are converted into open water. Access canals are widened 3.1 to 7.4 ft/yr (0.94 to 2.2 m/yr) (Johnson and Gosselink, 1982) and widening in some canals can range from 2% to 15% annually, causing the canal to double in width every 5 to 35 years (Turner 1985). Turner (1985) estimated that widening of old canals can almost equal the area of new canals added each year.

According to the most recent studies, conversion of marsh directly into open water and spoil habitat from dredging canals accounts for 5% to 10% of the total land lost each year in south Louisiana (Cahoon and Holmes 1989, Turner 1985, Scaife et al. 1983). The subsequent widening increases land loss to 10% to 20%. Previous

Table 7. Comparison of various canal configuration impacts

acres (hectares)	100 ft Canal (30.5 m)	Parallel Slip	500 ft Canal & Slip (152 m)	1500 ft Canal & Slip (457 m)
With Berm	0.65 (0.26)	2.95 (1.19)	4.73 (1.91)	10.99 (4.449)
Without Berm	0.51 (0.21)	2.52 (1.02)	4.04 (1.63)	9.09 (3.68)

studies also have linked density of canals with land loss rates (Scaife et al. 1983) and have implicated canals as being responsible for up to 90% of the land loss because of the indirect influence on coastal subsidence (Craig et al. 1979, Scaife et al. 1983, Turner et al. 1981, Turner et al. 1983).

Canal dredging creates spoil along the edges of the canal. The habitat created by spoil disposal is much different from the natural levee found along the banks of natural streams. The artificial levee or spoil bank has a lower soil organic content, a higher bulk density, and is typically much wider than a natural channel berm. After deposition, dewatering and oxidation of organic matter causes spoil banks to shrink up to 50% within the first six months (Nichols 1959, Cahoon and Holmes 1989). The invading vegetation on these spoil banks is upland shrub/scrub communities dominated by woody terrestrial vegetation such as shrubs and trees that are not found in coastal marshes except along natural levee banks.

In addition, the change in elevation again is critical because small changes in surface elevation influences hydrology and plant succession. Most spoil banks are continuous providing a barrier to sheet flow and drainage of surface waters across the marsh. Continuous artificial levees prevent drainage and/or can delay drainage of the surrounding marsh increasing flooding duration (Swenson and Turner 1987). Prolonged inundation then affects soil/water chemistry which then affects plant growth and species composition.

Spoil banks can also alter subsurface water flow and drainage since the weight of the spoil can compress the organic layer of marsh to approximately 60% of its original thickness (Nichols 1959). Therefore the below ground flow has a more restricted area to flow through and flow rate is then reduced. Spoil banks can block tidal flooding and reduce sediment and nutrient supplies to the marsh thus affecting the rate of vertical accretion, a critical problem in Louisiana's naturally subsiding marshes (Boesch et al. 1983).

The dredged water habitat that is formed from canal dredging is also different from the natural water habitat of the area. Canals are usually straight rather than meandering, they are deep 8 to 9 ft (2.4 to 2.7 m) rather than shallow, and the soft organic bottom is often replaced by a hard clay bottom, reducing the amount of suitable benthic habitat available. Dredging also resuspends nutrients and pollutants and returns them to the marsh surface thus decreasing water quality. Water turnover rates and water quality can be variable (Cahoon 1989). Oxygen depletion and thus decreased population size or fish kills may result from little turnover combined with an accumulation of organic debris in semi-open or closed canals (Adkins and Bowman 1976, Lindstedt 1978).

Pipelines

Pipelines and pipeline canals are another by-product of oil and gas development. Pipelines have been laid throughout Louisiana and are concentrated in south Louisiana and offshore. For example, Barrett (1970) estimated that 4,500 miles (7,240 km) of pipelines crossed wetlands in Louisiana in the 1960's. This does not include canals. By the late 1980's it was estimated there were approximately 12,000 mi (19,300 km) of pipelines in Louisiana's coastal zone and the Minerals Management Service (1992) reported 16,000 mi (25,700 km) of pipeline offshore in 1990. No reliable estimates exist for pipelines in north Louisiana.

Pipeline installation displaces bottom sediment, destroys habitats and the surrounding biota (Tabberer et al. 1985). They also interfere with drainage, and straight channels allow saltwater intrusion and dewatering of the marsh (Minerals Management Service 1992). The extent of the impact of a pipeline depends on the method of installation and the mitigation measures taken (Wicker et al. 1989). The degree of impact depends on whether the right of way is backfilled, the stability of the location, and the sediment supply to the system (Wicker et al. 1989).

MITIGATION

Land development activities such as highways, shopping malls, housing and industrial projects, and oil and gas in wetlands negatively affect, alter, or destroy the land and water in these protected areas. Oil and gas development activities affect wetlands in different ways. Wetlands are protected by federal, state, and local programs because they are ecologically important by functioning as water purification systems, groundwater recharge and flood storage areas, by trapping sediment, and providing wildlife habitats. Wetland function, losses, management, and mitigation are discussed by several authors (Salvesen 1994, White et al. 1989, Kusler and Kentula 1990, Kusler 1983, Mitsch and Gosselink 1993, and Dunbar et al. 1990). Several terms frequently used for wetland mitigation are summarized in table 8.

Development activities such as oil and gas operation permanently change wetlands directly or indirectly primarily by altering hydrology, which affects soil chemistry and the distribution of vegetation. Dredge and fill operations are the primary activities that change wetland elevation by creating uplands at spoil disposal sites or by creating waterways at the dredge site. Section 404 of the Clean Water Act provides for regulation of dredge and fill activities and aims to minimize impacts to wetlands from such activities.

Mitigation means to reduce adverse impacts. Most impact reduction can be accomplished by moving to a different site, reducing the project size, or modifying the project to a point where no significant degradation occurs. The word mitigation did not appear in the Section 404 regulations until 1986; however, the concept has been used since the inception of the program. In addition, the term mitigation has been used more often since 1987 when the Environmental Protection Agency (EPA) set a goal of "no net loss" of wetlands, which became national policy and prompted more vigorous evaluation of projects proposed in wetlands. Some view wetland creation or replacement as the only means of mitigation; although, this is ecologically the least desirable, economically the most costly, and

Table 8. Terms frequently used in mitigation and compensatory mitigation.

BANKS

Mitigation Bank

A system in which creation, enhancement, restoration, or preservation of wetlands is recognized by a regulatory agency as generating compensation credits that would allow future development of other wetland sites. Future development activities may or may not be previously identified when a bank is established.

Compensation Credit

The unit of wetland value that is recognized as the basis for comparing the destroyed wetland to the banked wetland offered in compensation. Credits can be either in units of acres, habitat units, or numbers.

MITIGATION STRATEGIES

Wetland Creation

To convert or alter upland, shallow aquatic, or nonjurisdictional environments into a wetland community.

Wetland Restoration

To return degraded or destroyed wetland values or functions to their former wetland conditions. Restorations brings a wetland to its prior condition.

Wetland Enhancement

To alter an existing wetland or improve specific functions at the expense of others. To add, or increase particular wetland functions and values to levels not present under previous natural conditions or to slow natural impairment of existing values and functions. Enhancement does not necessarily bring a wetland to its prior condition and may produce a new condition.

Wetland Preservation

To provide legal protection to natural wetlands that would otherwise be lost to lawful activities. Some do not recognize this as a mechanism to accrue credits in a mitigation bank because it does not contribute additional wetlands for the ones that are lost and does not support the policy of "no net loss" of wetlands.

Wetland Exchange

To convert one wetland type into another.

Table 8. continued.

LOCATION

On-site Mitigation

To create, enhance, or restore adjacent wetlands in an amount to sufficiently mitigate for a specific development project, but not producing surplus compensation credits that would be available for other development sites.

Off-site Mitigation

To create, enhance, or restore wetlands outside the development project area in an amount to sufficiently mitigate for a specific development project, but not producing surplus compensation credits which available for other development sites.

TIMING

Up-front

Mitigation that occurs before the development project begins. This is often required when impact of a project is unknown or the success of the proposed mitigation is unknown.

Concurrent

Mitigation that occurs at the same time as the development project. This is the common timing for most projects.

After

Mitigation that occurs after the completion of a development project. This timing is often discouraged because it is the least reliable and the most difficult to regulate, evaluate, and ensure completion.

Table 8. continued.

LOCATION	
On-site	Mitigation that occurs within the same watershed or ecosystem as the lost wetland. On-site is the preferred location of mitigation projects.
Off-site	Mitigation that occurs in a different watershed or ecosystem from the one where wetlands were lost.
COMMUNITY	
In-kind	The community used for mitigation contains the same species as the community that was lost to development. In-kind mitigation is usually the preferred.
Out-of-kind	The community used for mitigation contains different species composition from the community that was lost to development. Sometimes this is used to replace a common

logistically the most complicated mitigation option.

While the term mitigation is simple—reduce adverse impacts—implementation has been perceived quite differently by agencies, developers, landowners, and the environmental community in method, timing, and duration. In 1978, the Council on Environmental Quality (CEQ) published regulations required to implement the National Environmental Policy Act (NEPA). These regulations included mitigation responsibilities (40 CFR Sections 1500-1508).

The CEQ regulations define mitigation in a sequence as follows:

1) Avoid impact altogether by not taking a certain action or parts of an action.

2) Minimize impacts by limiting the degree or magnitude of the action and its implementation.

3) Rectify the impact by repairing, rehabilitating, or restoring the affected environment.

4) Reduce or eliminate impact over time by preservation and maintenance operations during the life of the action.

5) Compensate for the impact by replacing or providing substitute resources or environments.

CEQ's regulations for mitigation states to avoid what you can, minimize where possible, and compensate for the damage you have done. These principles of mitigation must be followed in the sequence that they have been listed.

Three agencies, EPA, USFWS, and National Marine Fisheries Service (NMFS) follow this mitigation sequence. In the past the USACE has claimed that it did not have to follow the CEQ definition in sequence and had allowed compensation as the first mitigation measure. However, to standardize mitigation requirements under Section 404 Guidelines, the USACE and EPA entered a Memorandum of Agreement (MOA) in 1990 to clarify mitigation policy. The MOA condenses mitigation into three steps or phases—avoid, minimize, and compensate—and states that these phases must be followed in sequence and thus formalizing the "sequencing requirement." USACE agreed with the EPA to follow the CEQ sequence to help EPA attain the "no net loss" of wetlands policy.

There has been opposition to this mitigation policy from congressional delegations who have extensive wetlands in their districts. They have stated that this sequence may not be practical in areas with a high proportion of wetlands or where hydrological conditions are difficult to replicate. A modification of the MOA now exempts some areas in Alaska, Louisiana, Florida, and Maryland.

In many cases involving wetland development projects mitigation of wetland degradation or loss has become an issue in which regulatory managers require replacing land and habitat resources of equal value to those that have been lost. Generally developers and landowners prefer to convert wetlands into more economically productive uses such as homes, malls, industrial complexes, and oil and gas production platforms while regulators, resource managers, and conservationists prefer to preserve the natural productivity wetlands and to meet federally mandated goals and regulations. Conflict of wetland use is based on the perception of best use and value of the land in question. The agencies involved (USACE, EPA, USFWS, NMFS) in wetland regulation followed CEQ's lead on the sequencing process but have a different focus on implementation. EPA generally tries to maintain chemical and biological integrity of water, USFWS and NMFS aim to protect fish and wildlife habitat, and USACE seeks to balance competing interests.

The scientific community still considers many compensatory mitigation strategies, specifically restoration and creation, experimental. The trade offs remain uncertain. Because wetlands are unique, dynamic and complex systems, they are difficult to duplicate. The attempts to create a wetland through geology, hydrology, vegetation and soil type have not yielded reliable results (Kusler and Kentula 1990). Some wetland creation projects are very successful while others do very poorly; some do very well for a few years and then completely fail. These differences in success rates are not yet understood (Robert 1993). The science of wetland creation is still young and duplication of the natural environment has proven to be a difficult task. Waves, high water, invasion of weeds, and inappropriate salinity, water levels and flooding period are some of the factors that can contribute to wetland creation failures.

The most controversial form of mitigation is the creation of a new wetland. Supporters of wetland creation contend that wetland creation allows development to occur in wetlands especially where fill is unavoidable, while improving the overall quality and quantity of wetlands. They also assert that wetlands can be created where none existed before.

Critics of wetland creation argue that natural systems are difficult to duplicate and artificial wetlands are poor substitutes for them. Until scientists fully understand wetland dynamics and processes, these natural systems are best left undisturbed or protected. Critics also contend that the success of marsh creation has been either limited or premature because true success can only be judged by the longevity of the project.

For implementing a wetland replacement strategy, type and location of replacement wetlands also becomes an issue. The EPA and USFWS usually prefer in-kind replacement, which means the same wetland type. These agencies believe that in-kind replacement is the best way to restore specific lost wetland values. Sometimes these agencies prefer creation of a different wetland type from the original that is lost. Out-of-kind replacement may be used to attract certain species to an area or develop previously lost habitat. The regulatory agencies also prefer on-site mitigation, which usually means it is located close to the development project or within the same hydrologic system. Off-site mitigation may be an option if on-site mitigation is not economically or technically practicable.

Minimization of wetland impacts by avoiding the damage caused by resource extraction processes is the goal of state and federal regulatory programs. Finding profitable ways to extract a nonrenewable resources from under the surface without destroying the renewable surface resource is a daunting mission. Major impacts in wetland operations occur during construction of well sites, pipelines, and production facilities in wetland areas ill suited for this type of construction. Because oil and gas operations are destructive to wetland ecosystems, finding techniques to minimize impacts while continuing to allow operations is necessary. A careful examination of existing technologies to find less destructive methods and applying unique new technologies or unconventional or other untried methods is necessary.

Mitigation strategies are techniques for eliminating or minimizing environmental impacts in the work area. These strategies include techniques such as directional drilling or air-transportable rigs, waste generation control by using a closed-loop mud system to reduce the site size by using a bulk mud system, a smaller rig, and/or a coiled tubing rig to drill the well and by planning and consultation with the various regulatory agencies to reduce impacts. The following is a discussion of mitigation strategies that either avoid or minimize impacts of the first two steps in mitigation sequencing requirements.

Planning

The best way to minimize impacts of any operation in wetland areas is to first minimize the length of the route by carefully planning the location of the access route and final site. In forested wetlands, the drill site should be located in existing open clearings to minimize tree cutting. If no open clearings exist at the planned drill site, trees should be cut and stacked on the edges of the clearing to provide wildlife habitat as requested by the appropriate wildlife agencies. The natural contours of the land should not be altered.

In marsh environments, one method to minimize impacts is to use open-water areas for site location. Open-water sites cause less damage to the surrounding environment than sites impacting marsh areas. If no open-water areas are available, then a piled structures could be used to minimize impacts. Route planning to avoid sensitive habitats like endangered marsh grass beds, oyster seed beds, reservations and oyster leases is environmentally and financially beneficial.

Current well-site planning is a function of the geological factors alone. Well locations are designated by lease and subsurface geological structure. In the past, little thought was placed on access to the well site or the cost of arriving at the point directly over the planned well. The accepted industry practice was to draw a straight line from the existing waterway, canal, or road to the planned location and have it surveyed and permitted.

Wetland permitting regulations have and are causing the well site selection process to change. New canal dredging or road building is discouraged if it would impact wetland areas.

Present wetland access in Louisiana requires a permit depending on location from USACE and/or DNR/CMD. To reduce impacts DNR/CMD and USACE formed a review process called "Geologic Review" to scrutinize proposed operations and determine if alternative means of reducing impacts are applicable. Each of these permits require that access plans for an individual well be reviewed in the geologic review process (see **Wetland Permitting Requirements**). This process, which began in 1983, uses an outside geologist and petroleum engineer to review the proposed operation. To reduce bias and allow data presented to be held confidential a geologist and engineer from Louisiana State University were used until 1992 when state personnel were assigned to the process.

Originally, the geologic review process was designed to reduce the impacts of canal locations on coastal wetlands. It was later expanded to impacts on non-coastal wetlands as well as areas covered by the USACE–New Orleans District. The process was further expanded to large projects in northeastern Louisiana and for wells covered by the Vicksburg and Galveston Corps districts.

To minimize impacts, this process could require applicants to change the surface location of a proposed wellsite by drilling directionally or moving to a geologically equivalent site if technically and economically feasible. The geologic review process allows various environmental agencies to review and comment on the proposed permit and to provide options to avoid impacts and incorporate minimization strategies into the project.

The geologic review process is a forum for the permitting and commenting agencies and the applicant to put forth their individual concerns with personnel conducting the review who could explain each sides' position to the other. During geologic review the geologic and engineering information was reviewed confidentially at the meeting. After this review and an explanation of the proposed access route, the permitting and commenting agencies expressed their concerns about the project. If possible a consensus was reached on how to best reduce the impacts of a proposed operation. To reduce impacts various techniques evolved throughout the history of the process. Some of these include directional drilling, site size reduction, using closed-loop systems or bulk mud systems, site relocation or examination of alternative access methods such as board roads instead of canal access. The geologic review process had the same steps each time to promote fairness to all applicants. Decisions made at these meetings had direct bearing on whether a proposed location would be permitted and the cost for the location and the resulting well.

The first question to be answered is, "whether the well can be moved to a site outside wetland areas by moving to a geologically equivalent site or by directional drilling." The geologic and engineering well information is examined to determine if any alternative equivalent geologic sites exist. A geologically equivalent site is a location that would test the structure in the same manner as proposed by the applicant. If an available site would allow the structure to be tested drilling vertically, the process personnel recommends that the well be moved to this site if it would cause less environmental impact. If no such site can be found, directional drilling of the well from a location that causes less impact is examined. Directional drilling radius is limited by process guidelines that limit directional well build rates to 2°/100 ft (2°/30.5 m) and maximum angle to 30° for simple kicks and 20° for S-shaped kicks. Cost limits for directional wells cannot exceed an additional 33% above the cost of a vertical well. If the well can be directionally drilled within the guidelines, the process personnel recommend to the that the well be drilled directionally.

If it is determined that the well would be unfeasible to move or drill directionally, the process turns to minimizing the impact of the proposed work. The site plans are examined to determine the best means of access. If a route cannot be agreed on at the meeting, a field examination to determine the best route may be needed. Standardized road and canal dimensions are requested of the applicant. Before this process began the applicant asked for a specific dimension for clearing or as slip location and the permitting agency granted the request without examining the request to see if it was reasonable or excessive. The process allows standardization of well-site dimensions for canal and board road locations. Well-site dimensions are reduced to the minimum required for each particular rig or by the depth of the well.

Geologic review has caused oil and gas companies to change the way they pick wetland locations in Louisiana. Because meetings are only held if a well impacts wetland areas, companies have moved well locations out of these areas to reduce permitting time and costs. Companies now set up internal review mechanisms to define possible problem areas in the permitting process. As a planning tool, the information required for a "Geologic Review" meeting highlighted the information that was important and needed by the permitting agencies to evaluate a potential drill site. Companies that collect and provide the necessary information and justifications for their positions have found that this review process is more a formality than a problem or a delay.

To measure the success of geologic review some way to accurately measure its impact needed to be found. Figure 10 shows that in the early 1980s about 3,000 permits per year were issued, but since the price collapse in 1986, the number has steadily decreased. This leads to the conclusion that fewer wells mean fewer impacts on wetlands. A more accurate way to measure success is to determine the average area required per location per year. However, information on board road impacts required is difficult to obtain because of the USACE numbering systems; therefore, we are limited to examining the effects of this process on canal size.

The average acreage required for each canal location has declined over time (figure 11). When the program began, incremental decreases in the average area occurred until 1987 when a larger decrease occurred. This larger decrease was caused by the implementation of the general permits for canal locations GP-2 as described in the section entitled, **Louisiana Permitting Process**. After 1987 slow decline occurred until 1991 when a large increase is shown. This increase can be attributed to six very long (over 10,000 ft [3,050 m]) canals that were permitted that year where as only one long canal per year had been permitted the during previous three years.

Several of these long canals took from two to three years to permit because of their expected impacts. These canals were to test new deep gas prospects developed with 3-D seismic interpretation techniques.

The total number of canal locations causing marsh loss (figure 12) and subject to the process has averaged about 30 each year since the new general permits were implemented.

Another measure of success is to examine the total number of acres of marsh impacted by canals (figure 13). The area of marsh impacted has declined from around 775 acres (314 hectares) to about 100 acres (40.5 hectares) per year of direct impact to habitat.

Some explanation of the numbers presented is needed. This number represents only the coastal zone impact, not the total acres impacted for all operations in wetland areas. Each year additional canals are dredged in the Atchafalaya basin inside the USACE jurisdiction but outside the coastal zone. Because the USACE permitting system does not use numbers but names that are reusable, it was impossible to accurately compile data on the additional impacts of these canals. The numbers here represent direct impacts, and no estimation of total impact is attempted. Data are incorporated according to the date a permit was issued and not the year it was applied for.

These figures show that through cooperation, regulatory activities effectively reduce impacts while still allowing access into wetland areas. However, at some point no additional savings will be possible under current conditions. Under current general permits, from a minimum of 2.95 acres (1.19 hectares) to 4.73 acres (1.91 hectares) of marsh is presently impacted per well location. For board roads, depending on ring levee size up to 5.95 acres (2.41 hectares) can be impacted per well site (See **Impacts of oil and gas development** pg. 70). Unless new technological innovations occur continued reductions in average site size will not be possible.

At present we trade from 2.95 to 5.95 acres (1.19 to 2.41 hectares) of renewable marsh for an unknown amount of a nonrenewable resource. The challenge for the future faced by regulators and extractors is to continue to decrease the areas impacted each year for resource extraction without raising the cost of extracting the resource

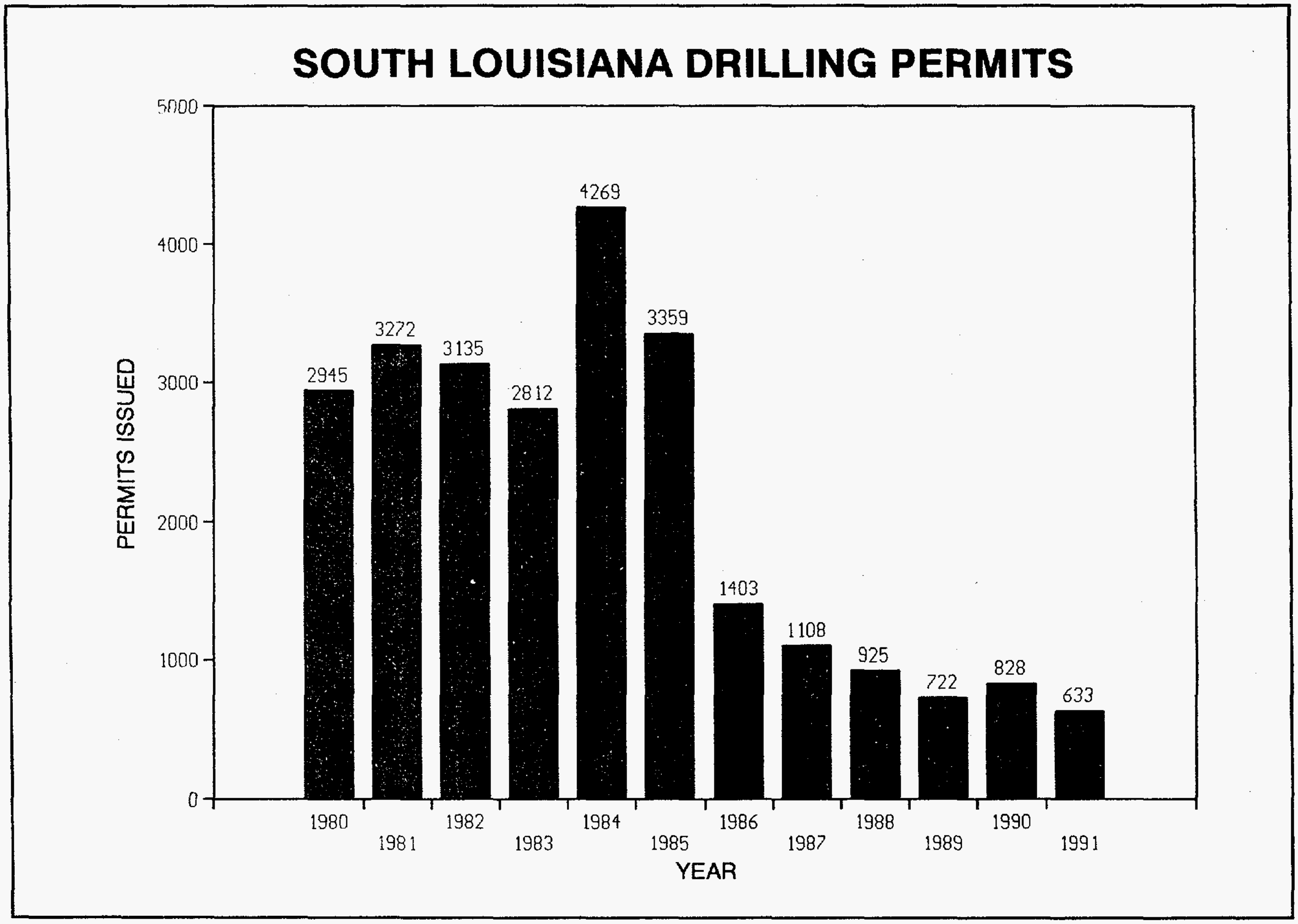

Figure 10. South Louisiana drilling permits issued by year.

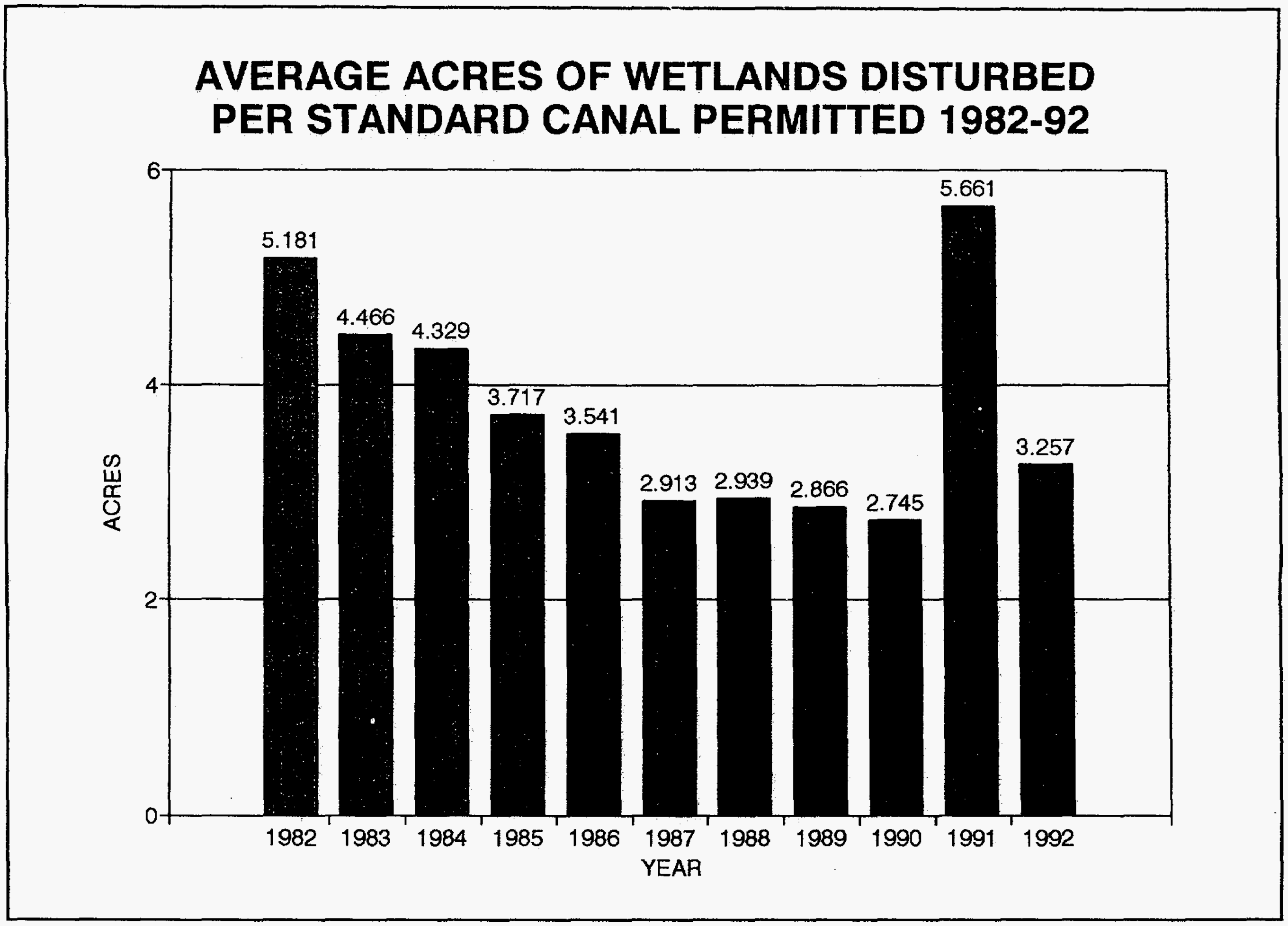

Figure 11. Average acreage impacted by canals causing direct marsh damage for each canal location by year.

to unprofitable levels.

Early use of command and control regulations that limited activity and provided mechanisms to evaluate impacts were successful in decreasing impacts because no regulations had existed. Over time the yearly incremental savings that can be obtained by these types of regulatory programs decrease and become asymptotic in nature. Wetland regulations concerning well location size have reached that point. Continued refinement and redefinition of these regulations cause large increases in compliance costs for little or no additional environmental benefit. This factor presents a solid case for changes in how we regulate future activity. If the regulatory community is reasonable and pursues incentive-based regulatory strategies instead of continuing to expand the current command and control regulations, further reductions in impacts per location may be possible. The industry needs to continue to examine ways to lower the overall cost of finding reserves while reducing environmental impacts. Incentives to promote innovation and technological progress to satisfy regulatory and industry goals can and will reduce costs and decrease environmental impacts.

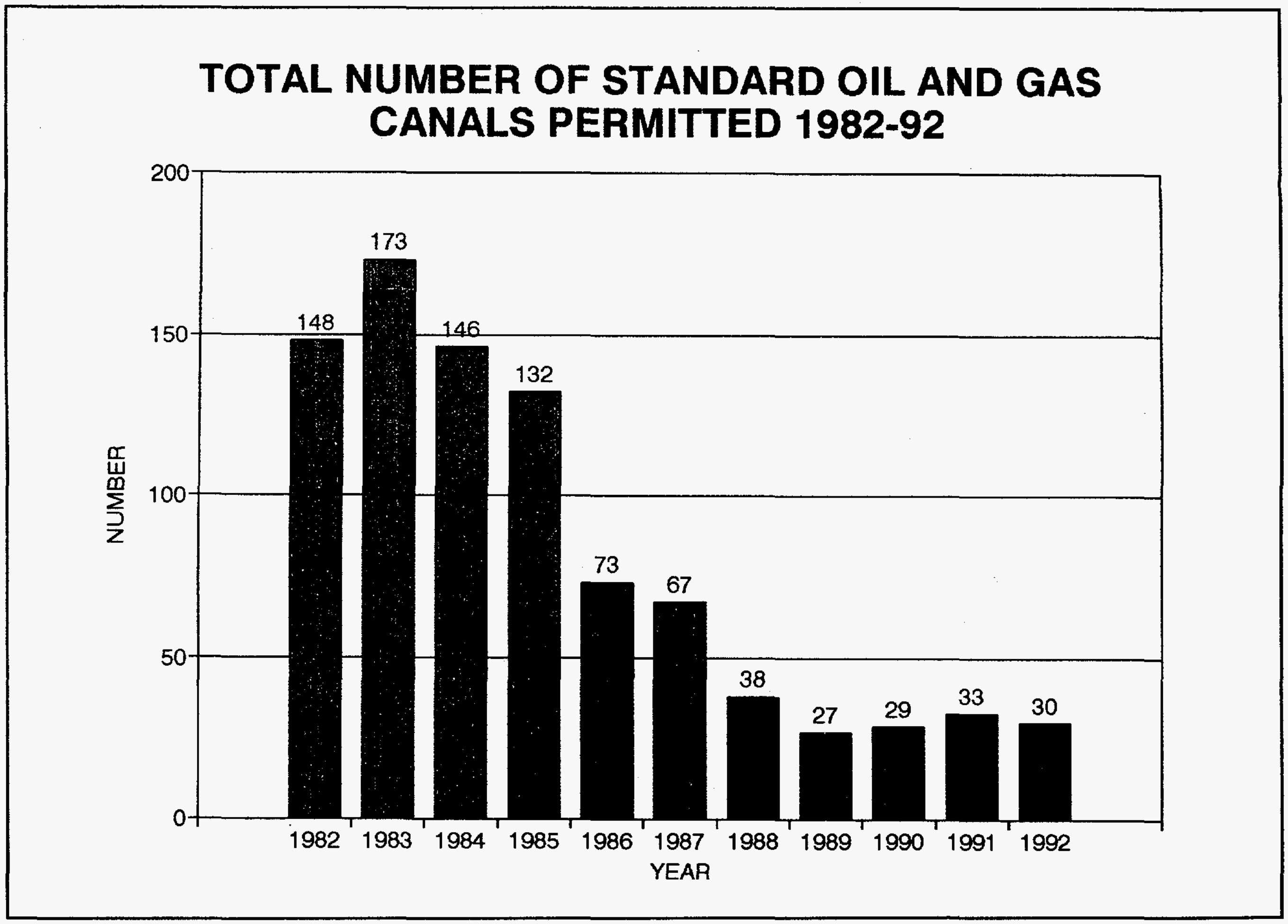

Figure 12. Total number of canals causing marsh damage by year.

Innovative Techniques

To reduce impacts, we must examine current practices to find areas where reductions in site size are possible and beneficial. One of the major concerns of the regulatory agencies is drilling mud pits, discharges, and mud waste disposal. Open drilling pits take up large areas on a proposed well site. Up to one-half of the entire area can be used for a mud pit (figure 14). To eliminate long-term liability and reduce the area needed for drilling pits, the use of closed mud systems for wetland operations has become standard operating procedure through the geologic review process. Where applicable non-toxic drilling muds can still be discharged if they meet discharge standards. Closed-loop mud systems originally were developed to reduce barite losses on deep high-pressure wells. A side benefit of the system is that closed loop operations reduce the wetland areas impacted by drilling operations by reducing location size (figure 15). Closed-mud systems are economic on deep wells even though they cost an extra $1,000–$3,000 per day over a conventional mud system because of the cost saving generated by recovering the barite in the mud. Requiring the use closed systems on environmental grounds placed a significant economic burden on wells where the system would have not been used normally. To encourage smaller location sizes, compromises were worked with the regulatory agencies to allow normal muds with no environmentally polluting additives to continue to use open drilling pits. However, to limit environmental impacts, if the operator elects to use the open pit no additional space is allocated beyond the space needed for a closed system. This allows reduced environmental impacts while saving the operator money by not requiring a closed-mud system.

No site size reductions attributable to mud systems have been possible for canal locations because wells drilled by a barge rig use a shale barge to collect cuttings and discharge filtered water according to DEQ regulations.

Since 1987 when USACE expanded regulatory coverage in Louisiana, companies have adjusted their operations to limit environmental impacts. In response the need for smaller location sizes several operating and service companies have created managed reserve pit systems consisting of several reserve pits (some of them lined) to forestall the use of closed-loop systems (Pontiff et al. 1990, Thurber 1992). Other more radical changes include redesigned pit construction to use a V-shaped design that boosts efficiency and reduces cost. This plan created by Conoco uses 5,700 ft² (530 m²) compared to 22,500 ft² (2,091 m²) for a normal open pit while saving around $10,000 per well (Gulf Coast Oil World 1994).

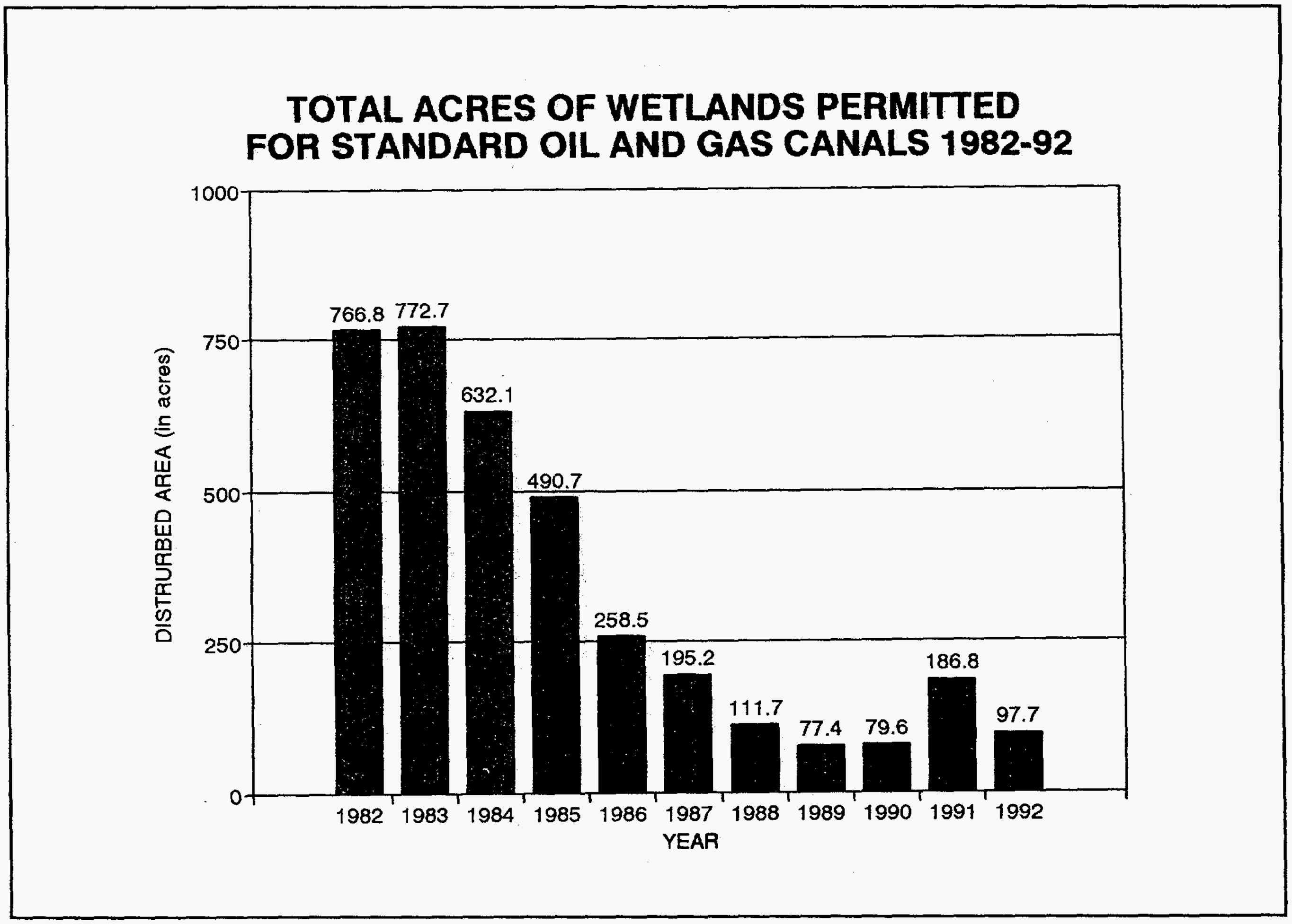

Figure 13. Total acreage permitted for standard canals by year.

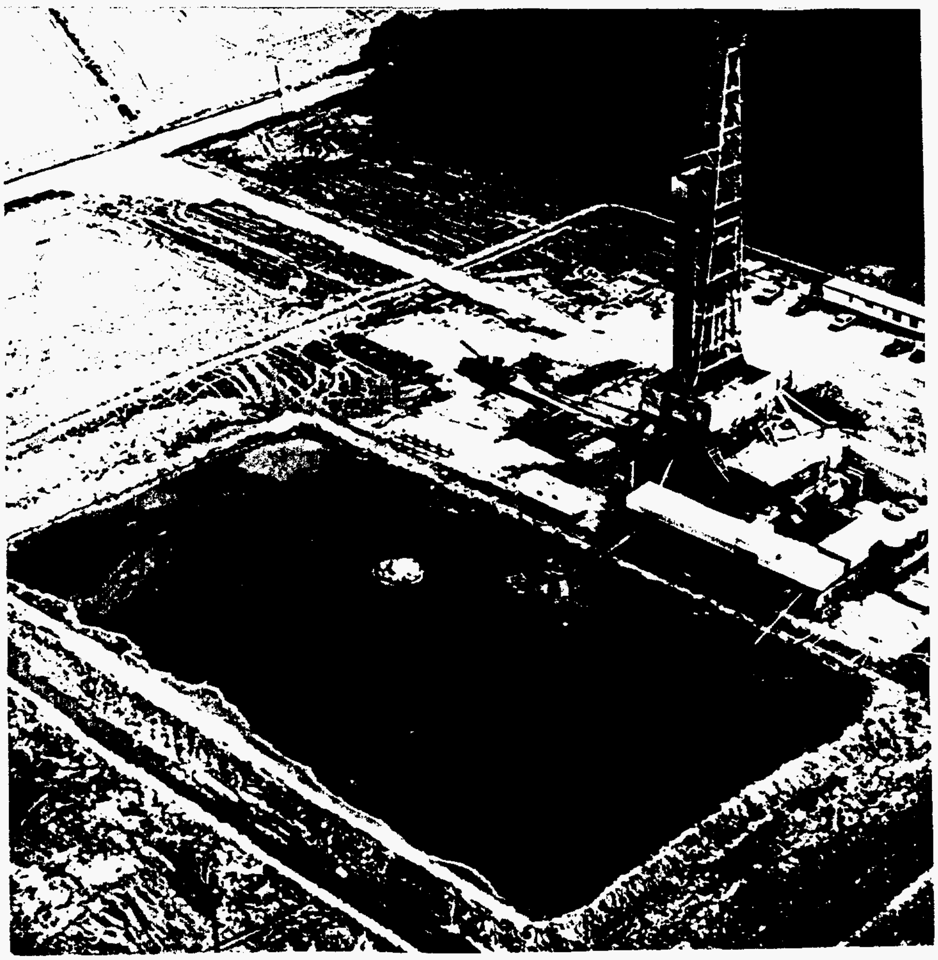

Figure 14. Drilling operation using open mud pit. (Courtesy SWACO Mud Systems Lafayette, LA)

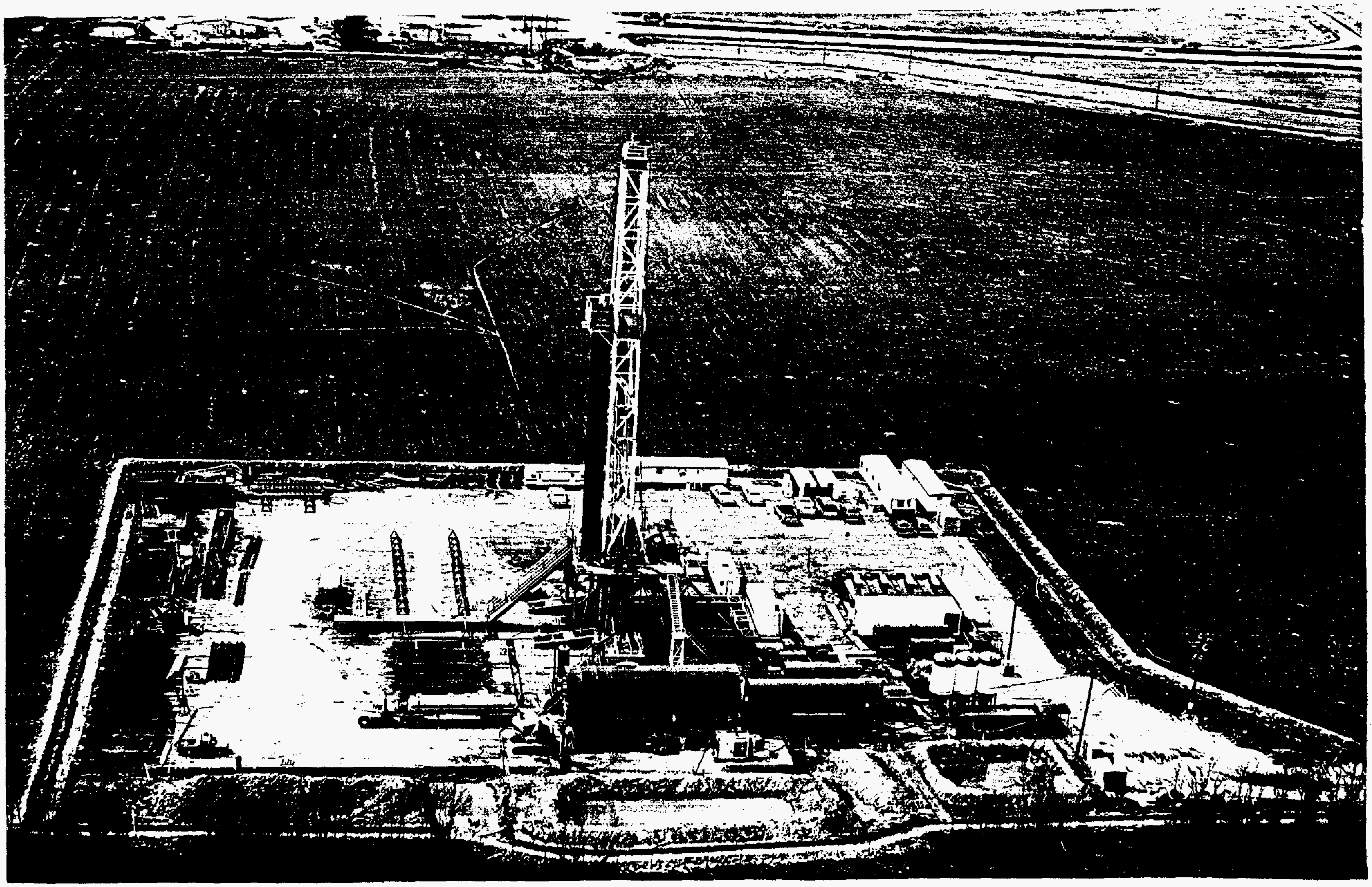

Figure 15. Closed-loop well location in south Louisiana (Courtesy SWACO Mud Systems, Lafayette, LA).

Another innovation is the creation and use of bulk mud containers to reduce waste generation, prevent spills, and reduce liability and costs. Currently, mud, mud additives, and chemicals arrive at a drill site in 50 or 100 lb (23 or 45 kg) sacks or 5 gal (19 L) buckets. Rig personnel must physically open each container to place it in the mud system. This generates significant amounts of waste from the pallets, shrink wrap, plastic buckets, and the empty sacks.

Sack breakage and spills can cause product losses of 5%–15% per well. These spills can be time consuming and in some cases costly to clean up. To prevent these types of problems from occurring, recyclable bulk additive containers were created. British Gas tested the system on a 13,402 ft (4,085 m) well in Texas. The system of 1,000 sack (2,268 kg) tanks for mud and 550 gal (2,082 L) stackable containers for additives was highly successful in reducing waste while saving the operator $5,000 compared to conventional operations. This system reduces the area needed for mud storage and equipment while reducing potential spills and long-term liability. This system is cost effective and applicable for use in wetland areas and should be required on all wells in Louisiana.

Directional drilling is another technique that reduces impacts. Directional drilling is a technique to target a specific subsurface point and drill to it. Presently, the regulatory agencies can require directional drilling to prevent environmental impacts.

The main types of directional drilling are simple, S-shaped and horizontal wells (figure 16). Horizontal wells can be divided into short, medium, and long radius wells, depending on the requirements of a planned well location. Directional and horizontal drilling techniques were developed for offshore areas to minimize the costs associated with building drilling and production platforms.

Directional and horizontal drilling provide many environmental benefits. Accessing wells in wetland environments (see **Impacts of Oil and Gas Development**) causes severe direct short-term and indirect long-term environmental impacts and directional drilling technology that allows the well to be drilled from upland sites or previously impacted sites is beneficial. At the present time directional drilling that is required by the regulatory agencies is limited on technical and economic grounds. Regulators will need to adapt to the changing technological climate and create updated guidelines incorporating the increased capabilities of directional and horizontal drilling techniques.

At present horizontal drilling would not be required in Geologic Review because the drilling costs are excessive. Horizontal drilling costs average 100% more than the expected straight well cost, assuming trouble-free operation. (Coulter 1993). However, ultimate recovery using this technology may be three to four times what a vertical well would produce and fewer wells are needed to drain a particular reservoir, reducing overall field development costs. Horizontal wells are used successfully offshore to reduce environmental exposure and costs. It also should be noted that over time horizontal drilling costs will decline as technological innovations continue to take place. Several operators in Louisiana are planning horizontal wells in deeper prospects in north-central Louisiana. This technology could reduce the number of wetland locations needed to produce equivalent amounts of oil or gas. Other states such as California are examining the use of horizontal drilling to alleviate residents' environmental concerns by allowing extended reach horizontal wells to be drilled from shore locations instead of building platforms (Wright 1993).

To reduce impacts, regulators in Louisiana must update their directional drilling guidelines and promote horizontal drilling when practical and economical. The agencies should request that companies to examine the feasibility of using horizontal drilling to explore for and develop reservoirs as was done in the early 1980s with directional drilling.

Other drilling innovations include slim-hole drilling rigs. Slim-hole drilling rigs are standard rigs that drill a 3 to 4.5 in. (7.6 to 11.4 cm) wellbore compared to a standard 7.87 in. (20.0 cm) wellbore. The smaller wellbore allows a smaller rig to be used to drill deeper prospects (Moore 1992).

For shallow wells, slant rigs offer a way to reduce location size while drilling from long distances. Slant rigs were designed mainly for pipeline crossing bores, but the addition of a mud system allows reaching shallow targets while avoiding surface or subsurface hazards (Smith 1992). For shallow depth fields where multiple wells are required this can allow complete development from one pad location. This type of system would be very useful in south Louisiana where several shallow (from 1,000 to 1,500 ft deep (305 to 457 m) gas reservoirs have not been developed because long canals through undisturbed wetland areas are needed to develop these reservoirs.

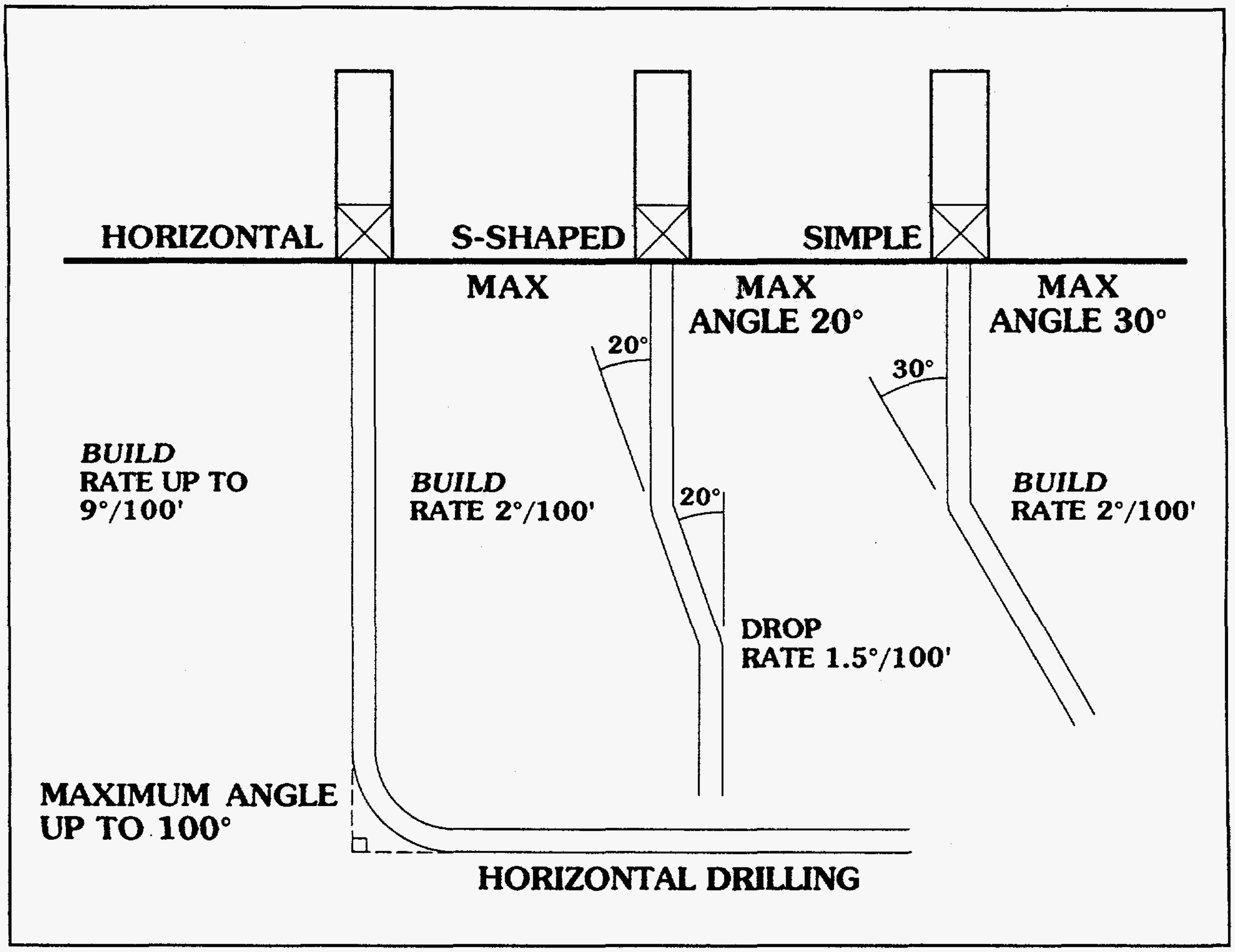

Figure 16. Diagram of a simple, s-shaped and horizontal well configurations.

Technological innovation is not limited only to conventional drilling rigs. New types of drilling that do not use a standard drilling rig and all its ancillary equipment are being developed around coiled tubing. Coiled tubing drilling (CTD) may completely change how oil and gas is explored for, developed, and produced. Coiled tubing is regular well tubing without the thread and collar joints needed to break tubing into transportable lengths. Instead the tubing is continuous and wound around a drum for transport and operations (figure 17). Current manufacturing processes allow tubing sizes from 0.75 in. (1.9 cm) outside diameter (OD) to 4.5 in. (11.4 cm) OD tubing. Coiled tubing was developed to reduce the cost associated with producing and working over existing wells. However, the advent of horizontal drilling has led to the use of coiled tubing in drilling applications.

CTD can significantly reduce the environmental impacts of drilling operations. Present drilling operations using CTD rely on a conventional rig to drill the well close to the desired producing formation and to set casing. The CTD rig is then brought on location to complete and produce the well. Future operations are planned using a coiled tubing rig from first casing point to finish. The major limitation is that at present jointed casing used to safeguard freshwater sands cannot be run and cemented without a conventional rig. Research is progressing on hybrid CTD units allowing casing to be run without a conventional rig. Hybrid units will run conventional and coiled tubing (Newman 1994).

The environmental impacts of using CTD are greatly minimized compared to a conventional rig. Areas used to store tubulars on a conventional rig site location take up more space than the complete CTD assembly. A complete CTD site consisting of a trailer mounted mud unit, a trailer-mounted coiled tubing reel, injector and control cabin, a crane for handling the rig-up and drilling assembly along with necessary storage space for fluids, and special items will fit in a location of 7,800 ft^2 (0.18 acres or 0.07 hectares). The soil-bearing capacity required for this type of location are less than a conventional rig allowing board road locations in areas unable to now support these operations. (Tracy 1994, Rike 1993, Gronseth 1993).

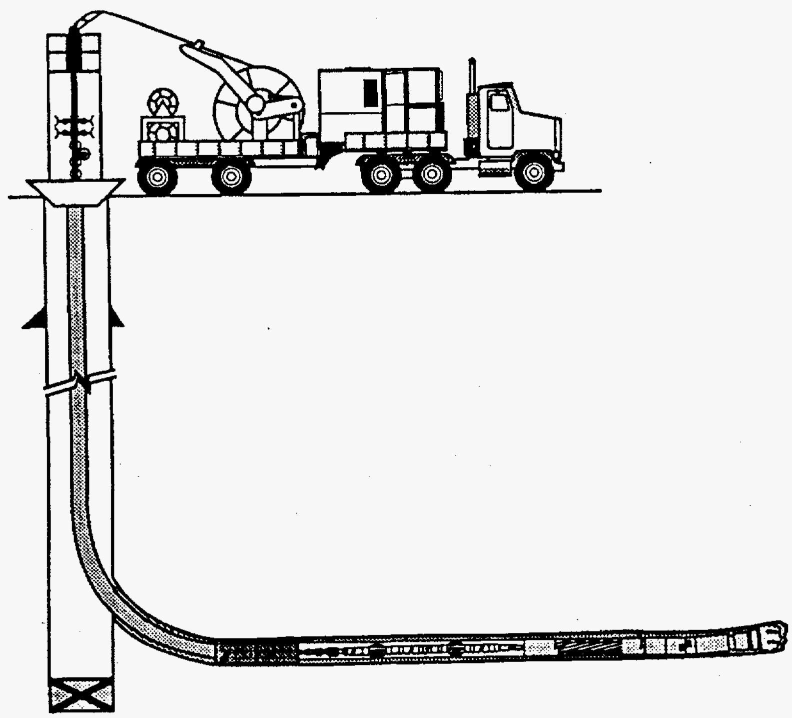

Figure 17. Diagram of coiled tubing unit used for drilling operations. (adapted from Tracy 1994).

Coiled tubing well sizes can vary from 2.75 to 6.25 in. (6.98 to 17.14 cm), and the small volumes of cuttings are completely contained using the on-board fluid system. If necessary the cuttings tank can be emptied to allow continuous operations. Because disposal volumes are small off-site disposal of the cuttings usually occurs (Rike 1993). Deep drilling with a CTD rig may require additional space and mud handling capability.

Coiled tubing drilling is safer than conventional drilling operations as most well accidents occur at the rig floor when tripping in or out of the well. CTD is safer from both a personnel and a well control viewpoint. Because there are no pipe connections, rig floor personnel are used only to initially make up the tool necessary to drill (mud motor, bent sub, bit, and collars) and guide this assembly into the injector head. After bottomhole assembly (BHA) make-up and guiding through the injector head only a minimum number of personnel if any at all should be on the rigging. From a liability an insurance cost standpoint alone this factor will reduce drilling costs. Blow-outs usually occur because of the constant in-out motion caused by conventional tripping operations. This swabbing can cause the well to flow uncontrollably or blow-out. CTD allows better well control by better control of bottom hole pressure thus preventing blow-outs. If a blow-out occurs it allows rapid response to contain and circulate out the kick as fluids can be pumped down the tubing immediately.

Ecnomically CTD has shown major cost reductions compared to conventional drilling depending on the application. Atlantic Richfield Co. (ARCO) has successfully used CTD rigs in environmentally sensitive areas of

Alaska (Rike 1994). Estimates of the cost savings using CTD to sidetrack existing wells from existing locations to increase reserves are $500,000 per well compared to $2.5 million for a new well or $1.7 million for a conventional side track (Simmons 1993). Additional cost savings occur when coiled tubing strings are left in the well as a production string. To prevent failure coiled tubing is used a limited number of times for drilling applications. The used tubing can then be put in an individual well as a production tubing. This process is very advantageous as well maintenance costs are lower than jointed tubing.

Another use for the tubing is to replace flowlines in sensitive areas. Initial cost of coiled tubing is 40% to 50% less than jointed line pipe. Coiled tubing can be laid as a flowline much faster than standard methods. For example a south Louisiana operator laid 6,500 ft (1,980 m) of flowline in one day compared to 4 to 5 days that would be required using conventional methods. Less environmental damage occurs because back-and-forth travel by the laying crew is significantly reduced as one continuous track is made across the marsh (Hightower 1994).

Coiled tubing is a new technology, and problems have and will occur with its implementation and use. However, each month new innovative uses for this technology are announced in trade publications. This technology has the potential to greatly reduce the environmental cost of oil and gas operations with the added benefit of reducing the economic cost of extracting the resource. Regulators need to embrace this technology and promote its use where beneficial.

It should be noted that all technological innovations are not environmentally beneficial. One of the new technologies being applied more and more in Louisiana and elsewhere is three-dimensional seismic (3-D) surveys. This refinement of existing seismic technology is allowing oil and gas companies to increase their success ratio for exploratory wells and, once a discovery is made, to map reservoirs and additional development well sites (Shirley 1994). This technology also is being used in all of the wetland areas of Louisiana. Over time this should increase discovery and productivity and combined with newer drilling methods reduce the number of wells needed to produce new reserves. Significant new discoveries have occurred using this technology in areas expected to be unproductive (Durham 1994).

This increased productivity is not without cost, in this case environmental and financial. 3-D is expensive to shoot onshore (about $50,000 per mi^2 or $19,300 per km^2) and causes large impacts in wetlands (Shirley 1994). Seismic crews use marsh buggies and airboats to move around in coastal wetland areas and both methods are destructive depending on soil and vegetative conditions. Mitigation of the damages caused by seismic crews is expensive and adds to the cost of obtaining the data. For 3-D to provide environmental benefits an alternative means of access to wetland areas is needed.

Alternate Access Methods

Methods that allow access for seismic work and straight hole well locations while safeguarding the renewable resources on the surface need to be investigated and where practical and economic used. Innovative methods of access that are technologically feasible and minimize impacts include hovercraft and helicopters. Another proposed system the "cyclocraft" also is examined.

Hovercraft

Hovercraft are skirted platforms that use air pressure for lift. The skirt holds the air under the platforms while air is pumped in to raise the pressure under the skirt. As the pressure rises the craft lifts allowing air to move out from under the skirt. Lifting capacity depends on area and pressure differential. Propellers or ducted fans are used to move the craft and as control surfaces. Hovercraft are presently used by commercial industry and the military to move personnel and cargo. Hovercraft were evaluated for technological utility for use as an alternative to marsh buggies by Sikora et al. (1983) and Sikora (1988). Sikora also examined additional uses for this technology and recommended that hovercraft be used for access to drilling locations in marsh areas. Implementation of these recommendations has not been seriously considered by industry; although, Shell Western Exploration and Production is using a small hovercraft for production activities including crew replacement and well pumping. This hovercraft has proved to be too small and unstable in high winds and seas and is considered by the company to be unreliable. This fact made other companies reconsider using hovercraft for production work.

Cahoon and Holmes (1989) stated that technological factors were preventing hovercraft use. Some technological issues may need to be addressed to adapt existing hovercraft for use in drilling operations in wetlands. However, the main barriers preventing hovercraft operations are not utility or environmental impact but availability and economic costs. The only hovercraft large enough in the United States at this time are the Navy Landing Cushion Air Vehicle (LCAC) (figure 18) and the Army HF-40 shown in figure 19. No other hovercraft large enough to move sections of rig are available for lease or rent in the United States at this time.

For drill-site access some preliminary work has been conducted by two Houston firms that want to build a hovercraft drilling barge; unfortunately, economic factors forced them to cancel their plans. Use of hovercraft to transport drilling, workover, coiled tubing, seismic, and other oil and gas exploration equipment would be beneficial in preventing additional wetland loss. With this goal in mind, a new company called Hoverfreight International was formed by from former Textron Marine personnel. This company plans to be operational and have hovercraft available by early 1995 for lease or rent in the United States and overseas. The hovercraft used will be the HF-40 shown in (figure 19).

This craft has a 40-ton capacity, a speed of 45 kts. and ground pressure of 15.4 psi. They plan to use this craft to move a land rig to locations where soil will support land operations or to use a modular system called Flexi-float to build a platform to work off in locations where canal access is needed. Existing ground transport containers can be loaded directly on to the deck of this machine, and it can be rigged for roll-on and roll-off capability. The company will have smaller hovercraft available for crew replacement and hot-shot services. They plan to offer a full line of transport services for operations in sensitive areas. Development of this capability should be encouraged by environmental regulators.

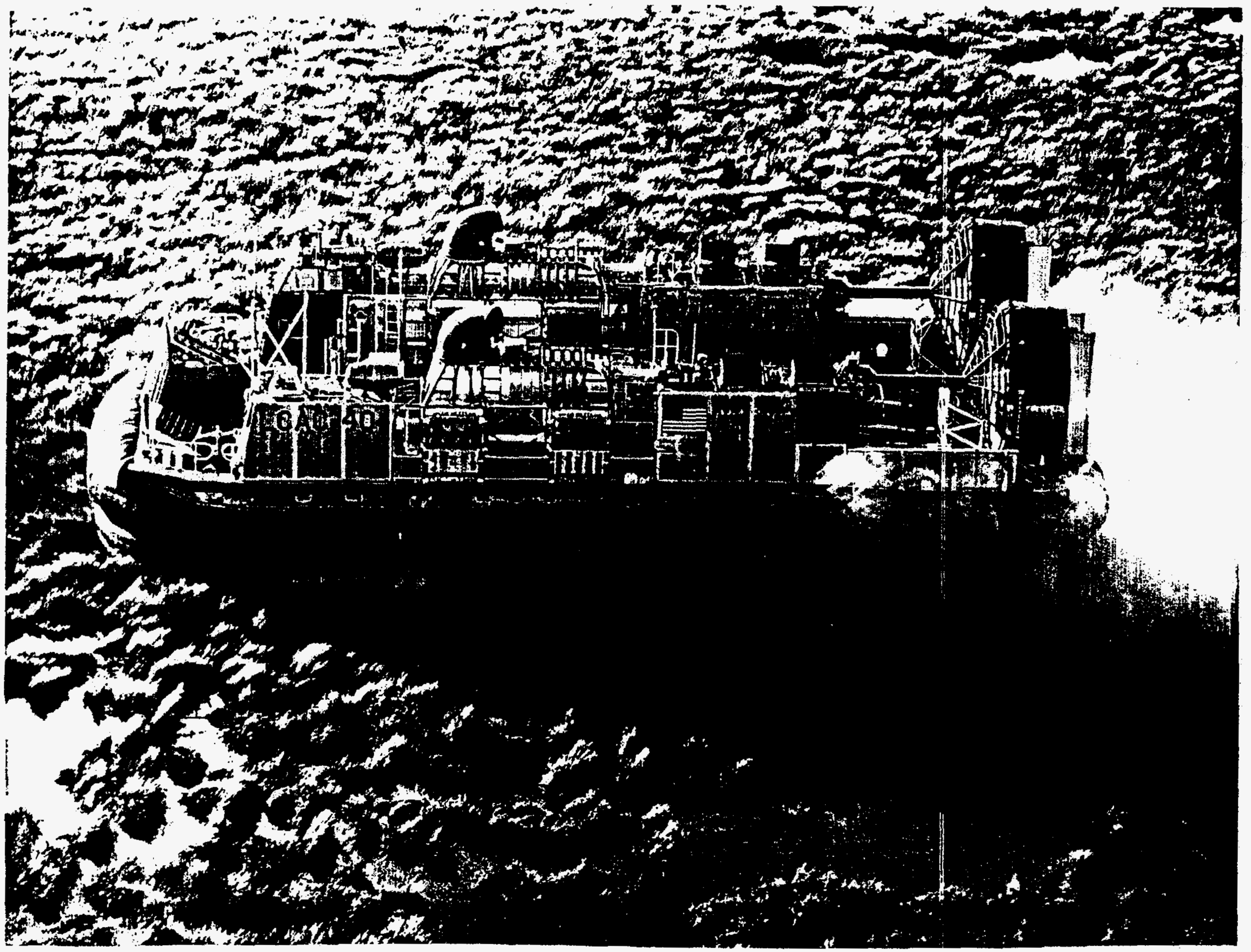

Figure 18. U.S. Navy Landing Craft Air Cushion (LCAC) on trials over south Louisiana marsh. (Courtesy Textron Marine Systems, New Orleans, LA).

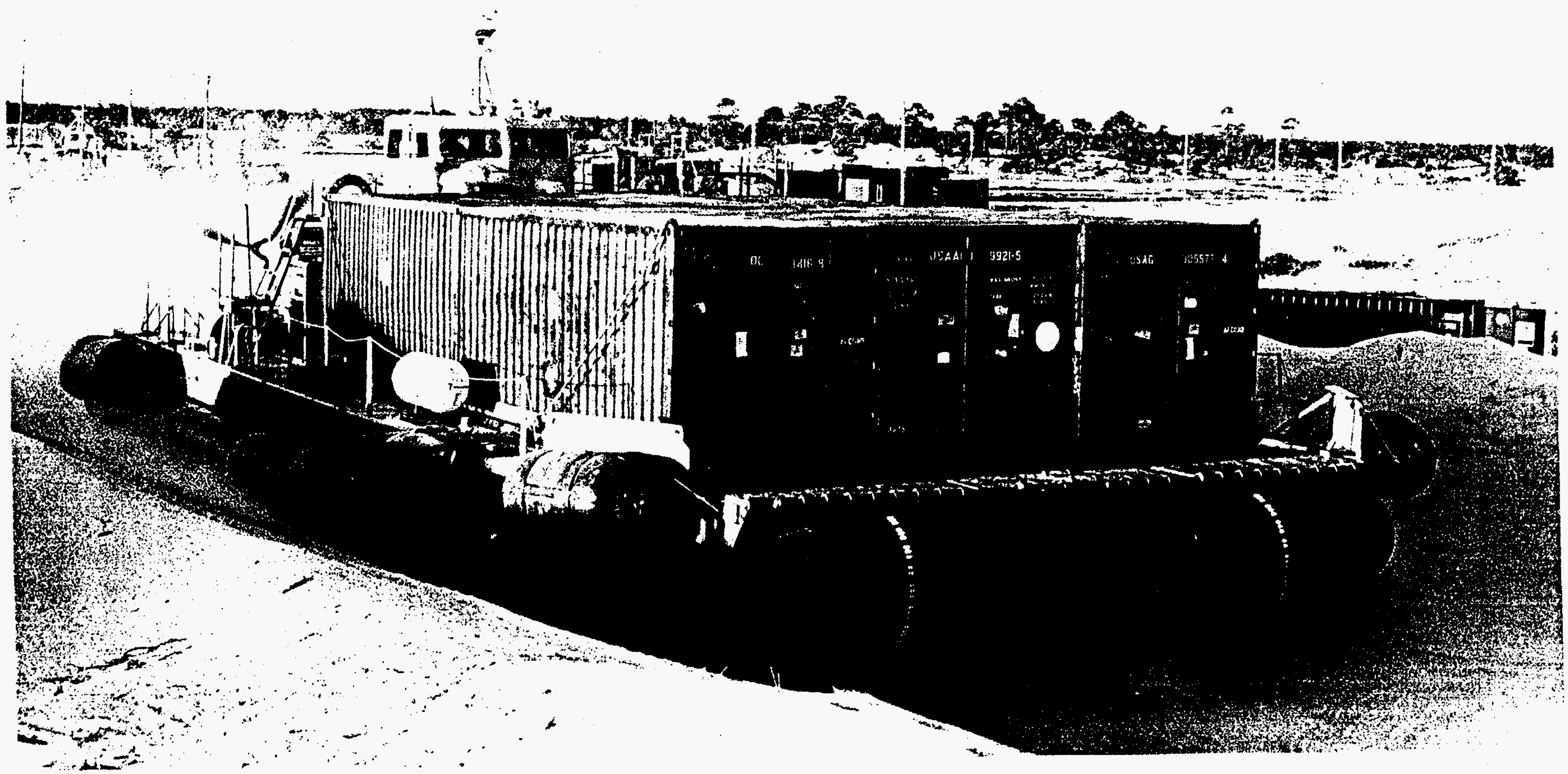

Figure 19. U.S. Army HF-40 used to transport cargo. (Courtesy of Hoverfreight International, Houston, TX).

Helicopters

Helicopters have been available and are presently used in oil and gas exploration operations. Helicopter use is presently limited to personnel transport, emergency evacuation and critical parts replacement transport onshore and offshore. Various types and sizes of helicopters are used in south Louisiana, but none have been used to transport a drilling rig to location as of this writing.

Helicopter rig transport was developed for remote areas and is still used extensively in Papua, New Guinea. One well in the United States has been drilled with a helicopter transported rig. This was the North Fork well drilled in the Shoshone National Forest, Wyoming in 1985 using a Boeing Vertol 107-II (figure 20). The U.S. Forest Service required the use of a helicopter rig to prevent building a 28 mile road through the forest to the well site. All equipment was transported by air using a helicopter. The rig used broke down into 4,000 lb (2,032 kg) units. The well drilled was a 10,000 ft (3,048 m) well with normal pressure and took 83 days to complete. It was a technical success for helicopter operations but was a dry hole (Bureau of Land Management 1985).

Columbia Helicopters presented a study for wetland operations allowing them to offer a competitive service and load capability using their newly acquired Boeing 234 Chinook helicopters. These tandem rotor craft are capable of transporting from 10 to 14 ton (9.10 to 12.7 MT) loads at sea level, allowing most standard land rig components to be transported without special handling. Time requirements for location building rig-up and rig-down presented in the study were comparable with land operations (Malstrom 1990).

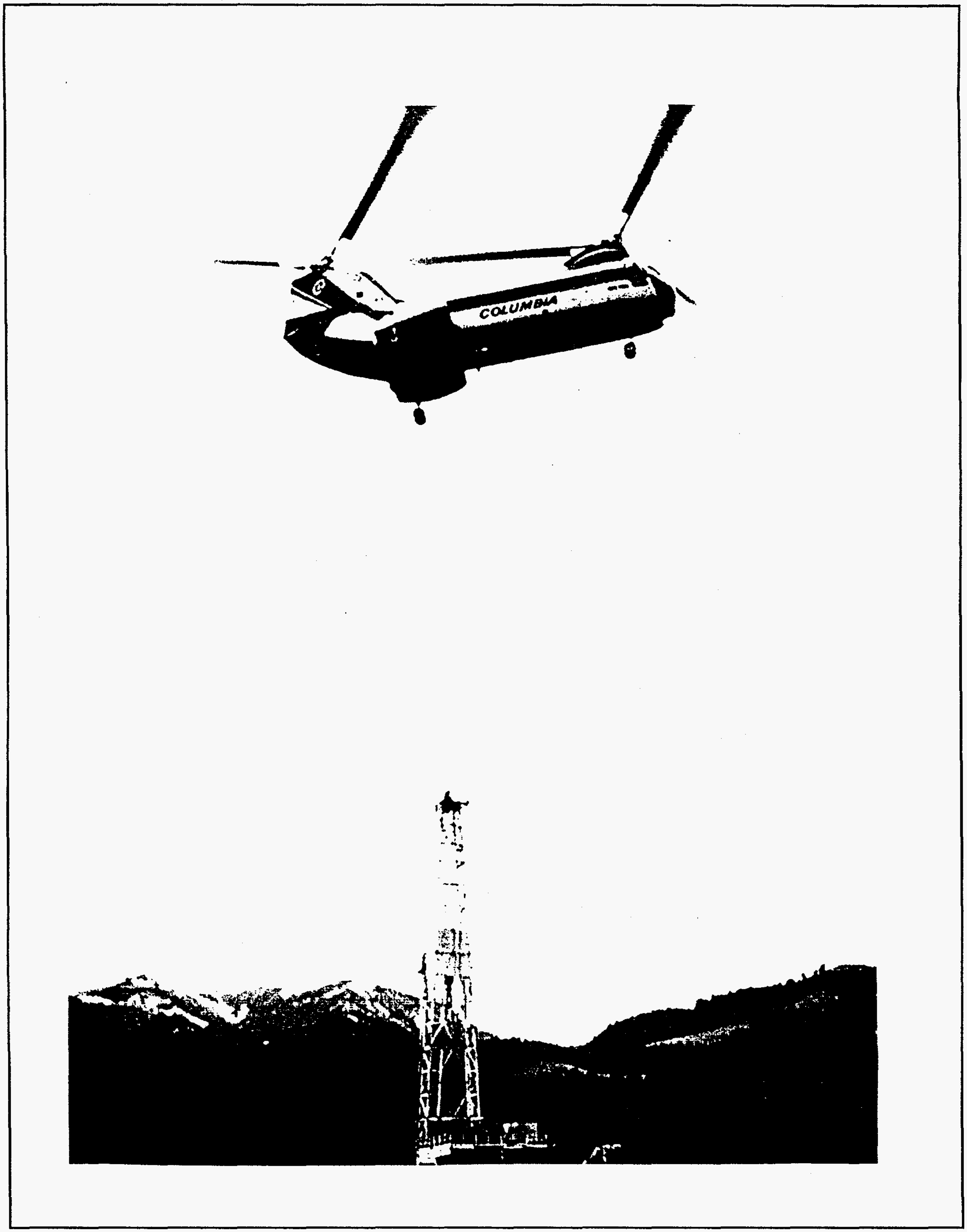

Figure 20. Boeing Vertol 107-II used to drill the BLM well in Wyoming (Courtesy of Columbia Helicopters).

Cyclocraft

The concept of combining the lift of an aerostat and the maneuverability of a helicopter was generated in the early 1970s in response to a need for an economic, short-haul, heavy-lift aircraft for harvesting timber in remote areas of the Pacific Northwest. Two approaches have been tried, balloon or aerostat lift and heavy-lift helicopters, neither provided a viable economic solution to the problem. The chosen solution was to incorporate the best of both systems into an Aerocrane as shown in figure 21.

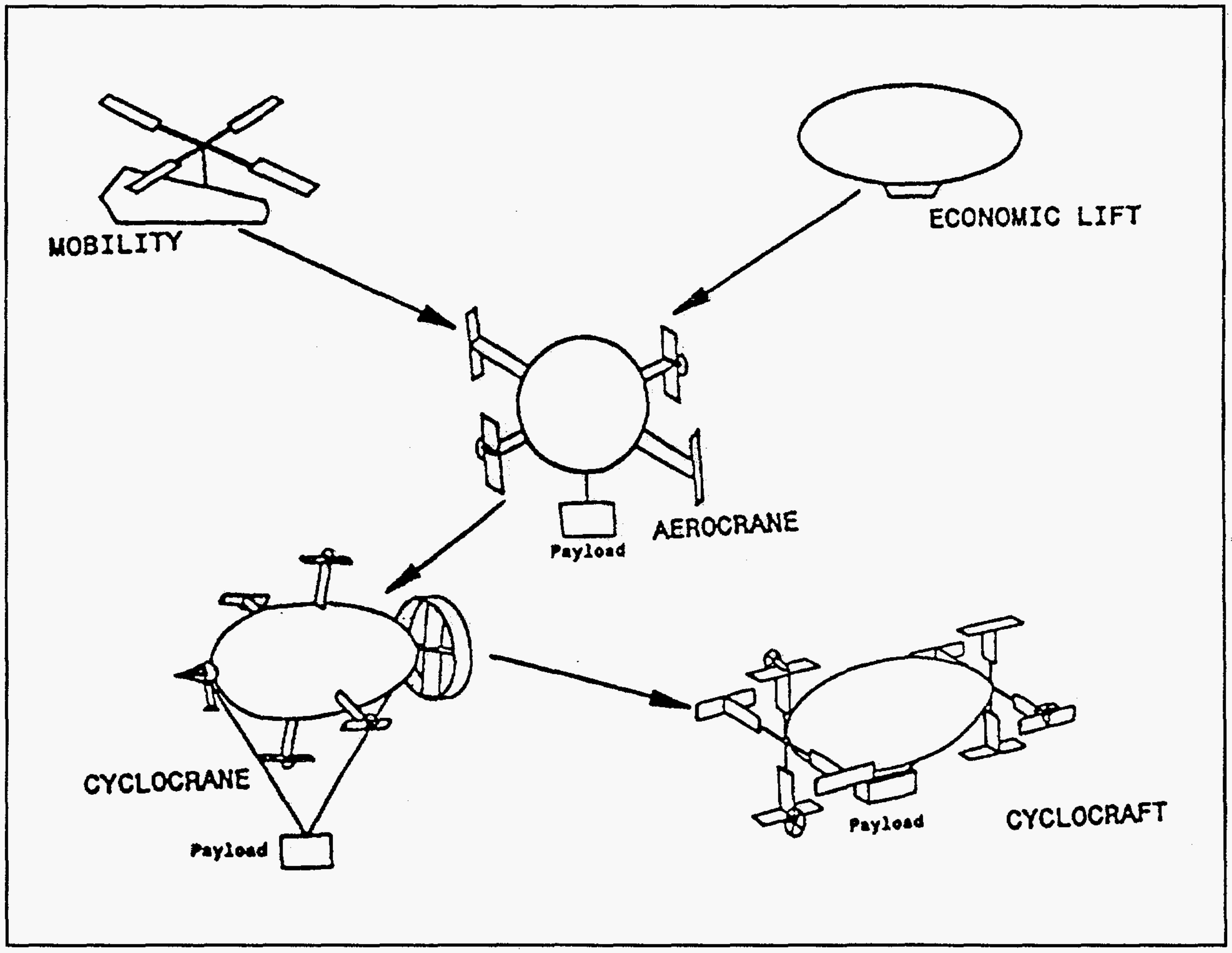

Figure 21. Evolution of heavy-lift cyclocraft (adapted from Stevens 1993a).

After testing, this design was abandoned in favor of the cyclocrane. This configuration was successfully tested from 1978 to 1990. Mission Research Corporation (MRC) believes that the cyclocraft design (figure 22) would allow economic heavy-lift operations with minimal environmental impact.

The need for a minimum impact access method for drilling and production operations in wetland areas of Louisiana and the world can be met by the Cyclocraft. This prototype with an optimum 45-ton (40.8 MT) load capacity would be capable of transporting all equipment and supplies necessary for drilling operations at a wetland drillsite (Stevens 1993a).

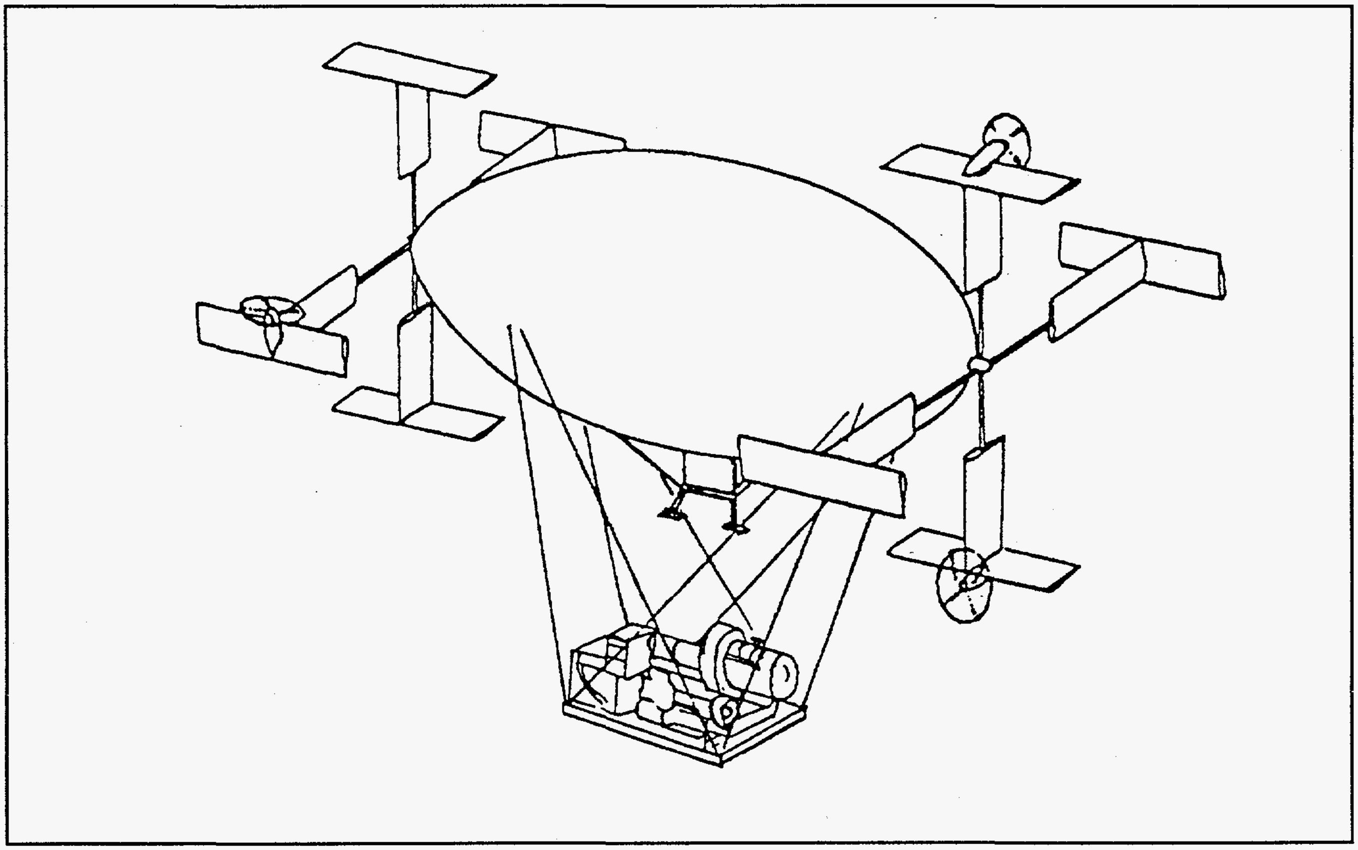

Figure 22. Diagram of a cyclocraft transporting drilling rig parts. (adapted from Stevens 1993a).

To understand and evaluate the environmental impacts of this system a thorough explanation of how this system will work is required. Figure 23 gives a broad overview of the entire operational system involved in using a cyclocraft to access wells in wetland areas. The home base is planned to be located in New Iberia with the outlying forward base and truck/barge staging area. The truck/barge landing site will be at an existing open site suitable for use by the cyclocraft. The system assumes that no additional preparation will be needed at this site because it will be in upland areas or open water, and no additional wetland damage should occur.

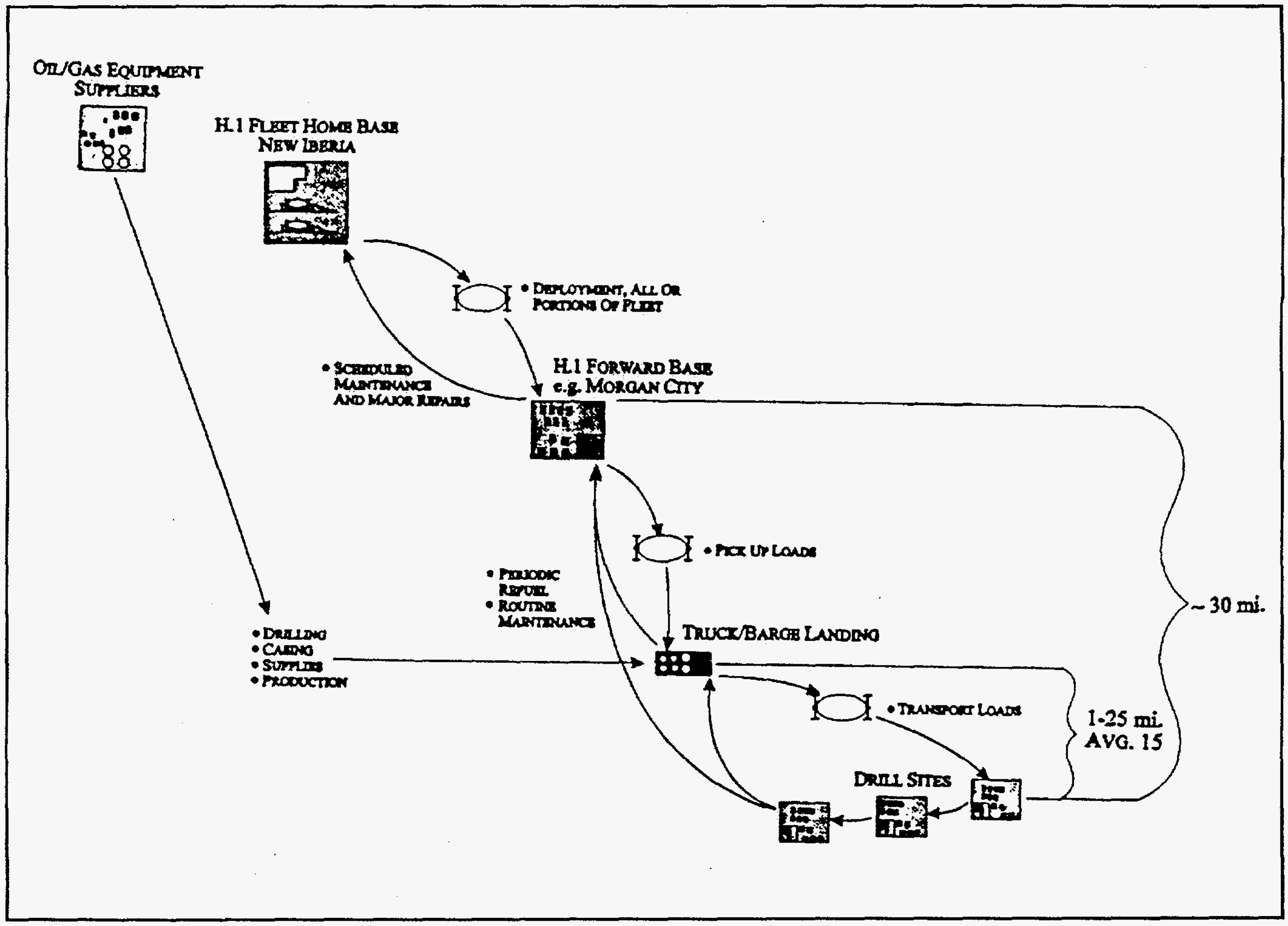

Figure 23. Operational layout of cyclocraft system (adapted from Stevens 1993b).

The cyclocraft system will move equipment to the desired well location by air where a pile driven platform (figure 24) will be constructed. The pile driven platform was chosen to minimize environmental impacts of cyclocraft operations. This platform will be constructed by moving a 50-ton (45.4-MT) crane into the location and driving 365 piles to form the base of the platform. The crane used to drive the piles will be on marsh mats each weighing 2,000 lb (907 kg) or placed on flexifloat barges in open water areas (Pack and Eggington 1992). Once the piles are driven and the decking is attached, operations on the marsh surface will cease and all operations will take place on the deck. The rig components, closed-loop mud system, personnel quarters, and other necessary equipment including drill pipe and casing, logging equipment, and cementing equipment will be transported to the

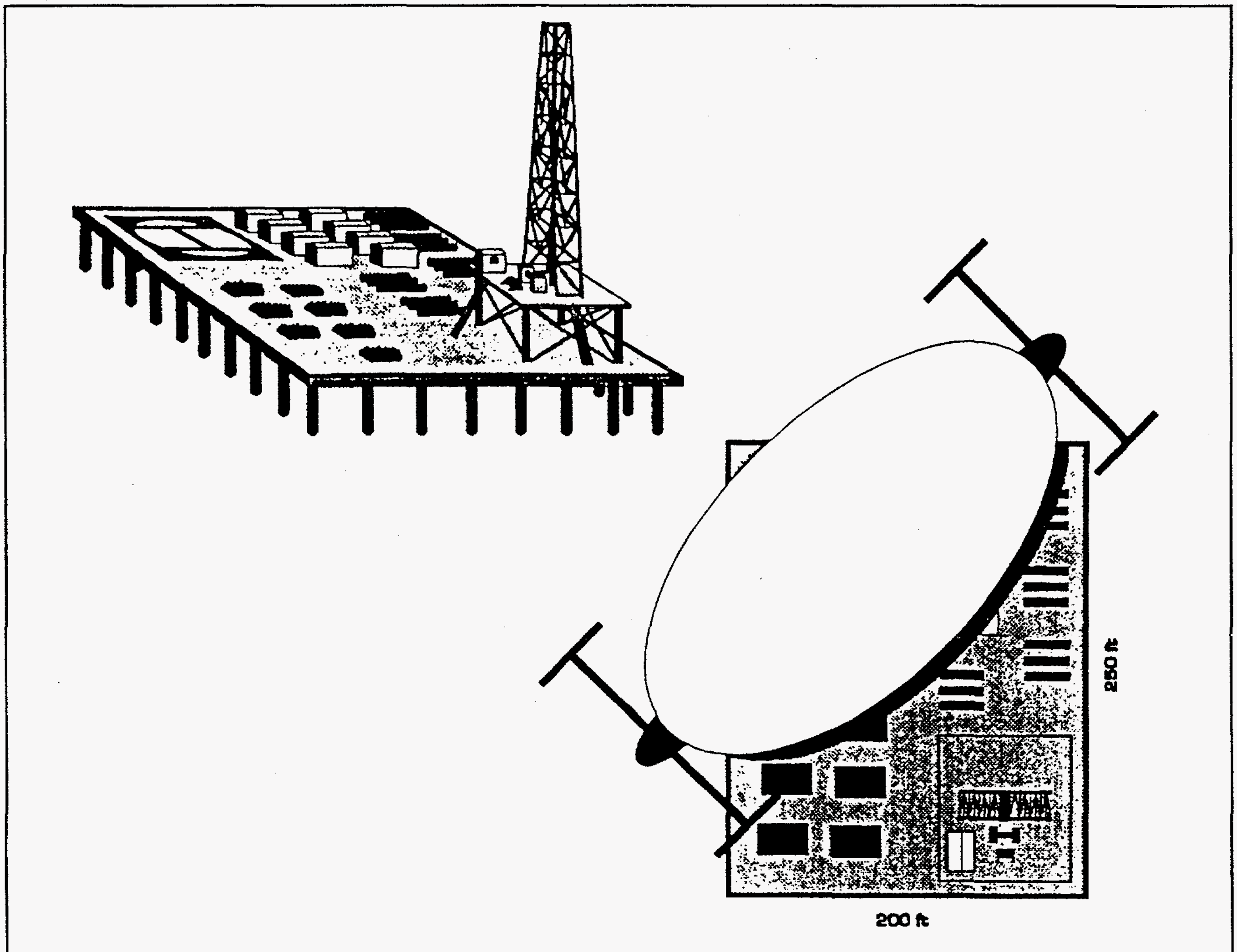

Figure 24. Schematic of pile driven platform (adapted from Stevens 1993a).

location as needed. Extra or one time use equipment will be stored on the supply barge.

One of the limiting factors of alternative access systems is how to transport large volumes of liquids for drilling operations and to solve the problems associated with transporting these liquids. The cyclocraft system provides a unique solution by using an inland barge which will be located within three miles of the drill site, as a supply base, and loaded with the fluids needed for drilling operations. From this barge a 3 in. diameter polypipe (figure 25) would be towed to the drill site across the marsh. This pipe will transport liquids to the drill site and drill cuttings and excess drilling mud from the drill site to the barge for treatment, storage, and disposal. After pigging to clean

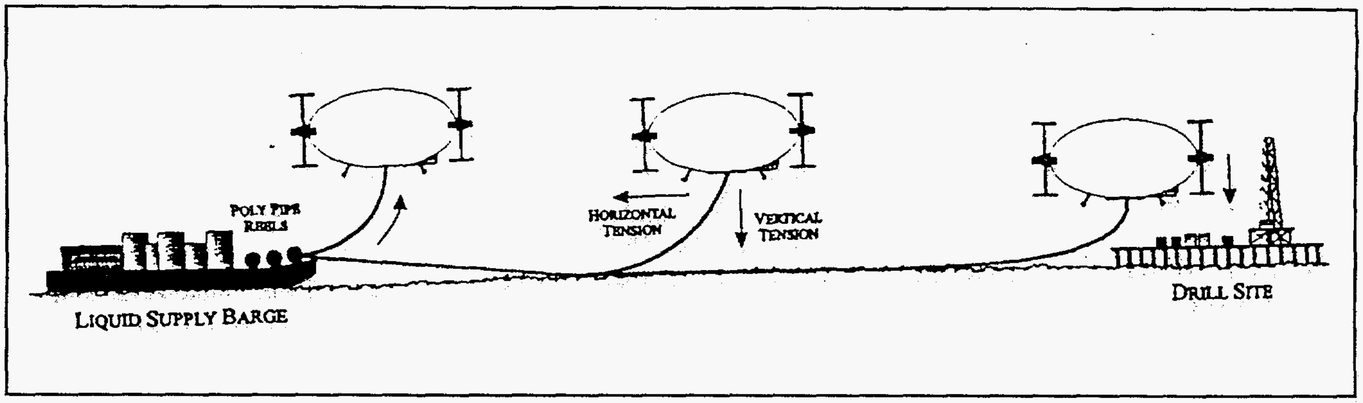

Figure 25. Proposed polypipe system for transporting fuel, cement, drilling mud and waste cuttings (adapted from Stevens 1993b).

the pipe the poly pipeline is also used to transport fuel to the rig location.

Use of the poly pipe line eliminates the need for the cyclocraft to transport the mud, drill cuttings, and other liquids needed for operations. This reduces the total transport requirements by over 23 million lb (10.4 million kg) of material (Pack and Eggington 1992), thereby reducing the cost of the cyclocraft system and allowing it to compete with present access methods. Present plans call for the liquids supply barge to hold excess equipment if necessary. When drilling is complete, the H.1. Cyclocraft would either remove the pilings and platform in the case of a dry hole or bring in production equipment along with flowlines for production to begin.

Environmental Impacts of Alternate Access Methods

Direct impacts

Even though each of the access methods reduce impacts on wetland environments they do not eliminate all impacts. Each system impacts wetland habitats in similar ways. Impacts of the various alternate access systems are summarized below with current access impacts.

Direct changes to the wetland environment are minimal for all systems in open areas where line of sight access to a location exists. The use of any alternate access method to transport oil and gas exploration and production equipment will have minimal direct physical impact on the environment during the transportation phase of the operation. Because the helicopter, hovercraft, and cyclocraft are airborne, no new roads or canals will be built for access. Direct impacts will occur mainly at the actual drill site and are expected to be minimal. At present, plans require a 200 by 250 ft (61 by 76.2 m) area (1.15 acres or 0.47 hectares) to adequately perform drilling operations for all the access methods unless a coiled tubing rig can be used in the future reducing the area needed to 0.46 acres (0.19 hectares).

Helicopters will directly impact wetland areas only at the proposed drilling or production site. Hovercraft and cyclocraft will impact additional areas. Hovercraft will impact along the route to the proposed location and have little impact on the marsh surface because their loading ratio is low and the impacts that do occur are not permanent (Sikora et al. 1983). To evaluate the environmental impacts of Navy hovercraft, an environmental assessment was performed at the Naval Coastal Systems Center, Panama City, Florida, at the Crooked Island test site in March 1984 (Naval Command Systems Center 1984). Crooked Island is a Gulf coast barrier island with vegetation and soil conditions similar to those that exist in some parts of south Louisiana. Because hovercraft exert such a small pressure differential on the vegetative surfaces tested, no visible damage was found in most cases. If the craft hovered in one spot for long periods of time more extensive damage to vegetation occurred. No disturbance of the root systems was found from hovercraft operations, allowing damaged vegetation to recover naturally in a short time. Erosion effects were seen in unconsolidated fine sediment (dunes and beach sands) after repeated low-speed transits. These environments are highly susceptible to damage from wind erosion.

Additional environmental monitoring has occurred in Louisiana from 1988 to present.
Textron Marine Systems, builder of the LCAC, is using part of a wildlife preserve to test the long-term environmental effects of hovercraft operations. In April 1993, some members of the technical review committee for the project and project personnel were invited to evaluate environmental conditions first hand. We rode on an LCAC on a test run and examined the vegetation for damage. We found little visible damage to the vegetation except for some stalk damage. Examination of the track used the previous year for tests and showed that the vegetation was healthier and more robust than the surrounding vegetation. This seemed to be an unexpected benefit of the hovercraft operations. Textron provided us with the results of a 50 pass test over marsh vegetation to us. This series of photographs show no visible degradation of marsh vegetation and no visible footprint of the passing of the LCAC (figure 26).

Impacts in forested wetlands will be more significant to operate a hovercraft system. For access to the location a 50 to 60 ft (15 to 18 m) path through the trees will need to be cleared and a level path made for access. For distant wells significant wetland areas will be impacted for access.

The cyclocraft system would impact wetland areas in addition to the drillsite by towing a flexible pipeline across the marsh to transport liquids to and from the well. The impacts of this operation are significant because a 10 ft (3 m) right of way is needed for this line in all types of terrain including forested wetlands. Details of the cyclocraft system and the environmental impacts on wetlands are described in Eggington et al. 1994.

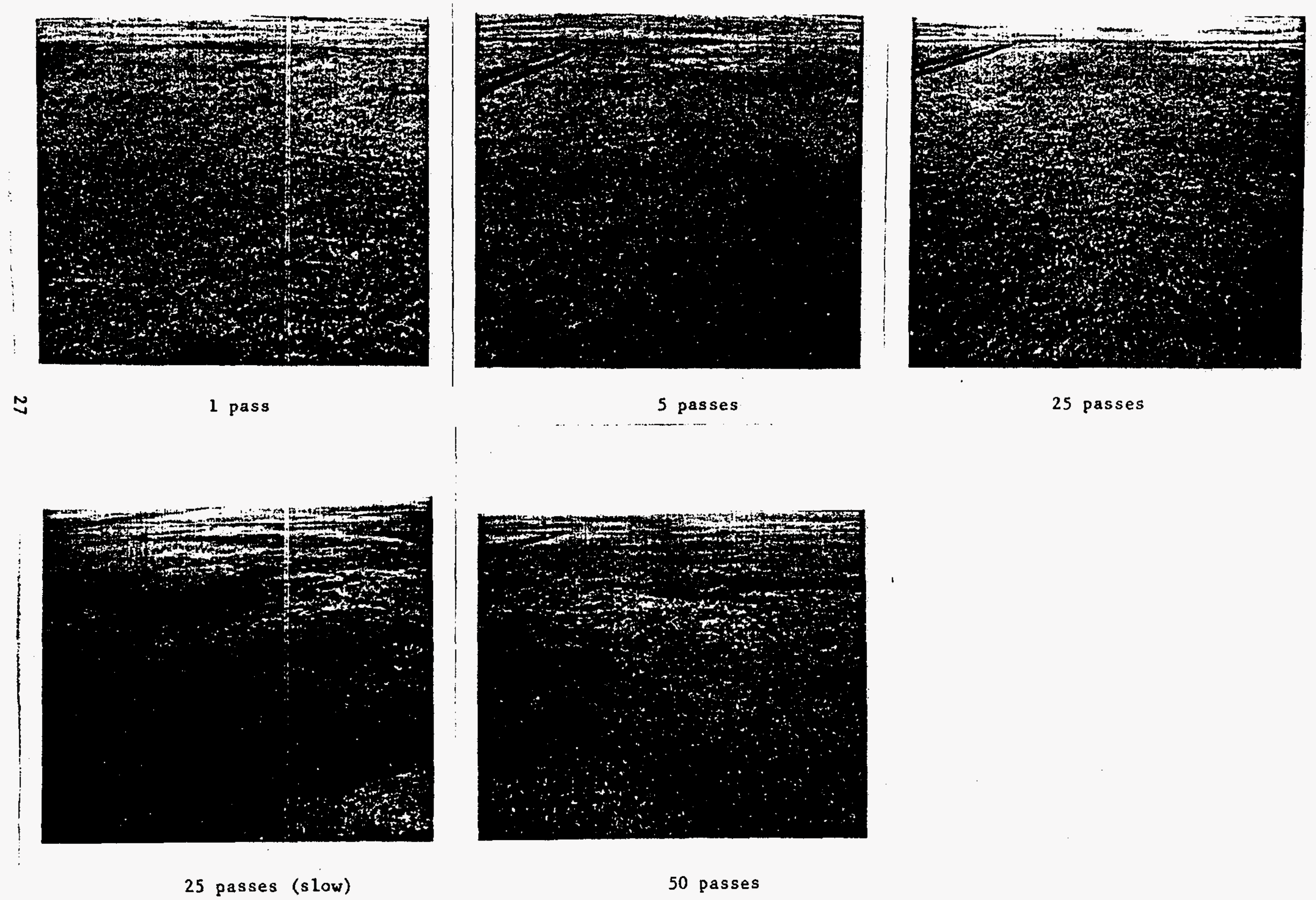

Figure 26. Environmental monitoring of hovercraft impacts on environment. (Courtesy Textron Marine Systems, New Orleans, LA).

Noise impacts for all systems are significant. Helicopter and hovercraft noise depends on power plant, rotor size, and speed. Noise levels can range from 90 db for small helicopters to 125 db for military turbojet, heavy-lift helicopters such as the Chinook (Draves 1993, Malstrom 1993). Test data presented by the engine manufacturers to Mission Research Corporation place the noise level in the 90-db range (Eggington 1993b). Because all alternate access systems reach such noise levels they can disturb nesting bird colonies as do similar operations in wetland areas. Noise and commotion can upset the colony and alter the breeding patterns of various bird species found in wetland areas. The commotion caused also could disturb feeding and possibly spawning of estuarine organisms as well.

Other direct effects on habitat from operations include downwash when picking up and unloading cargo. Hovercraft downwash effect are minimal because pressure differentials are small. Calculated downwash for cyclocraft is 35 ft/sec (10.7 m/sec) or 24 mph (37 kph) in two rectangular areas 132 by 67.5 ft (40 by 21 m) at the front and back of the aircraft. These downwashes will only be noticeable when payloads exceed 23 tons (21 MT) (Eggington 1993b). The downwash created by the aircraft does not exceed normal wind gusts that occur naturally any time in all areas of south Louisiana and will not create any long-term impact. Large helicopters downwash can exceed 105 ft/sec (32 m /sec) or 75 mph (121 kph) and can cause significant damage to plants (Draves 1993, Malstrom 1993). At these wind speeds damage to plants can occur. This may include stalk breakage, leaf loss, and impacts from foreign objects that could cause mild to severe damage to the plants.

In shallow water, below 3 ft (0.9 m), minor turbidity problems were associated with the passing of the hovercraft. Effects were minor and short in duration with conditions normalizing within 30 minutes of passage (Naval Command Systems Center 1984).

Direct effects of board roads, canals, helicopters, hovercraft, and cyclocraft are summarized (table 9) using criteria established by Cahoon and Holmes (1989). All affect wetland habitat in one way or another, but all the alternative access systems eliminate many potential impacts compared to current access practices.

Table 9. Comparison of direct impacts of alternate methods and existing methods of access (modified from Cahoon and Holmes 1989).

Direct Impacts	Bd. Rd.	Canals	Helicopter	Hovercraft	Cyclocraft
Loss of marsh habitat	X	X	X	X	X
Loss of shallow water habitat	X	X			
Loss of forested wetland habitat	X	X	X	X	X
Direct conversion to open water	X	X			
Direct gain of upland habitat	X	X			
Direct conversion of marsh/swamp to"nonproductive" sites	X	X			
Increased ponding	X		X	X	X
Compacted marsh surface	X	X	X	X	X
Changes in plant growth	X	X			
Changes in habitat diversity	X				
Gain of 8' deep open water		X			
Resuspension of nutrients and toxins	X	X			
Increase in turbidity	X	X			
Changes in soil/ water chemistry	X	X			
Disruption of natural drainage pattern	X	X			
Changes in surface and subsurface hydrology	X	X			
Noise, Commotion during construction operations	X	X	X	X	X
Destruction or burial of biota	X	X	X	X	X
Potential for interrupting fish spawning and feeding	X	X		X	
Interferes with movements of estuarine organisms	X	X			
Potential for disturbing bird nesting by noise.	X	X	X	X	X

Table 10. Comparison indirect and chronic environmental impacts for alternate and present access methods (modified from Cahoon and Holmes 1989).

Indirect impacts.					
Altered Process	Bd Rd	Canal	Helicopter	Hovercraft	Cyclocraft
Wave action		X		X	
Sediment distribution	X	X			
Water circulation and turnover; stagnant water	X	X		X	
Deeper channels with increased hydrologic efficiency		X			
Intercepted fresh water flow	X	X			
Hydrologic isolation of surrounding wetlands.	X	X			
Saltwater intrusion	X	X			
Surface hydrology and drainage changes	X	X	X	X	X
Subsurface hydrology and drainage changes	X	X	X	X	X
Physical/Biological Impact					
Marsh compaction.	X	X	X	X	X
Reduced vertical accretion in surrounding wetlands	X	X			
Changes in vegetation dynamics:species:composition, organic matter production and accumulation	X	X		X	
Changes in mineral accretion and soil nutrition	X	X			
Possible negative influence on aquatic/ benthic organisms		X			
Forest succession	X				
Changes in soil/ water chemistry	X				
Changes in frequency/duration of inundation	X	X			

Indirect Impacts

Indirect impacts are long-term changes in the ecosystem that cannot be necessarily directly linked to one specific activity. The primary indirect impact caused by canal and board road activity is the alteration of local and regional hydrology. Changes of salinity regimes and plant communities and to some extent introduction of pollutants are changes in the ecosystem in response to hydrological changes. Fewer direct impacts will have fewer types of indirect effects on the wetland environment.

The alternate access systems do not impact the marsh surface in the significant ways that canals and board roads presently do these impacts are the direct conversion marsh habitat to open water or blockage of the natural drainage pattern. This alteration of the sheet or surface flow is the most significant indirect impact caused by canals and board roads. Alterations in surface hydrology occur through construction of channels and spoil banks for access (See **Impacts of Oil and Gas Development**, page 70).

All of the access methods will cause compaction of some parts of the site location. For canals, the area under the barge and the spoil banks will cause compaction, affecting subsurface flow. The weight of spoil compresses the surface of the marsh up to 60 percent of its original thickness (Nichols 1959), thereby reducing the cross-sectional area available for flow. Board roads also compact marsh sediment in the area over which dredged spoil and boards are laid. Compaction also can occur along the borrow ditch where the dredge is located during construction. The same type of marsh compaction occurs during the initial construction phase of for all the alternative access methods including helicopters, hovercraft, and cyclocraft during site creation. This change in hydrological flow caused by spoil banks, road dumps, and boarded locations can have a long-term effect, while the alternative access methods with their limited construction space requirements should have a short-term effect on the marsh substrate. This short-term effect can still damage the marsh surface, preventing the return to its original elevation and ponding can occur in areas where little new sediment is deposited.

Sheet flow and surface hydrology would not significantly be affected by the alternate access methods. Building at the well site will create some long-term indirect impacts, but they will be significantly less than canal or board road locations. Table 10 compares the indirect impacts of current access methods with the proposed alternative access methods. Note that helicopters have the least direct and indirect impacts. Hovercraft have the most direct and indirect impacts of the alternative access methods mainly because of the hovercraft shallow open-water performance and the need for a level path in forested wetlands. The differences between the alternative access methods is very small compared to the difference between current access methods and all of the alternative access methods. Additional environmental factors and detailed economics need to be examined to find the most cost-efficient and environmentally beneficial system.

Other Considerations

Cost considerations are an important aspect of operating in wetland areas. We evaluated cost data on the helicopter operations performed in the United States and overseas from Columbia Helicopters (Malstrom 1992). Operational cost data for hovercraft were obtained courtesy of Hoverfreight International (O'Brien 1994) and projected cost for cyclocraft from Mission Research Corporation (Eggington 1993b). From this data, the operational cost was calculated for each system on combined per ton and per hour basis and the results are shown in table 11. Based on current economics, hovercraft technology was found to be the most cost effective, making this system the most desirable option to reduce wetland loss. However, if cost is the only factor used as the basis for comparison, then the cost of operating a hovercraft is significantly higher than trucks or barges ($40 vs. $1-2) but less than a cyclocraft or a helicopter ($40 vs $70-168). This table does not summarize access costs because too many independent variables exist to calculate comparable access costs for each method.

Availability becomes an important consideration for all of the alternative access methods. At present none of these alternative methods are immediately available to use in Louisiana. Helicopters are available in the United States and could be operational if the helicopters were brought to Louisiana. Significant infrastructure currently exists to service offshore platforms that could be used to service helicopters transporting drilling rigs. Hovercraft are unavailable at present, but Hoverfreight International is attempting to buy surplus military models to use in wetland and arctic environments. The cyclocraft is still in the development stage by Mission Research Corporation.

Table 11. Comparison of various access methods on a cost per ton and hour basis.

	Operational cost $/hr	Lifting Capacity Tons (MT)	Cost per ton /per hour
Truck	$80	40 (36)	$2.00
Barge	$200	200 (180)	$1.00
Helicopter	$2355	14 (13)	$168
Hovercraft	$1601	40 (36)	$40
Cyclocraft	$3166	45 (41)	$70

MITIGATION BANKING

The final phase in the "sequencing requirement" for mitigation in wetlands is compensatory mitigation for unavoidable losses. Compensatory mitigation incorporates strategies such as enhancement, preservation, restoration, and creation. One concept that has been developed to incorporate these mitigation strategies is mitigation banking.

Wetlands mitigation banking is a relatively new resource management concept that generally provides for advance compensation for wetland losses. Mitigation banks can incorporate all strategies of wetland mitigation such as creation, restoration, enhancement, and preservation for accruing bank credits. Several authors (Salvesen 1994, White et al. 1989, Wilkey et al. 1994, Reppert 1992, and Environmental Law Institute 1993) have discussed mitigation banking in detail. Table 8 summarizes key definitions related to mitigation and mitigation banking.

From a national perspective, the legal basis for mitigation and mitigation banking is through the Fish and Wildlife Coordination Act (FWCA) originally passed in 1934 and Section 404 of the Clean Water Act (CWA) of 1977. The FWCA requires that USACE consult with the USFWS, NMFS, and the head of applicable fish and wildlife agencies concerning any water resource development project which they permit. The FWCA requires that USACE consider specific recommendations made by these agencies for mitigation of fish and wildlife habitat losses pertaining to USACE projects.

Most of the mitigation banks implemented so far are a response to the initiatives developed under FWCA. Section 404 of CWA establishes specific environmental criteria which must be met for activities that are permitted under Section 404. These criteria actually provide a more definite basis for mitigation of wetland losses than FWCA. In addition, the 1990 MOA between EPA and USACE specifies policy and procedures which determines mitigation and mitigation banking as an acceptable form of compensatory mitigation. At least nine states, California, Colorado, Louisiana, Maryland, New Jersey, North Dakota, Oregon, Texas, and Wyoming have statutes authorizing wetland mitigation banks (Environmental Law Institute 1993).

Mitigation banks are typically large blocks of wetlands with designated values that have been estimated by a pre-approved system. Wetland losses and values are estimated as wetland credits in the bank in several ways. Some credit values are based on wetland function. Fish and wildlife habitat values are estimated either through habitat-based methods such as USFWS habitat evaluation procedures (HEP) or by the Wetland Evaluation Technique (WET). WET incorporates broader physical and biological functions of the wetlands than the HEP method does. Another method simply tabulates acreage of wetland types. This method compensates by replacing lost wetlands with the same wetland type acre for acre.

These wetland values, however calculated, are deposited into the bank as credits that are theoretically similar in quality and scaled in size to the wetlands lost. These credits are similar to cash deposits in a bank account and can be withdrawn when unavoidable losses occur during a project.

The objective of a bank is to replace the physical and biological functions and human-use values of wetlands prior to a development activity. Mitigation bank credits are not a substitute for other mitigation options, such as avoiding and minimizing impact, but as a last option for wetlands compensation.

Compensatory mitigation does not always mean an acre-for-acre in-kind replacement for lost wetlands. Replacement could occur with more or less acreage of a different wetland type from the lost one and would depend on the value of the wetlands lost compared with the value of the wetlands located in the bank.

Mitigation banks can take the form of a dedicated bank or of a commercial bank. A dedicated bank is generally sponsored by a single entity and is associated with compensation of wetland losses associated with specific types of construction activities. A commercial bank is established by the private sector whose wetland credits are available for purchase in the open market. It provides credits for a variety of activities causing wetland losses. Banks have been industrial banks, highway-related banks, port-related banks, federal projects banks, commercial banks, and wetland mitigation trusts. Many mitigation banks at this time are associated with highway construction and port development activities.

The number of active banks in 1992 varies according to author and criteria. Reppert (1992) reported 37 active banks in 15 states and 28 planned banks in ten states. The Environmental Law Institute (1993) reported 46 mitigation banks in 17 states (table 12). More than half of the banks reported by Environmental Law Institute

(1993) are located in California (17) and Florida (8). Almost 75% of the banks are either state highway banks, port authority banks, or local government banks. Of the 46 banks reported by the Environmental Law Institute (1993), only six were private banks used solely for advance mitigation. The only privately owned bank which offers credits for commercial sale is the Fina LaTerre Bank, located in Louisiana. There are three publicly owned banks: two in California and one in Oregon that also sells credits. Environmental Law Institute (1993) also has identified 64 additional proposed banks.

Table 12. Number of existing and planned Mitigation Banks by state as of June 1992, from Reppert (1992) and Environmental Law Institute (ELI 1993).

	Reppert (1992)		ELI (1993)
State	**Existing**	**Planned**	**Existing**
Alabama	0	1	0
Arkansas	0	1	0
California	11	0	11
Florida	0	10	8
Georgia	0	2	1
Idaho	3	0	3
Indiana	2	0	2
Louisiana	2	1	2
Maryland	0	1	0
Minnesota	1	0	1
Mississippi	4	1	4
Montana	1	0	1
Nevada	1	0	1
New Jersey	0	5	0
North Carolina	2	0	2
North Dakota	3	0	1
Oregon	3	0	1
South Carolina	0	1	1
South Dakota	1	0	1
Tennessee	2	0	1
Virginia	4	0	4
Wisconsin	1	5	1

Most of the established banks used restoration or enhancement as the basis for compensation credits. Of the banks reported by Environmental Law Institute (1993) 31% use habitat-based valuation methods, 26% use acreage, and the rest use other schemes. Most compensation ratios are 1:1 or higher.

Wetland mitigation banking appears to be a valuable and practicable compensatory mitigation option for developers who accrue several small wetlands losses due to repetitive activities such as highway construction or oil and gas activities. These types of activities cause piecemeal loss of wetlands that alone does not appear significant but contribute to high cumulative losses over time. On-site compensation is not usually feasible where losses are small; therefore, mitigation banking could, in many cases, be a good option economically and ecologically for compensation for such losses. Critics of this view argue that loss of small unique isolated wetlands should be replaced with in-kind wetlands rather than as a piece of a larger project because these small wetlands contain communities and serve a function that is not replaced in a large block.

The advantage of mitigation banking to the developer is that it allows the consolidation of minor losses to one large area off-site and provides for compensation *before* the wetland loss takes place. These save the developer and regulatory agencies time and money.

Wetland mitigation banking, although an option, has not become a major factor in compensatory mitigation. The concept is still new and has not been proven to be either ecologically or economically sound because there has been little experience with long-term mitigation banking issues. Furthermore, wetland creation, which is one method for forming banks, is still a fledgling science and has not yet yielded reliable results. Wetland mitigation banking can only be long lived and successful while: it has a defined role for meeting wetland protection objectives; it is in demand; it can serve to meet ecological and economic goals; and the regulatory climate remains in favor of it.

RANKING OF MITIGATION OPTIONS

One of the major challenges for regulators and industry is to rank possible mitigation alternatives by environmental benefit and economic cost. For industry to remain profitable mitigation solutions that provide environmental benefit for minimum economic cost are needed. To better illustrate which mitigation options provides the least environmental impact for the least economic cost the following diagram presents an arbitrary ranking for the various mitigation solutions discussed (figure 27). The matrix presents approaches to minimize environmental impacts for developing a field and the approach strategies are ranked by economic cost. For example: Helicopters are ranked a 1,5 showing that the use of helicopters would be environmentally beneficial but at present cost prohibitive. The intent of this matrix is to create a planning tool for industry and regulators for showing the direction that mitigative access options should take. The goal for both parties is to implement strategies shown in the green areas whenever possible. A secondary goal would be to reduce either the environmental or economic cost of the strategies shown in yellow and red areas to allow implementation and use. If those cost cannot be reduced these strategies should be avoided either on economic or environmental criteria.

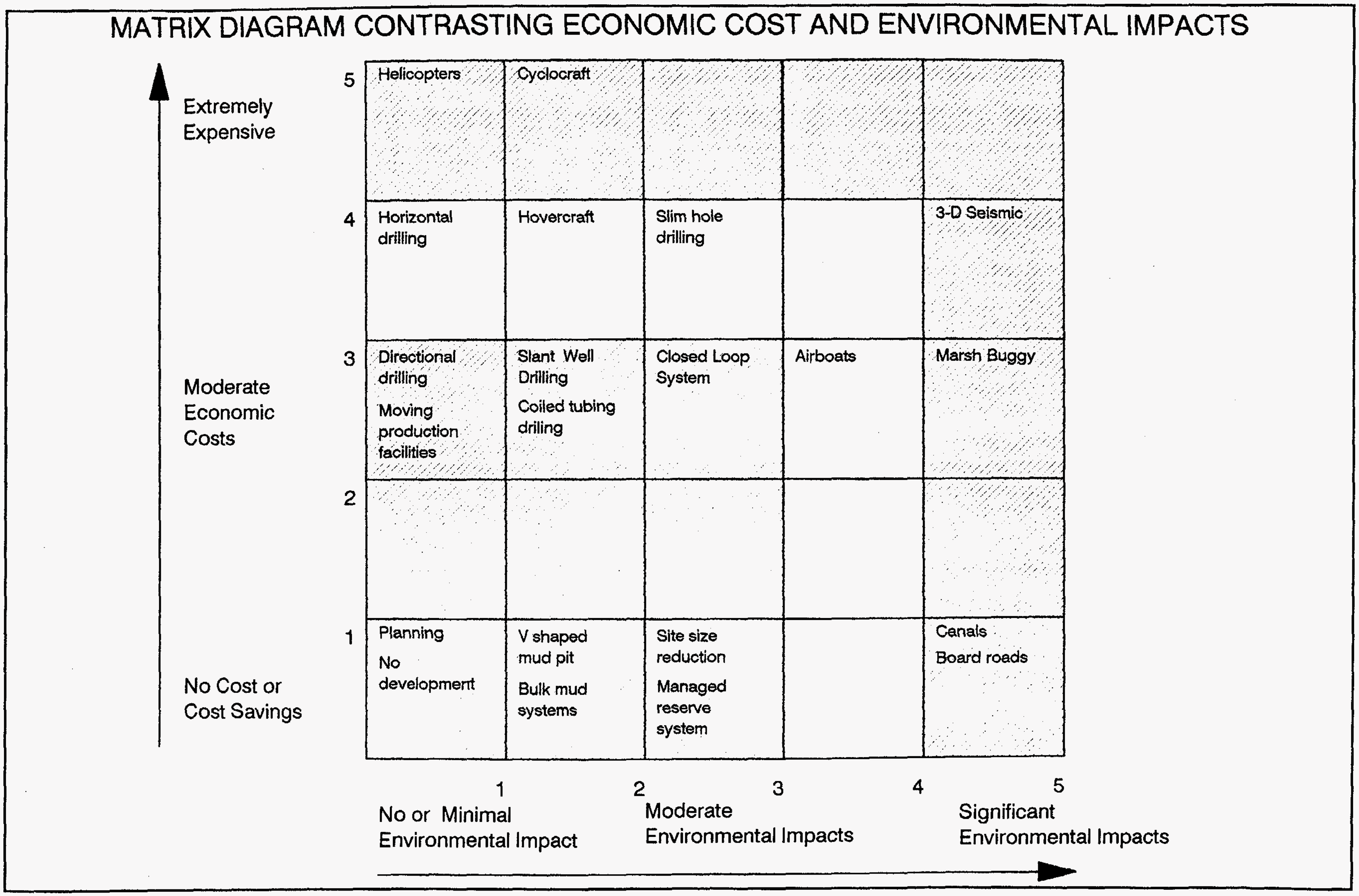

Figure 27. Matrix diagram contrasting and ranking environmental impacts of various mitigation options and economic cost.

CURRENT FIELD STUDIES

This study selected10 fields currently producing in Louisiana to examine possible future environmental effects of new operations caused by enhanced methods, in-fill drilling or other future extraction techniques in wetlands. The ten fields selected are shown in figure 28 and represent a cross-section of fields in wetland areas. Seven of the10 fields are located in fresh areas, two in intermediate marshes and one in brackish marsh. We attempted to include fields in all types of wetland areas found in the state from bottomland hardwoods to fresh and brackish marsh environments. All the fields selected have or are expected to shortly have secondary and enhanced recovery projects. Current cumulative production for the fields selected is tabulated in table 13.

The method used for compilation of field data in Louisiana is rather complex. The primary unit used to gather production and subsurface information about a field is the LUW or lease, unit, and well code assigned by the Louisiana Office of Conservation. A LUW code can consist of all the wells on a particular lease, all the wells in a defined unit, or in the case of single well units a single well. This system was designed to record production information not geologic or geographic information. This is the only system in Louisiana used to gather information on oil and gas operations, and all published information is based on this system. To obtain information on a

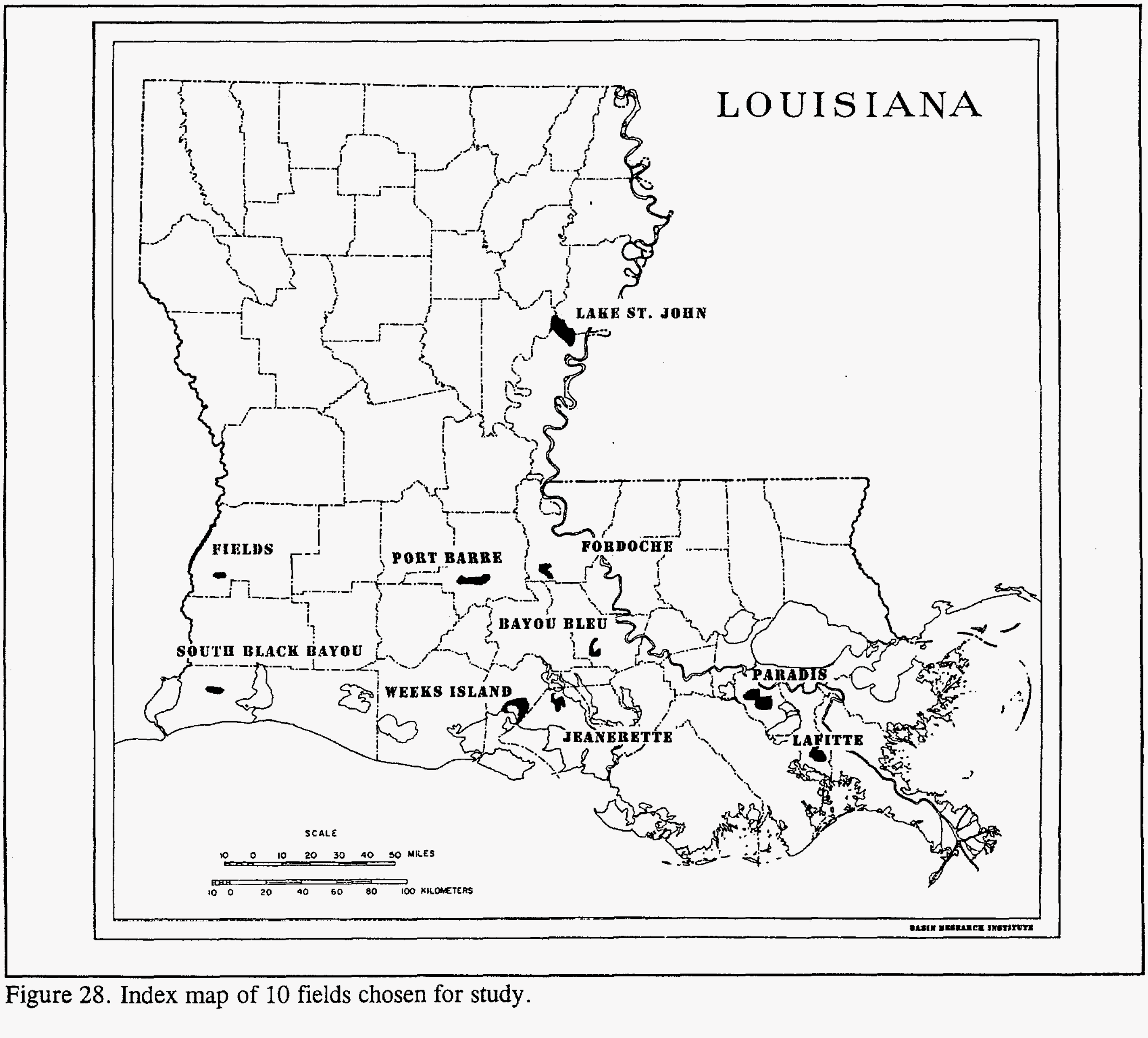

Figure 28. Index map of 10 fields chosen for study.

Table 13. Cumulative Production for study fields.

TOTAL PRODUCTION AS OF 7/15/94		
	Cumulative Gas Production Gas+Casinghead gas Mcf.	Cumulative Liquids Production Crude+Condensate bbls.
Bayou Bleu	289,703,010	39,556,186
Black Bayou, South	24,059,949	8,786,741
Fields	35,693,253	6,815,983
Fordoche	280,210,230	58,743,131
Jeanerette	527,410,333	47,459,370
Lafitte	310,119,488	258,068,868
Lake St. John	468,763,254	85,898,418
Paradis	1,326,377,510	144,771,209
Port Barre	61,190,863	53,409,691
Weeks Island	531,707,789	242,711,819

particular field from this data base, numerous LUW codes may need to be examined. An individual well may be part of several LUW codes in course of the life of a well or each reservoir sand package may have its own LUW code associated with it. A LUW code may change for a well as sands are depleted, and another sand is placed in production. The system is very inefficient and complex and as with any large data base, data entry errors still exist. Until the mid 1980s personnel at the Department of Natural Resources provided some amount of quality control for data that were entered into the system. In later years tight budgets have reduced the staff and very little quality control if any is done today.

In this study the production and all pertinent state unitization records for each field were evaluated. Reservoir sand nomenclature and depths are pertinent only to the field under consideration. Nomenclature used in this study is as has been recorded in the state data base.

Because of the large numbers of units associated with each field ranging from 17 to 256, depending on the field, examples presented in this study are representative of overall general field structure. Because non-contiguous sands and completely dissimilar reservoirs in different fault blocks are included in each field, the examples presented do not specifically represent all different types of reservoirs found in that field. Reservoir specific information has been noted where presented.

For evaluating field data well information for each field was downloaded into a commercial geographic information system (GIS) GeoGraphix. A surface map spotting each well location was then created using digitized quadrangle maps from the United States Geological Survey at (1:100,000 scale and 1:24,000 scale). Because of the limited availability of the 1:24000 quadrangle data only the Weeks Island field plot could be computer generated using this type of surface data.

To examine surface effects or landscape change around oil fields in wetlands, aerial photography from four fields that have been in production for about 60 years was examined. Photography of two fields, Bayou Bleu and Jeanerette, was photo interpreted for three time periods and mapped on a scale of 1:24,000. The maps were digitized and processed on an Intergraph GIS system. The data were processed to produce land cover maps for each year and to calculate area of each land cover type for each year. Differences in the areal extent of land cover also were calculated. Two other fields, Paradis and Lafitte, were examined using data from DNR/CMD and aerial photography.

Most of the photography used to assess the four oil fields were obtained through Stennis Space Center and LSU's Map Library in the Department of Geography. For the photo interpretation and mapping of Jeanerette and Bayou Bleu, photography from the 1950s and 1970s and the most recent available was used (table 14). For this analysis, land cover was classified into seven categories: wetland, no vegetation, altered vegetation, impacted developed, natural water, agricultural/urban developed, and human-made water (canals). Four categories, no vegetation, altered vegetation, human-made water, and impacted/ developed, are associated with changes in land cover around oil and gas activities in wetlands. Land cover classified as no vegetation occurs in areas once vegetated but vegetation has since died or been covered. Most of these types of areas occur in a open area around production sites or within an impounded area. Vegetation was considered altered if color reflectance and texture varied from the surrounding area and the area was distinctly shaped. Often altered vegetation occurred in areas previously classified as no vegetation or impacted/developed. Altered vegetation typically occurred around shell pads and along roads and canals. Some of the linear features such as roads and canals were difficult to distinguish

Table 14. List of photography examined for Bayou Bleu, Jeanerette, Paradis, and Lafitte oil fields.

Field	Photo date	Type	Scale	Agency
Bayou Bleu	10/90	CIR	1:40,000	USGS
	9/73	CIR	1:42,914	NASA
	4/52	B&W	1:23,600	USGS
	11/40	B&W	1:20,000	ASCS/USDA
Jeanerette				
	11/89	CIR	1:40,000	USGS
	10/78	CIR	1:66,000	NASA
	2/56	B&W	1:60,000	US Army
	11/40	B&W	1:20,000	USCS/USDA
Paradis				
	12/90	CIR	1:63,000	NASA
	5/72	CIR	1:60,000	NASA
	2/53	B&W	1:20,000	USCS/USDA
Lafitte				
	12/90	CIR	1:63,000	NASA
	10/78	CIR	1:66,000	NASA

and therefore most changes in roads and canals were not analyzed through the polygon approach but noted as a qualitative changes in the landscape through examination of the photography. This yielded qualitative information such as general conditions of the area, new roads, canals, impoundments, and general landscape changes over the study period were numerous but too small to map. Because the mapping effort concentrated on wetland areas there was no attempt to distinguish oil and gas activities from other development areas outside wetlands.

For the Lafitte field, habitat data from CMD's GIS system were obtained and evaluated for the surface area of the field. Photography from 1953, 1972, and 1990 was also examined. Historical landscape changes are presented in the land classifications used by that system and described in Mossa et al. (1989). The photography was examined to determine qualitative features of this field.

CMD data was also acquired for the Paradis field. However, only 1984 TM data were available. This data can only provide habitat and area of each classification for 1984. Suitable photography of this area also was difficult to acquire; therefore, only 1978 and 1990 photography was examined.

Bayou Bleu

Bayou Bleu field is a series of faulted anticlinal reservoirs located in south central Louisiana about 20 miles west of Plaquemine in Iberville Parish. Bayou Bleu field is located in a freshwater swamp/bottomland hardwood forest just north of the Upper Grand River on Bayou Bleu, which is a distributary of Bayou Grosse Tete. The area is seasonally or semi- permanently flooded; therefore, species composition varies, depending on flood duration. The area also contains some shrub/scrub communities and fresh marsh. It is not within Louisiana's coastal zone boundary.

The field discovered in 1929 and at last count had, 344 verified wells and has produced almost 290 BCF of gas and 40 million bbl of oil (table 13). Surface map of the field with presenting well locations is shown in figure 29. The Office of Conservation has assigned 62 LUW codes to the field covering 41 pay sands from 800 to 13,000 ft (244 to 3,962 m) (Louque 1989). The field has produced from various 13 sand horizons and 62 production units have been formed in the field. Field production peaked in 1971 in this field and gas production peaked in 1975 (figure 30). Production in the field is currently declining slightly.

The Schwing sand was the discovery sand has been continuously produced. During its life time, various units have been created for this sand, and several fault blocks have been produced. Figure 31 shows a subsurface map of one unit in the Schwing sand. Note that the fault blocks to north, east and south also produce from this sand but are in different units. Substantial amounts of information are available about this unit because the operator, Mobil Exploration and Production, planned to steam flood this sand. This sand has original bottomhole pressure of 750 psi (5151 kp) and is currently being water flooded. The sand has a porosity of 32% and permeability ranges from 500 to 4000 md. Because of the low gravity of the oil (17° API) being produced the operator thought that steamflooding of this sand would increase overall recovery. In the original plans recovery would increase for this block from 787,000 bbls to 1,973,000 bbls. The estimate of oil saturation at completion with the steam project is from 15-20 % compared to 50 % without steam injection.

With these figures in mind several new wells were drilled and other wells were worked over in the unit. A steam flood began in 1988 but discontinued in 1991 because of economic factors. Incremental increase in field production can be seen in the field as a whole. Increase in production for this individual unit was from 87,720 bbl of oil in 1989 to 116,509 bbl in 1990 then declining to 112,839 in 1991. The steam injection increased incremental production but was not economical because the additional cost of steam injection was not offset by the increase in production. Current estimates indicate that only 50% of the mobile oil present in the reservoir will be produced; another more economical enhanced recovery method may be tried to recover this oil. Even though steam injection has stopped, current recovery still exceeds that before the project began.

In later years deeper wells were drilled to find additional deeper sands below the Schwing and several additional reservoirs were discovered. The structural configuration for one of these reservoirs the Cib-Haz No. 6 reservoir is shown in figure 32.

Historical Landscape Change

Black and white photography from 1952 and color infrared photography from 1973 and 1990 was interpreted and mapped for the surface area of the Bayou Bleu field. The field covers about 81 million m^2 of surface area. It is assumed that 100% of the area was once wetland, and by 1952, 96% (78 million m^2) of that area remained wetland. Land cover for the Bayou Bleu field is presented in (figure 33-35).

A brief examination of black and white photography from 1941, twelve years after the field discovery, revealed that the field is located in the middle of a cypress swamp with some surrounding marshes. Access to the field is a combination of canals and roads. By this time one main road with two roads connected to it crossed the field. There were also three canals connected to these roads in 1941. These roads and canals were to form the basic infrastructure for development of the field. Shell pads were clearly visible on the 1941 photography, five were located along the main north/south road, and eight along a smaller side road to the east.

By 1952, intense development is clearly visible on the black and white photography. The network of roads and canals to service the area has enlarged, and several small roads leading to production sites are also visible. Some of the land was cleared for operations and a major north/south canal (Superior Canal) was constructed. Of the total 81 million m^2 area in 1952, 6% was already impacted by development in this field (table 15, figure 33).

In 1952, there were several small logging roads and trails on the eastern outskirts of the mapped area. Several of these roads are not visible on later photography, and the vegetation appears to have recovered. In addition, several small roads, which are access roads to well sites, are clearly visible. By 1952, 148,000 m^2 of wetland were converted into oil and gas development facilities, and 2.3 million m^2 were altered in some manner by vegetative change (table 15).

In 1973, additional development was evident by cleared and altered areas. However, the 1973 photography was taken during very high water and much of the central field was saturated and had to be classified as either water or unvegetated land cover (figure 34); therefore, quantitative comparisons with 1952 and 1990 land cover were difficult.

The total wetland area decreased during this time period by more than 3 million m^2. The natural water area increased by 1.4 million m^2 as a result of the high water. All categories of land cover increased during this time period (table 15) at the expense of wetlands or already altered wetlands. Areas with the greatest increase were natural water (as a result of flooding) and agricultural development. Human-made water bodies (canals) increased by 98,000 m^2; no vegetation and altered vegetation areas increased by 517 and 356 thousand m^2, respectively.

The infrastructure has increased since 1956. Several new roads and canals were constructed in the northern section of the field. Some new development also occurred in the southern section of the field. Most of the access routes to development in 1952 were extended to accommodate additional development of the field during this period.

By 1990 most of the roads and canals were in place. There appears to be five areas where canals were extended since 1973. There are also several areas where roads, canals, and production areas were overgrown by vegetation. These are areas designated as altered vegetation in figure 35. Some streams are not easily discernible on the photos, and there are several new canals. In some areas the roads are revegetated, and therefore, the road is difficult to distinguish. Some of the older platform areas have become overgrown with vegetation resulting in an increase in altered vegetation and decrease in the no vegetation land cover classification (table 15 and figure 35). These areas are easily discernible because of texture changes and color changes. Several new canals and roads occur in the area but were too small to map at the scale used in this study.

Differences between 1973 and 1990 occurred mainly in a decrease in natural water and non vegetated areas (table 15 and figure 35). Human-made water bodies increased by 319 thousand m^2 and altered vegetation and oil and gas development increased by 370 and 385 thousand m^2 since 1973 while no vegetation decreased by 436 thousand m^2. Much of this change can be attributed to the differences in land cover classification during a high water event (1973) and a dry year (1990). In addition, some of these changes are due to revegetation of impacted areas and to new development.

The area is also characterized by several areas of altered wetlands that were not mapped. Small access roads to well or drill sites are evident. These areas are typically surrounded by altered vegetation sites. Because the Bayou Bleu field is not adjacent to other significant industrial/residential development, and all roads and canals lead to production sites changes that have occurred in the wetlands surrounding the Bayou Bleu field are primarily a result of oil and gas activity there.

of oil and gas activity there.

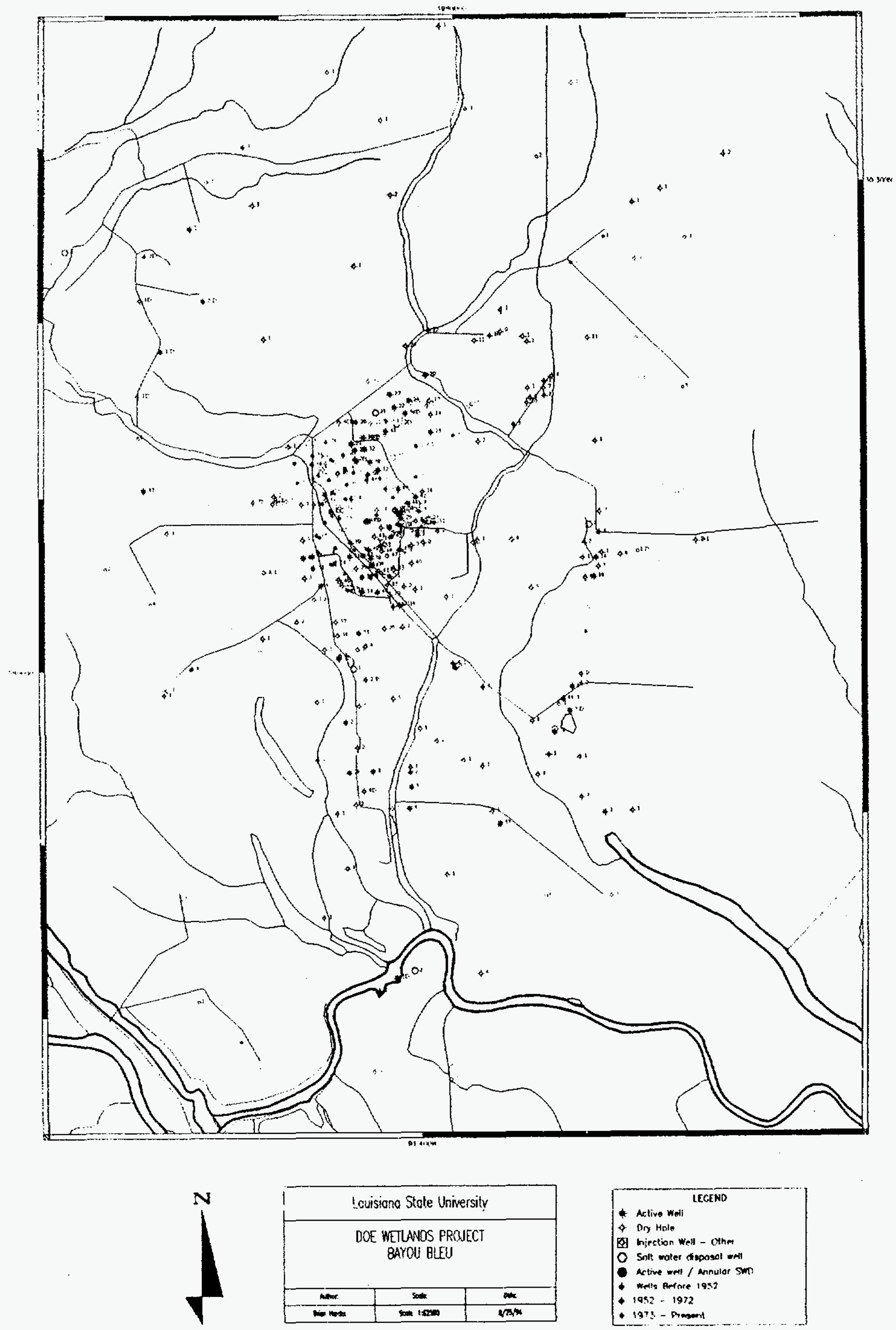

Figure 29. Surface map of Bayou Bleu field.

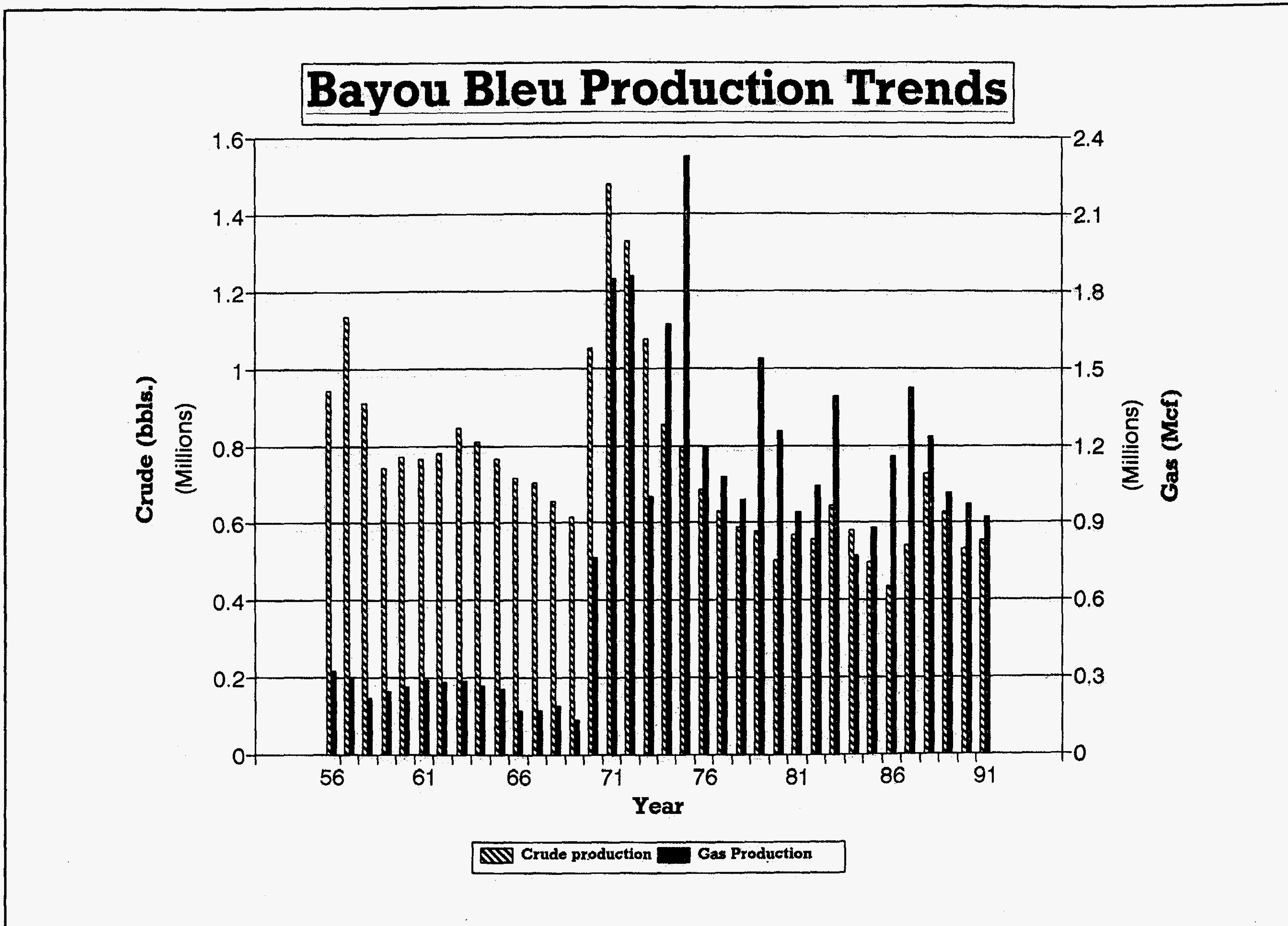

Figure 30. Bayou Bleu production trends 1956 - 1991.

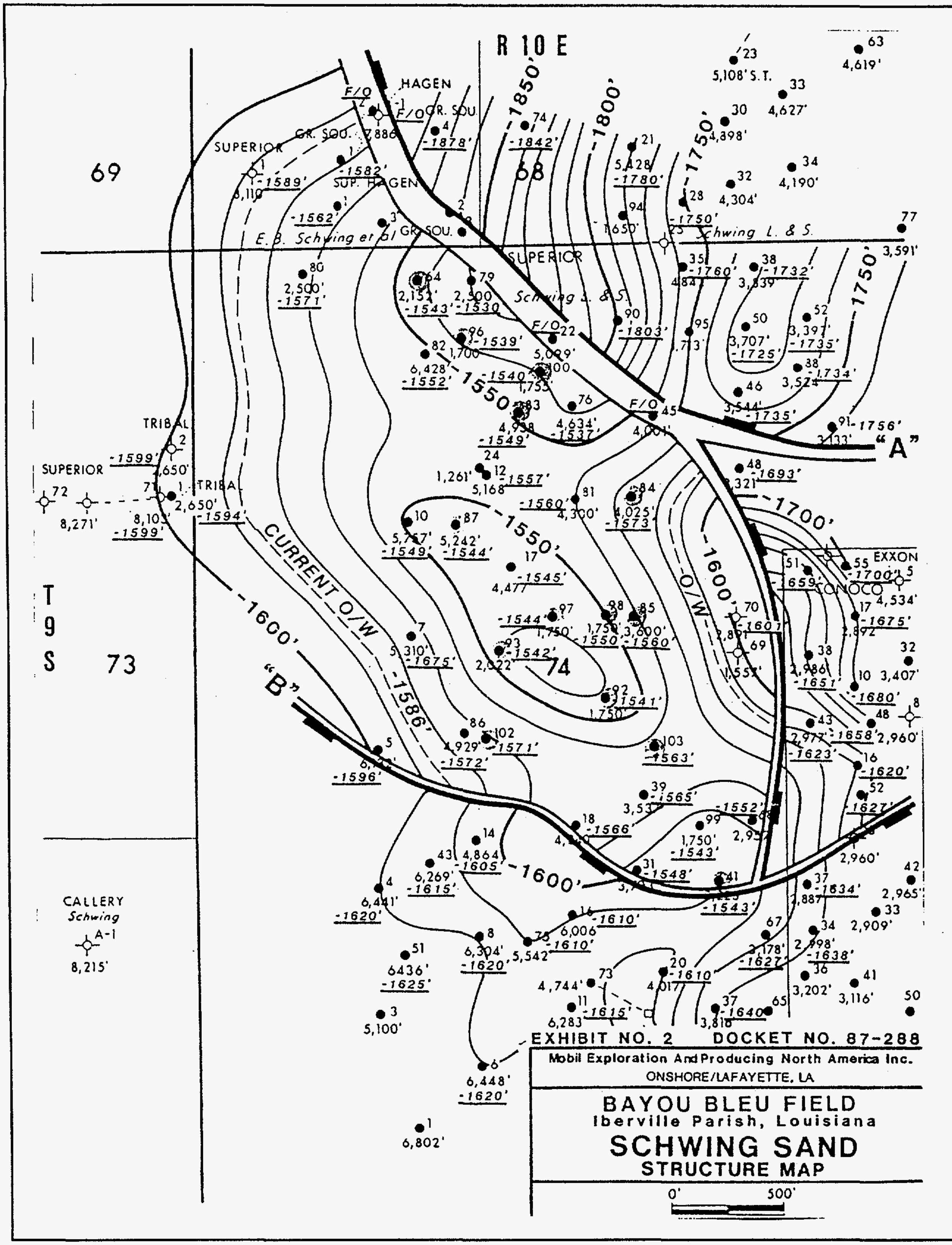

Figure 31. Subsurface map of one of Schwing sand unit Bayou Bleu field. (Louisiana Department of Natural Resources, Office of Conservation Hearing files Docket 87-288)

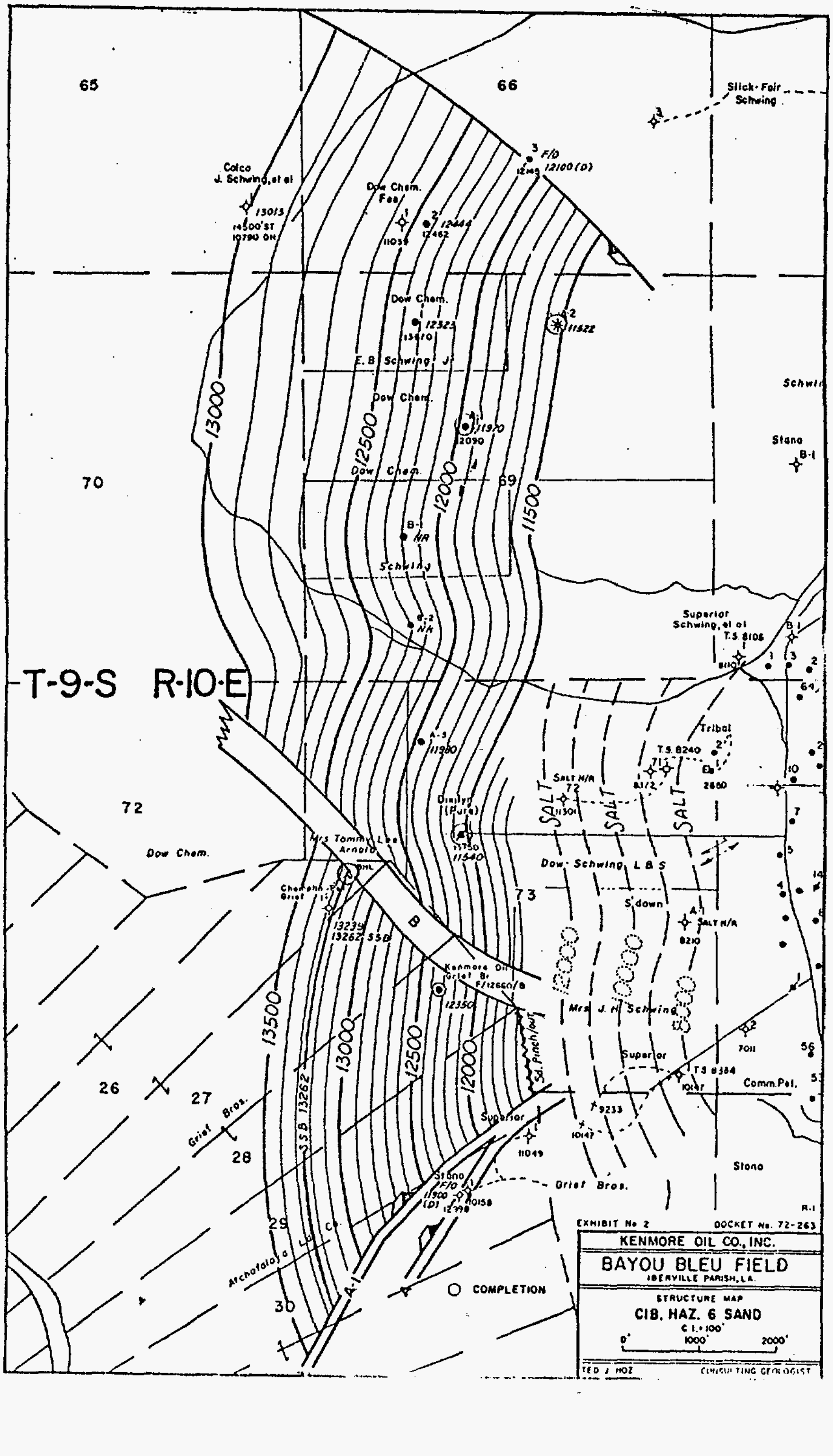

Figure 32. Subsurface structure map of Cib-Haz No. 6 sand Bayou Bleu field. (Louisiana Department of Natural Resources, Office of Conservation Hearing files Docket 72-263)

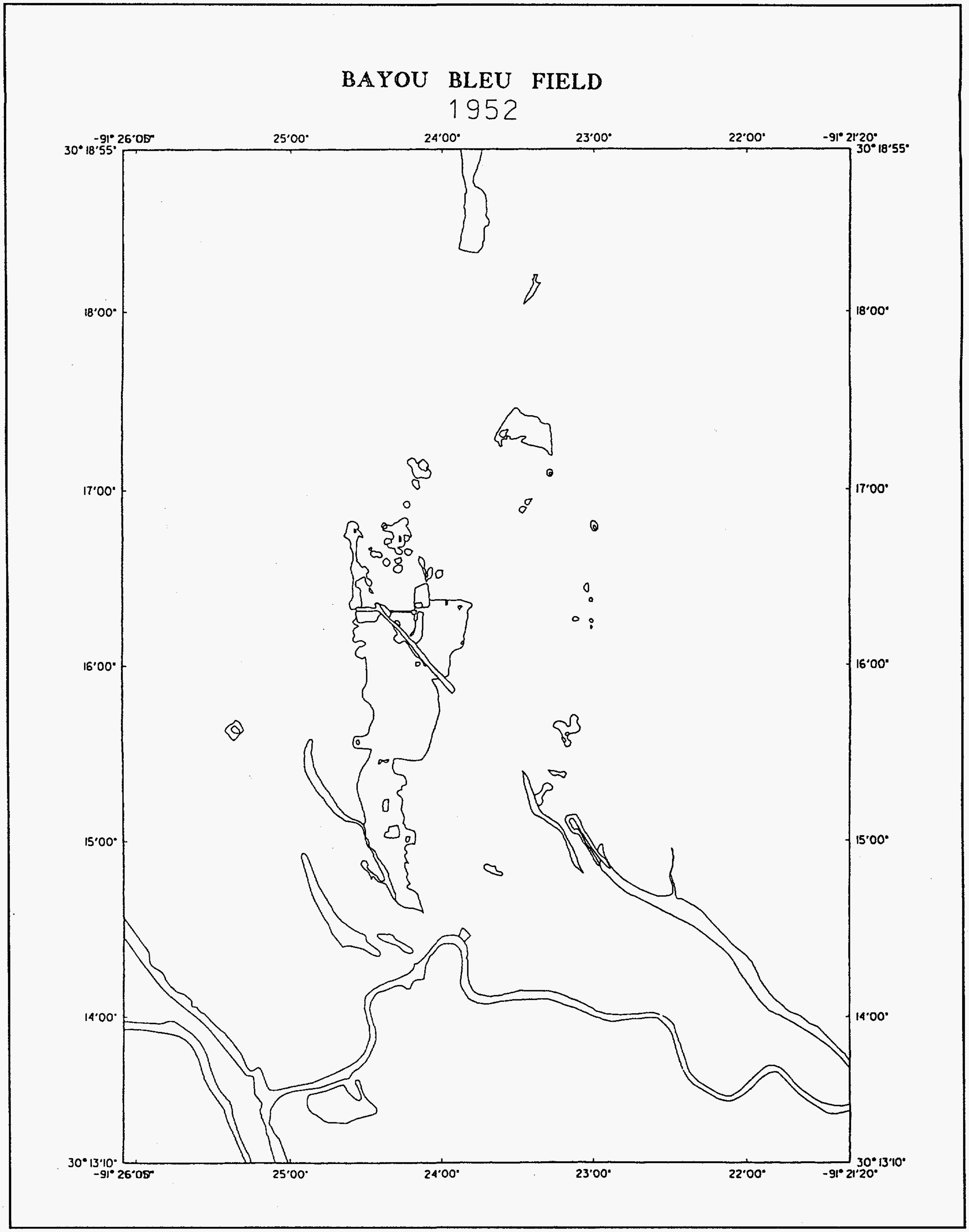

Figure 33. Land cover map for Bayou Bleu oil field in 1952.

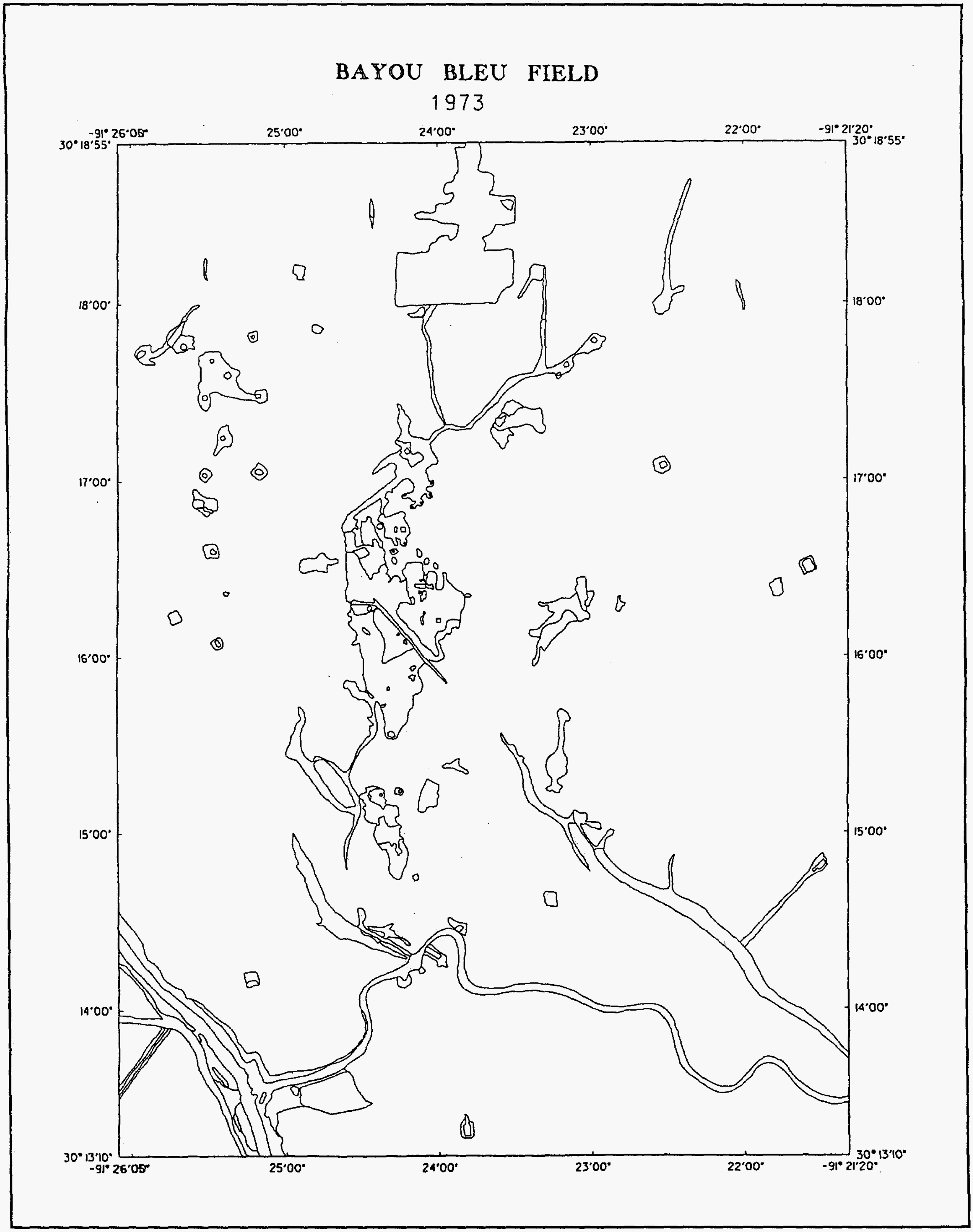

Figure 34. Land cover map for Bayou Bleu oil field 1973.

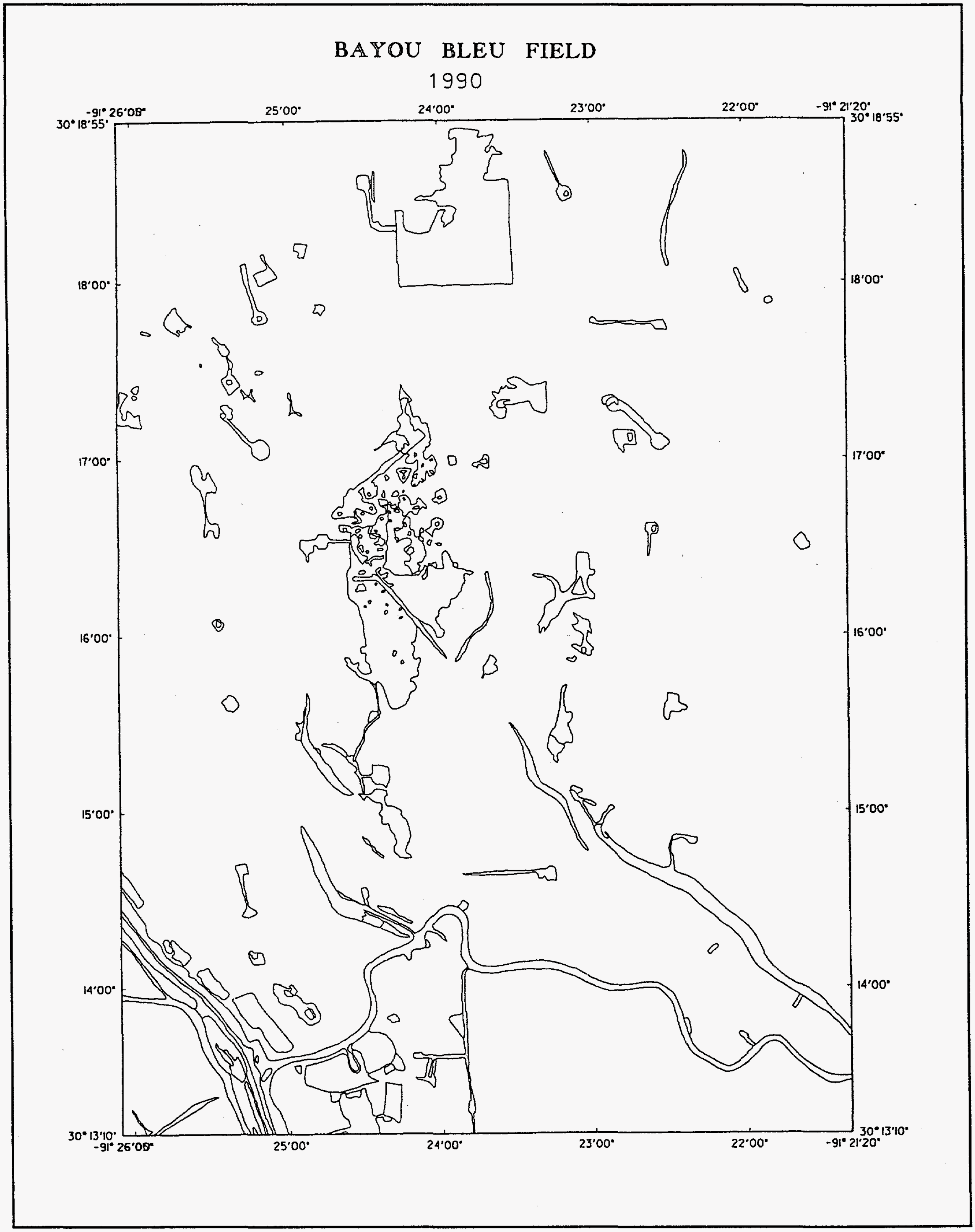

Figure 35. Land cover map for Bayou Bleu oil field 1990.

Table 15. Land cover area for Bayou Bleu 1952, 1973, 1990 in square meters.

LAND COVER	1952	1973	1990
Wetland	76,148,317	72,718,930	72,742,872
No vegetation	0	517,415	81,557
Altered vegetation	2,299,444	2,655,635	3,025,971
Impacted/ industry	147,558	161,786	547,038
Water			
Natural	1,840,860	3,283,978	1,827,622
Human made	280,739	378,807	698,039
Agricultural/ developed	215,050	1,215,916	1,304,152

Fields

The Fields field is located west of Bear Head Creek near Fields, Louisiana, in the southwestern part of the state in Beauregard Parish. It is located in a fresh area and probably supports bottomland hardwood forest. Fields is not located within Louisiana's coastal zone boundary. Fields is an anticlinal reservoir structure discovered in 1943, whose original wells targeted the Cockfield Formation and in this process discovered a deeper sand the Fields sand, which named the field. A series of producing reservoirs beginning at a depth of 7,500 ft (2,286 m) and continuing until 10,800 ft (3,292 m) have been discovered by the 60 wells drilled in the field. At present 18 LUW codes have been issued for productive sand blocks, and 7 producing horizons were found. The field has produced almost 36 BCF of gas and 7 million bbl of oil (table 13). The historical production curves (figure 36) show classic retrograde reservoir behavior for the different individual reservoirs with production peaking rapidly and a drastic fall off after the peak as reservoir energy and pressure decreases. Production in this field is currently in decline.

The color coded map of surface locations (figure 37) shows that the original wells were drilled to the Fields sand in a rectangular pattern. This was a standard pattern of development on a 40-acres (99 hectare) spacing used to develop oil fields at that time.

A structure map of the Fields field showing the eight original development wells set in this pattern (figure 38). The wells to the southeast on the other high were drilled later and into the Cockfield, Lower Cockfield, and Fields Sands. From the original development wells, additional wells were drilled on the flanks to delineate the extent of the reservoir.

The Fields sand was an oil producer with limited gas production. The Cockfield, Lower Cockfield, and Fields sands are now depleted and have no current production. The Fields field is not a candidate for additional development, although, 50% of the original reserves may still be present. Because of the type of reservoir (retrograde gas condensate) wells were initially placed to maximize recovery from this reservoir.

The Wilcox "B" sand was discovered in 1966 (figure 39). The Wilcox "B" sand had an initial reservoir pressure of 7,392 psi (50.96 x 10^3 kp) and the original oil in place (OOIP) was estimated at 6.5 million barrels of condensate. The Wilcox "B" is the most prolific reservoir in the field. The production curve shows this reservoir to be retrograde in nature behavior with production peaking in 1969 and later gas breakthrough in 1980.

Faulting has formed three large anticlinal gas capped reservoirs. These deeper horizons were developed using a minimum of wells because of the types of reservoirs present. The northern reservoirs are water drives while the southern is a retrograde gas-condensate reservoir. There are several directional wells that were drilled to develop the water-drive reservoirs. These directional wells were used to improve reservoir position not for environmental reasons. Upward thinning of the sands and reservoir geometry were the criteria used to select the wells that location of the seven productive wells that were drilled for the southern Wilcox "B" unit. The higher wells were converted to injection wells in 1968 and gas was injected to stabilize reservoir pressure and prevent retrograde behavior and premature depletion.

Early development wells were placed where convenient as this field was not located in an area classified as wetlands until 1987. Before that time it was considered as uplands and not subject to wetland regulations. Board roads were used to develop the field. Drainage patterns were altered by these road dumps, and these were not restored after operations but were left in place.

Development of this type of field under current wetland rules would be much different with the upper sands of the Fields and the Cockfield being drilled from locations determined by the need for injection wells to prevent retrograde behavior. One or two injection sites may be developed in wetlands, depending on individual reservoir geometry. Producing and flank wells could be drilled using directional techniques from injection well pads or from non-wet sites outside the wetland areas. Field development of these reservoirs today could be done in most cases from existing non-wet sites. Careful planning would minimize surface effects. Roads would be restored to pre-project conditions after operations.

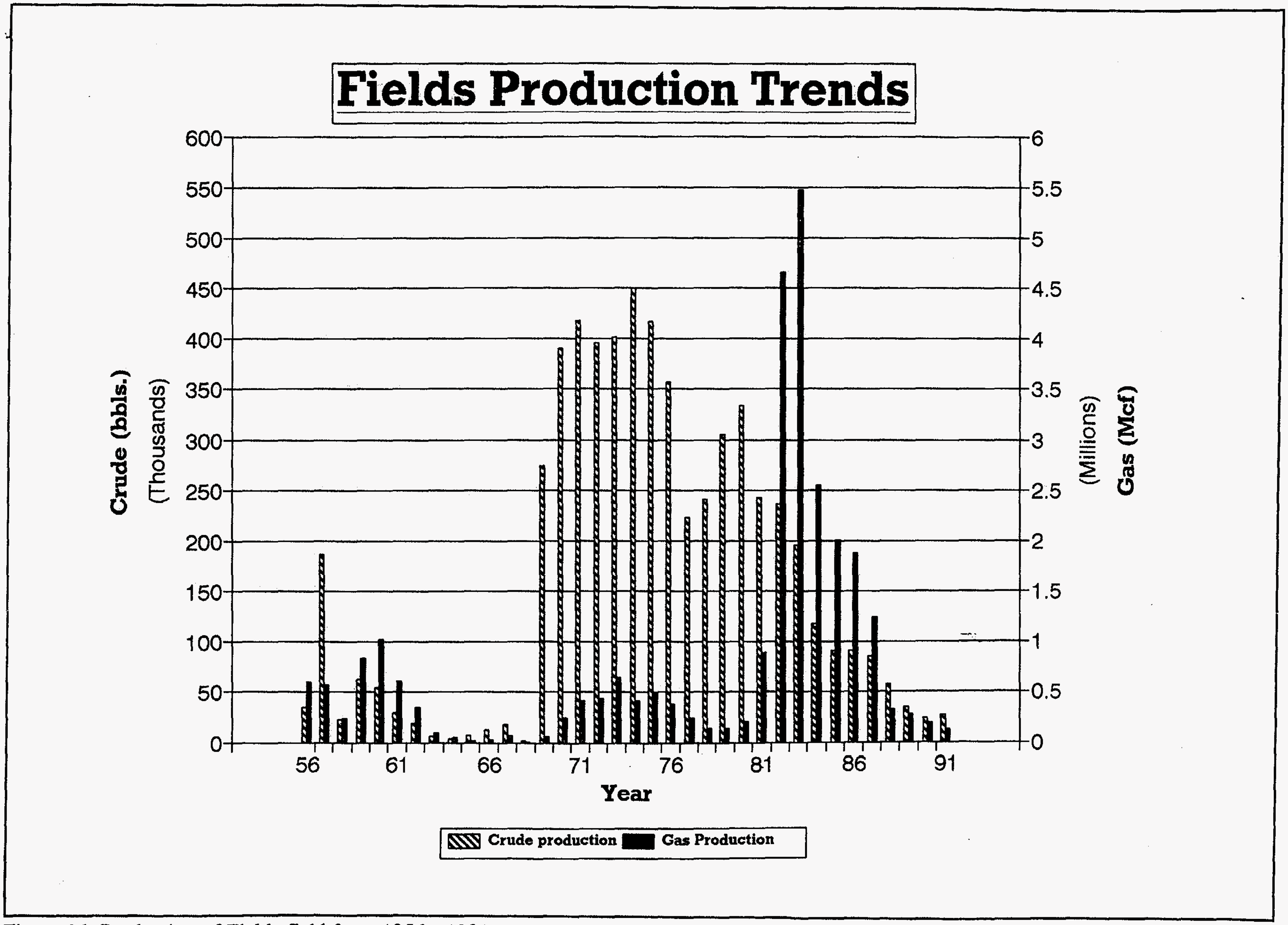

Figure 36. Production of Fields field from 1956 - 1991.

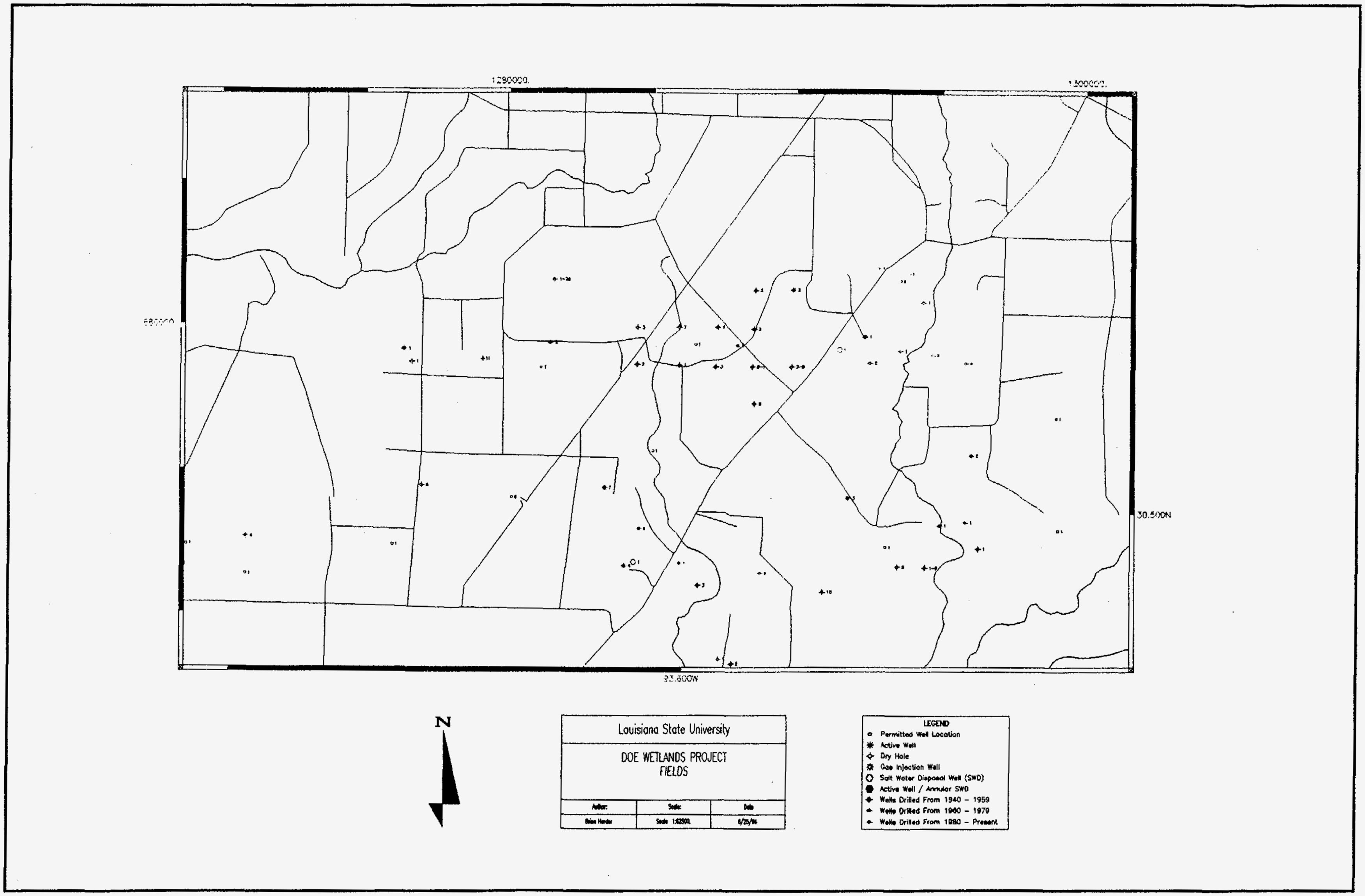

Figure 37. Surface map of Fields field color coded by discovery date.

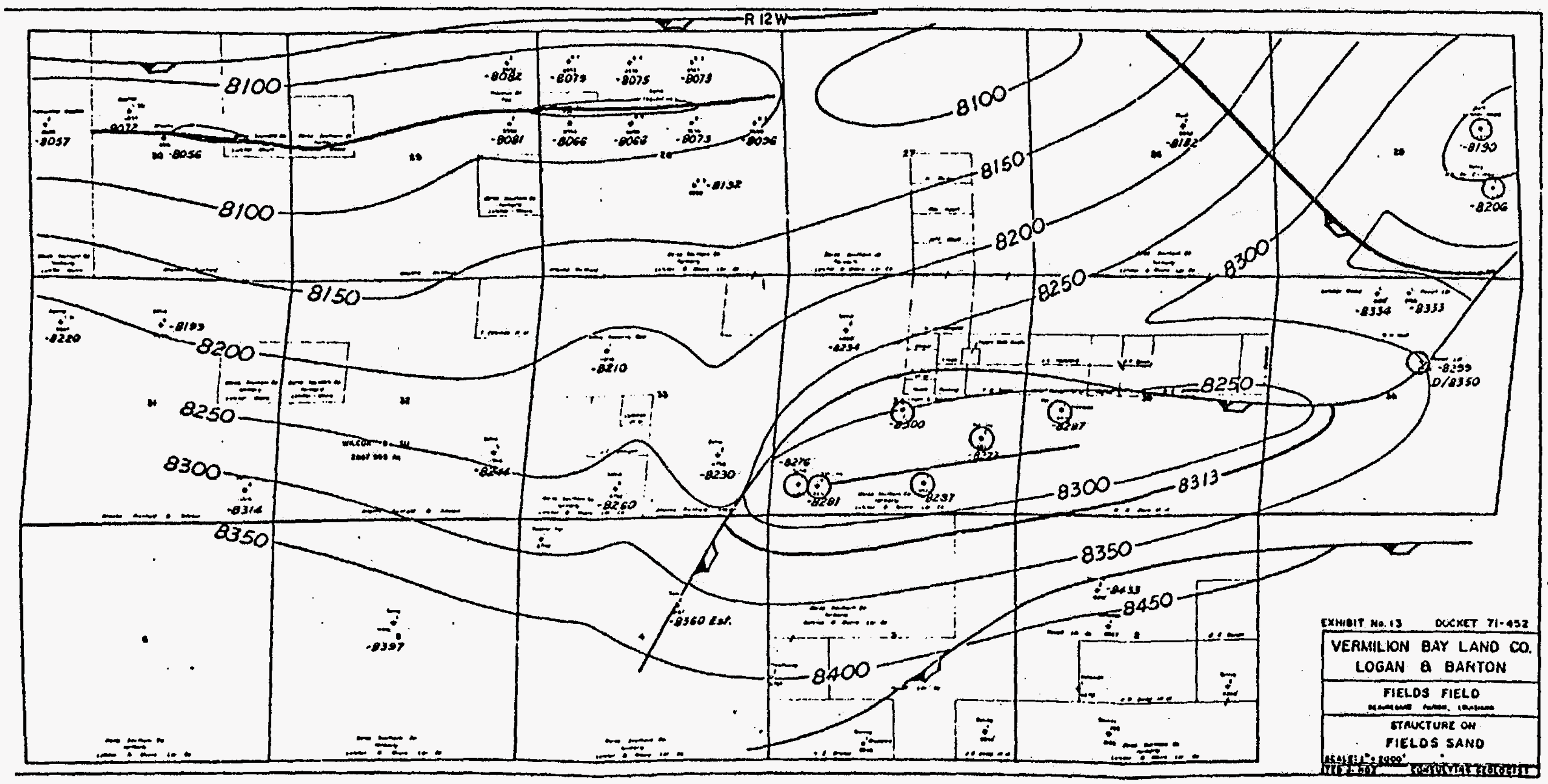

Figure 38. Subsurface map of the Fields sand. (Louisiana Department of Natural Resources, Office of Conservation Hearing files Docket 71-452)

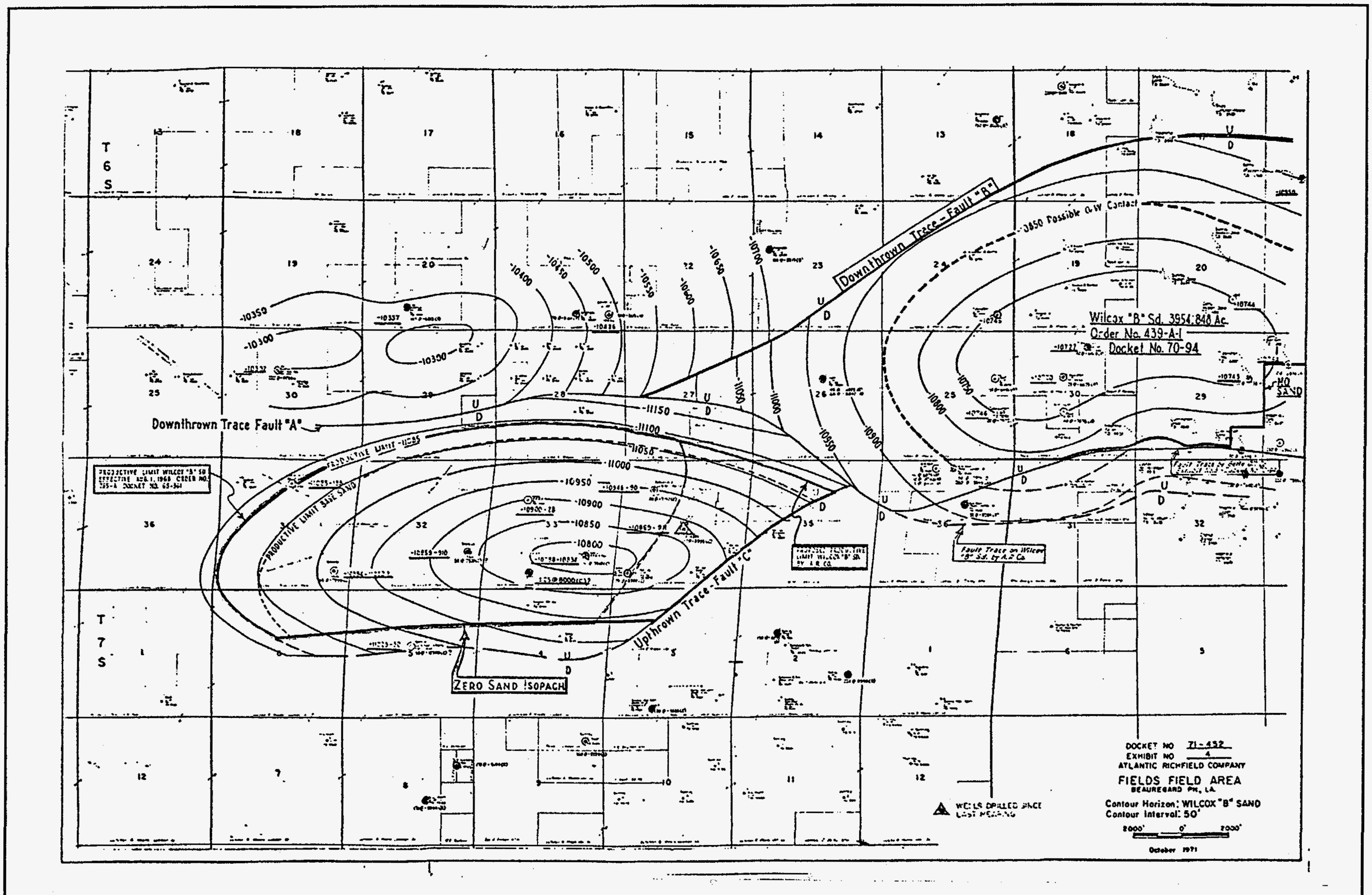

Figure 39. Structure map of Wilcox "B" formation Fields field. (Louisiana Department of Natural Resources, Office of Conservation Hearing files Docket 71-452)

Fordoche

The Fordoche field lies just east of the Atchafalaya River in south central Louisiana near Fordoche in Point Coupe Parish. It is located mostly in a upland. However the field extends into a mixed cypress swamp and bottomland hardwood forest in the northern reaches of the Atchafalaya Basin is not within Louisiana's coastal zone boundary. The field was discovered in 1949 and is made up of a series of shallow, dipping anticlinal reservoirs bounded by a growth faults to the north. The field has produced more than 280 BCF of gas and almost 59 million bbl of oil (table 13). At present 208 wells have been drilled and the Office of Conservation has formed 88 producing units from 24 producing horizons found. The reservoirs present were subject to retrograde behavior; although, partial water drives exist for some of the reservoirs. Gas production in the field peaked 1969 with oil production peaking a year later (figure 40).

The 8,000 ft (2,438 m) sand was the original sand discovered in 1949 with field-wide development of this and other sands occurring rapidly in the early 1950's. A series of parallel roads were used for development and can clearly be seen in the surface map of well locations (figure 41). The structure map of the "J" sand (figure 42) is representative of the structure present in the upper sands of the field. The dark blue wells on the surface map show the rapid development of the field and the subsurface map of the "J" mirrors this development. These upper sands are partial water-drive retrograde gas reservoirs and pressure maintenance operations were developed early on for these sands. Initial pressure maintenance began in the late 1950's and early 1960's for most of the reservoirs.

Development proceeded south with the discovery of the Sparta and Wilcox formations to the south and east in 1966. Development of these sands began in the late 1960s on 160 acre spacing with 36 wells drilled in the initial four year development. Eight reservoirs were encountered from 11,300 to 13,900 ft (3,444 to 4,237 m). The Sparta sands are undersaturated oil reservoirs. The Wilcox 3, 4, and 5 (W-3,W-4,W-5) are retrograde gas-condensate reservoirs and the W-8, W-12, and W-15 are undersaturated volatile oil reservoirs. The W-8 sand structure is representative of all the Wilcox sands found in the field (figure 43).

The production trend for the field showed a classic decline for oil and gas production until the mid-1980s, when the Sparta "B" sand was found productive. Rapid decline and rates of pressure depletion was typical of all the Wilcox sands. Primary recovery for the Wilcox was placed at 26 to 36% of original oil in place for the oil reservoirs and condensate recovery rates were predicted at from 19 to 25%. Gas injection proposals using nitrogen and natural gas were used to raise recovery ratios to 47–54% for oil and from 30–46% for the gas reservoirs (Eckles 1981). Gas cycling and injection projects were initiated on the Wilcox sands. No additional well locations were used for the projects. Although Sparta "B " production rose field wide crude production decline was slowed by gas cycling, the overall trend was in decline. Production increased slightly in 1987 and has since slowly declined. Oil production again declined as blowdown of the Sparta "B" sands began in 1988. This increased gas production will deplete as reservoir energy declines.

Since the discovery of the Sparta "B" sands additional sands were found productive to the east of the original discovery in the Cockfield and Frio formations from 9,000 to 9,400 ft (2,743 to 2,865 m). These sands were developed and began production in early 1991. This new production has increased field-wide crude production slightly. Production of the field will again increase because additional wells in to the Frio are currently being drilled.

This development will be using existing locations and directional drilling to reduce environmental damage. All the wells drilled that might affect wetland areas have been directionally drilled since 1990. Future development is trending off to the southeast and will mostly be in wetter areas.

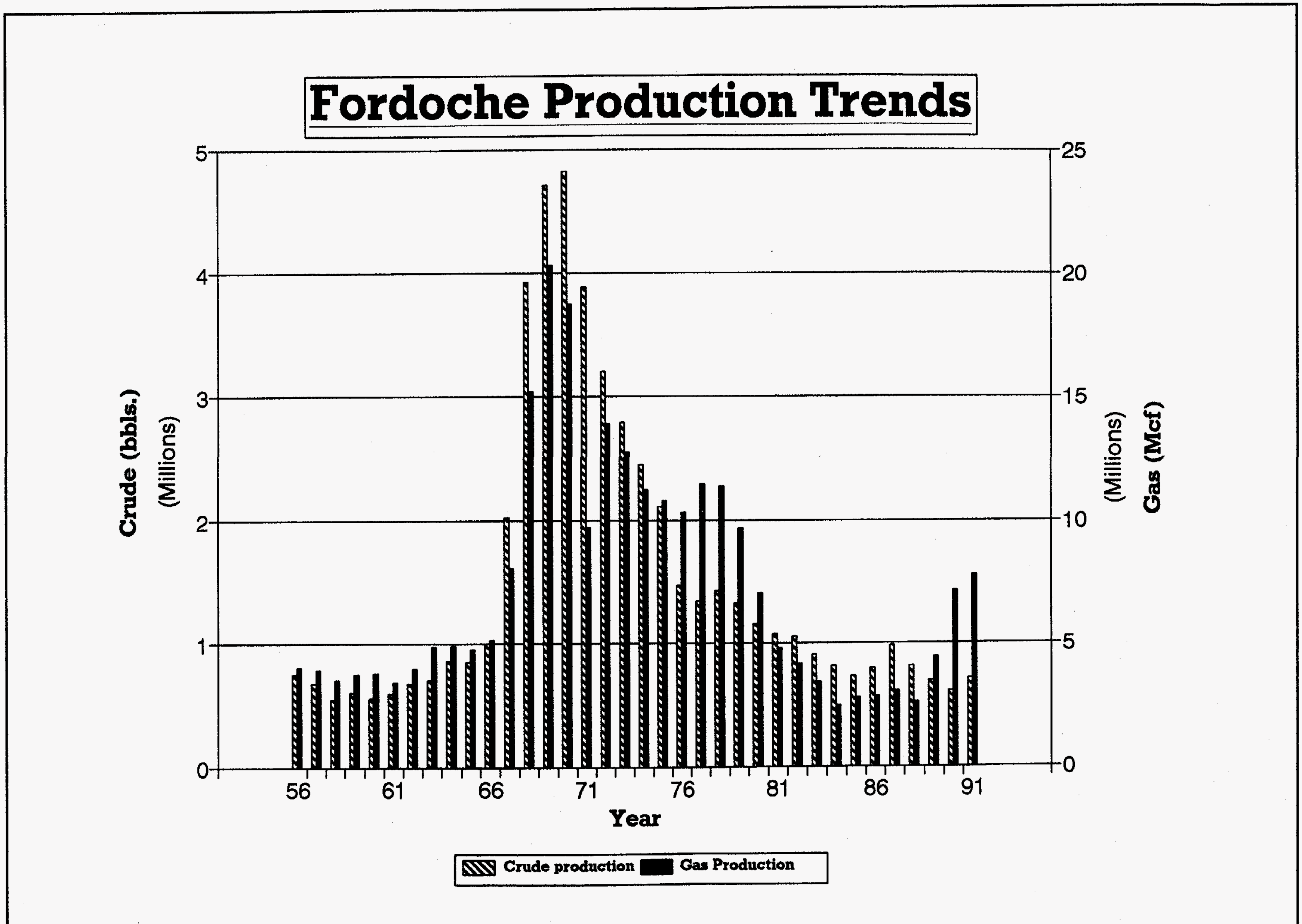

Figure 40. Field production for Fordoche field 1956-1991.

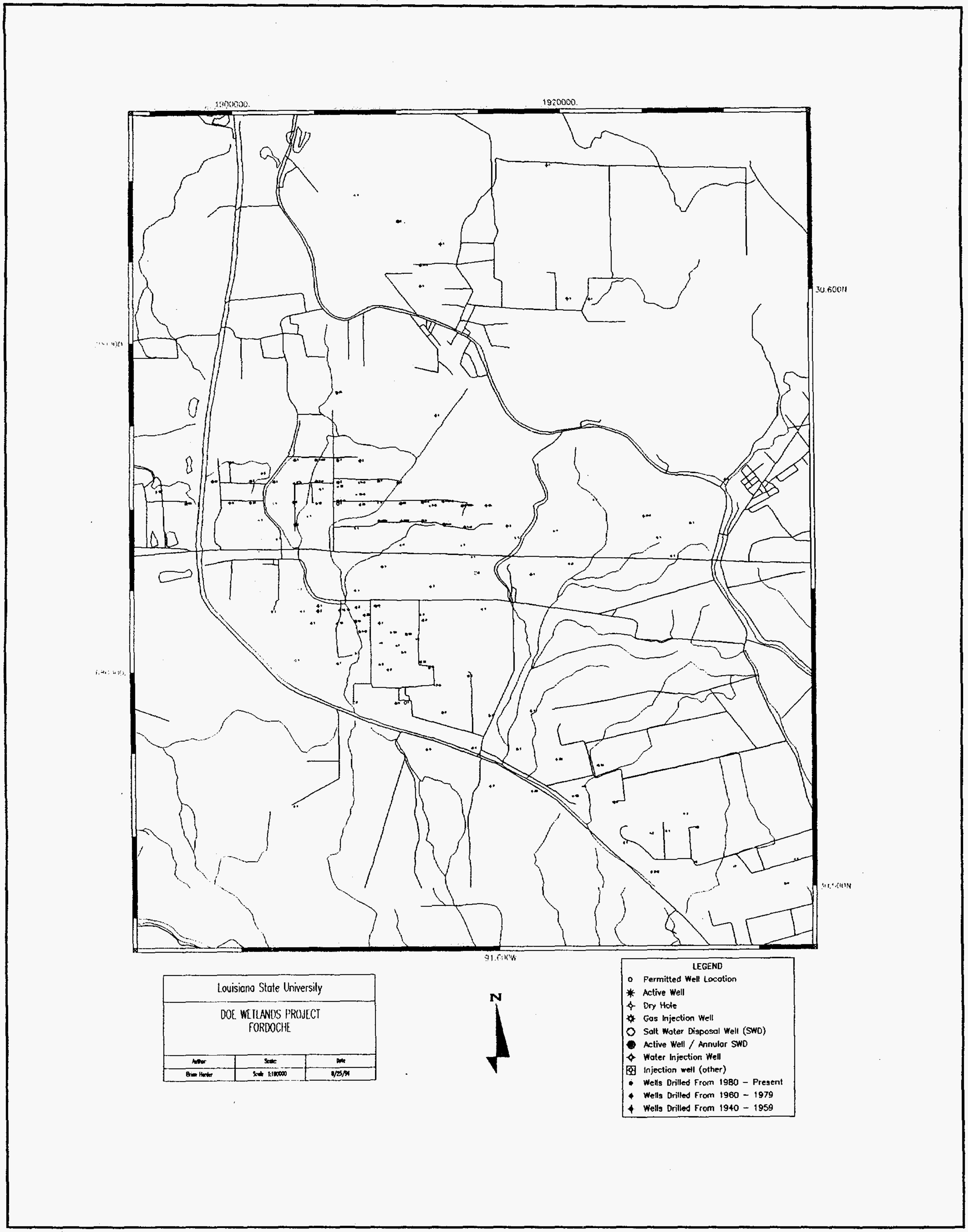

Figure 41. Surface map of Fordoche field development.

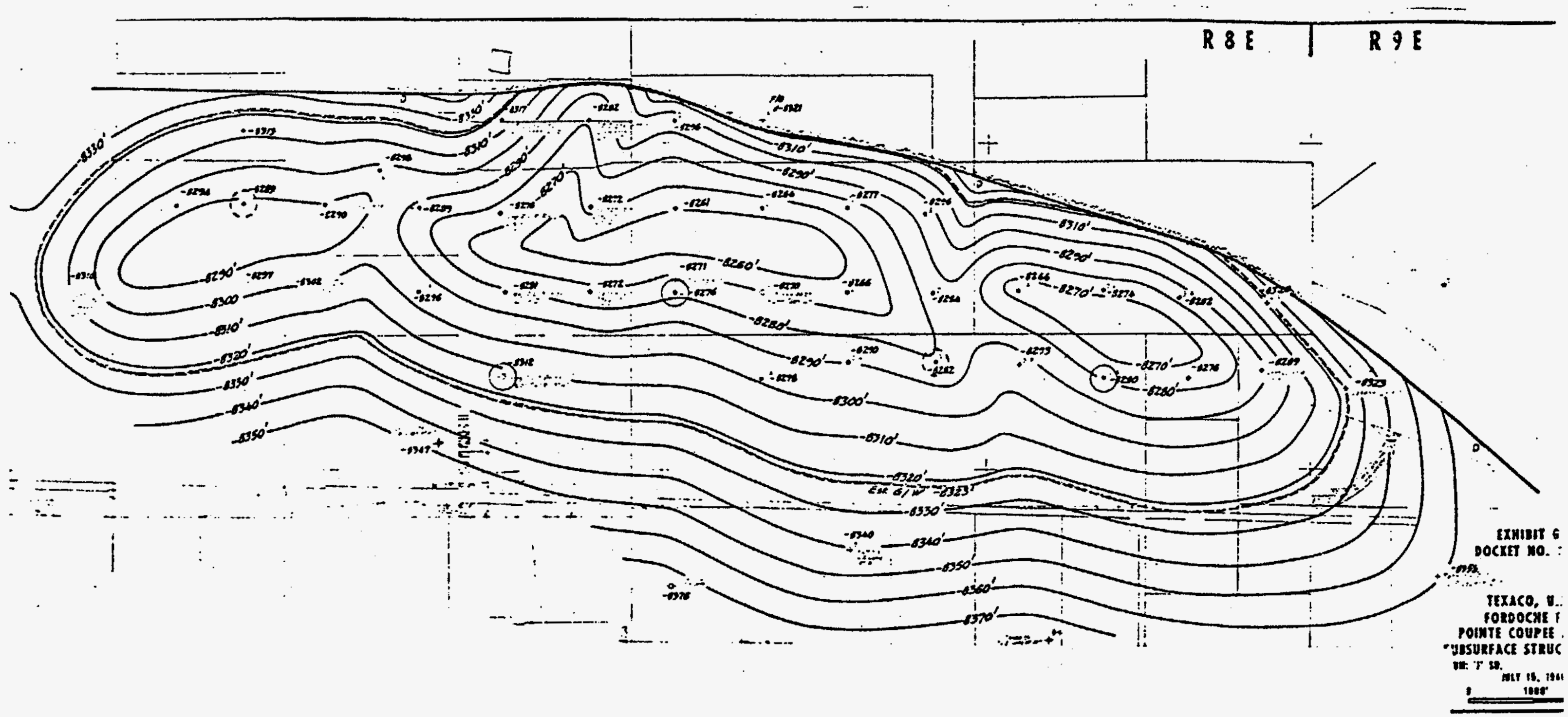

Figure 42. Subsurface of "J" sand Fordoche field. (Louisiana Department of Natural Resources, Office of Conservation Hearing files Docket 76-617)

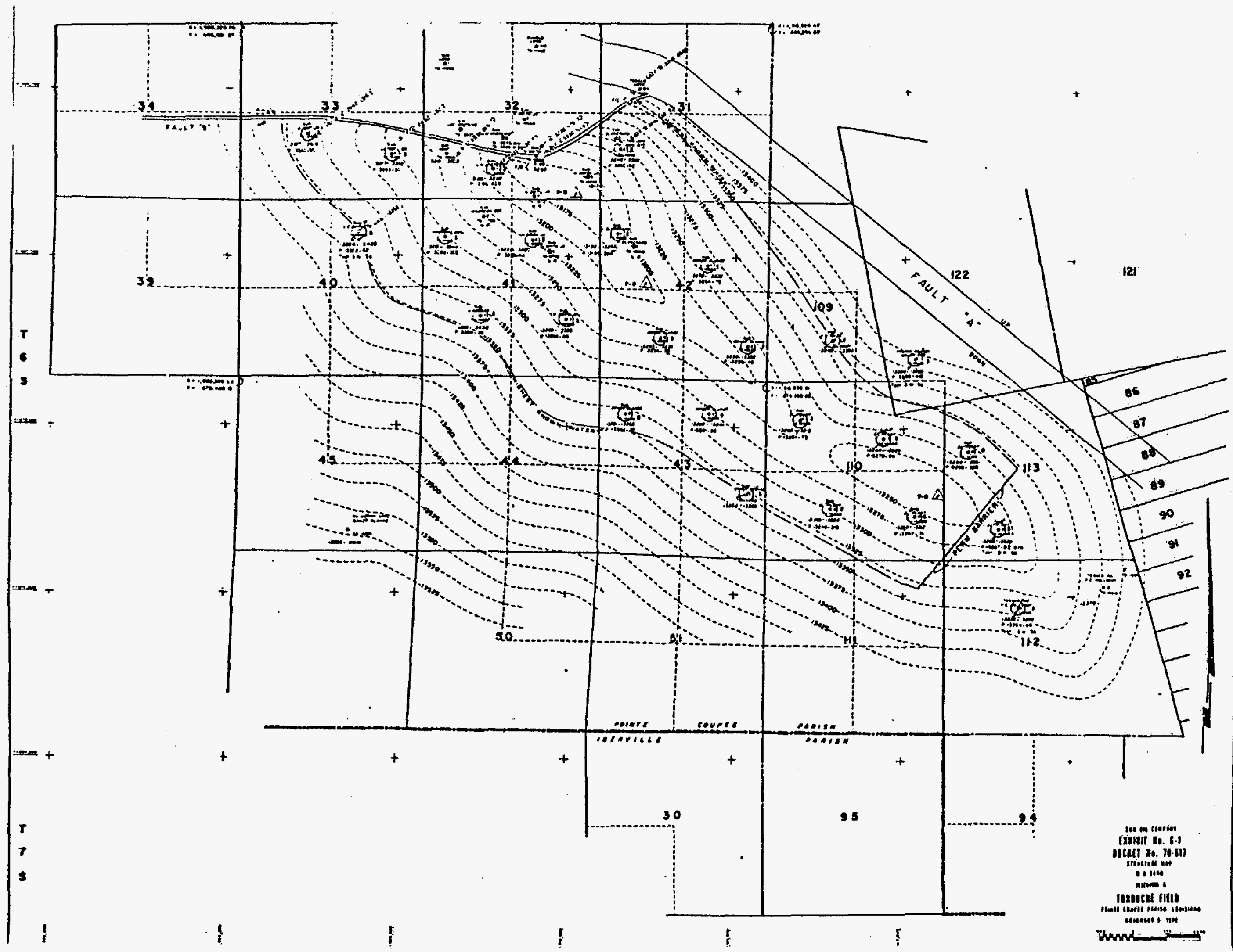

Figure 43. Subsurface map of W-8 sand Fordoche field (Louisiana Department of Natural Resources, Office of Conservation Hearing files Docket 76-617)

Jeanerette

The Jeanerette field, discovered in 1935 by Herton Oil Company, is located in south central Louisiana in Saint Mary Parish. The field crosses Bayou Teche just south of Lake Fausse Pointe and west of Grand Lake in the Atchafalaya Basin. Jeanerette is located within the boundaries of Louisiana's coastal zone in a freshwater swamp. Less than half the field is located in a cypress tupelo swamp. The remaining area is completely developed primarily for agriculture with some industry and residential development. The field has produced more than 527 BCF of gas and 47 million barrels of oil since 1936 (table 13). The Office of Conservation has recorded 362 wells in this field as of January 1992. The field produces from 18 recognized sand packages, and 126 units have been created in the field. This fields crude production rate peaked in 1938 (figure 44), and gas production rates peaked in 1964 (figure 45). Initial field production was mostly oil with little gas production until 1954. Fieldwide production rates for oil and gas rose until the mid 1960s when rates began to decline.

Surface map of the field is shown in figure 46. The field is a deep seated salt dome with numerous producing reservoirs found between various upthrown and downthrown fault blocks (Dobie 1970). The original producing sands were found from 6,200 to 7,200 ft (1,890 and 2,194 m) and consisted of the "R" and "Q" sands.

The "Q" sand has produced from eight distinct fault blocks as shown in figure 47, which is a structure map of the existing "Q" sands (Dobie 1970). Production in the various fault blocks has proceeded over time. These reservoirs are natural water drives with estimated recoveries exceeding 60% OOIP. Most of these sands have produced for thirty to forty years. In the mid 1980s carbon dioxide (CO_2) injection using the "huff-puff" injection technique were started to increase overall recovery. Other projects are currently planned using this technique. The huff-puff technique is a simple method to increase recovery. Carbon dioxide is an immiscible fluid injected through a producing well into a reservoir until the sand is saturated. Then the well is placed on production and the CO_2–saturated oil is produced increasing recovery by an additional 10% of OOIP. Surface facilities for this type of enhanced recovery technique are minimal consisting of a holding tank for the CO_2, a heater to raise the gas temperature to atmospheric ranges, and a pump to raise the pressure for injection in the well. No additional separation equipment or well locations are necessary for this type of enhanced recovery technique. The environmental effects of this type of operation are minimal consisting of a small area or platform for the equipment.

Additional sands were subsequently found in the Jeanerette field with additional production in the Siphonina davisi and Planulina sections found from 10,800 to 14,500 ft (3,292 to 4,420 m). Various sand reservoirs are fault separated and productive in upthrown and downthrown blocks. Figure 48 is a field-wide map of the top of the Siphonina davisi sand and is representative of the structure present for this and the other deeper sands. Additional production was found in the Abbeville section and numerous wells have been drilled to the deeper horizons since 1978.

Field-wide production declined until 1985 when the first huff-puff enhanced recovery operations were begun, and the deep Abbeville sands were discovered to be productive. Production is currently rising as additional wells have been added to the field and additional enhanced recovery projects have begun. This field is an excellent candidate for additional enhanced recovery and in-fill drilling projects. Because of its concentrated development pattern additional environmental effects should be limited. Flank wells should be directionally drilled from existing locations, and additional surface facilities need to be restricted to previously impacted areas. Coiled tubing operations or drilling will be very effective in this field.

Historical Landscape Change

Landscape characteristics and land cover of the Jeanerette field were mapped from photo interpreted black and white photography from 1956 and color-infrared photography (CIR) from 1978 and 1989. The field covers more than 183 million m^2 of surface area. In 1956, 60% (111 million m^2) of that area was either developed uplands or agricultural land cover. Most of the remaining area encompassed forested wetlands and water from Lake Fausse Pointe. A brief examination of black and white photography from 1940 five years after the field discovery revealed a similar pattern of development in the area.

Land cover for the Jeanerette field is presented in figures 49–51. Most of the areas depicted on the map as impacted areas (no vegetation, altered vegetation, impacted/industry, and human-made water) represent those areas that could be easily mapped at a scale of 1:24,000. Smaller areas were not mapped however, examination of the photography will discuss altered features such as small roads and canals that were too small to map for polygon analysis. In addition, slight changes in vegetation such as a decrease in vegetative cover or density seen by color or texture changes are not depicted on these maps. The general category of wetland refers to natural areas and all other categories with vegetation are generally altered wetlands. These areas represent either direct impacts, a change due to perturbation, or recovery from perturbation.

It appears that most of the oil and gas activity in the Jeanerette field has occurred in the areas labeled agricultural/developed. There was no attempt to map the well site and roads to them in this developed area because it is not classified as wetlands.

The earliest photography available for the area was black and white photography from the Department of Agriculture in November of 1940. In 1940, the boundary between the agricultural/developed area and the wetlands is similar to the 1956 boundary. From the available photography, it is apparent that a large portion of the area was developed for agricultural and residential purposes before 1940. The wetland area is composed primarily of a mixed cypress swamp and is located in the northern section of the field. This area is semi-permanently flooded. The landscape analysis with respect to oil and gas activities will be focused on in this area.

Some oil and gas activity in the wetland is apparent in 1940 because a canal south from Lake Fausse Pointe cuts halfway through it. In addition, a north/south road, which originates in the agricultural area, cuts through the swamp on the western side. This road is visible throughout the series of photographs. There are no large shell pads or key hole slips apparent along these features in 1940. Another short road into the swamp is also present on the mideastern side. A small, shell well site is visible at the end of this road. Other distinctive features in this photography are several dendritic roads in the middle of the swamp to the east. These roads are not visible in 1956 and are assumed to be logging roads.

In 1956 eight production sites are visible in the swamp and most are connected to what appears to be either a permanent road or canal. Most of the roads and canals in this area were too small to map for calculating area; however, several are visible. There is altered vegetation in the lower section of the wetland that appears to be a large, cleared grass area surrounding a well site in the middle of swamp. Access to well sites in this field is a combination of roads and canals.

Some slight changes in color and texture are discernible on the western side of the swamp indicating a difference in habitat. The National Wetlands Inventory maps indicate that these areas have less frequent flooding and contain no cypress, but are composed of broad leaved deciduous trees. These areas of different species composition and flooding regime remain constant throughout the study period and are clearly visible on the 1978 and 1989 photography.

Calculations from the mapping effort show that the surface area of the field encompasses 183 million m^2 (table 16) and that about 29% of the area (53 million m^2) was wetland in 1956 and less than 1% of the wetland area was altered by human activity (figure 49).

By 1978, a major canal was constructed through the southern portion of the wetland. Only the widest section of the canal was mapped. About 13 well sites are visible in 1978 (figure 50). Roads leading to the well sites are more clearly visible than in 1956, and three additional roads were built between 1956 and 1978. One previously existing road is clearly visible and appears enlarged or less vegetated. One additional canal was constructed in this area. There is also an area to the west that appears to be impounded and has a vegetation change from thick forest to sparse trees and bare ground.

In 1989 two additional canals cross the area and a large impounded area separates a part of the swamp from the main wetland by a levee and a canal. It appears that activity in the wetlands surrounding this field is minimal. Most of the altered landscape has occurred along the fringes of the swamp since 1956 (figure 51). Wetland area decreased by 15% here (table 16). Some of this loss is related to oil and gas activities, but most is related to encroaching agricultural development (table 16).

Access to this field is a combination of roads and canals. Canal area almost doubled between 1956 and 1978. It appears that roads were built through drier areas. Some canals and roads were revegetated with different communities as indicated in the photography by color and texture changes.

Between 1956 and 1978, 15% (6 million m^2) of the wetland was lost to development such as conversion to agricultural lands, canals, roads, and oil and gas development (table 16). Most of this development was for agricultural purposes (5 million m^2, table 16). Less than 3% of the wetland area was altered for development of this field.

Changes in the wetlands in this field were minimal because most of the infrastructure developed for this field was located in already existing agricultural or developed lands. Most of the wetland loss between 1952 and 1989 is not solely due to oil and gas activities.

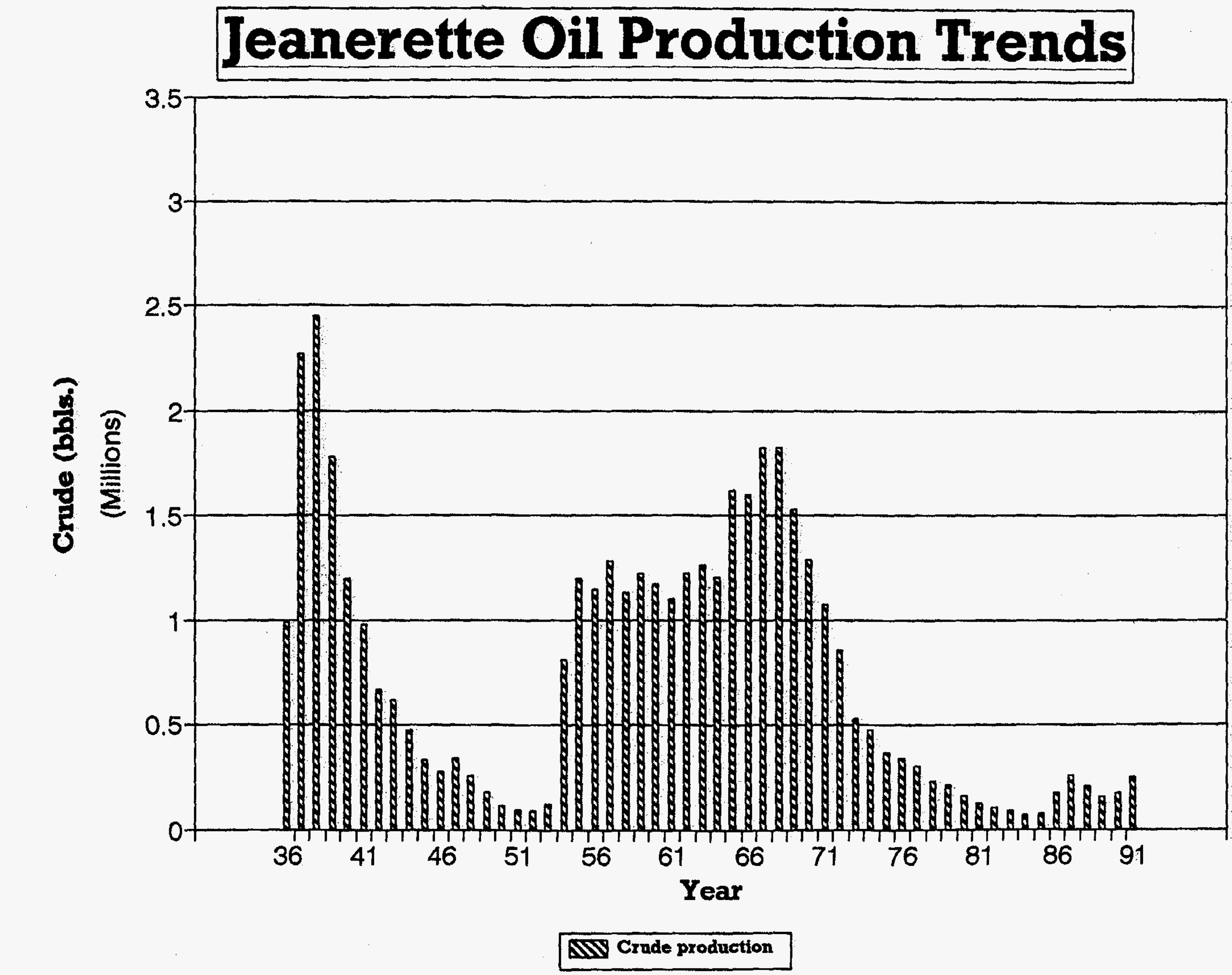

Figure 44. Crude production trends for Jeanerette field 1936 - 1991.

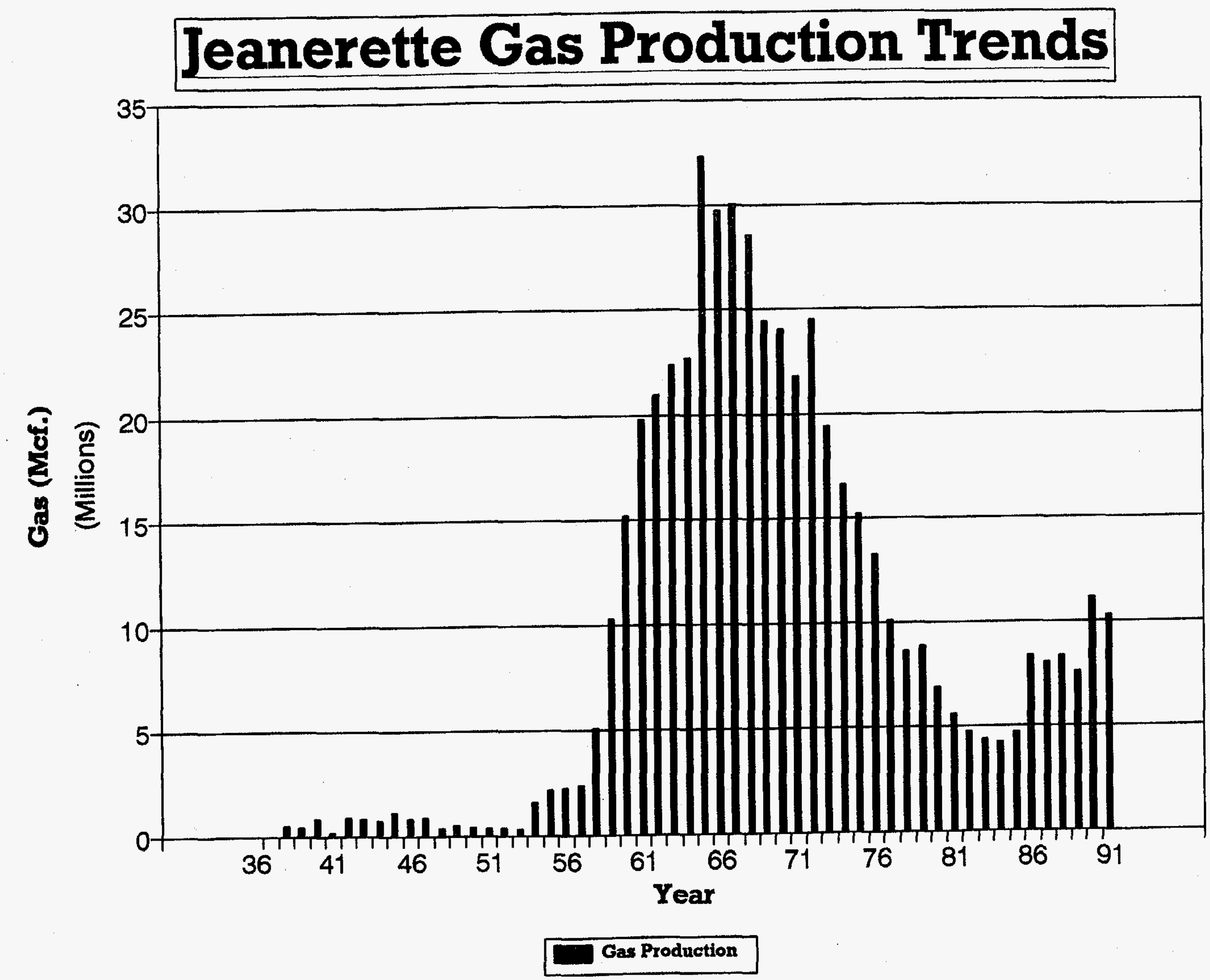

Figure 45. Gas production trends for Jeanerette field 1936 -1991.

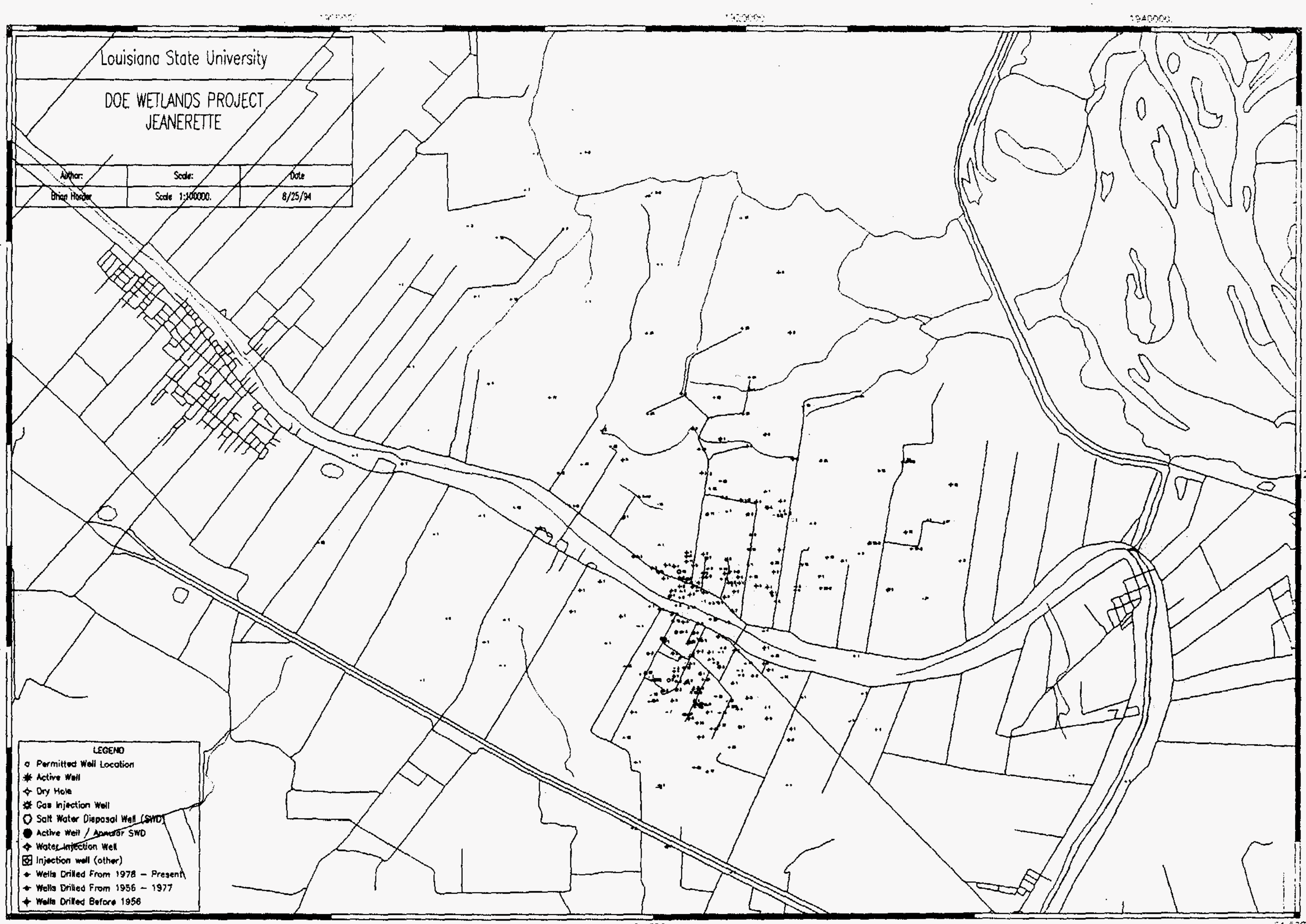

Figure 46. Surface map of wells in the Jeanerette field.

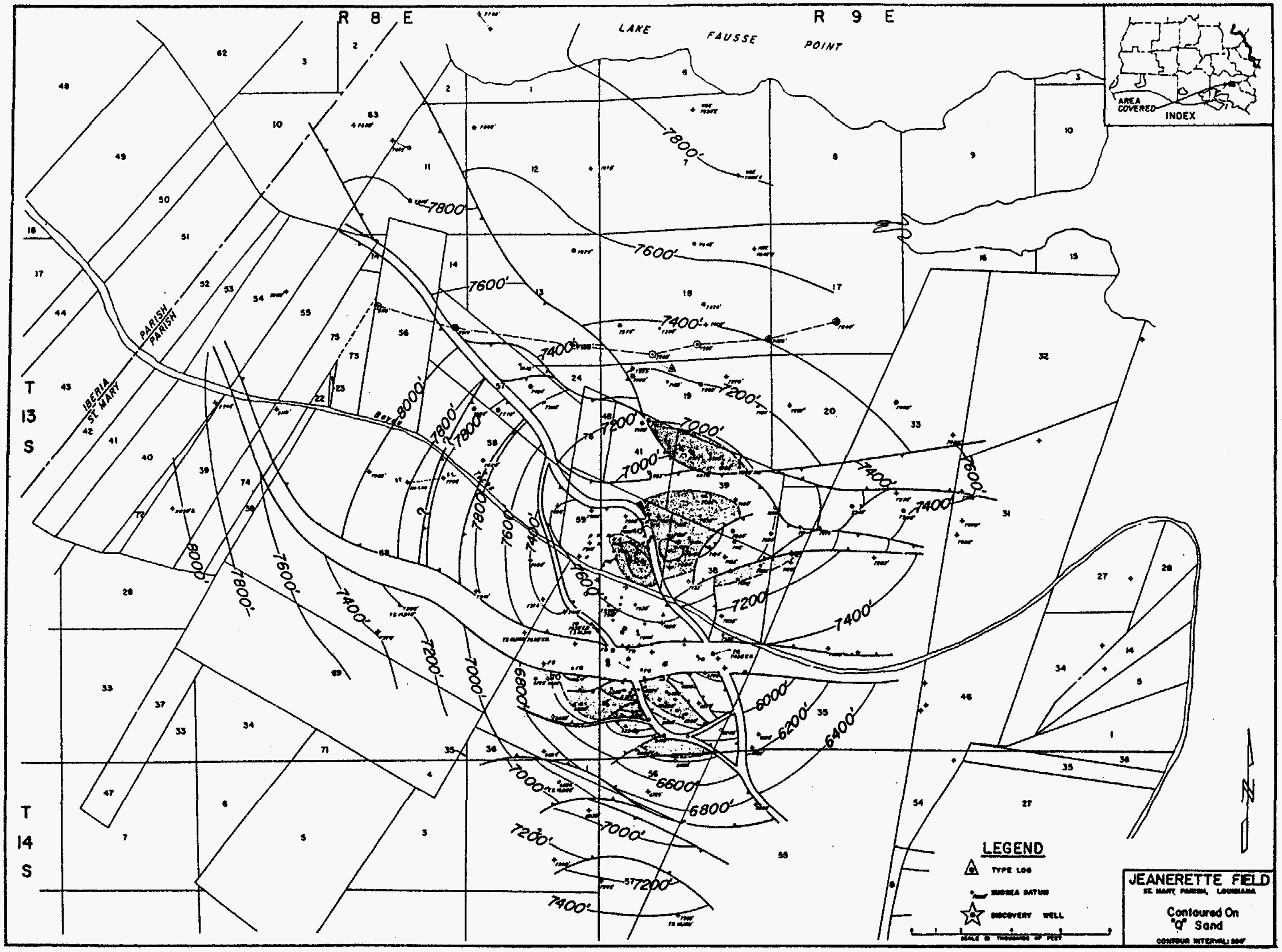

Figure 47. Subsurface map of "Q" sand Jeanerette field. (From Dobie 1970)

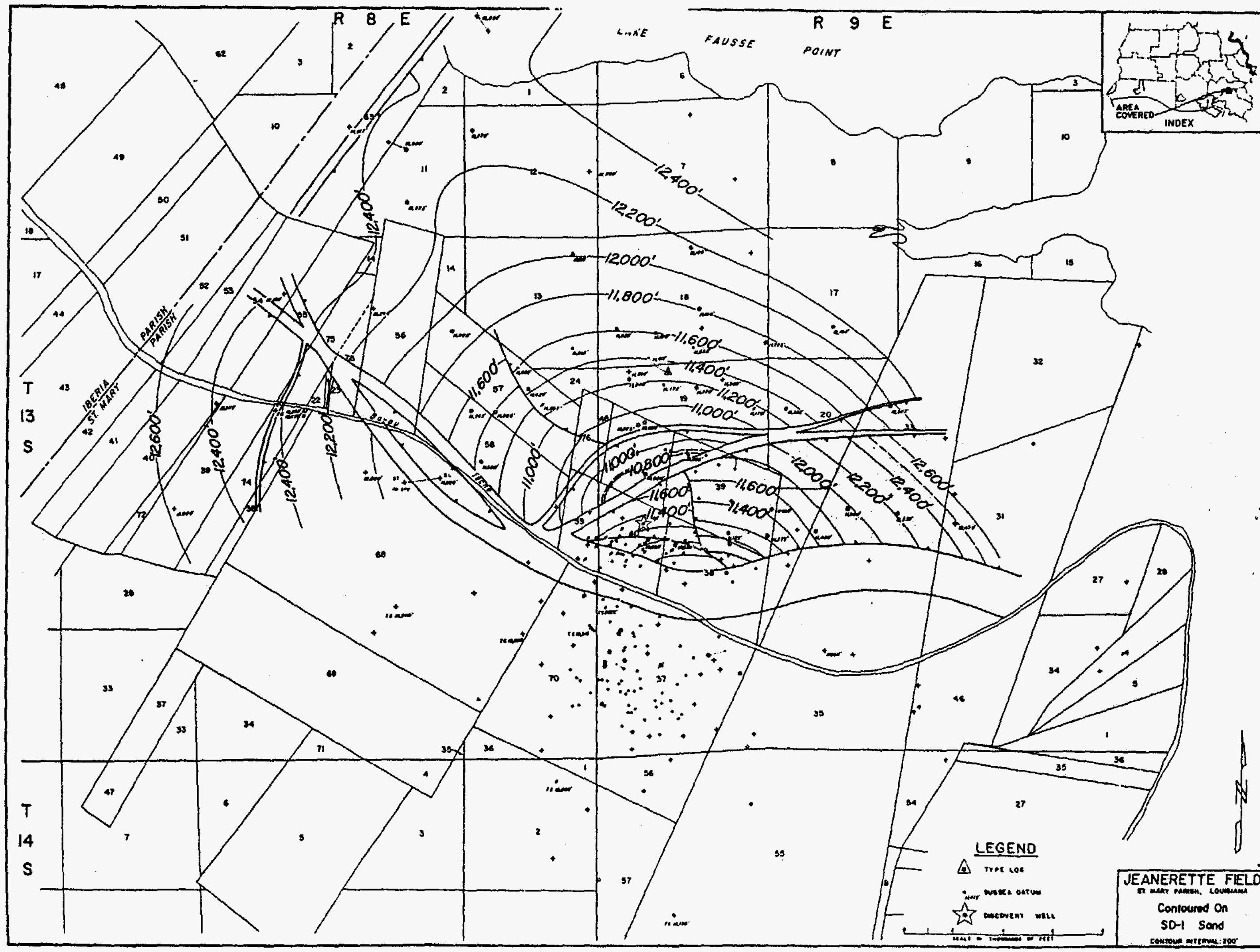

Figure 48. Subsurface map showing structure of *Siphonina davisi* (SD-1) sand. (From Dobie 1970)

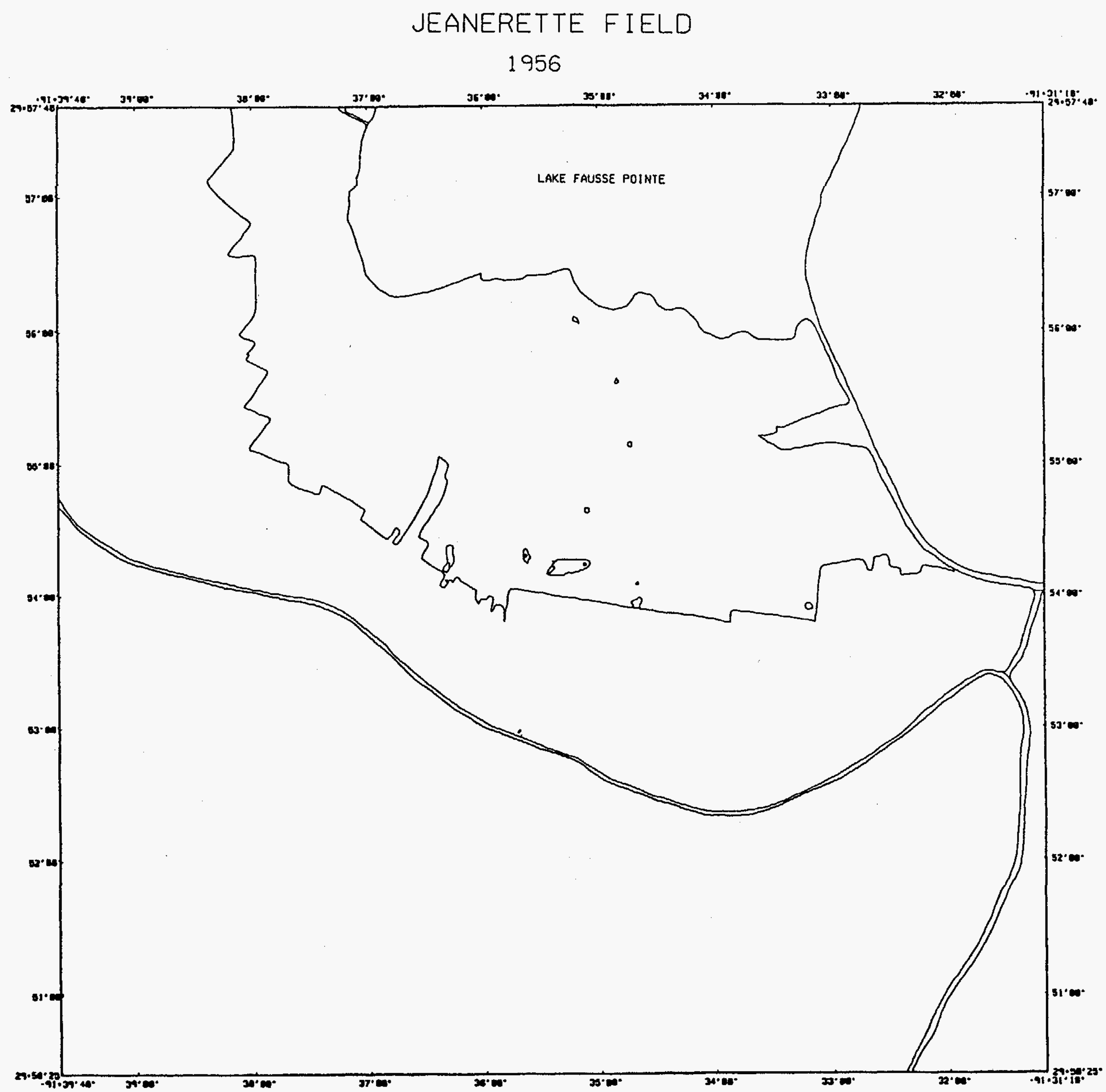

Figure 49. Land cover map for Jeanerette oil field in 1956.

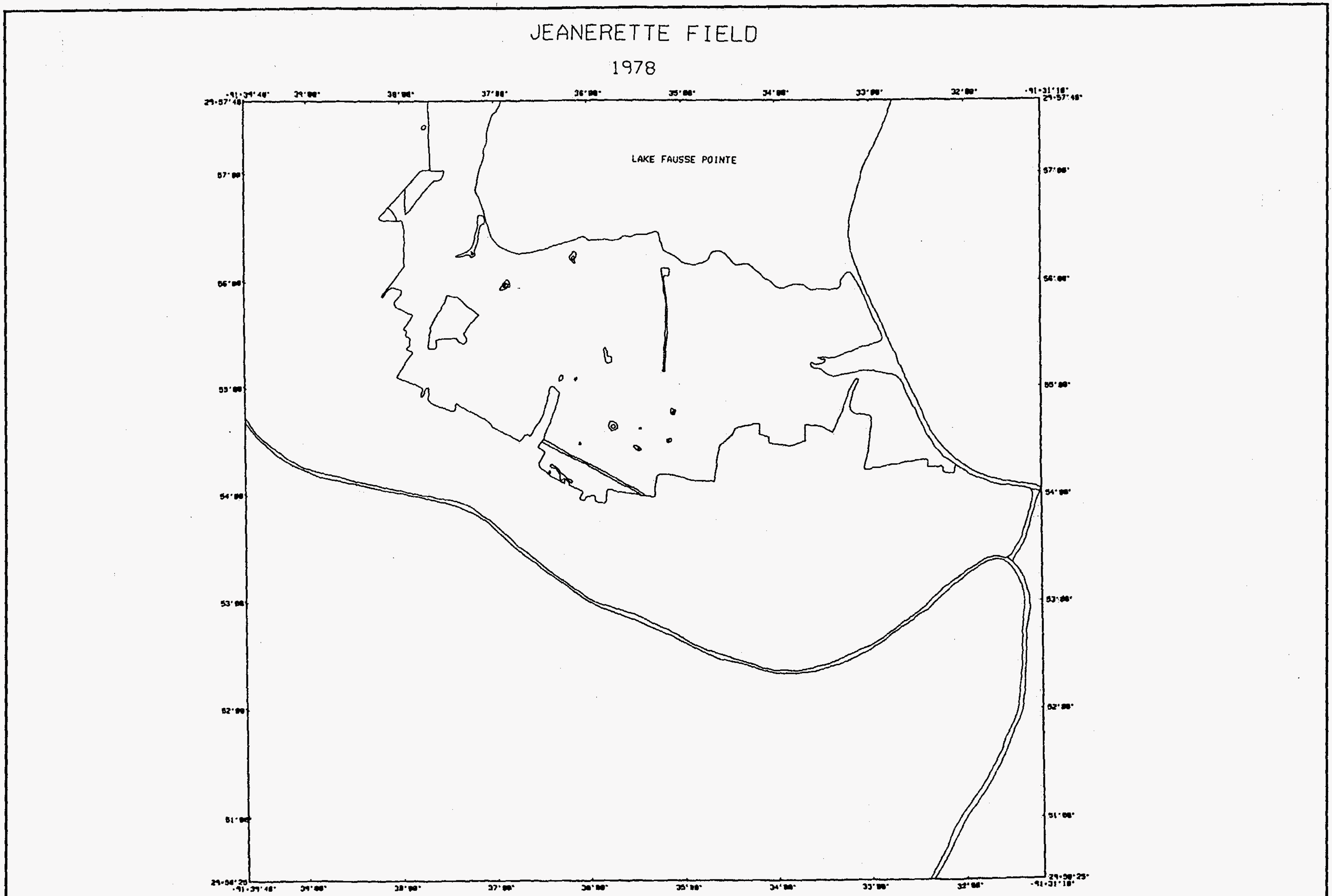

Figure 50. Land cover map for Jeanerette oil field in 1978.

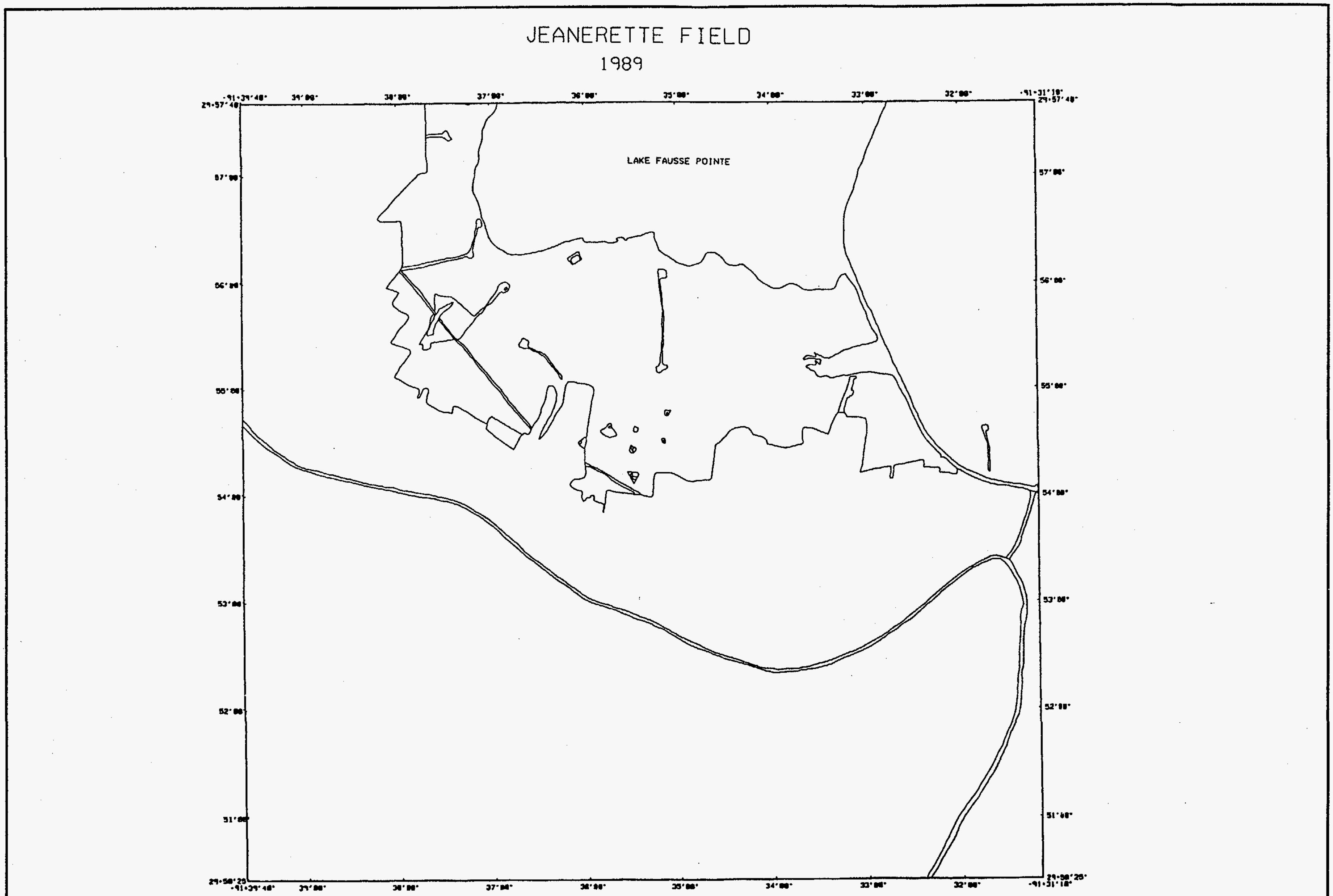

Figure 51. Land cover map for Jeanerette oil field in 1989.

Table 16. Land cover area for Jeanerette 1956, 1978, 1989 in square meters.

LAND COVER	1956	1978	1989
Wetland	52,720,450	46,386,237	45,230,233
No vegetation	0	64,237	4,735
Altered vegetation	148,797	21,493	1,133,244
Impacted/ industry	33,032	30,761	28,089
Agricultural/ Developed	110,673,767	115,961,392	117,123,899
Water			
Natural	19,563,080	19,793,427	19,553,672
Human made	128,680	123,102	195,820

Lafitte

The Lafitte field is located in southeast Louisiana in Jefferson Parish. It lies just northeast of Little Lake between Bayou Rigolets and Bayou Dupont. The Barataria Waterway crosses the field. The Lafitte field is located within Louisiana's coastal zone boundary in brackish marsh. The field is underlain by a deep seated salt dome that was discovered by early reflection seismic survey that identified the salt dome. Texaco began oil production in 1935, and since the field was discovered it has produced more than 310 BCF of gas and 258 billion bbl of oil (table 13).

Since its inception over 600 development wells have been drilled in this field. Productive sands are found from 3,200 to 11,400 ft (975 to 3,475 m) with over 65 pay sands and 256 individual units recognized by the Office of Conservation. The reservoirs found in the field are predominantly oil reservoirs with dissolved gas. Production has been continuous since 1935 onward with a number of sands still in production today. Field-wide oil production rate peaked in 1968 (figure 52) with gas production peaking in 1971 (figure 53). As the production figures demonstrate, this field is in the later stages of decline, however, oil production rates still exceed 1 million bbl per year. A surface map of the field is shown in figure 54.

A structure map of one of the upper sands found in the field is shown in figure 55. This map is a small portion of the field, but the structure is representative of the faulted blocks present throughout the field. The drive mechanism for this reservoir is a strong water drive allowing over 65% of the OOIP to be produced.

A second structure map showing a larger area but, the same type of fault block development is shown in the Upper Dupre sand structure map (figure 56) . This map is representative of the structure found throughout the field, and consists of continuous sands broken by faulting caused by the upward movement of the salt dome. The geology is dominated by the localized conditions caused by the salt uplift.

Enhanced recovery using the huff-puff technique to inject CO_2 began in 1985, but it was used in only a limited number of reservoirs and did not markedly alter the overall decline trend however a slight increase in crude production is seen (figure 52). Additional wells plan to be converted to huff-puff when economics allow conversion.

Historical Landscape Change

Photography for the Lafitte oil field was acquired for 1978 and 1990 and examined to determine qualitative changes in the landscape. Photography from the 1940s from the Soil Conservation Service was not available. However land cover and land cover changes were derived from CMD's habitat mapping study and data from Mossa et al (1989). These data provided land cover for 1956, 1978, and 1984 for the field. The maps produced for this field reveal a striking alteration of the surrounding wetlands (figures 57–59). The primary change between 1956 and 1978 is the conversion of entire fresh marsh to brackish marsh (figures 57 and 58 and table 17). For the study period a drastic reduction in land area and a two-fold increase in water occurred in this area. In addition the waterways in the area are primarily canals rather than sinuous bayous, and the amount of land was reduced by about 25%.

Examination of aerial photography indicates that access to this field is solely by canal. The CMD data indicate that by 1956 the landscape was already altered considerably. Several major canals traverse the area, which was originally solid marsh. Numerous small canals were constructed and many have the typical keyhole configuration at the well site. About 6% (858 m^2) of the total area was human-made water (canals). It appears by the landscape that this field was rapidly developed between 1935 and 1956.

In 1978, the area again changed dramatically. More than 46 million m^2 of fresh marsh was replaced by brackish marsh and water. Ponds enlarged and more canals were constructed. Wetland area decreased by 27% from 47 million m^2 in 1956 to 30 million m^2 in 1978 (table 17). Wetlands were replaced by an increase in natural water, human-made water bodies, and spoil deposits. The area covered by water more than doubled over the time period. Spoil and shrub communities increased dramatically from 118,067 m^2 to almost 5 million m^2. The increase in shrub communities can be attributed to the increase in canals and spoil deposits. By 1978, 14% of the area had become canals and spoil deposits.

The land classes changed during the 1984 analysis. Land cover was categorized into either brackish or broken marsh, water, forest, and shrub/scrub. The broken marsh category adds confusion to the changes in marsh and water area because it incorporates marsh area that was classified as water in 1978. If a section of marsh was deteriorating and primarily more than 50% water, it was classified as water in 1978. In 1984, the same area would be classified as broken marsh. Overall there is a net loss of viable marsh in the area and water increased mainly as new ponds and enlarging ponds and canals. Examination of the 1978 and 1990 photography clarifies where broken marsh and open water occurs, which is primarily where canals and spoil banks are the most dense. The photography also shows that land cover in some areas appear thinner and less vigorous, ponds and canals have enlarged and canals.

It is apparent from the photos that access to this field is solely through canals and natural water bodies. Virtually all of the present infrastructure was in place by 1978 because very few new canals were constructed between 1978 and 1990. It can be assumed that most of the activity associated with developing small canals occurred between 1956 and 1978 because the 1956 maps from CMD illustrate fewer canal locations.

Virtually all of the changes in landscape in the Lafitte field are due to development of the field. The typical configuration of the canals in this area are solely for oil and gas purposes. The area has had high-interior marsh loss because it has lost about one-third of its solid marsh cover since 1956. Altered hydrology and changes in the salinity regime are major factors contributing to this loss.

The Lafitte field is an prime example of how oilfield development in wetlands contributes to overall wetland loss. This field could have been developed using from six to twelve discontinuous canals using directional drilling and parallel slips for most of the wells (figure 60). Direct impacts of this development strategy would not be insignificant, but the direct wetland losses could have been reduced from 50% to 90% using this type of plan for development.

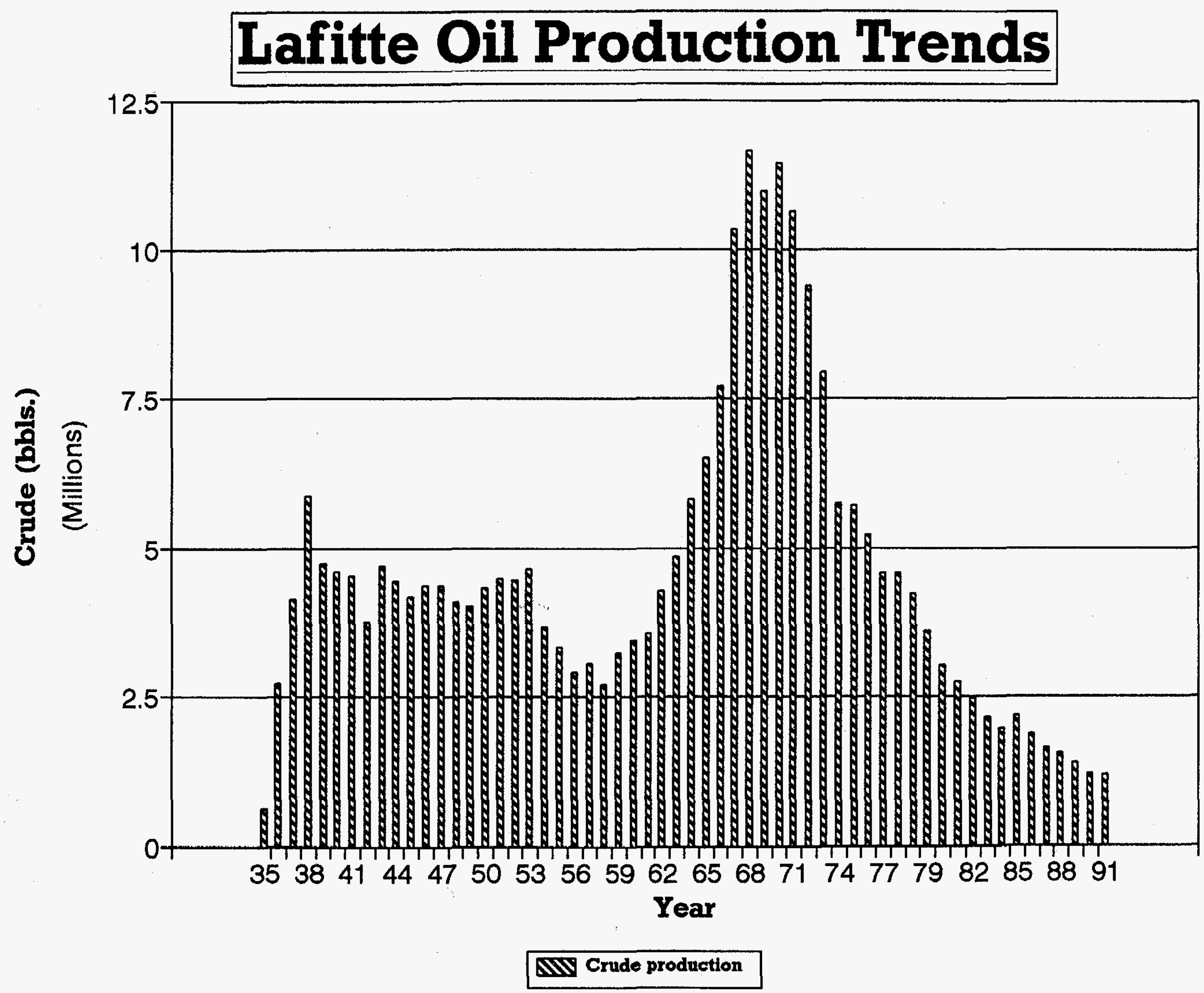

Figure 52. Crude production for Lafitte field 1935 - 1991.

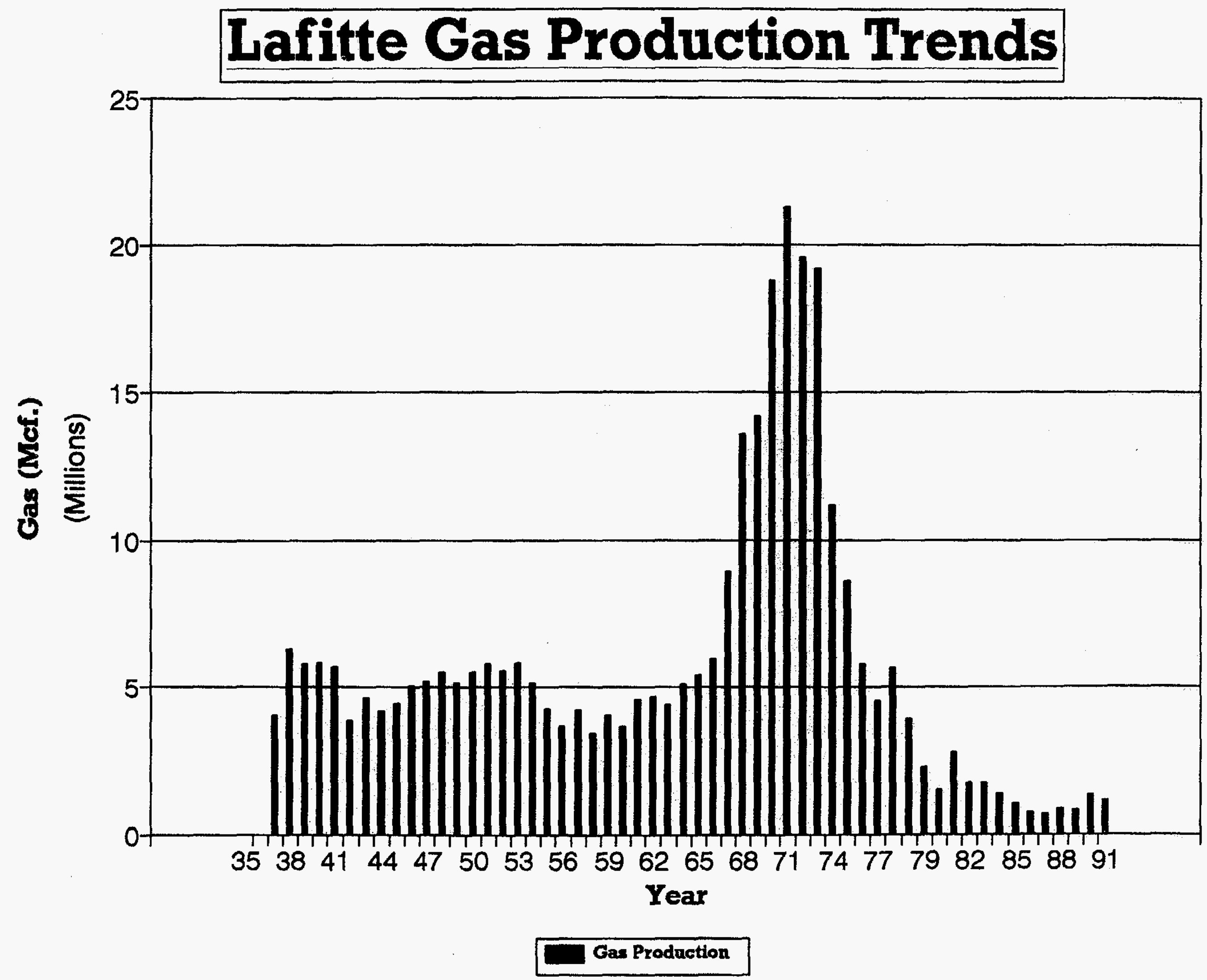

Figure 53. Gas production trends for Lafitte field 1935 - 1991.

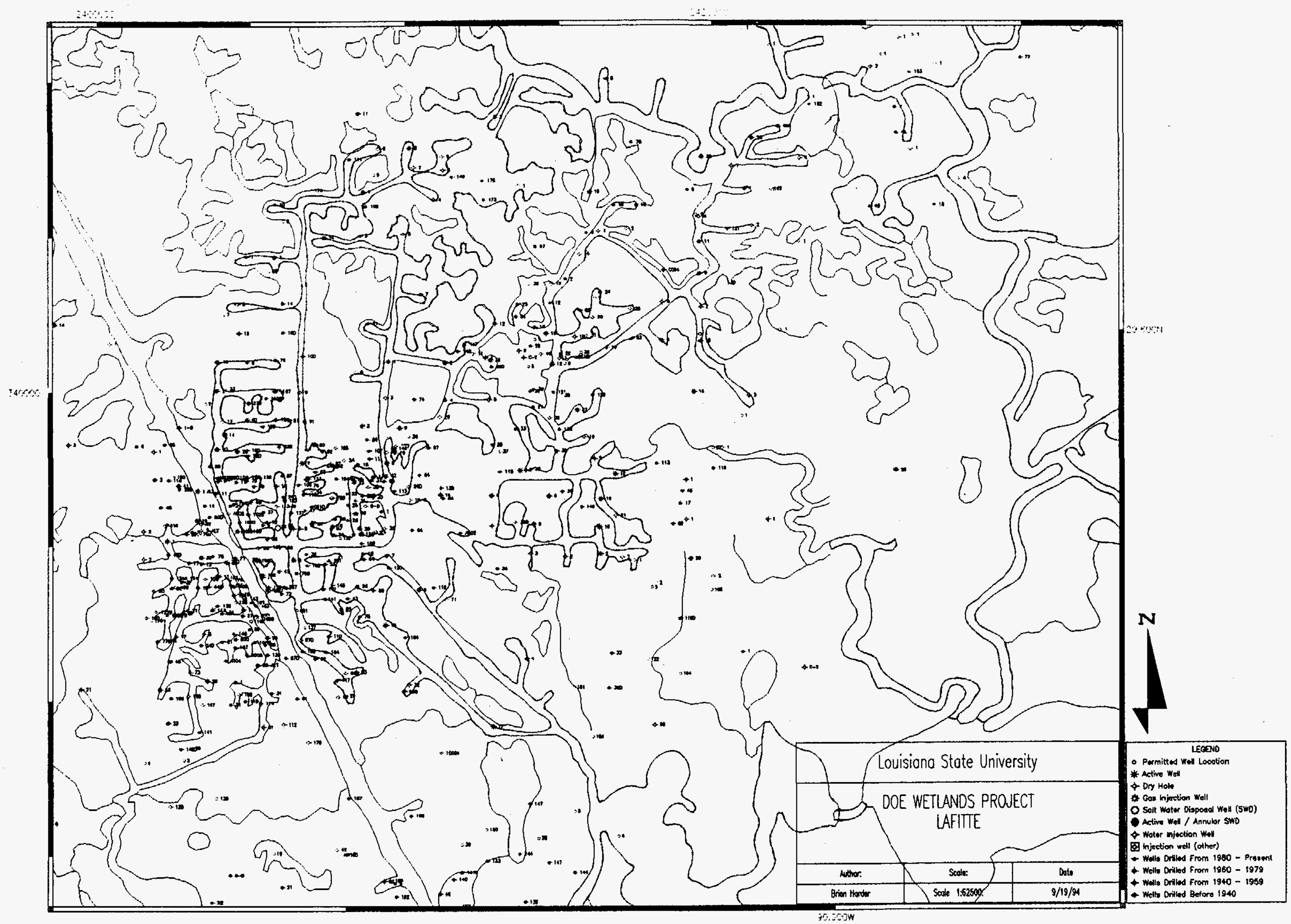

Figure 54. Surface map of wells drilled in Lafitte field.

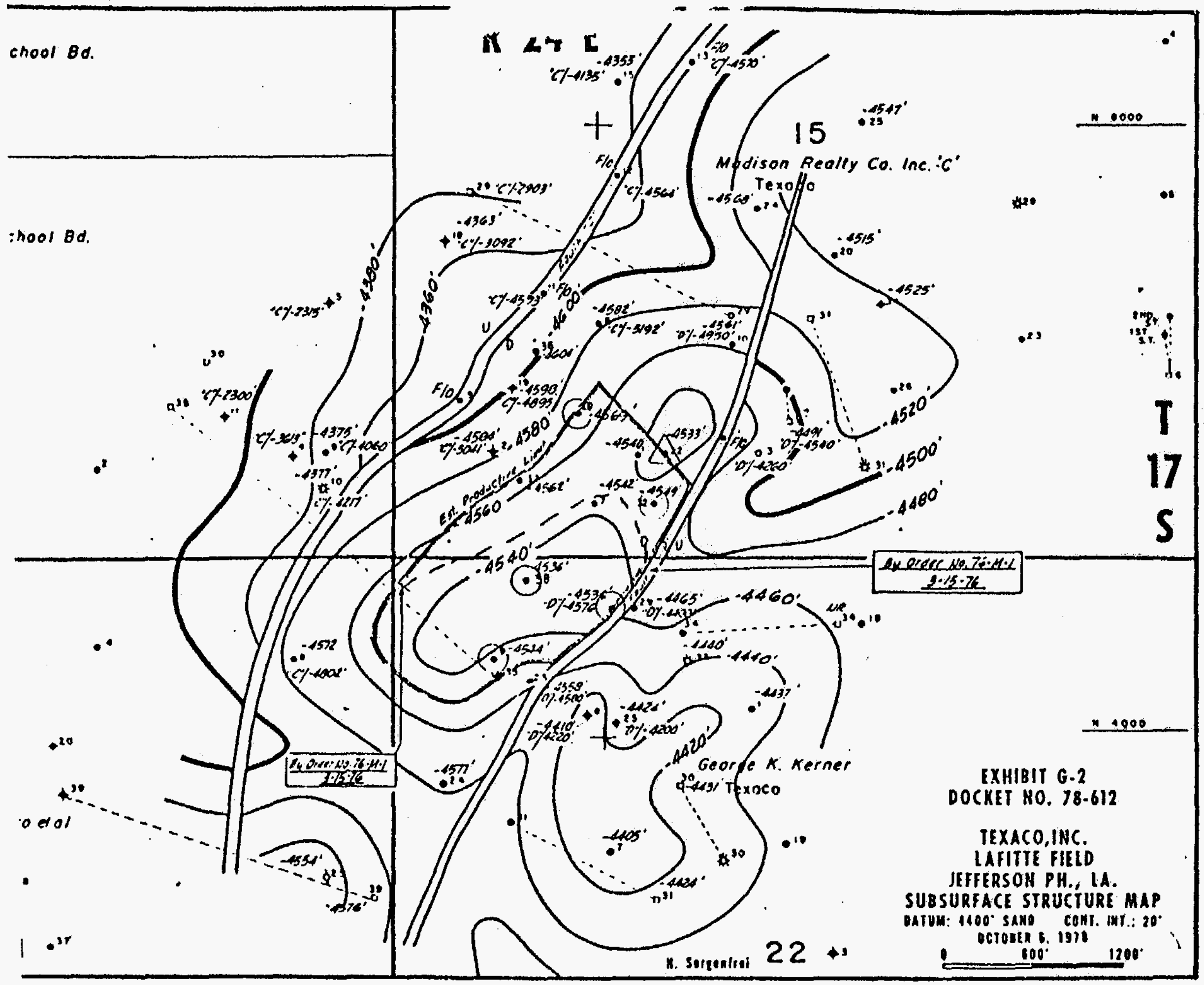

Figure 55. Subsurface of portion 4400' sand found in Lafitte field. (Louisiana Department of Natural Resources, Office of Conservation Hearing files Docket 78-612)

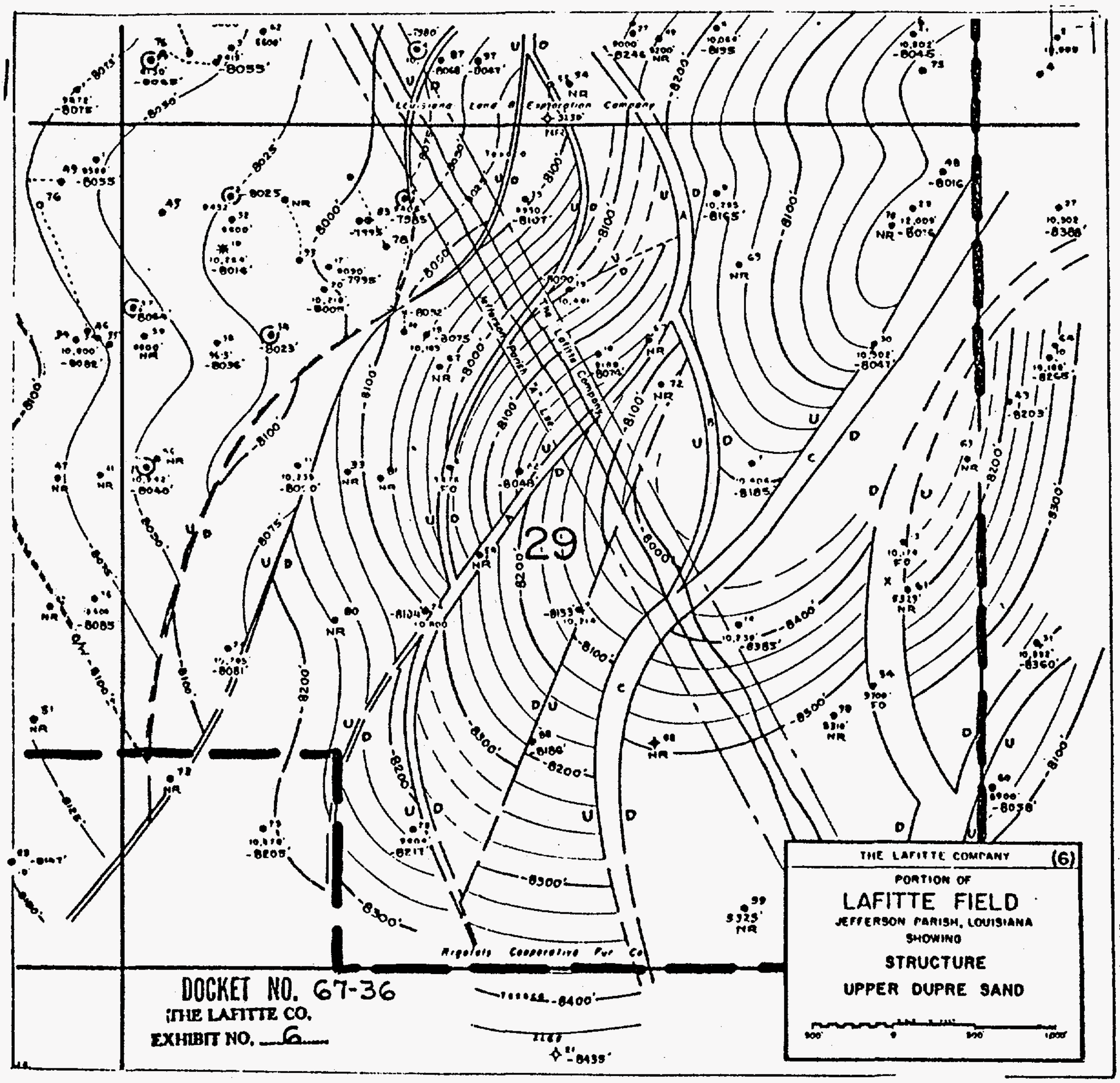

Figure 56. Subsurface map of portion of Upper Dupre sand in Lafitte field. (Louisiana Department of Natural Resources, Office of Conservation Hearing files Docket 67-36)

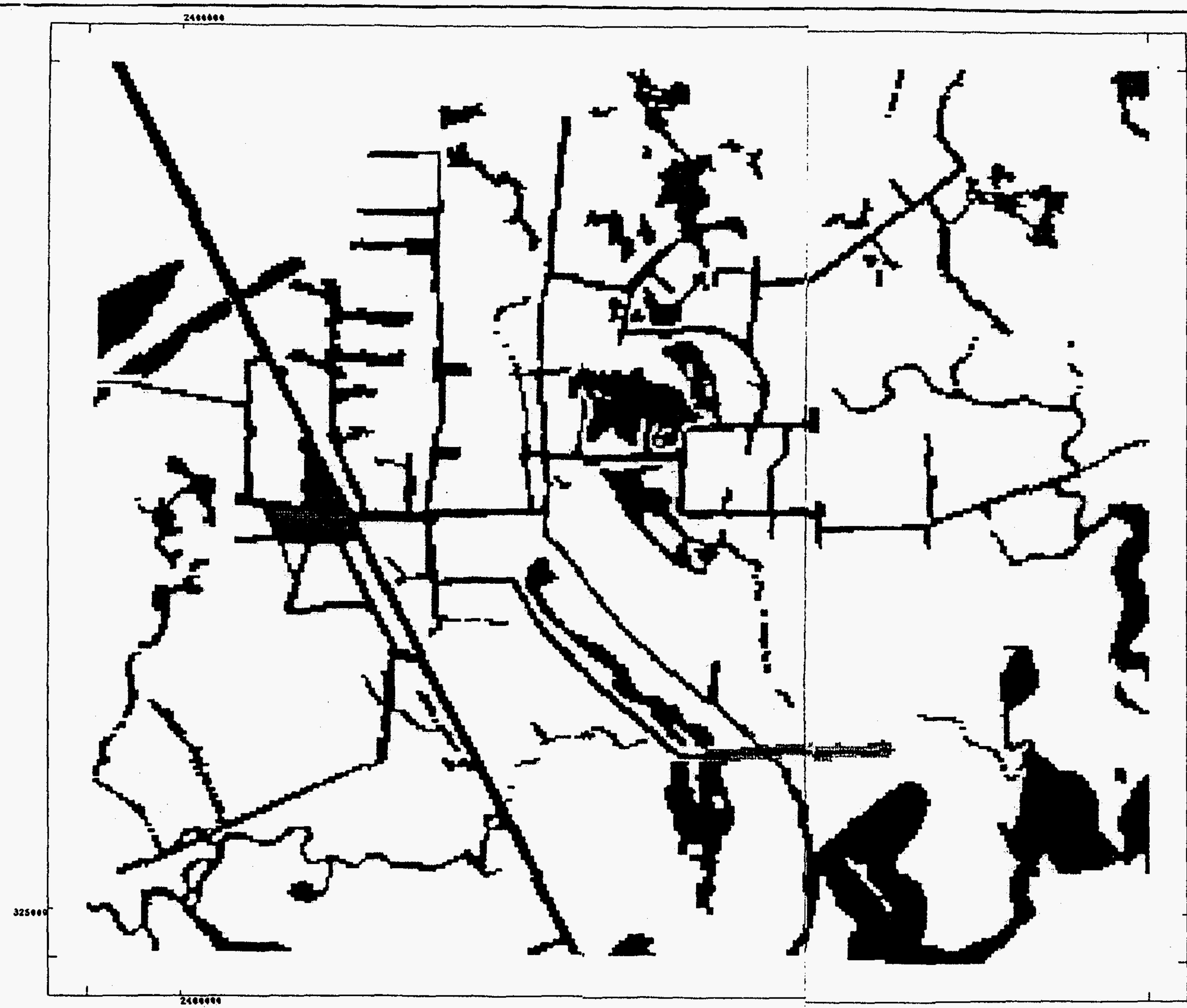

Figure 57. Land cover map for Lafitte oil field in 1956.

Figure 58. Land cover map for Lafitte oil field in 1978.

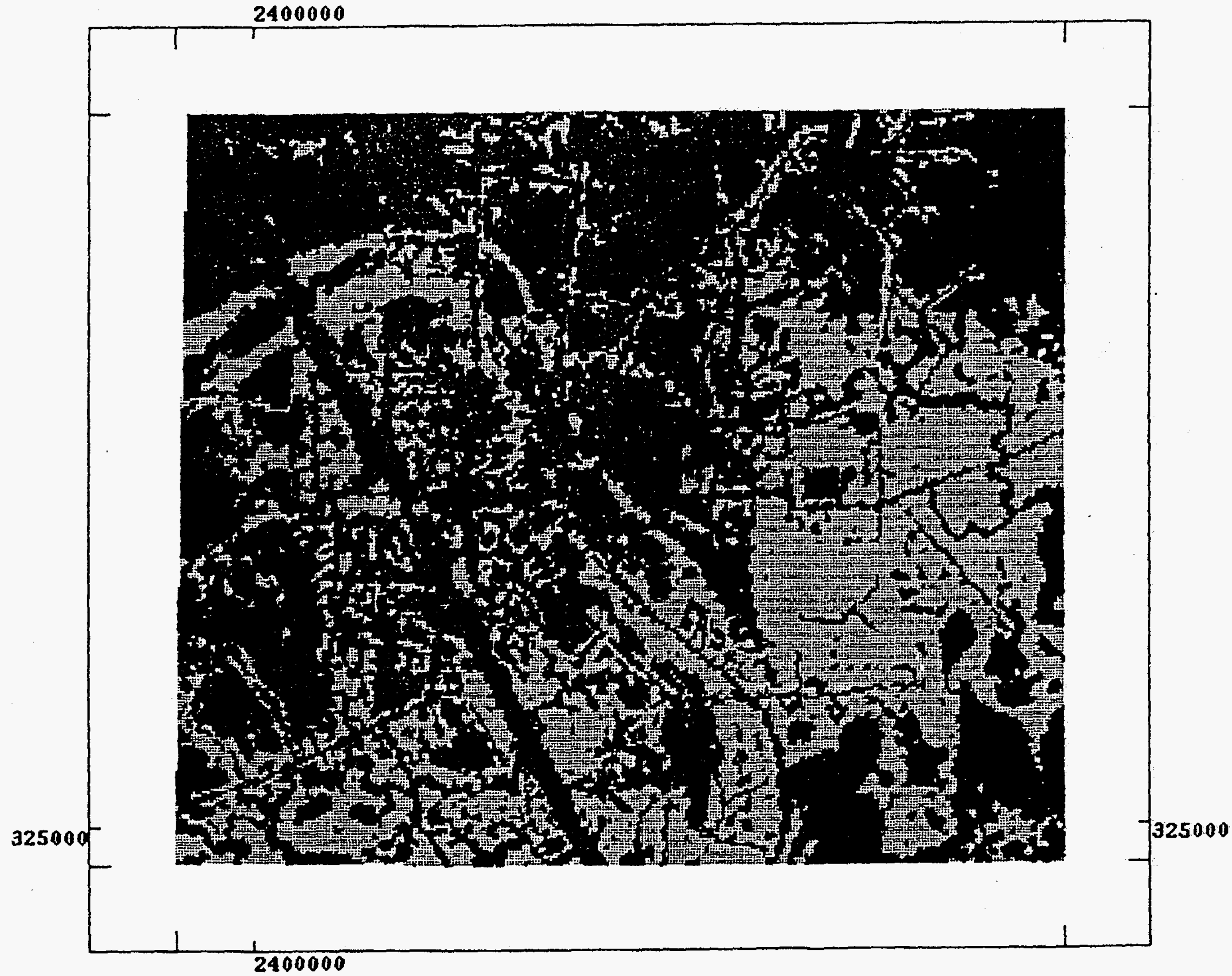

Figure 59. Land cover map for Lafitte oil field in 1984.

Table 17. Land cover area for Lafitte for 1956, 1978, 1984 in square meters (from Coastal Management Division, Louisiana Department of Natural Resources).

LAND COVER	1956	1978	1984
Wetland			
Fresh Marsh	46,545,939	0	0
Brackish Marsh	0	29,551,538	21,940,167
Broken Marsh	-	-	15,756,865
Forest	714,036	738,399	623
SS/ Spoil	118,067	4,928,902	1,103,848
Agricultural/ developed	130,564	243,010	-
Water			
Natural	5,803,483	13,978,338	18,682,971
Human made	3,472,719	7,996,188	-
Inert	699,042	46,229	-

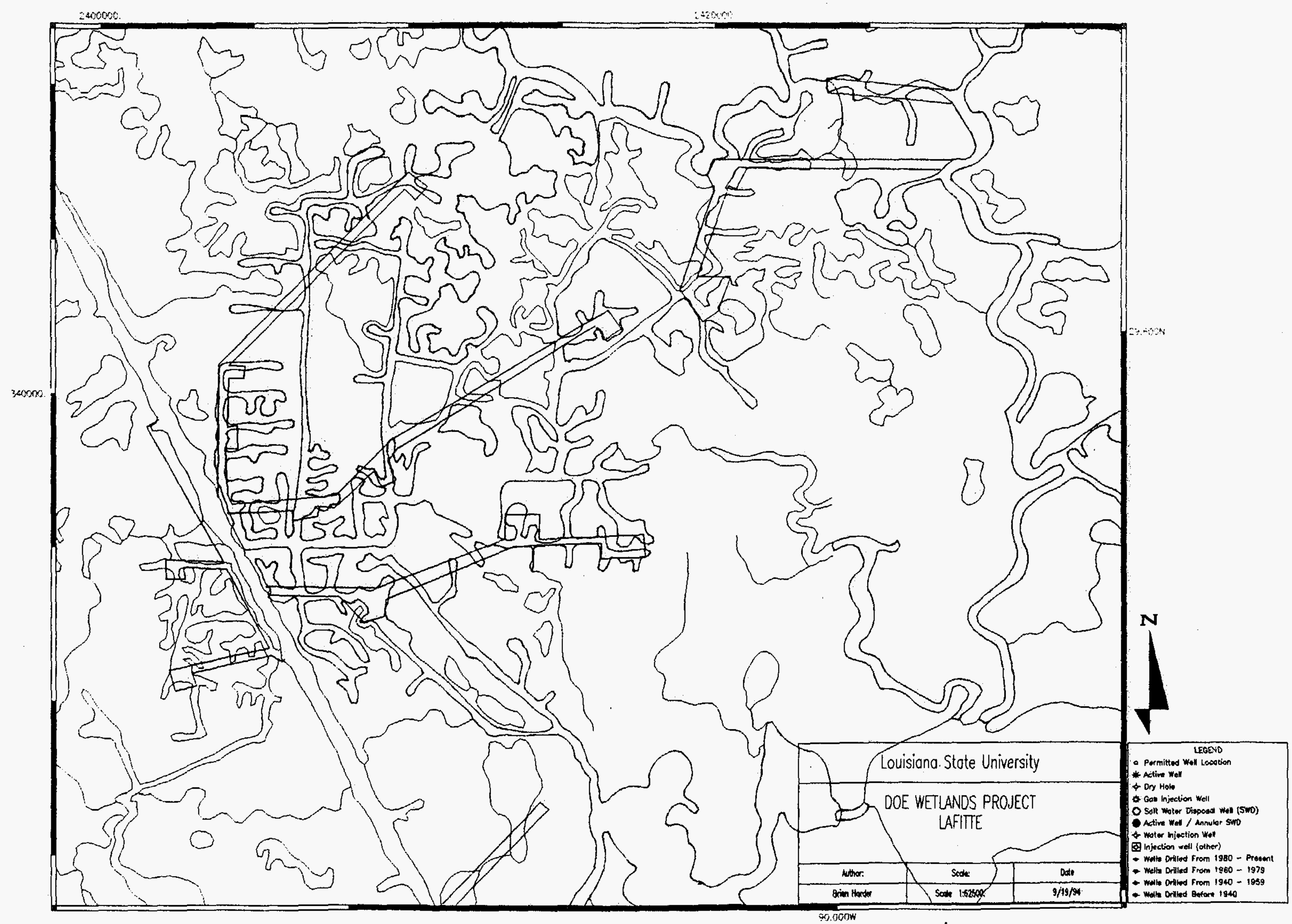

Figure 60. Possible development scenario of Lafitte field to minimize impacts.

Lake St. John

The Lake Saint John field is located near Spokane, Louisiana, in the northeastern part of the state in bottomland hardwood forest and swamp between the Mississippi and Tensas rivers in Concordia/Tensas parishes. The Lake St. John field is an elongated deep-seated salt dome structure with oil and gas found in formations around the flank of the structure and above the salt and is the only field studied in north Louisiana for this project. The field was discovered in 1942 and has produced almost 469 BCF of gas and 86 million bbl of oil (table 13). Since that time over 581 wells have been drilled to various producing horizons from 3,400 to 10,750 ft (1,036 to 3,277 m). There are 7 productive sand horizons, and 75 units formed in the field. Oil and gas production from 1956 to 1991 is shown in figure 61.

The field is in wetlands and sits on top of an oxbow lake created by the Mississippi river shown in the surface map of the field (figure 62).

Early production was centered on the Wilcox "A" at 3,400 ft (1,036 m) and the Basal Tuscaloosa formations at 9,000 ft (2,743 m) with production beginning from both these formations in 1943. The elongated dome structure of the field can best be seen by examining a map of the Basal Tuscaloosa (figure 63). Wells were drilled to produce all of the fault blocks shown A through I in the 1940s. The Basal Tuscaloosa sand has an undersaturated gas cap, and the original wells were placed at the top gas cap. Later development indicated individual sealed fault blocks and as a consequence later wells were placed at the highest structural location in each fault block if possible.

The gas cap drive is a highly efficient producing mechanism for the Basal Tuscaloosa. For this reason numerous injection wells were drilled to increase efficiency. The Basal Tuscaloosa is divided into three distinct horizons (upper, middle, lower). The lower sand has good continuity but, the upper and middle are spotty and lenticular, which lead to decreased sweep efficiency.

Additional zones have been produced on top of the domal structure with producing sands from 3,400 to 4,500 ft (1,036 to 1,372 m) being produced . Figure 64 is a structure map of the productive portion of the 4,370-ft sand. This map clearly shows the directional wells used to develop reservoir sand underlying the lake. This series of sands was developed in the 1960s as production declined from the Basal Tuscaloosa. Field-wide production continued to decline until the mid 1980s when the deeper Paluxy sand was discovered and began production. This production brought yearly field production back up to about 140,000 bbl of oil; however, gas breakthrough has occurred and production is expected to decline rapidly.

This field was developed using board roads and gravel pads. Because this field was discovered during the war years development was rapid and direct. Later development of the shallower sands occurred in the middle 1960s and was also very rapid. Numerous well pads were constructed to produce the shallow sands. To limit well costs, wells under the lake were directionally drilled. If this field were discovered today this field could have been developed with directional wells for the deeper horizons and horizontal wells to drain the upper shallow sands from pads in non-wet areas preventing impacts to wetland areas.

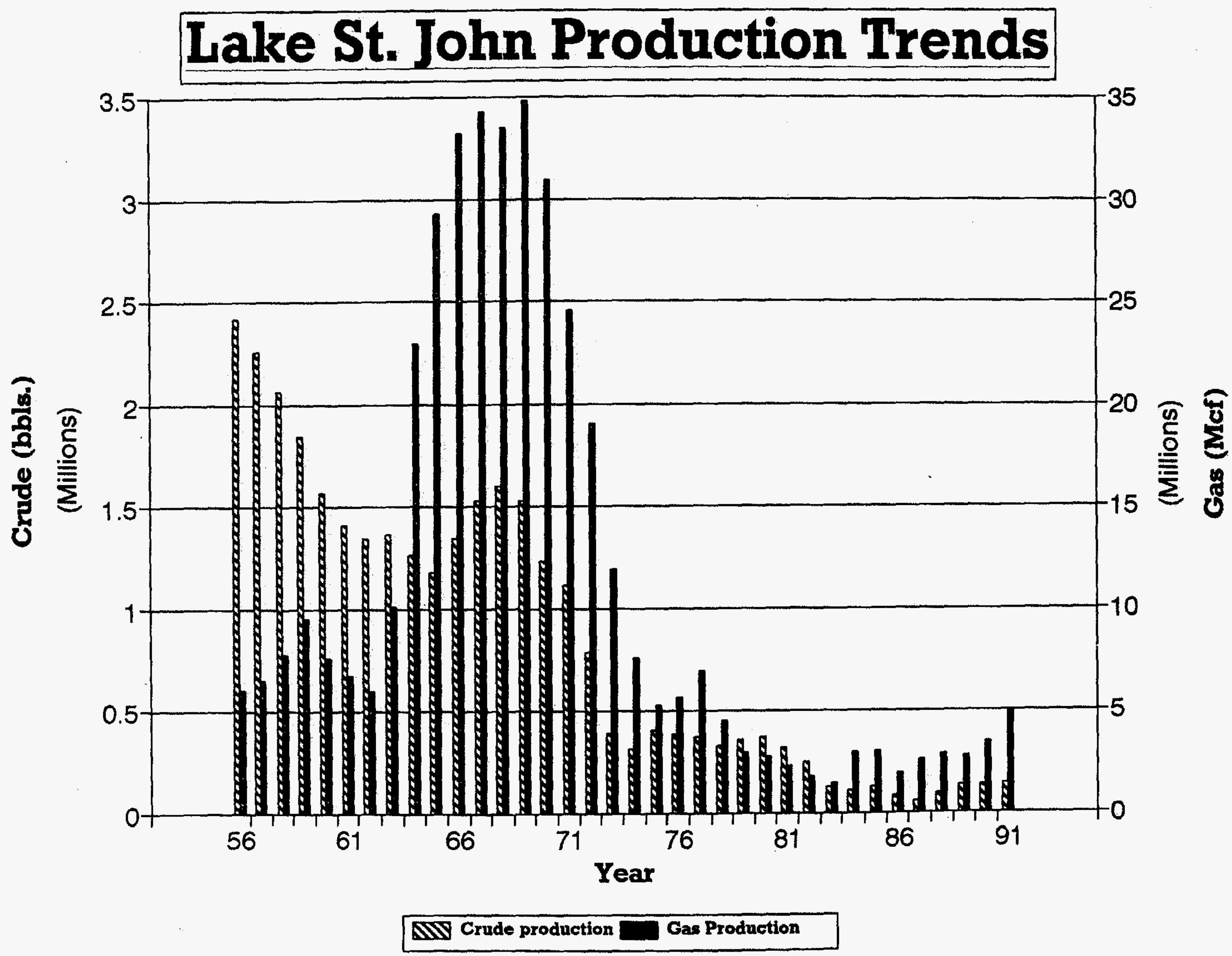

Figure 61. Production trends for Lake Saint John field 1956-1991.

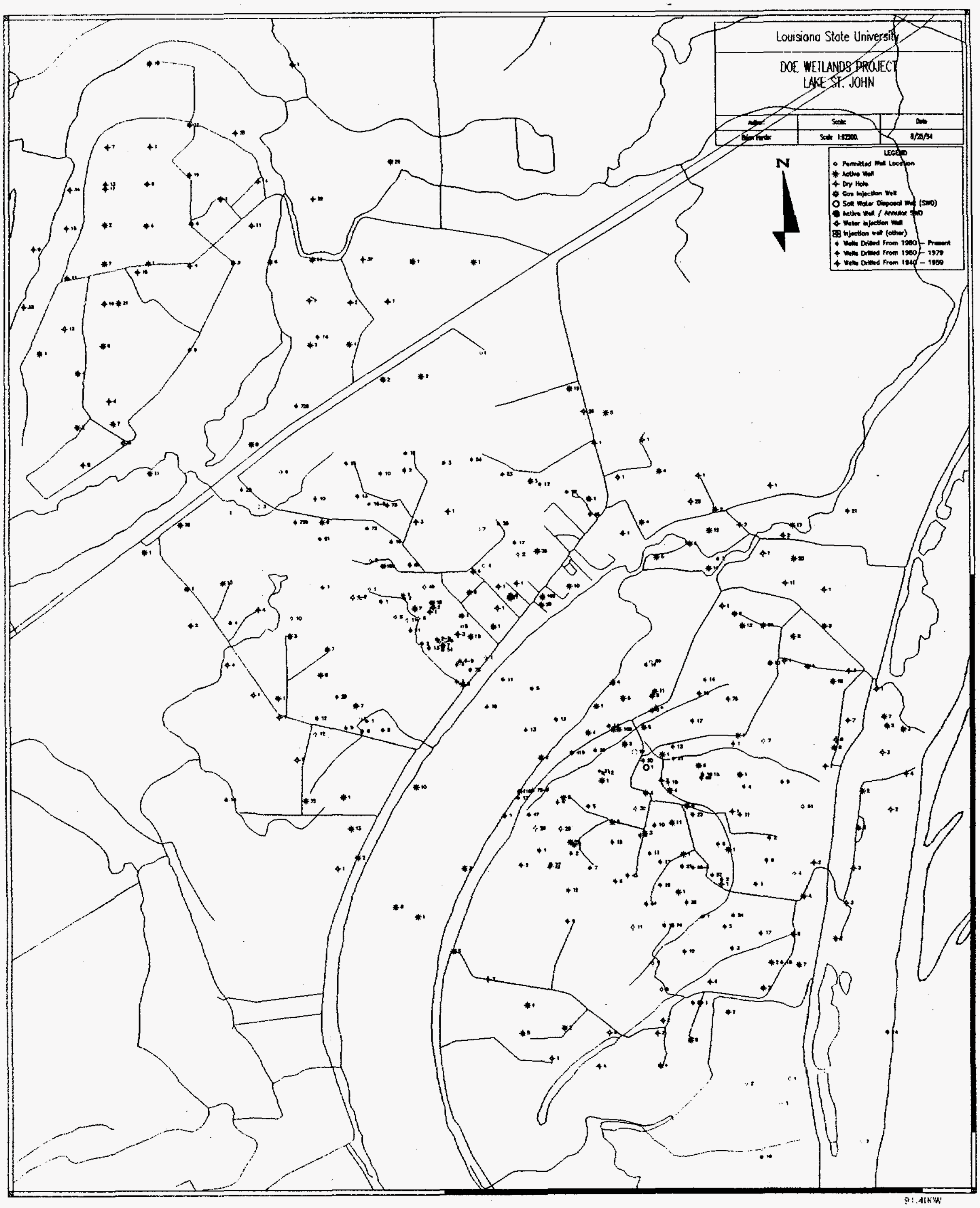

Figure 62. Surface map of Lake St. John field with well locations.

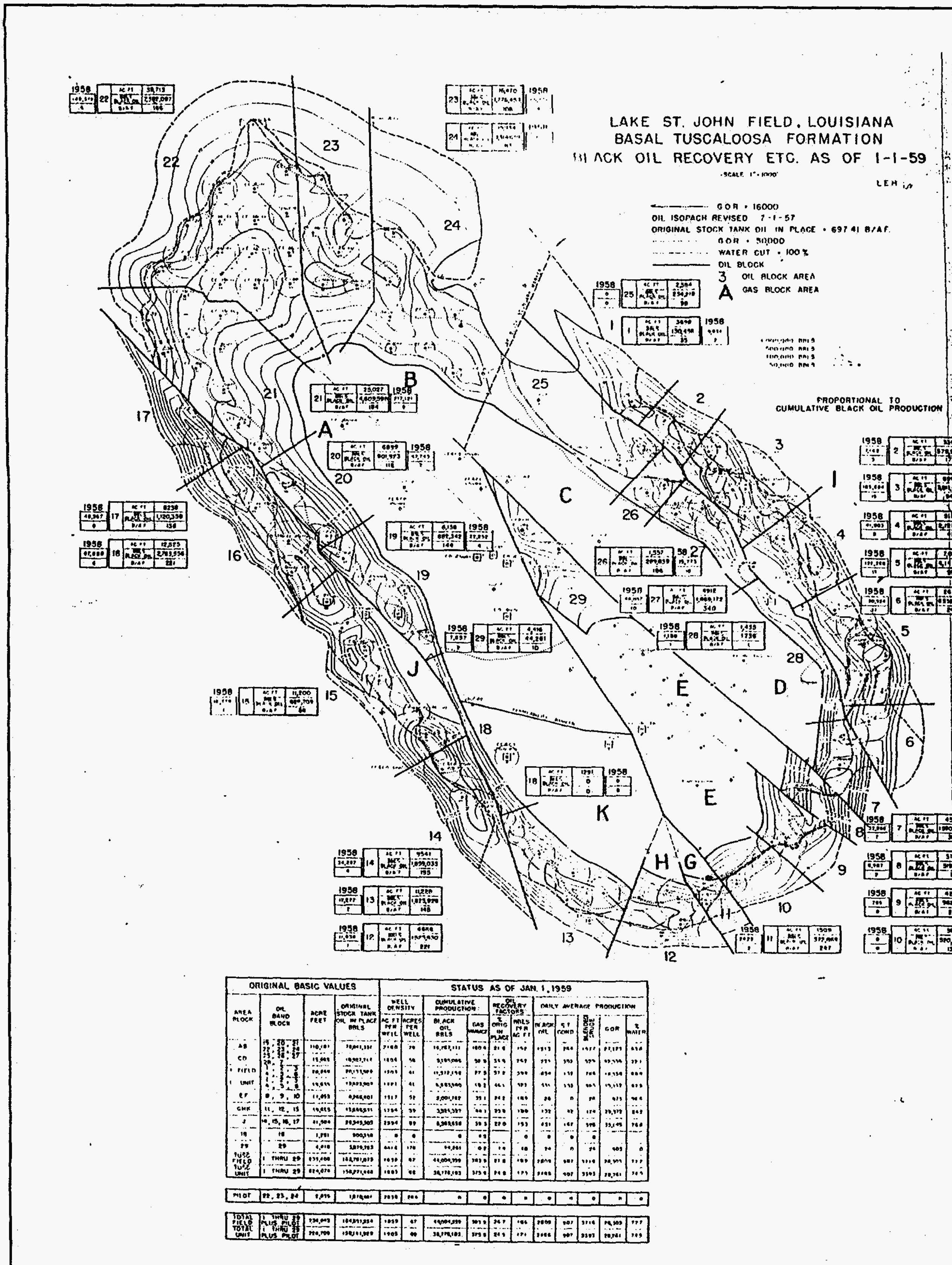

Figure 63. Subsurface map of Basal Tuscaloosa formation in Lake St. John field. (Louisiana Department of Natural Resources, Office of Conservation Hearing files Docket 60-35)

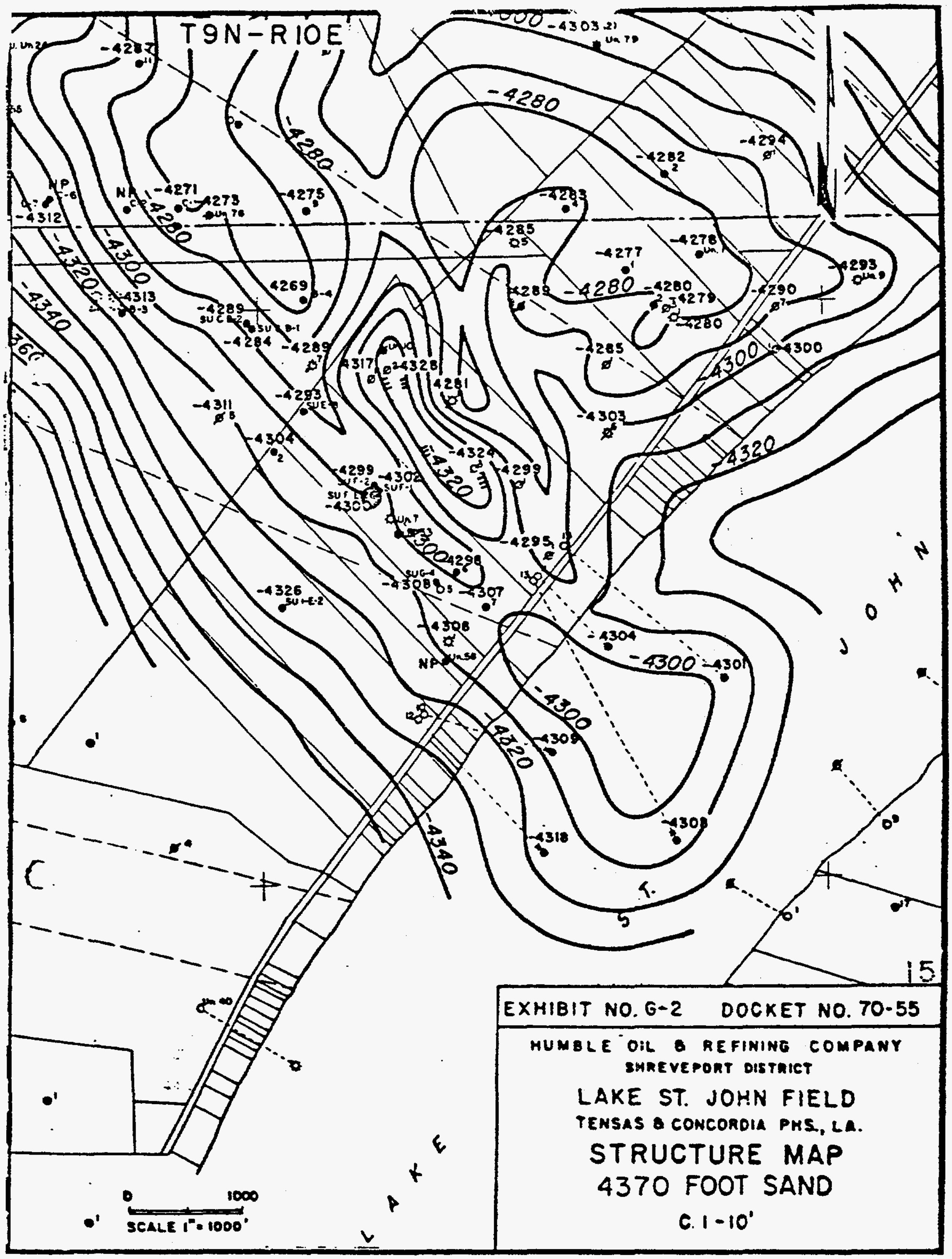

Figure 64. Structure map of the 4370' sand Lake St. John field. (Louisiana Department of Natural Resources, Office of Conservation Hearing files Docket 70-50)

Paradis

The Paradis field is located near the towns of Paradis and Des Allemand in southeastern Louisiana in St. Charles Parish. The field lies southeast of Lac des Allemandes and east of Bayou des Allemande within Louisiana's coastal zone. It lies in a fresh and intermediate marsh with some swamp in the area. The Paradis field found is a deep-seated dome structure with the top of salt found at 12,000 ft (3,658 m) on the peak of the dome.
Oil was discovered in 1939 (Stripe 1960) and since its inception 421 wells have been drilled in the field, which has produced more than 1.3 TCF of gas and 145 million bbl of oil (table 13). Numerous producing sands have been found with over 30 pay zones unitized by the Office of Conservation with 181 producing units being formed since the discovery of the field. Oil production peaked in 1969 (figure 65) and gas production peaked in the same year (figure 66).

Production trends for the field at this time show classic decline scenario. The rate of decline of crude production was slowed slightly in the 1980s with the beginning of a series of immiscible floods using CO_2 as the flooding agent. This has increased ultimate oil recovery and changed the oil decline curve slightly. Gas production continues to decline as reservoir energy is being depleted. There are plans for additional CO_2 floods to be instituted on other units to increase ultimate recovery. Low prices have delayed other flooding projects at this time.

Productive zones are exist from 8,000 to 11,700 ft (2,438 to 3,566 m) and are concentrated in two distinct producing areas that can clearly be seen on the surface development map (figure 67). Production is concentrated on the end flank reservoirs of an elliptical structure running northwest to southeast. Rapid development of the northwestern section of the field occurred with a series of board roads built to allow access for development of the field. Later development occurred in the early 1970s with most of the southeastern magenta-colored wells shown on the surface map being drilled at this time.

A structure map for 9,900 ft (3,017 m) sand (figure 68) shows the general field configuration and how the producing sands are affected by the underlying dome and the cross faulting caused by the salt intrusion. This reservoir is a depletion drive and has produced from the various fault blocks represented by this map over time.

The original discovery wells were drilled in the 1940s and 50s to sands from 9,000 to 10,500 ft (2,743 to 3,200 m) shown in blue on the surface map. Shallower production shown in the subsurface map of the 23 sand (figure 69) was developed in 1974.

The only data available for the Paradis field were 1984 TM data from CMD. Of the four fields examined on a landscape scale, Paradis has the most variable land cover patterns. It encompasses approximately 47 million m^2 of surface area and in 1984, land cover was comprised of 26% agricultural, 26% marsh, and 29% forest and swamp, and 10% water (table 18).

The field is close to the Mississippi River and is surrounded by various human activities such as residential, industrial, and agricultural development. Because the area has many different development activities, it is difficult to separate out oil and gas of the development.

Since 1953 access for developing this field is primarily through road construction especially in the middle of the field. The earliest access for development was via canal through fresh marsh and swamp. The widest canals in the field today were constructed prior to 1953 and were virtually the only access to the field at that time. Only small logging roads are visible in 1953. By 1972 the field's infrastructure was nearly complete, and few new roads and canals were built since.

Access in the northwestern corner of the field is primarily by canal and in 1990 many of the canals were choked with water hyacinth or have begun revegetation. This portion of the field has numerous small canals through the swamp. The mid to northeast section of the field, which is marked by a large patch of agricultural land, has rapidly deteriorated. Open water and broken marsh are present in 1972, by 1984 (figure 70) open water has increased, and broken marsh is prevalent. By 1990 the broken marsh and open water almost doubled and is clearly deteriorating.

Because the Paradis field is located in a multi-use area, it is difficult to assess the contribution of oil and gas activity on the changing landscape at this location. Alterations to marsh density have occurred in the area where oil access canals and roads were constructed. However, changes in the land cover were affected by alterations due to agriculture, other industries, and residential development as well.

Development of this field would be significantly different using current regulatory requirements. Numerous wells were directionally drilled in this field to allow multiple completions and because of geological structural requirements. Directional drilling could have reduced the number of well locations required by at least 50% . Six to ten multiple well pads (shown as blue boxes on the surface map) could have completely covered the northwestern flank. Six to ten additional pads (show as red boxes on the surface map) paralleling the existing state highway and parish road could be used to cover the southern flank of the field. Simple-kick directional wells from these pads not exceeding 1,500 ft (457 m) of horizontal displacement would allow all the presently known sands to be developed. Development of the top of the dome could be done from non-wet areas.

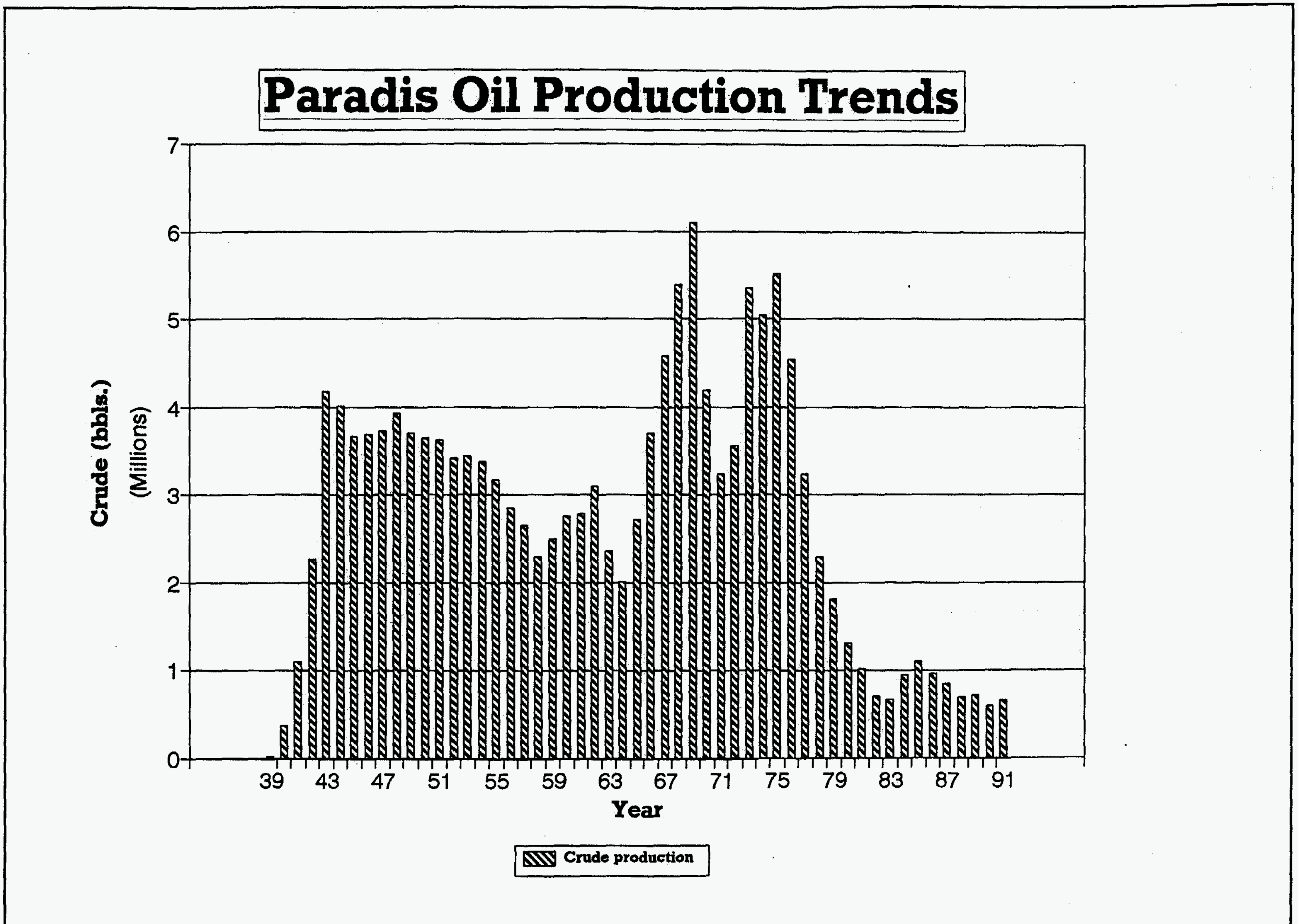

Figure 65. Oil Production trends 1939 - 1991 for Paradis field.

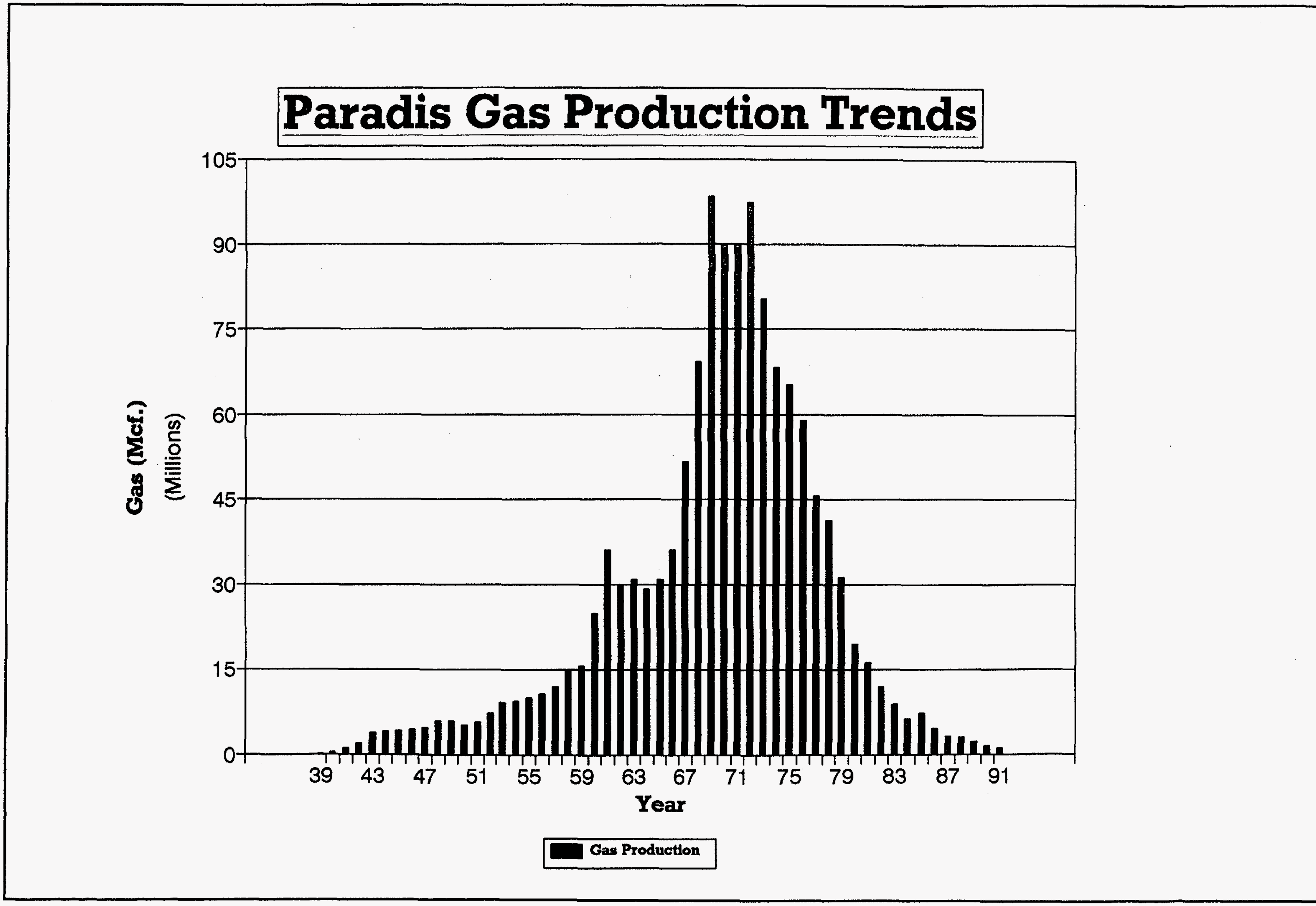

Figure 66. Gas production trends 1939 - 1991 Paradis field.

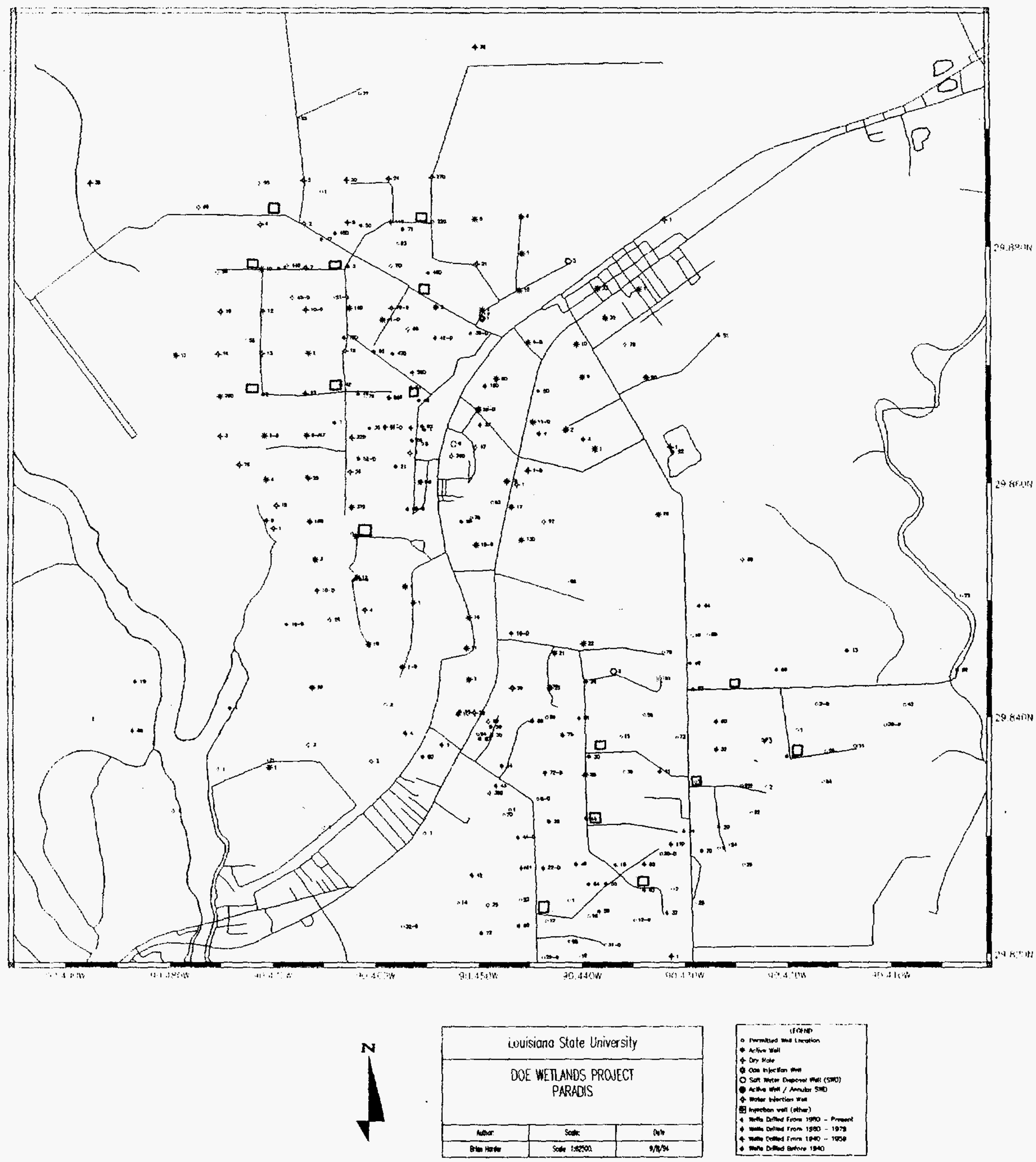

Figure 67. Surface map of Paradis field.

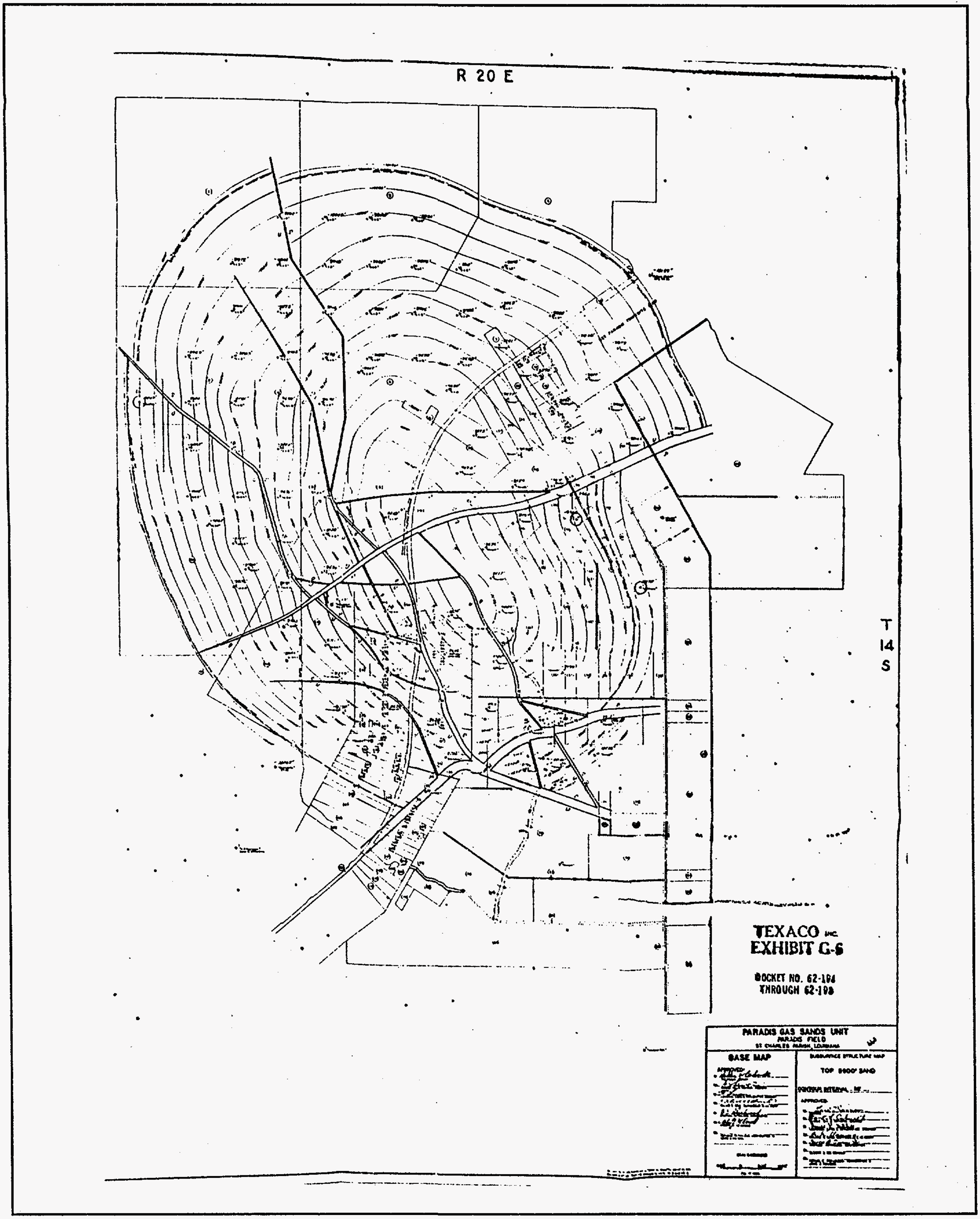

Figure 68. Structure map of 9900' Paradis field. (Louisiana Department of Natural Resources, Office of Conservation Hearing files Docket 62-194)

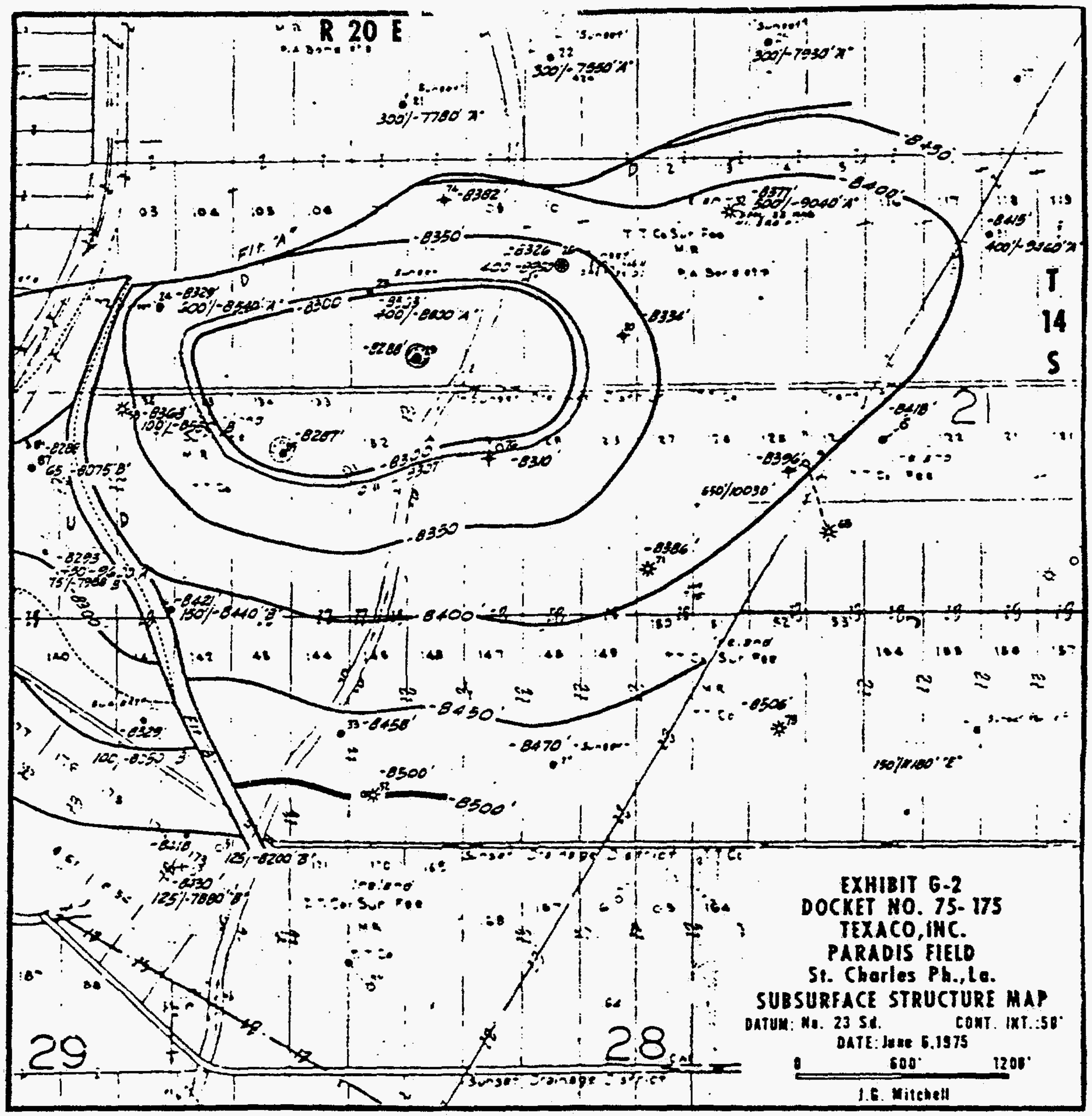

Figure 69. Subsurface map of 23 sand Paradis field. (Louisiana Department of Natural Resources, Office of Conservation Hearing files Docket 75-175)

Table 18. Land cover area for Paradis for 1984 in square meters (from Coastal Management Division, Louisiana Department of Natural Resources)

LAND COVER	1984	Percent Cover
Wetland		
Marsh	2,199,577	5
Fresh Marsh	7,685,710	16
Brackish Marsh	0	0
Broken Marsh	2,272,043	5
Forest	6,053,365	13
Swamp	7,603,249	16
SS/ Spoil	637,196	1
Mixed vegetation	1,323,118	3
Agricultural	12,302,884	26
Developed	2,282,038	5
Water	4,596,558	10

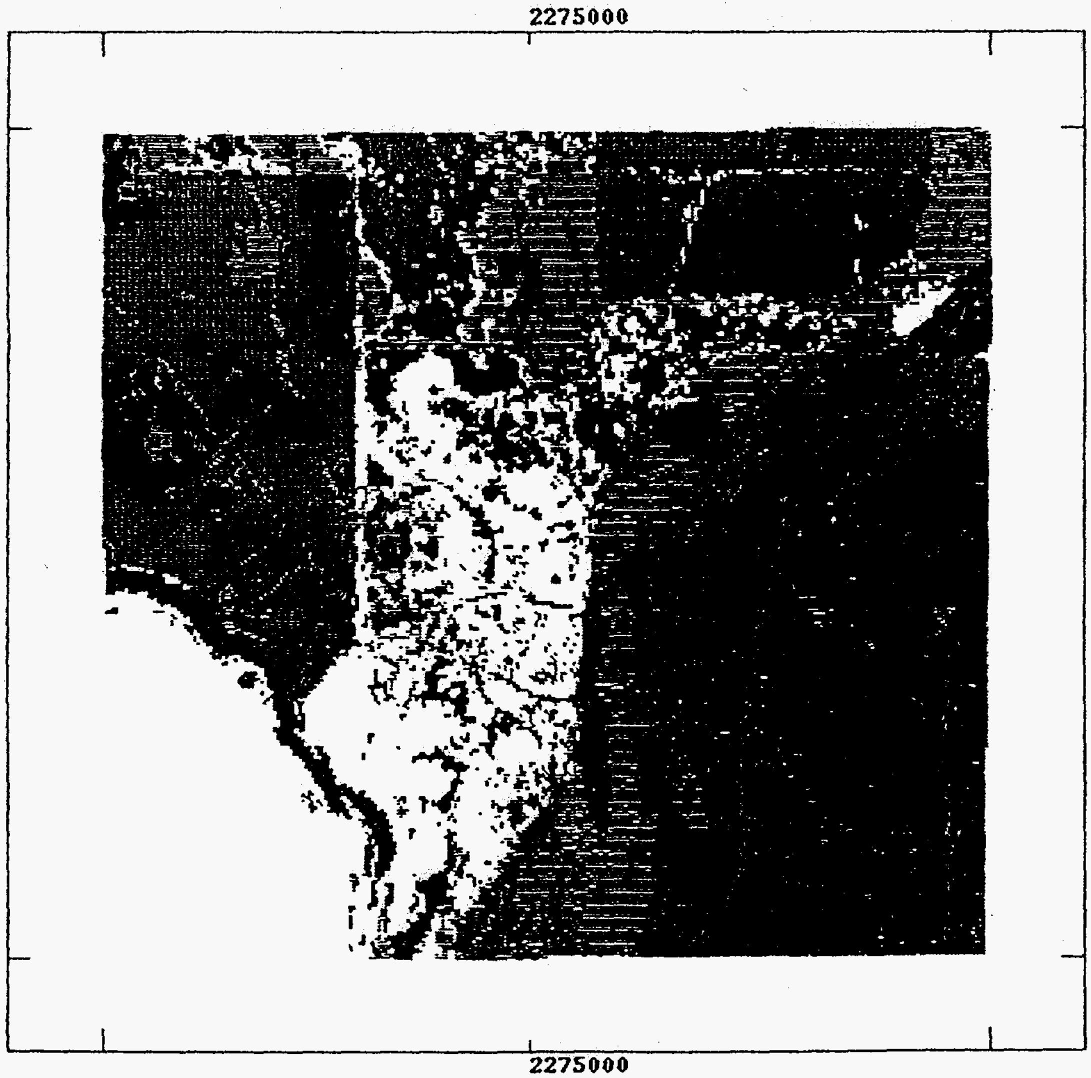

Figure 70. Land cover area for Paradis oil field in 1984.

Port Barre

Port Barre field is located south of Opelousas, Louisiana, in the south central part of the state in St. Landry Parish. The field lies on the west bank of Bayou Teche in a fresh area consisting of bottom and hardwood, swamp and marsh. This field is not located in Louisiana's coastal zone. The Port Barre field was discovered in 1929 and produced more than 61 BCF of gas and 53 million bbl of oil (table 13). The field is a salt dome feature with numerous flank reservoirs as well as shallow reservoirs developed above the top of the salt. Depth of production ranges from 2,500 to 13,900 ft (762 to 4,237 m). Early production was centered in sands from the Pliocene, Miocene, Heterostegina, Marginulina, Cib. Hazzardi, Marginulina texana, Nodosaria blanpiedi, Frio, Sparta and Wilcox sands (Stipe 1960). Units formed produce from seven sand packages, and 153 units have been formed by the Office of Conservation. Gas production peaked in 1964 and oil production peaked 1976 (figure 71).

Like most mature fields in south Louisiana, production in this fields shows classic decline behavior. Production peaks and begins a gradual decline as reservoirs deplete. In this case the decline curves are distinct for each production time frame. Early production peaked in 1964 and began to decline. New wells were drilled to the Wilcox in the 1970, which again increased production peaking in the mid-1970s and then declining rapidly. In the early 1980s an aggressive drilling program began on the shallow sands around 2,500 ft (762 m) and in-fill drilling to collect bypassed oil in the Wilcox was attempted. The aerial extent and reserves found were not significant enough to change the long-term decline of the field and depletion of this field will soon occur.

The surface map of the field is shown in figure 72. A map of the top of salt found in the Port Barre field (figure 73). The surface map development mirrors the top of the salt. Earliest development occurred on the top of the dome because the salt uplift is not in wetlands at the surface. Flank development proceeded to the west in 1930s, and with individual wells drilled to the east. Several shallow anticlinal reservoirs separated by sealing faults exist on the top of the dome. Production on top of the dome has proceeded throughout the life of the field with the latest reservoirs being completed in 1985.

The general structural pattern of the numerous flank reservoirs is represented by the map (figure 74) showing of a portion of the Futral sand. Additional reservoirs exist on all flanks of the dome at this level. Development in the wetland areas of the northern and eastern flanks occurred in 1940s and a later round of development in 1960s. Directional wells were use in the later round of development for structural reasons not environmental considerations.

Development of the field could have occurred with less damage to the parts of the field in wet areas on the northern and eastern flanks. By using a series of multi-well pads (shown in red on surface map) development of the field could have occurred with minimum impact on wetland areas. Because of the deeply dipping nature of the salt directional wells following the salt face could encounter multiple pay sands if carefully planned.

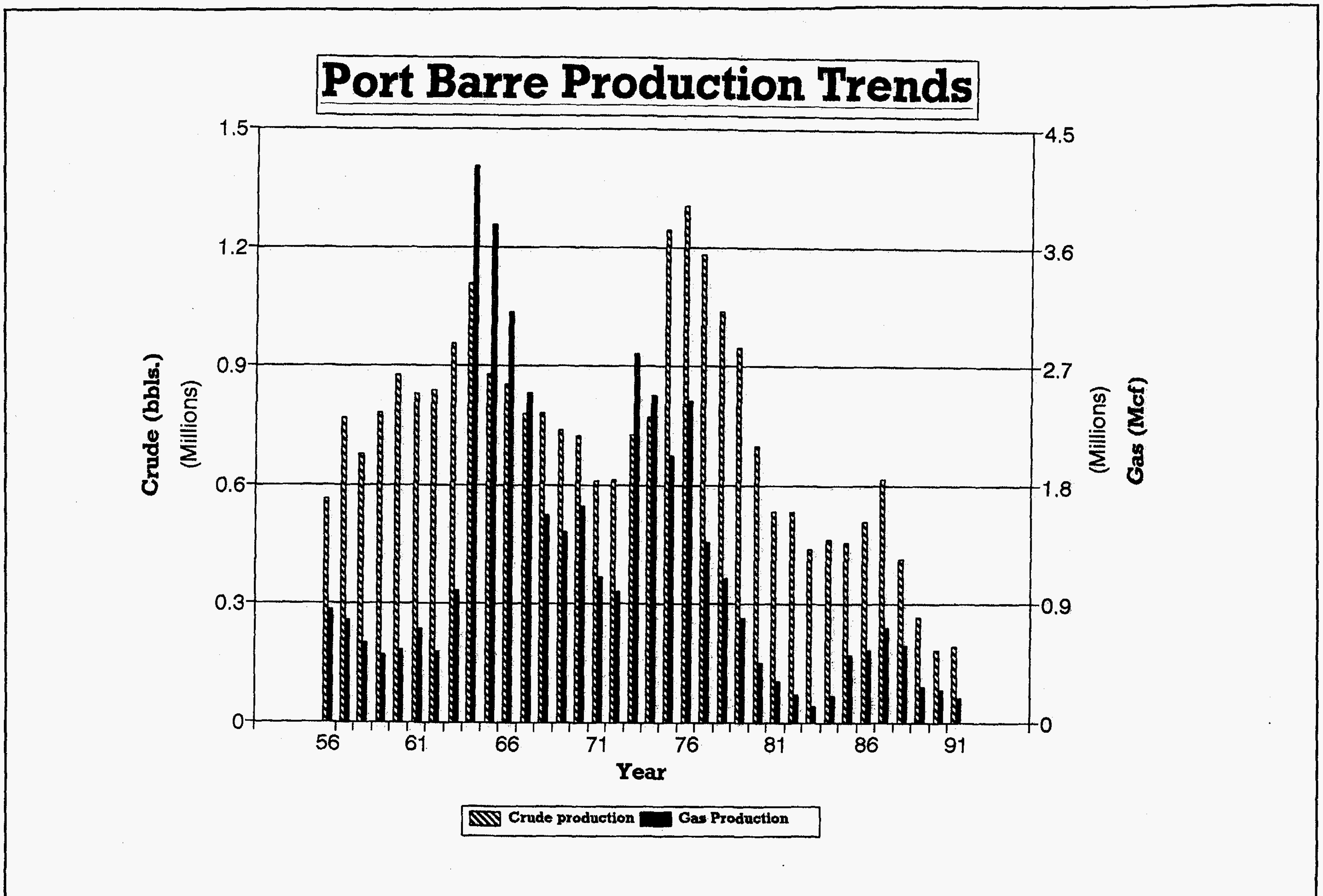

Figure 71. Production trends of Port Barre field 1956 - 1991.

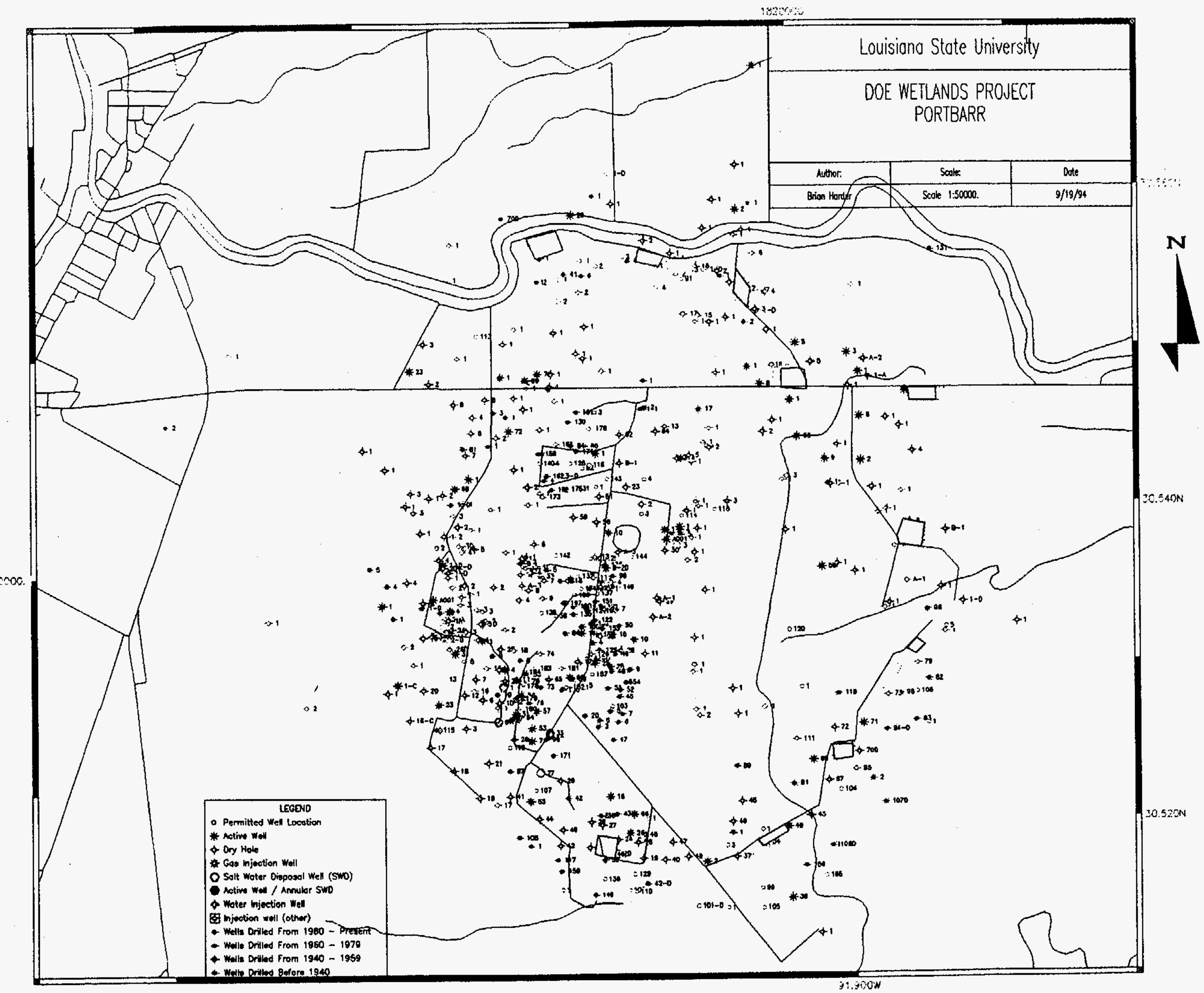

Figure 72. Surface map of Port Barre field color coded by discovery date.

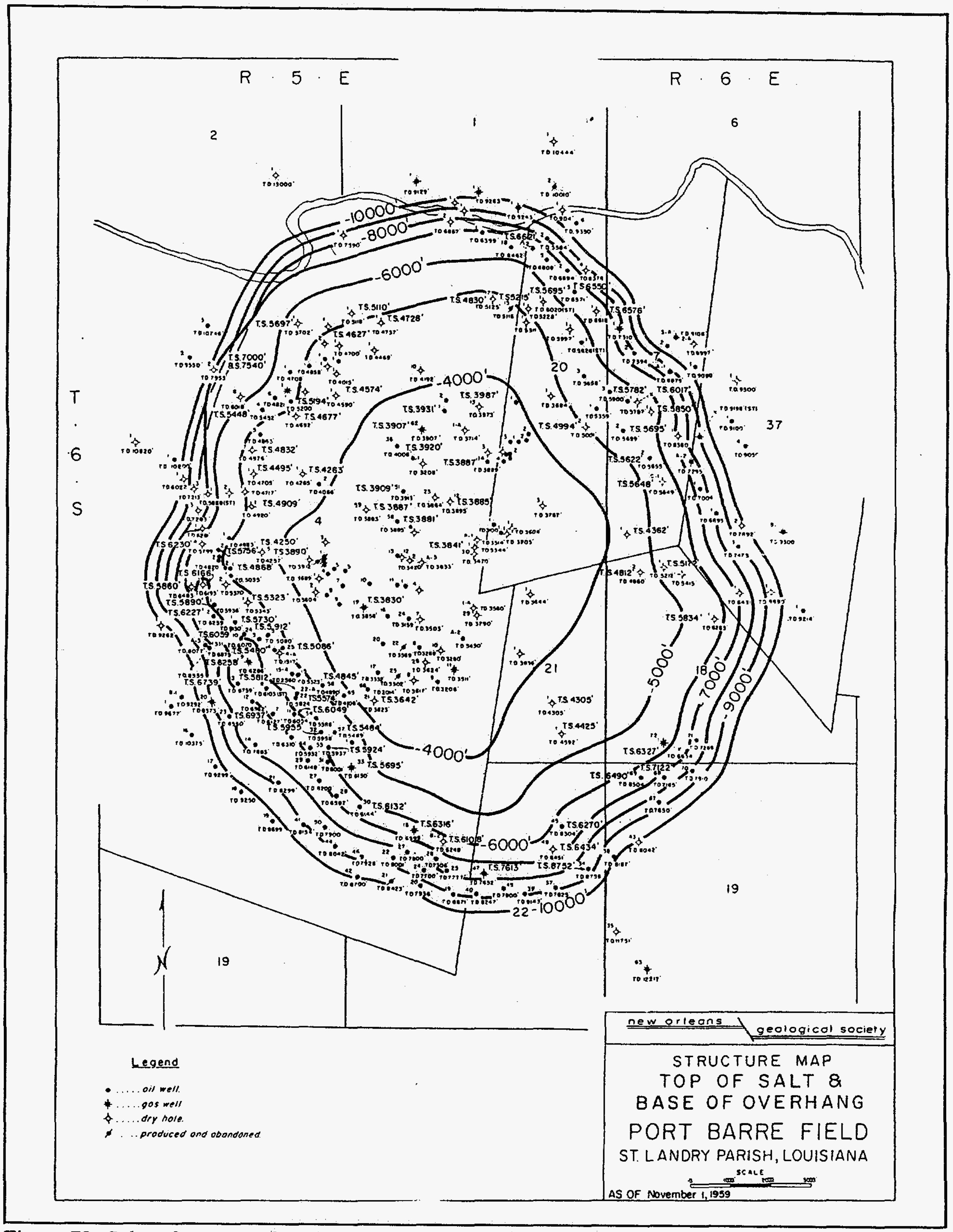

Figure 73. Subsurface map of top of salt found in Port Barre field. (from Stipe 1960)

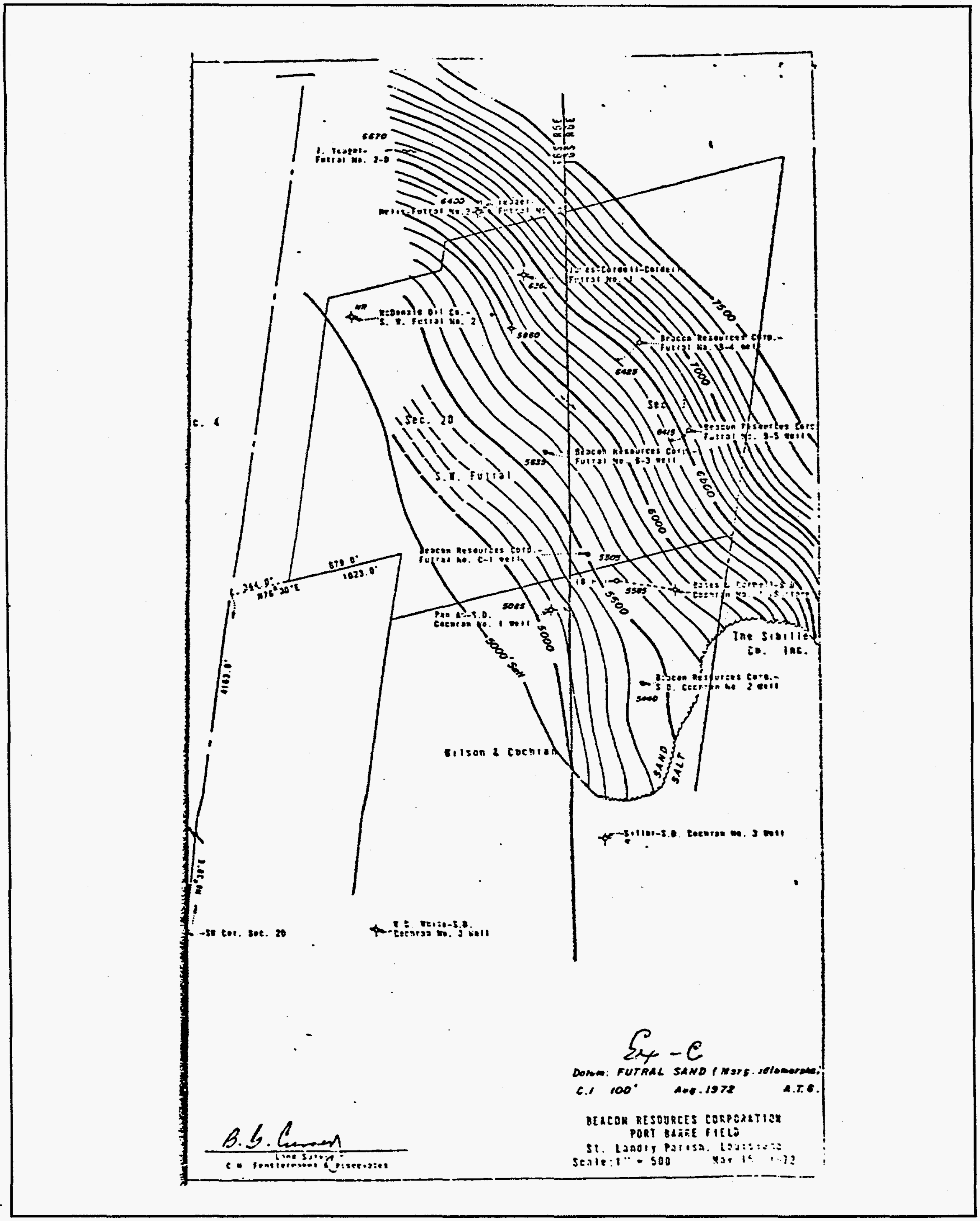

Figure 74. Subsurface map of Futral sand Port Barre field. (Louisiana Department of Natural Resources, Office of Conservation Hearing files Docket 72-349)

South Black Bayou

The South Black Bayou field is located in intermediate marsh just north of the Sabine National Wildlife Refuge in Cameron Parish in southwestern Louisiana. The field is located in the coastal zone and has produced almost 9 million bbl of oil and 24 BCF of gas since 1969 (table 13).

South Black Bayou field is a flank discovery of the Black Bayou salt dome field and was discovered in 1969. The field is southeast of Black Bayou and produces from the Frio series of sands with the *Marginulina howei*, Camerina "A" and "B" and Upper Hackberry sands also found productive in the field (Stipe 1960). Since its discovery 56 wells have been drilled to delineate the various reservoirs, and the Office of Conservation has created 17 producing units. The field is a series of faulted anticlinal discontinuous reservoirs trending along an east-to-west line paralleling the coast. Oil production peaked in 1970 and gas production peaked one year later (figure 75).

The production curves show decline behavior evident from 1972–1981 as the Camerina "B" sand was depleted. From 1981 onwards several new wells were drilled to the Upper Hackberry with the drilling program completed in 1986. Steady decline is evident since then and no new wells have been drilled.

Surface development features (figure 76) show two major road systems allowing field development. The reservoirs are volumetric in nature and from two to three individual fault blocks are produced from each of the various sand horizons. The structure map (figure 77) of the Upper Hackberry zone shows how the field relates to the Black Bayou salt dome and field. Development is not related to the dome but to the sealing faults shown to the south.

The Camerina "B" sand the first sand produced in the field in 1969. The subsurface map of this horizon is shown in figure 78. Production is from the various fault blocks running east to west and paralleling the coast. The trapping fault is fault "B" as shown in subsurface map.

Future production may exist in deeper horizons currently being evaluated, and this area is a prime area for development using 3-D seismic techniques. The field is entirely in wetlands and any new development will require extensive planning to minimize damages by using existing well locations and previously impacted areas.

Early development of the field was unregulated; however, later development in the 1980s was subject to wetland regulations this has limited the number of roads built in the marsh. Development in the 1980s used the existing roads from the 1970's for access. Directional drilling has been used but because of the high pressures encountered below, the Camerina sands development of the Upper Hackberry Formations was done with straight holes.

Future development of the deeper horizons below may be limited by the inability of the company to access potential well locations because of current regulatory requirements. Future wells because of the high pressures that will be encountered below the Upper Hackberry will be unfeasible to directionally drill. Alternate access will be required to develop wells to the south if wetland losses are to be minimized. Use of hovercraft to access possible locations in this area would be technically feasible because of the marsh environment.

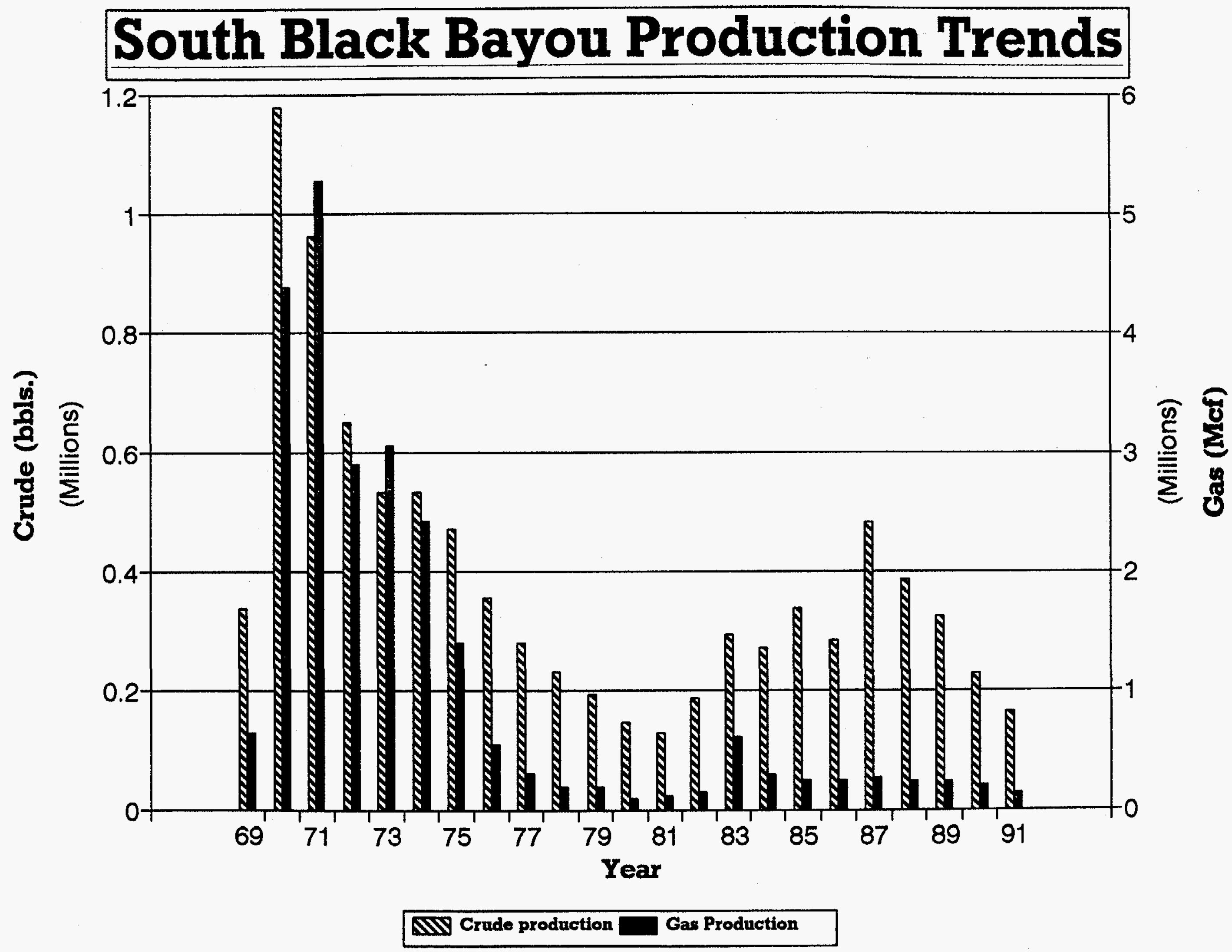

Figure 75. Production for South Black Bayou field 1969 - 1991.

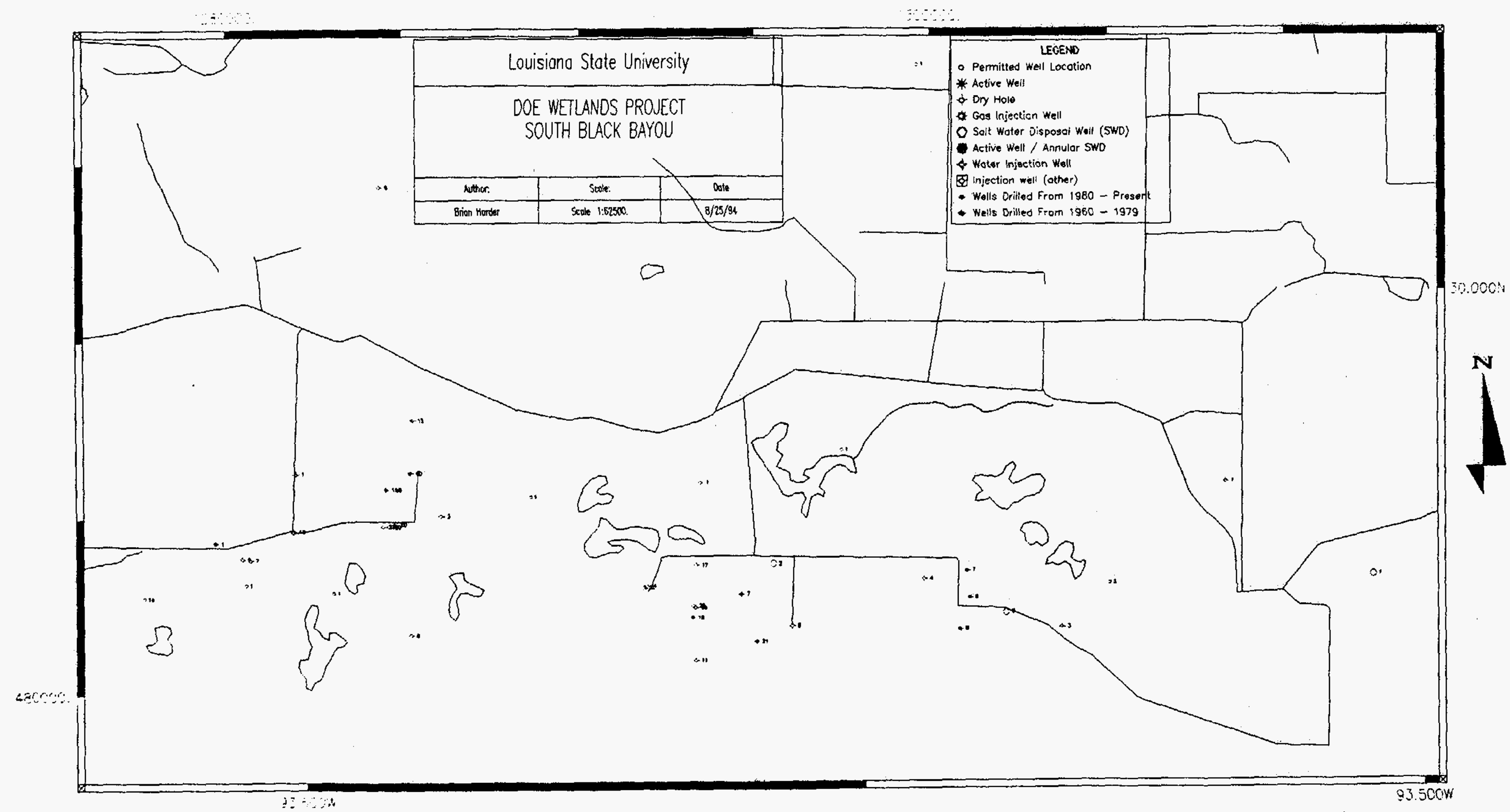

Figure 76. Surface map of South Black Bayou field.

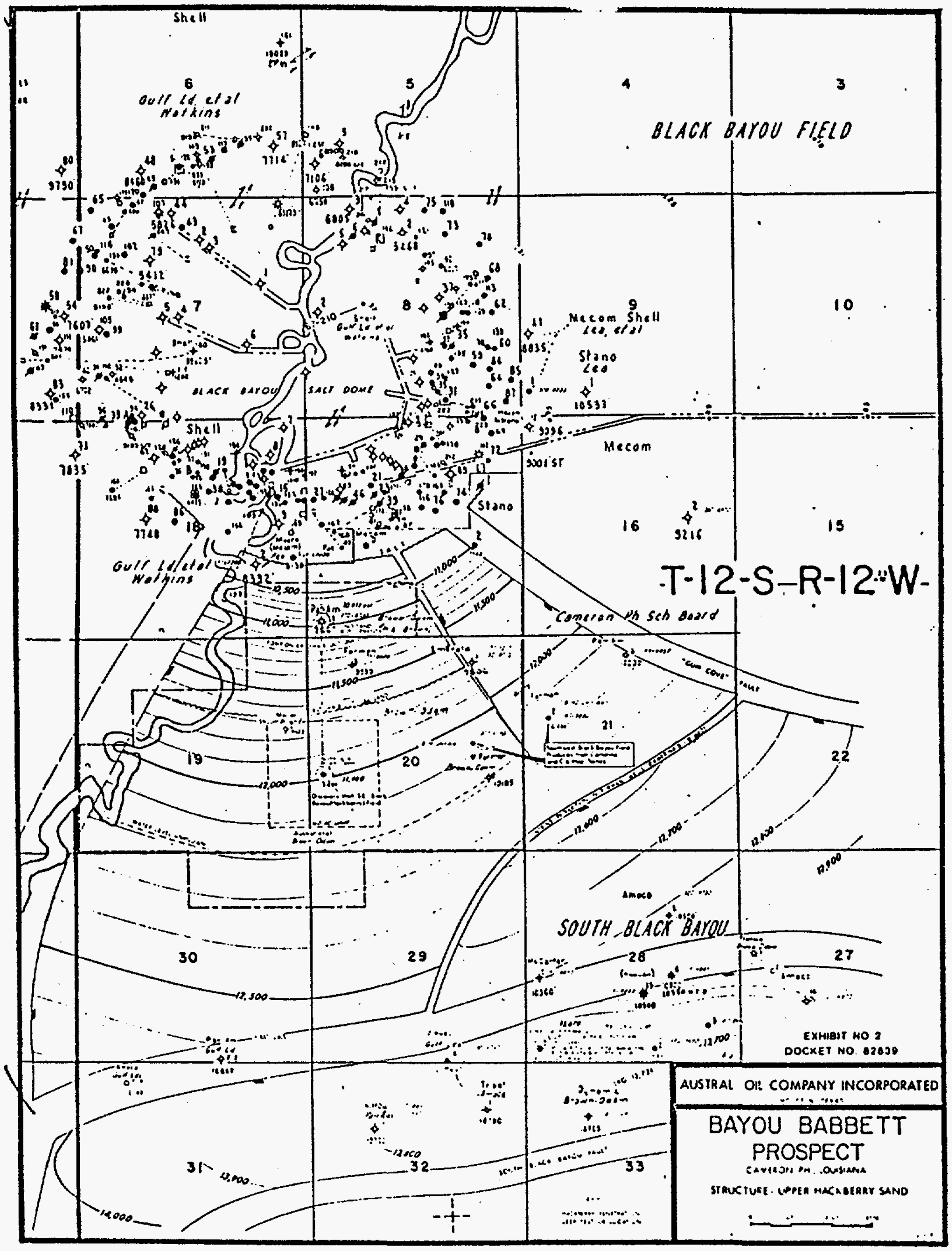

Figure 77. Subsurface map of Upper Hackberry sand South Black Bayou field (Louisiana Department of Natural Resources, Office of Conservation Hearing files Docket 82-839).

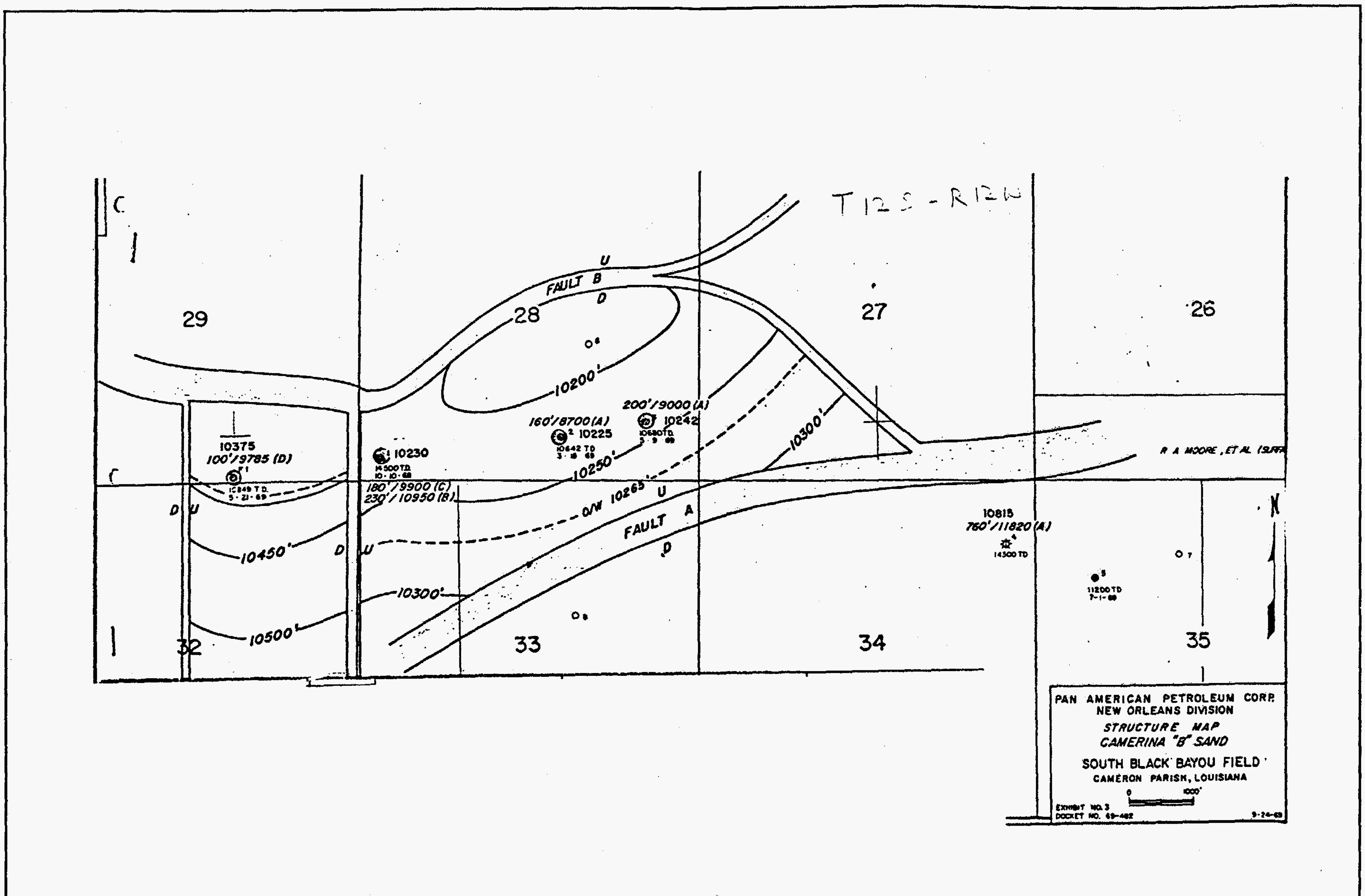

Figure 78. Subsurface map of Camerina "B" sand South Black Bayou Field. (Louisiana Department of Natural Resources, Office of Conservation Hearing files Docket 69-482).

Weeks Island

Weeks Island field is located about 20 miles south of New Iberia in the intermediate marshes of south central Louisiana in Iberia Parish. The Weeks Island salt dome is a piercement structure with the top of the salt at 43 ft (13 m) at its highest point on the top of the dome (Stripe 1960b, Waquespack 1983). This uplifting by the dome has raised the surrounding sediment creating what could be called an island. The island sits on coast of Louisiana with Weeks Bay to the west. Oil was first discovered at Weeks Island in 1897 by surface indications and seeps. Discovery of the salt dome occurred in June of 1897 with the drilling of F. F. Myles #4 well, but commercial oil production was not discovered until 1945 when the Shell Oil Co. #1 Smith - State Unit 1, which was drilled to a depth of 14,023 ft (4,274 m) (Stipe 1960b, Waquespack 1983). The field, which is located in Louisiana's coastal zone, has produced 243 million bbl of oil and 532 BCF of gas since 1945 (table 13). Production is concentrated on flanks; however, no production has been found on eastern flank. Northern and western flanks of the dome contain the bulk of the production from the field with the southern reservoirs being smaller in aerial extent. Productive sands are found from 5,600 to 19,500 ft (1,707 to 5,944 m). The field produces from more than 50 separate reservoirs and 183 units have been formed by the Office of Conservation. Oil production peaked in 1953 with gas production peaking in 1964 (figure 79). Several crude production peaks are present in this field with 1953, 1961, 1970, and 1987 being peaks for various stages of field development. Early liquids production was crude an later was primarily condensate.

Development proceeded around the dome as shown in the surface map of the field (figure 80). This field is made up of flank reservoirs surrounding the dome. To access these reservoirs and pay horizons human-made canals were dredged for access. Land access for oil exploration is limited however, land wellsites do exist on Weeks Island along the northern edge of the dome and are classified as upland because of the uplift caused by the salt dome.

Subsurface map of the top of salt is shown in figure 81. Note the northern edge of the dome dips almost vertically and high dip rates found around the dome. The subsurface structure of the north edge of the field is represented by figure 82 the "S " sand. The oil and gas is trapped against the salt and the reservoir is separated by faulting to east and west. The reservoirs found are strong water drives with gas caps. Pressure maintenance of the gas cap has been initiated on many of the reservoirs.

Deeper production along the north flank is shown in the " V4" sand shown in figure 83. Pressures found at this depth are normal and geopressure in the area is confined below 18,000 ft (5,486 m). Production of liquids is declining and gas production is rising as the deeper sands like the "V4" are produced. Weeks Island is mature, but deeper plays continue to be found in the field. Future development will occur when additional 3-D seismic that is currently being shot to cover the field is analyzed. Several deeper plays are currently under consideration for future development.

The environmental impacts of the past development of this field are significant. The canal systems created for access has allowed saltwater intrusion to the north and east affecting the existing brackish marshes. The marshlands that still exist are now saline marsh. Large areas have been opened to tidal ebb and flow. Because of the unique nature of the sub-surface pressure regime found in this area along the coast this destruction need not have occurred. Although numerous directional wells have been drilled in the field early development used mostly straight wells. Because normal pressures extend to 18,000 ft (5,486 m) all but the deepest sands now being developed could have been developed using directional drilling.

Development in the present regulatory environment would be much different. The portion of the field to the south could have been developed with wells from the non-wet areas on top of the dome and one or two multi-well canals or pads in the marsh to reach under the overhang from 6,000 to 12,000 ft (1,828 to 3,658 m) along the salt face. Development in the wet areas could minimize impacts by using discontinuous and disconnected canal systems and well pads from land locations to develop the field as shown in figure 84. Wells to the west could have been developed in open water requiring no new canals. The northern field could partially be developed from a land locations. Currently with no alternative access technologies in place a number of canals would have to be dredged to adequately develop this portion of the field. However, the use of parallel slips an careful route planning to minimize impacts could significantly reduce the areas impacted by these canals. Future development of this field can be done from existing canals and waterways. Limiting access by using alternative means should be explored for future development for this and other coastal fields in Louisiana.

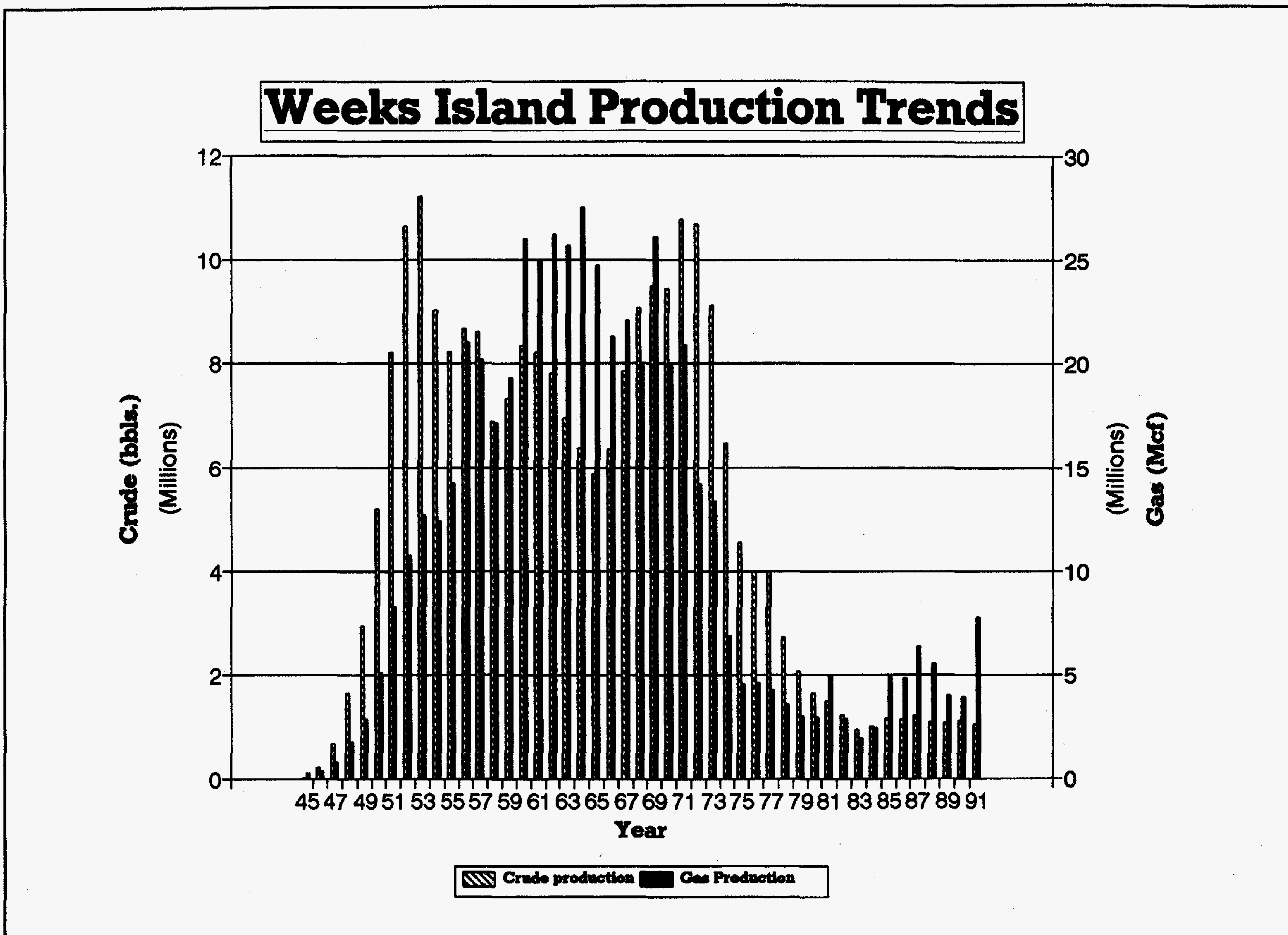

Figure 79. Production trends for Weeks Island field 1945 - 1991.

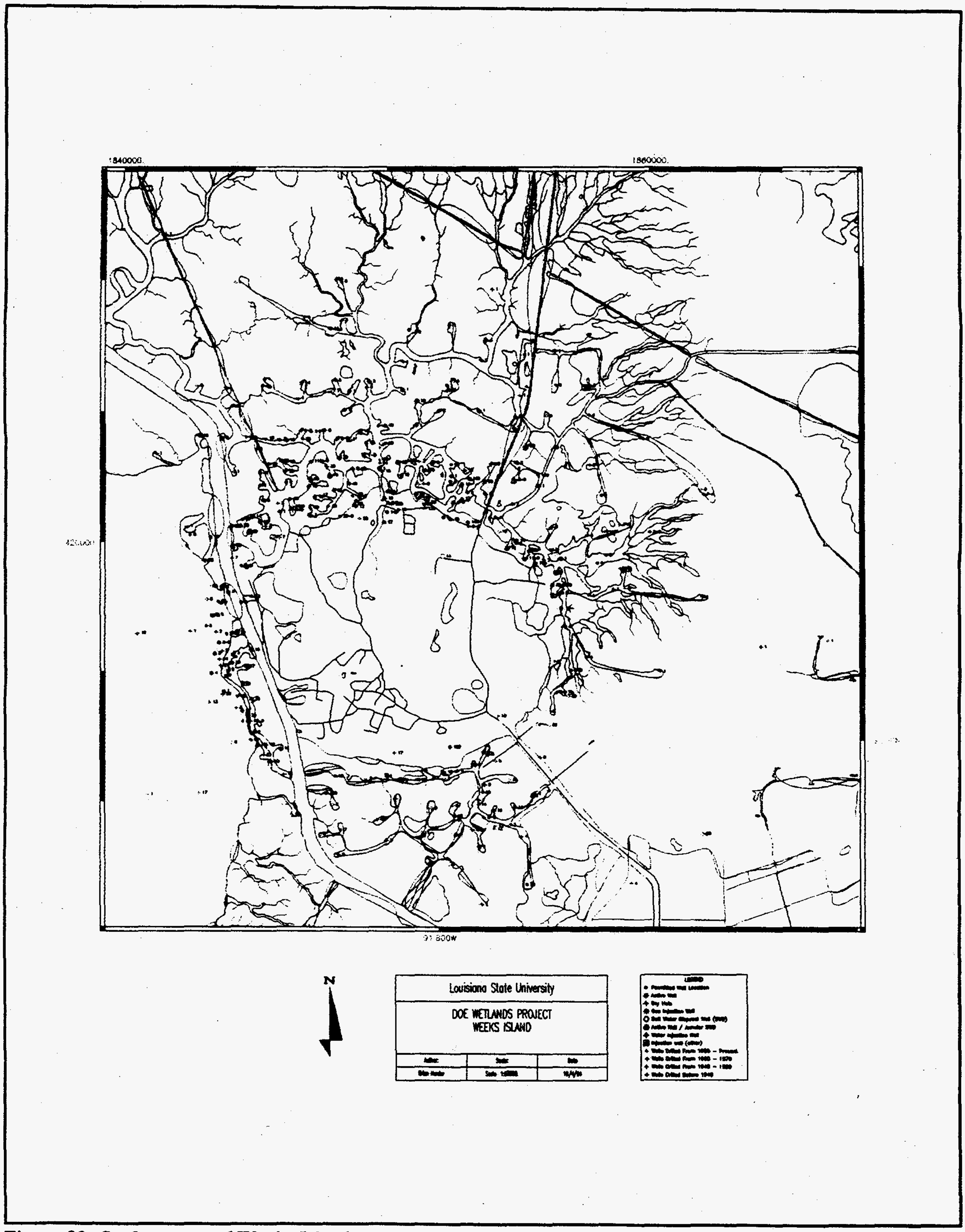

Figure 80. Surface map of Weeks Island.

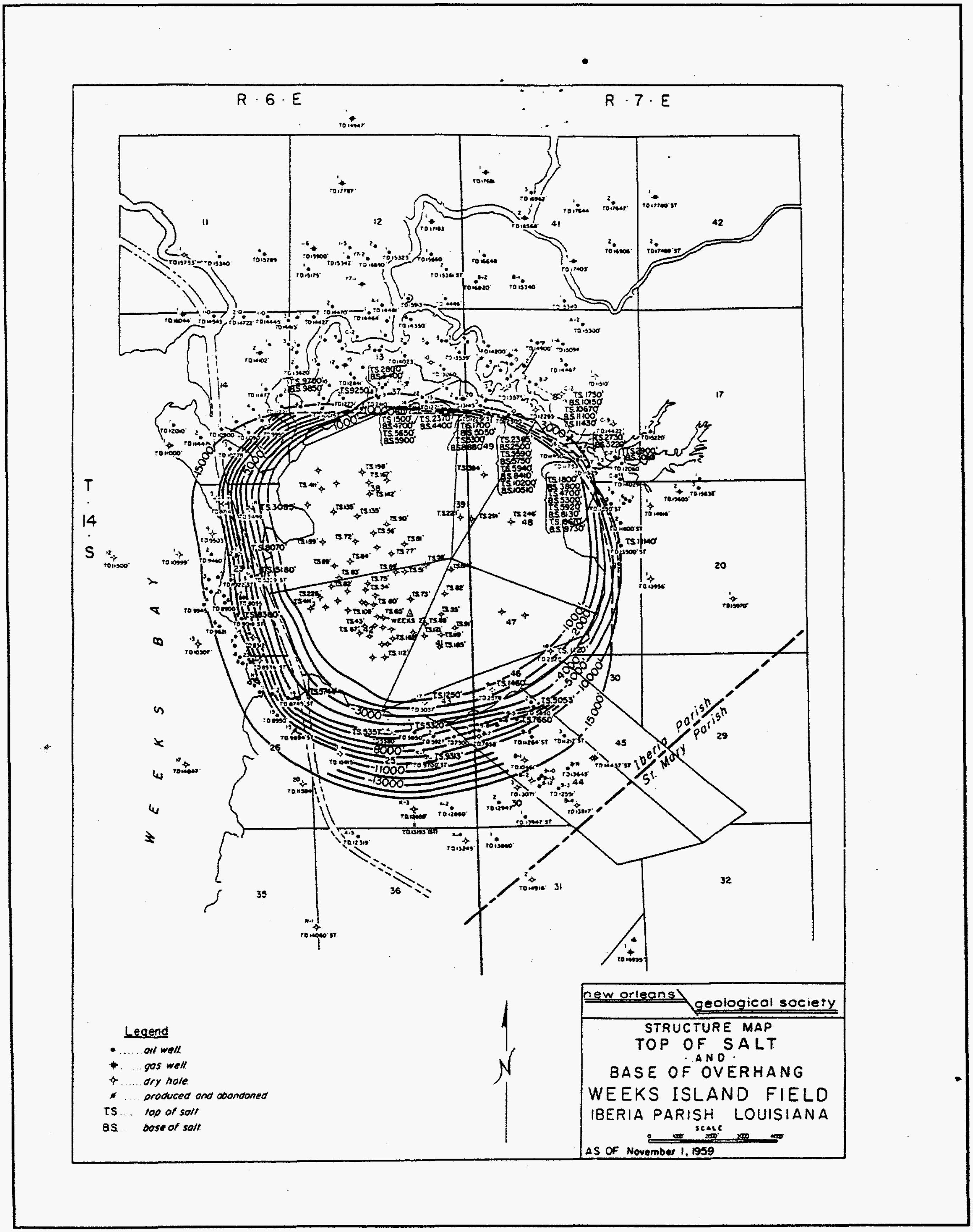

Figure 81. Subsurface map of the top of salt found in Weeks Island field. (From Stipe 1960).

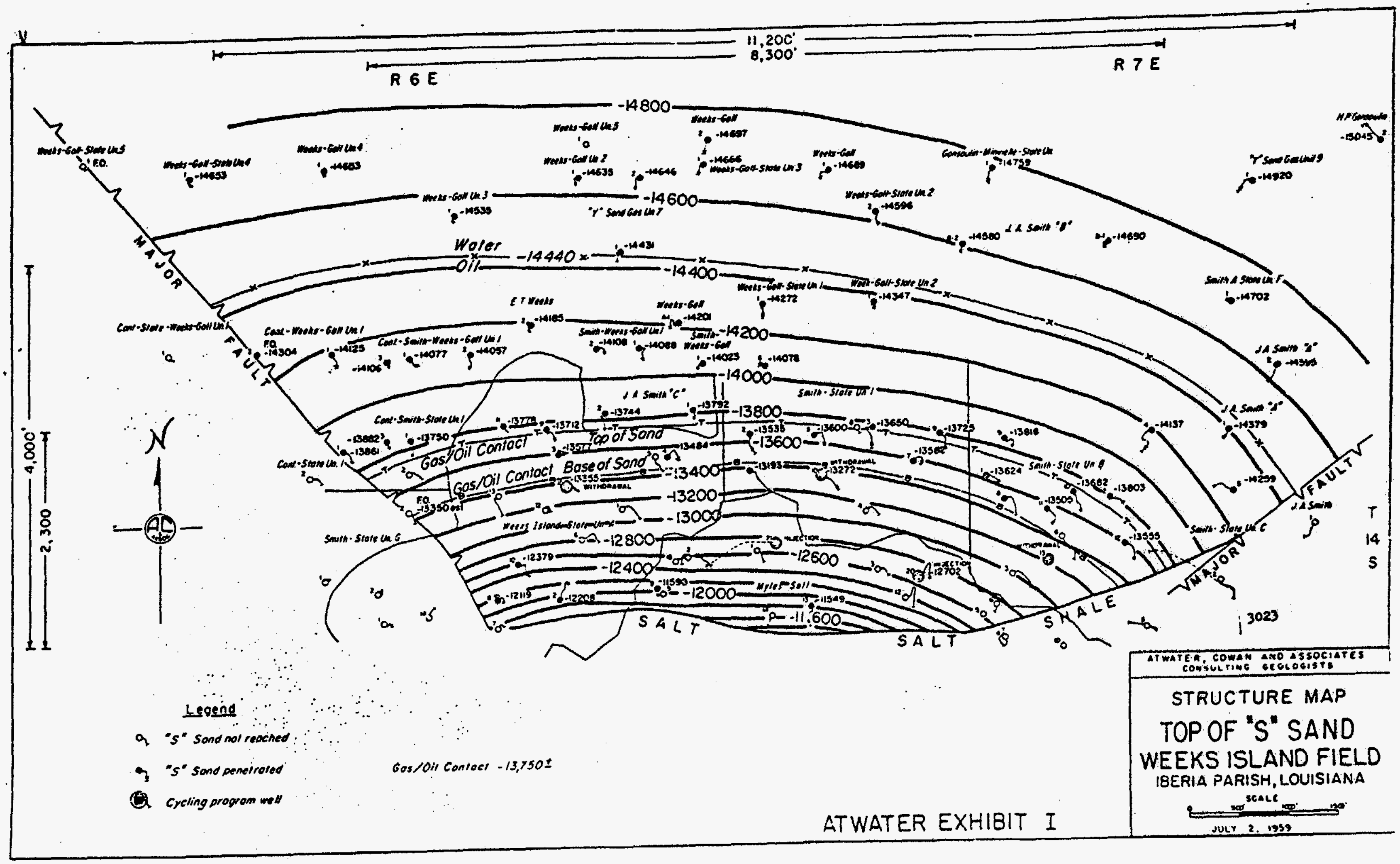

Figure 82. Subsurface map of "S" sand Weeks Island field. (Louisiana Department of Natural Resources, Office of Conservation Hearing files Docket 59-242)

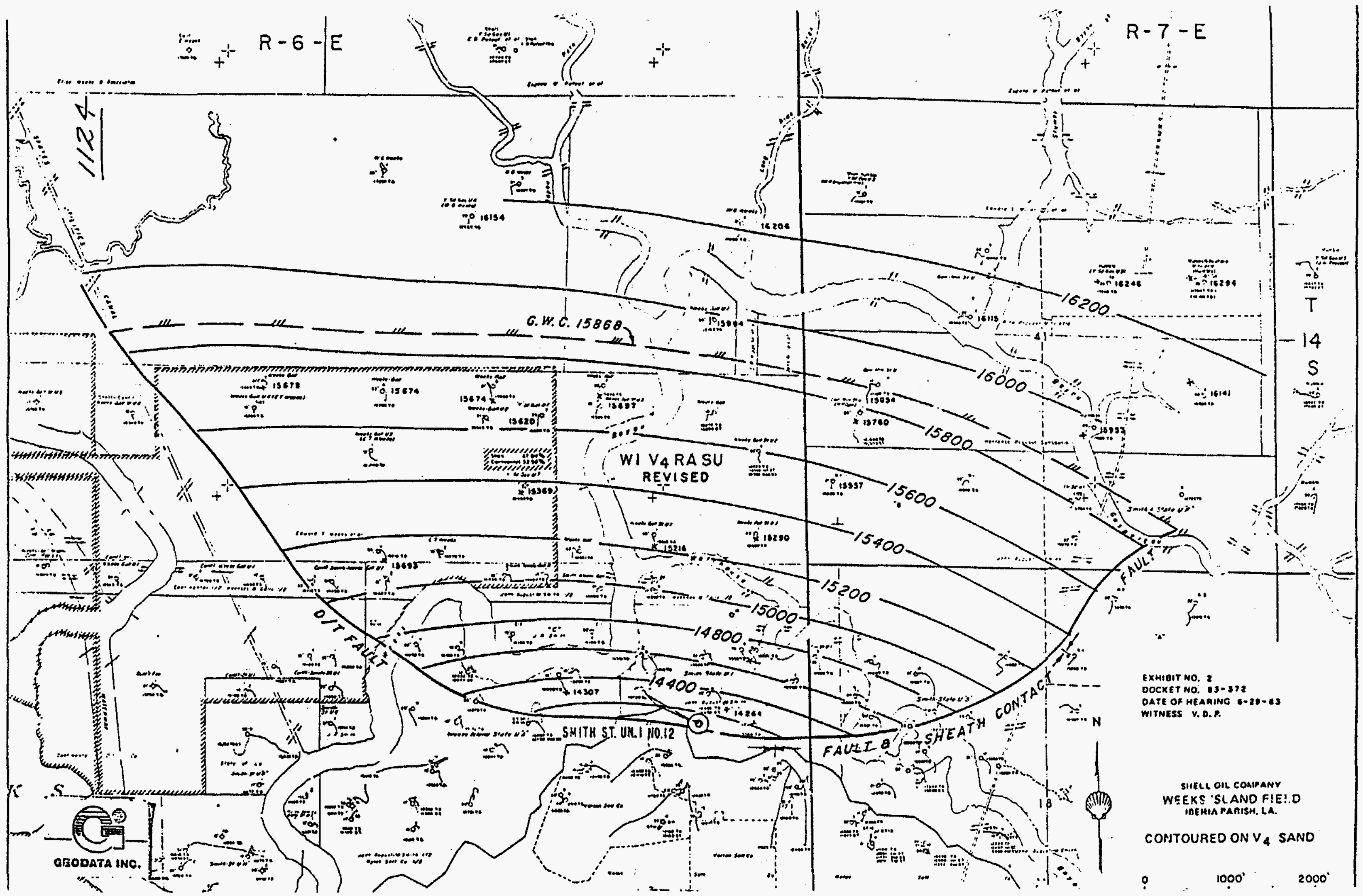

Figure 83. Subsurface map of "V4" Sand Weeks Island field (Louisiana Department of Natural Resources, Office of Conservation Hearing files Docket 83-372).

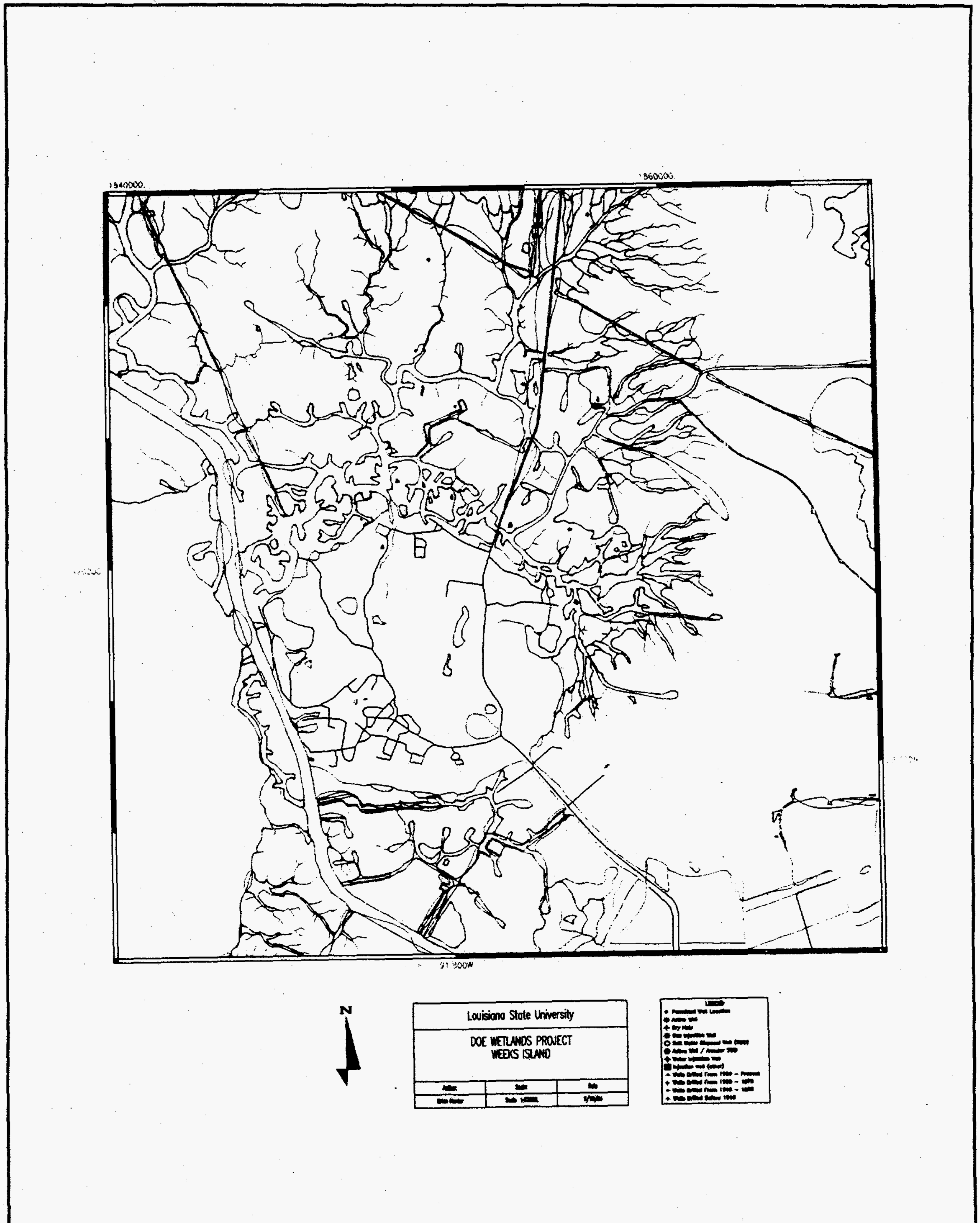

Figure 84. Possible surface location development scenarios for Weeks Island.

FUTURE WETLAND PRODUCTION

To estimate potential production trends and to estimate the number of future well locations in wetland areas we created econometric models to predict trends for north and south Louisiana. The overall goal of the models was to explain and predict exploratory drilling and estimate the number and size of fields that are expected to be found by a predicted drilling program. Therefore, two different but interrelated models are used. The models were developed by Farber and Dupont and an excerpted explanation of the models rationale from Farber and Dupont 1992 follows:

"The procedure used in this study is to first estimate undiscovered reserves. Figure 85 below shows the potential number of fields by field size relative to actual discoveries. Economic truncation limits observed discoveries to fields greater than size x. The problem is to estimate potential numbers of fields, by field size, from actual discoveries. A procedure developed by Attanasi and Haynes (1983) was used to make this estimation" (Farber and Dupont 1992).

"Next we estimate the number of fields, by size class, expected to be discovered as a result of a given amount of cumulative wildcat drilling activity. This estimate is also obtainable from the Attanasi and Haynes method, but is dependent upon the historic amount of drilling activity" (Farber and Dupont 1992).

"The basic method for estimating undiscovered reserves will be that of Attanasi and Haynes (1983), which is based on work by Drew, Schuenemeyer, and Bawiec 1982, and Arps and Roberts (1958). Known fields are divided into classes based on size (i.e., the number of barrels of oil known to be recoverable from the field) and arranged in order of discovery. There are stochastic and economic reasons why larger fields are most likely to be found first, and this is the basis for the method. To implement the method we used the following information: for each size class the average areal extent of the fields and the number found so far, the area of the "basin" (the area towards

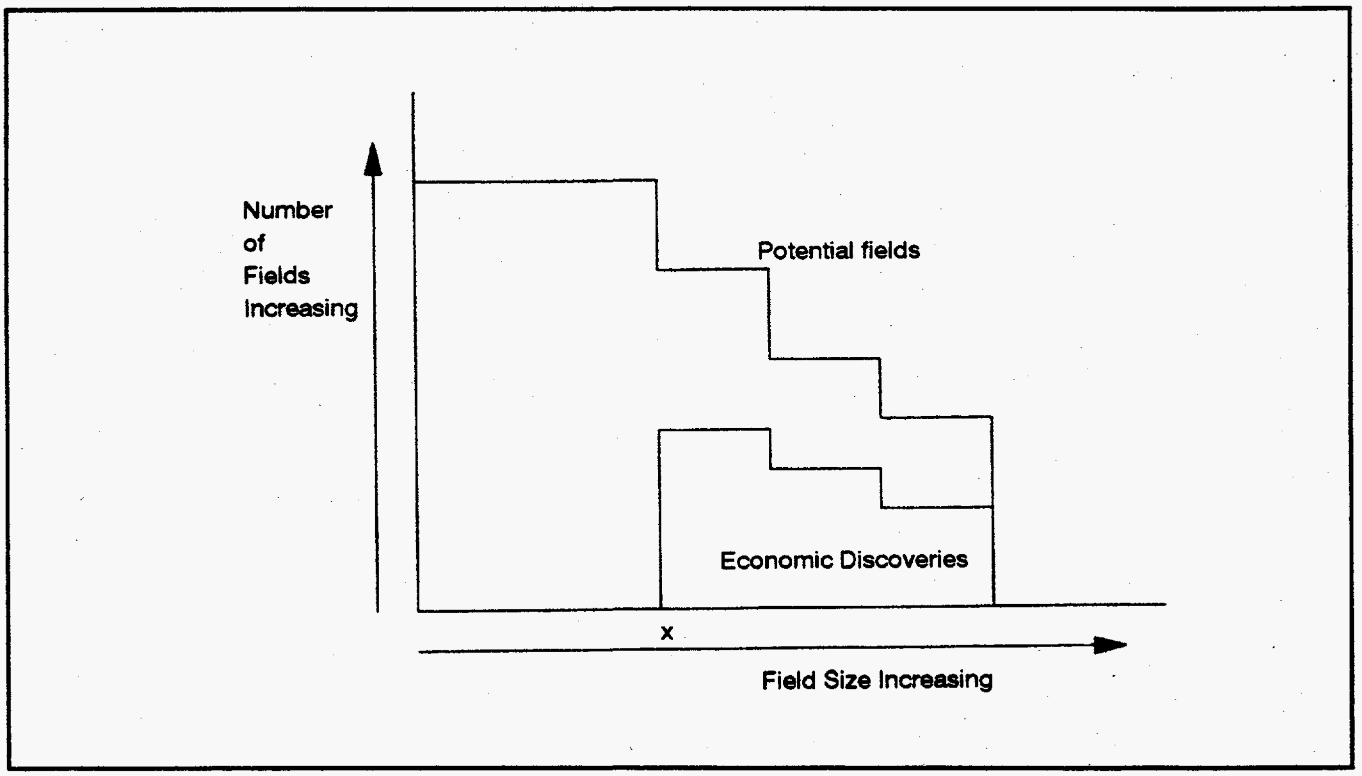

Figure 85. Relationship between potential fields and discovered fields. (Modified from Farber and Dupont 1992).

which this study is directed) and the cumulative number of wildcat wells drilled in the basin" (Farber and Dupont 1992).

The method assumes that "the proportion of undiscovered fields in a given size class declines exponentially as drilling continues" (Attanasi and Haynes 1983, p. 11). "We might also expect that the efficiency of discovery will vary across field sizes, and the model allows for that as well. Finally, we expect that certain smaller size classes may be affected by economic truncation. This means that while these fields have already been discovered they were not developed because it was not profitable. Hence, there are no data on these fields. By using the model on size classes which have not experienced this economic truncation, and by way of our assumption about the overall distribution of fields by size class, we can still estimate the number of fields in each size class remaining to be found,, regardless of economic truncation" (Farber and Dupont 1992).

"The following equation is used to estimate parameters:

$$1) F_i(w) = F_i(\infty)\,(1 - e^{-CiAiw/b})$$

where $F_i(w)$ is the number of fields in size class i discovered after w wildcat wells have been drilled, F_i(infinity) is the total number of fields in size class i. C_i is the drilling/discovery efficiency for size class i, A_i is the average areal extent of size class i and B is the basin size.
In making this model operational, we used the total number of wildcat wells drilled in the basin prior to discovery of each field. We used PROCNLIN in SAS with the METHOD=MARQUARDT option specified; this is a non-linear regression package which returned estimates for both the total number of fields in each size class and the efficiency of discovery for each size class" (Farber and Dupont 1992).

"Third we estimate expected exploratory drilling activity. This component is based on a statistical model of drilling activity developed by MacAvoy and Pindyck (1973, 1975)." This model predicts drilling activity in period 2 from the average size of new fields and the drilling success rate in period 1, as well as expected prices, and average drilling costs. At this point, the procedure becomes recursive, in that information from the second component of the model, discoveries by field size and success rates in period 1, are plugged into the third component to predict exploratory drilling activity in period 2, which then is plugged into the second component for a period 2 estimate of discoveries and success rates, and so on. The critical economic variables in the third component are expected prices and average drilling costs. Average drilling costs are expected to increase over time as drilling depths increase This important factor must be considered" (Farber and Dupont 1992).

"MacAvoy and Pindyck express total exploratory wells drilled in a given year as a function of the product of the average size of new finds, the success ratio for exploratory wells and an "expected" price, plus average total costs of drilling and the AAA bond interest rate. The "expected" price is just a moving average of the last three year's prices, and prices for oil and gas are included separately" (Farber and Dupont 1992).

The actual equation used is

$$W_t = \beta_0 + \beta_1 * Pr + \beta_2 * \mathrm{P} + \beta_3 * \mathrm{Q} + \beta_4 * \mathrm{C}' + \beta_5 * r$$

where W_t is the number of wells drilled in period t, Pr is the probability of success (which is itself a function of both current and cumulative drilling activity), P is the expected price path for oil and gas over the course of production in period t, Q is the expected size of oil and gas discoveries found from drilling undertaken in period t, C' is the derivative of the cost function with respect to current drilling , and r is an interest rate.

"The MacAvoy and Pindyck drilling model is used in conjunction with the Attanasi and Haynes procedure outlined above. By estimating the number of exploratory wells to be drilled in a given year, we use the Attanasi and Haynes equation, with the previously estimated total number of fields by size class and discovery efficiency by size class, to estimate the number of fields that will be found after w wildcat wells have been drilled. This procedure also allows us to estimate how successful exploratory drilling will be and we can use that in estimating the next round of exploratory drilling. Ultimately, this recursive procedure can be carried as far into the future as is desired, needing only a projected price path for oil and gas" (Farber and Dupont 1992).

North Louisiana

The estimate of the remaining undiscovered fields in North Louisiana conducted in a manner similar to that of Attanasi and Haynes (1983) (see also Arps and Roberts, 1958). This method assumes that fields are distributed log-normally by size (size meaning the total volume of hydrocarbons present in the field upon discovery) (see also Attanasi and Drew, 1985). Therefore, we studied the distribution of known fields after dividing the fields into nineteen reservoir size classes as shown in Table 19. Using this distribution and information on the average surface area of the fields in each class and the surface area of North Louisiana, it is possible to estimate the number of fields in each size class that remain undiscovered. This estimate is given in column four of table 19, and is represented graphically in figure 86. These results indicate that it is unlikely that any fields in size classes 1 through 5 (the largest size classes) remain undiscovered. This is merely a statistical reflection of the adage that the largest fields tend to be found first. However, it is possible that enormous numbers of fields in the smallest size classes may remain to be discovered at some future date.

One caveat is that some of the smaller fields may have already been discovered but not reported because they are not large enough under current economic conditions to be profitably developed and produced. This problem has been addressed in Farber and Dupont (1992) and Dupont (1993).

Table 19. Known and estimated fields in North Louisiana by class size.

NORTH LOUISIANA FIELDS			
CLASS	SIZE MILLIONS BBL	KNOWN	ESTIMATED
1	800	4	4
2	110	6	6
3	76	10	10
4	43	19	19
5	20	19	19
6	9.5	31	41
7	5.4	39	42
8	2.4	50	73
9	1.3	47	88
10	0.54	50	105
11	0.31	45	126
12	0.16	56	152
13	0.07	39	182
14	0.04	57	219
15	0.01	27	262
16	0.009	21	315
17	0.006	27	378
18	0.0021	21	453
19	<0.0019	25	544

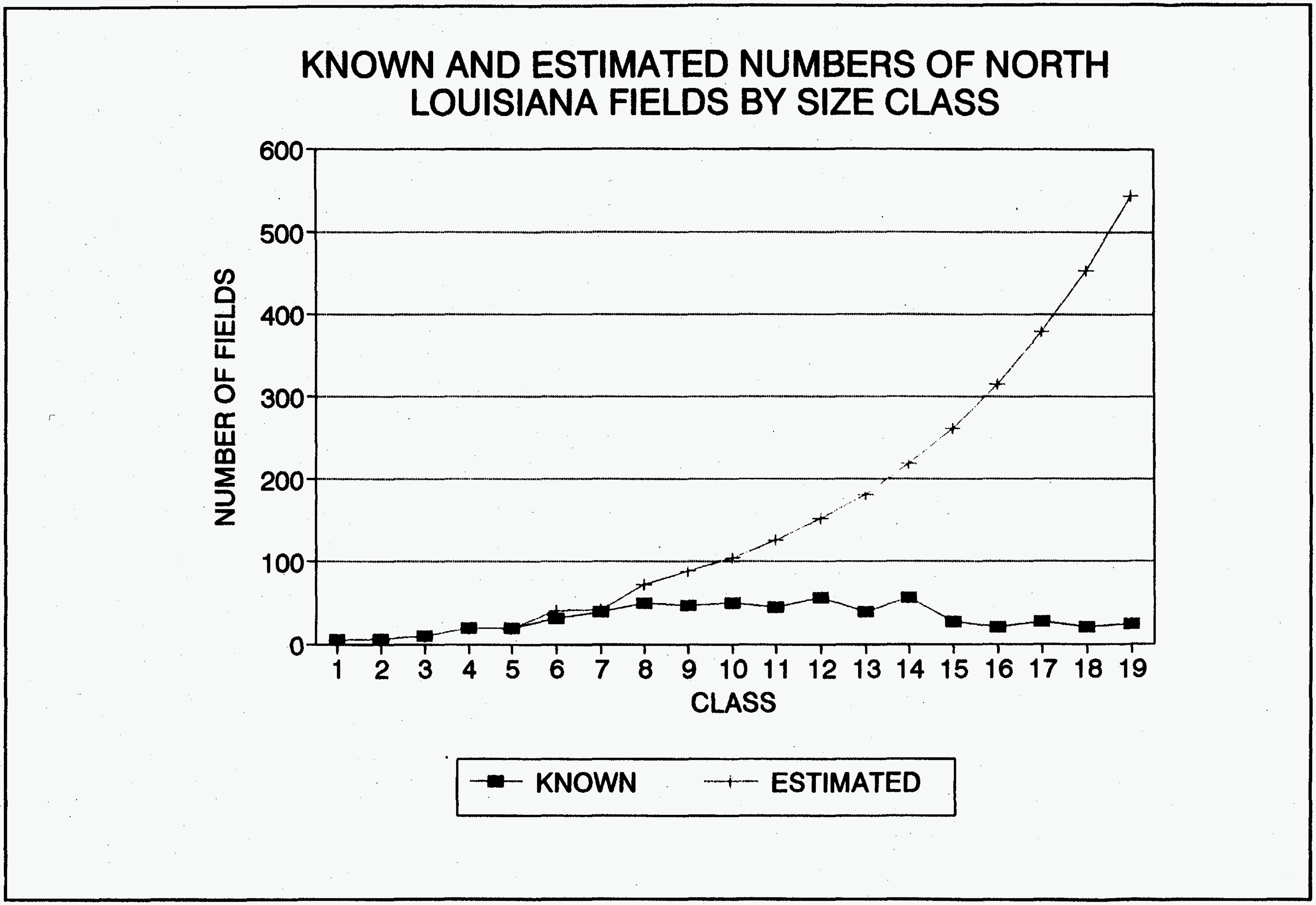

Figure 86. Distribution by class of known and estimated number of North Louisiana fields.

With an estimate of the remaining number of fields in North Louisiana and the size of these fields, it is possible to estimate the number of wildcat wells that will be drilled in a given year. This model starts with the assumption that drillers of wildcat wells are driven primarily by profit motivation, and that the primary explanation of drilling is the expected future price of oil and gas. Because prices and production vary between North and South Louisiana the weighted prices are calculated differently for each area. For North Louisiana combined real price (CRP) in dollars was calculated by adding the real gas price (RGP) using 1987 as a base year plus one/tenth of the real oil price (ROP) using 1987 dollars. This ratio was determined from past production ratios for oil and gas for North Louisiana. Other important variables are the size of the fields expected to be found and the success ratio of wildcat wells (given by the estimate of the number of fields remaining in each size class), the average drilling cost and the interest rate (see Megill, 1994). Expected future prices and success ratios are determined very simply by using immediate past values for these variables. Using past data for these variables, a regression was run to estimate the extent to which each variable influenced wildcat drilling. The results of this regression are reported in table 20.

The results are reported with their associated t-statistics (also called Student's statistic). These are two-tailed tests of the null hypothesis that the parameter is equal to zero. Relatively large numbers of the t-statistic lead us to reject the null hypothesis. In addition, a significance level is indicated based on the p value associated with the t-statistic. When a parameter is reported to be significant to the 0.05 level, that indicates a high level of confidence in the estimate. In addition, DW (Durbin-Watson) statistics are also reported. The Durbin-Watson Statistic is the result of a test for autocorrelation in the error terms. Generally speaking, a value of 2.00 for the DW statistic leads us to reject the hypothesis that autocorrelation is present, although the actual critical value will differ depending on various factors. For a review of regression analysis , see Judge et al (1988). For more details on the technical aspects of these models, see Dupont (1993), Pindyck (1978) and Camm, et al (1983).

Table 20. Drilling model regression results for North Louisiana.

DRILLING MODEL REGRESSION RESULTS	
Variable	Parameter Estimate (T- Statistic)
Intercept	254.28 (5.681)*
Combined Real Price	27.73 (5.681)*
Combined Size	-7.23×10^{-7} (-0.291)
Success Ratio	1228.68 (3.414)*
Average Drilling Cost	.001 (5.537)*
Interest Rate	-5983.20 (-8.479)*
Dummy	-205.38 (-5.030)*

From the regression we are able to obtain an estimate of the number of wildcat wells that will be drilled per year. We then analyzed the relationship between wildcat wells and total wells drilled finding a reasonable straight line correlation between the two. For North Louisiana the ratio was 11.5 wells were drilled for every wildcat well drilled. This relationship was used to calculate the low, medium and high ranges for total wells ("locations") shown in the tables. The results for North Louisiana are shown in the tables below. Table 21 is the low price scenario with the real weightequivalent (BOE) basis held constant to 1991 using 1987 dollars with a 1% real growth in interest rates and costs and a success ratio of 8%.

These results show that if price is constant and costs continue to rise, fewer wildcat wells will be drilled. The range low, medium and high are estimates of the total number of development well locations that will be drilled in North Louisiana for this price scenario. To estimate the number of wetland locations we only need to know the percentage of land in North Louisiana that is covered by wetland areas. Depending on the definition of wetlands used this can be from 20-50% of the area. According to the 1987 Corps of Engineers definition **(Wetland Habitats in Louisiana,** pg. 14), about 35% of North Louisiana is classified wetlands or 35% of the range of locations will be in wetland areas. If costs rise at a faster rate, because of changes in wetland regulations or other environmental regulations the decline in drilling in North Louisiana will continue at a faster rate than shown in Table 21. Since the drilling model is greatly affected by price we created two additional future price scenarios. One scenario has price, cost and the interest rate rising at a 1% annual real rate. The results of this forecast are presented in table 22.

These results indicate that higher real oil and gas prices do lead to higher levels of wildcat drilling, but the long-term outlook for North Louisiana continues to decline. This stems from the fact that North Louisiana is a mature producing province and unless some new technology lowers real drilling costs, or prices rise substantially the decline will continue. New technologies such as 3-D seismic and horizontal drilling may cause more wells to be drilled but the increased success ratio resulting from these technologies will tend to limit the number of wildcats because fewer wells will be needed to produce the same results.

The final forecast scenario has price increasing at 3.5% annual real rate, but costs and interest rates rising at a 1% annual real rate. Table 23 presents these results.

Table 21. Estimated range from low to high of well locations for North Louisiana using the low price scenario.

NORTH LOW		RANGE OF TOTAL LOCATIONS		
YEAR	WILDCATS	LOW	MEDIUM	HIGH
1993	84	907	966	1025
1994	77	832	886	939
1995	70	756	805	854
1996	62	670	713	756
1997	55	594	633	671

Table 22. Estimated range from low to high of locations for medium price scenario for North Louisiana

NORTH MEDIUM		RANGE OF TOTAL LOCATIONS		
YEAR	WILDCATS	LOW	MEDIUM	HIGH
1993	87	940	1001	1061
1994	82	886	943	1000
1995	77	832	886	939
1996	72	778	828	878
1997	67	724	771	817

From these results we can conclude that drilling will increase over the time frame shown in North Louisiana if large increases in price occur. As an illustration of this scenario's feasibility the combined real price (CRP) for north Louisiana rose 4.3% from 1991 to 1992 caused by a 9.9 % rise in average gas prices. Price rises of this magnitude usually do not continue. However, weather and regulatory changes may continue to increase real gas prices. Because of the heavy influence of gas prices on the CRP for North Louisiana, if oil prices stabilize or decline and gas prices continue to rise this scenario is possible for North Louisiana.

Table 23. Estimated range from low to high of number of well locations for high price scenario for North Louisiana.

NORTH HIGH		RANGE OF TOTAL LOCATIONS		
YEAR	WILDCATS	LOW	MEDIUM	HIGH
1993	92	994	1058	1122
1994	93	1004	1070	1135
1995	95	1026	1093	1159
1996	98	1058	1127	1196
1997	100	1080	1150	1220

South Louisiana

Results for South Louisiana were obtained using the same model. The known fields in South Louisiana were divided into nineteen reservoir class sizes and converted to barrels of oil equivalent (BOE) as shown in table 24. Using this distribution and information on the average area of the fields in each class and the area of South Louisiana, it is possible to estimate the number of fields in each size class that remain undiscovered. The estimated number of fields remaining to be found in each size class in South Louisiana are shown in table 24 and graphically represented in figure 87.

The distribution shown in figure 87 shows that the most probable fields that will be found in the future will be of class size six and below. South Louisiana has a greater potential to have new large fields than North Louisiana. Again the distribution allows us to estimate the future field class sizes for South Louisiana. Economical future fields in South Louisiana will be found between class size 6 and class size 12 using current price scenarios. For class sizes 13-15 possible development is marginal to uneconomic depending on costs. Most of the fields below class size 15 will be uneconomical to produce using current price scenarios.

Table 24. Known and estimated fields in South Louisiana by class size.

SOUTH LOUISIANA			
CLASS	SIZE MILLIONS BBL	KNOWN	ESTIMATED
1	800	17	17
2	110	24	24
3	76	25	25
4	43	48	48
5	20	54	54
6	9.5	41	48
7	5.4	50	58
8	2.4	32	50
9	1.3	33	55
10	0.54	19	66
11	0.31	15	79
12	0.16	15	95
13	0.07	11	114
14	0.04	9	137
15	0.01	8	164
16	0.009	5	197
17	0.006	5	236
18	0.0021	4	284
19	<0.0019	6	341

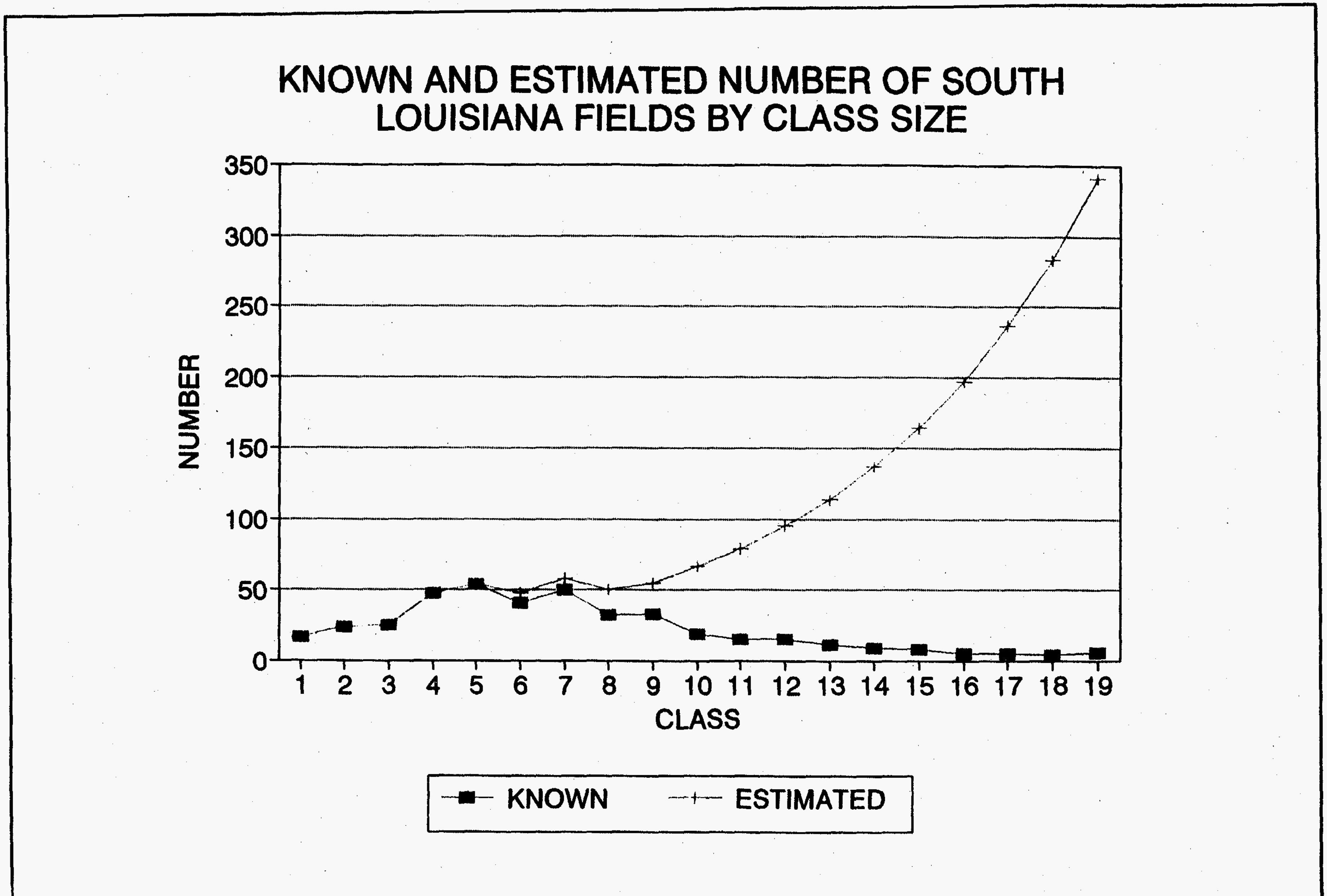

Figure 87. Distribution by class of known and estimated number of south Louisiana fields.

The same drilling model used for north Louisiana was used to estimate the number of wildcat wells drilled in South Louisiana. The results of this regression are shown in table 25.

Table 25. Drilling model regression results for south Louisiana.

DRILLING MODEL REGRESSION RESULTS	
Variable	Parameter Estimate (T- Statistic)
Intercept	166.25 (7.798)*
Combined Real Price	3.357 (2.569)**
Combined Size	2 x 10-6 (1.835)***
Success Ratio	252.66 (1.119)
Average Drilling Cost	1 x 10-5 (1.071)
Interest Rate	-770.35 (-2.248)**
Durbin-Watson	2.2559

* Significant at .01 level
** Significant at .05 level
*** Significant at .10 level

We were also able to estimate the total number of wells that will be drilled per year based on an estimated relationship between wildcat wells and total wells and the results are shown below for various price scenarios. To be consistent we followed the same format for south Louisiana fields. The ratio of wildcat wells to development wells found for south Louisiana was 7.1 development wells per wildcat well.

Table 26 is the low price scenario with the real weighted price on a BOE basis for 1991, using 1987 dollars as a base year, being held constant with a 1% annual real growth in interest rates and costs.

Table 26. Estimated range of locations from low to high for south Louisiana low price scenario.

SOUTH LOW		RANGE OF TOTAL LOCATIONS		
YEAR	WILDCATS	LOW	MEDIUM	HIGH
1993	58	399	411	422
1994	57	392	404	415
1995	57	392	404	415
1996	56	385	396	408
1997	55	378	389	400

Again as with north Louisiana the results show that if price is constant and costs continue to rise, fewer wells will be drilled. However, because South Louisiana is a younger producing area and large profitable fields can still be found the reduction in the rate of new drilling is less in than north Louisiana. This may be because the average cost of drilling on a per well basis in north Louisiana is $ 210,362 in real dollars vs. $1,458,794 for south Louisiana (Costs and indices for domestic oil and gas field equipment and production operations, 1987 through 1989). Because average drilling costs in south Louisiana are much higher than in the north, a 1% real increase in cost has a smaller effect drilling.

From the estimates of wildcat drilling we can then calculate a range for the total number of new locations that will most probably be drilled in south Louisiana per year. Again using the 1987 Corps definition of wetlands, about 75% of south Louisiana is considered wetlands and if urban areas are removed this percentage rises to 80%. Thereby 80% of the total locations will most probably be in wetland areas.

Because the drilling model is greatly affected by price, two additional price scenarios were created, table 27 shows forecast results for the "medium" scenario, in which price, cost and the interest rates all rise at a 1% annual rate.

Table 27. Estimated range of locations from low to high for medium price scenario for south Louisiana.

SOUTH MEDIUM		RANGE OF TOTAL LOCATIONS		
YEAR	WILDCATS	LOW	MEDIUM	HIGH
1993	67	461	474	488
1994	66	454	467	480
1995	66	454	467	480
1996	66	454	467	480
1997	65	447	460	473

The results show that the number of locations will remain constant or decline very slowly if costs and prices increase at the same rate. Small increases in price will not cause an increase in drilling.

Forecast results for the "high" scenario are shown in table 28. The "high" scenario has price rising at a 3.5% annual real rate with costs and the interest rate rising at a 1% annual real rate.

North Louisiana drilling is heavily influenced by gas prices whereas south Louisiana drilling is only slightly influenced by gas prices. Oil prices in south Louisiana are a significant part of the weighted price. Therefore, large increases in both oil and gas prices will be needed to increase drilling in south Louisiana. The CRP for south Louisiana actually declined 1.9% from 1991 to 1992. This decline is not encouraging for operators engaged in wildcat drilling. Technological innovation such as 3-D (three dimensional) seismic and horizontal drilling that reduce average drilling cost could increase drilling rates. in the short term. However, south Louisiana is reaching maturity and over time declines in exploration are inevitable. Changes in environmental and wetlands regulation that raise drilling costs will certainly contribute to this secular decline.

Similar results have been forecast by Megill (1994) in his explanation of how future prices effect exploration.

Table 28. Estimated range of well locations from low to high for high price scenario for south Louisiana.

SOUTH HIGH		RANGE OF TOTAL LOCATIONS		
YEAR	WILDCATS	LOW	MEDIUM	HIGH
1993	79	544	559	575
1994	80	550	566	582
1995	81	557	573	590
1996	82	564	581	597
1997	83	571	588	604

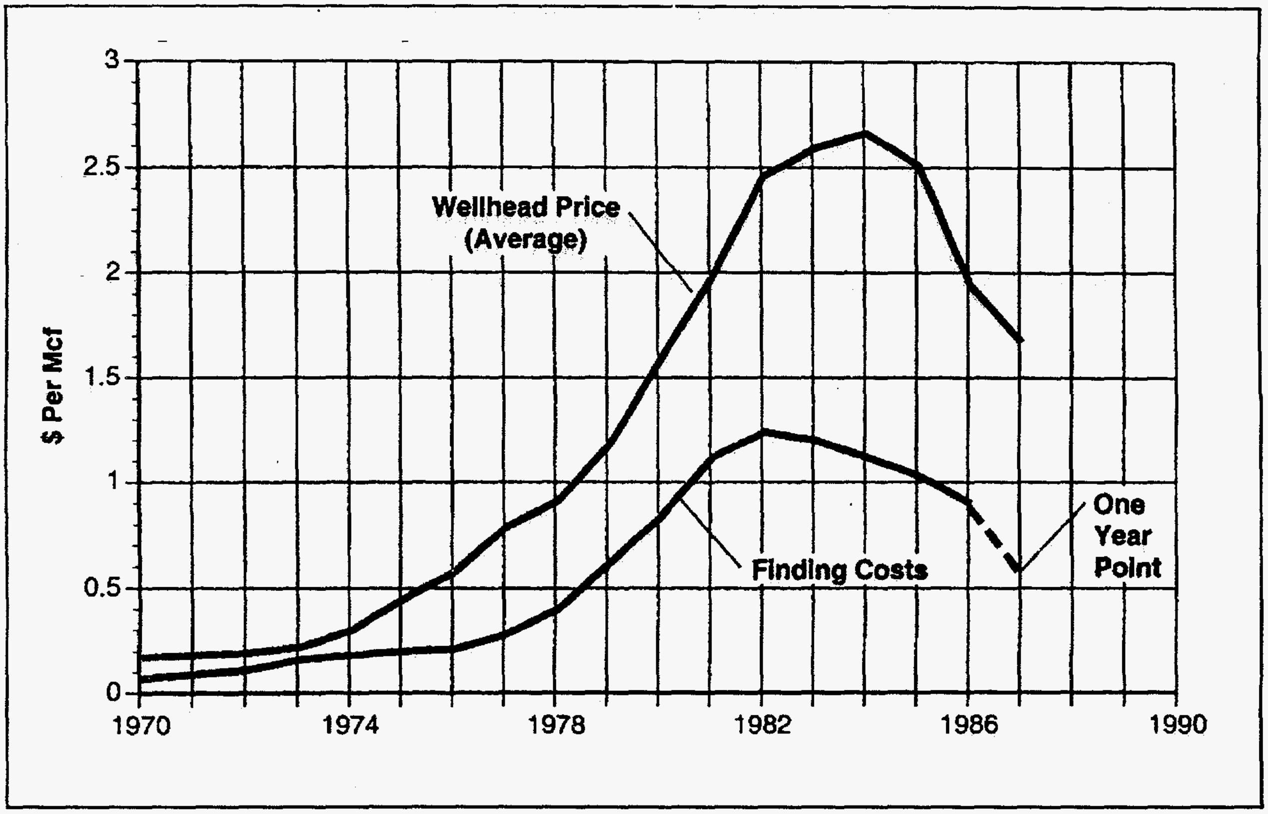

Figure 88. Finding cost per MCF follows wellhead price. (from Megill 1994)

He found a correlation between finding cost vs. average wellhead price for natural gas as shown in figure 88. He found that as prices rise finding cost and average drilling cost will rise but only after prices increase and that finding costs decline before prices decline. He also found that wellhead price and finding costs show a straight line correlation over time as shown in figure 89. The graph implies that finding cost on an MCF basis will be 50% of the wellhead price. Both these results are important for predicting future trends. Wildcat wells are planned, permitted and drilled using an expected future real price. If this expected price is reduced due to changes in environmental regulations then fewer wildcat wells will be drilled. New environmental regulations decrease future activity but generally do not affect current planned activities.

Farber and Dupont (1992) in their study on the effects of changing produced water regulations in south Louisiana found that new regulations shift the economic limit for producing fields and they discourage future drilling.

Table 29. Field size range estimates for new fields and success ratio estimates for South Louisiana

Year	New Fields	Success ratio	Average size (BOE)
1994	5-7	8.15%	251,150
1995	5-7	8.1%	251.050
1996	5-6	8.05%	250,950
1997	5-7	7.95%	250,825
1998	5-6	7.9%	250,750
1999	5-7	7.8%	250,550
2000	5-6	7.7%	250,450
2001	5-6	7.65%	250,150

Note: These estimates for field size and number of fields were based using current success ratios. Increased success ratios will reduce the number of wildcats drilled and increase the number of fields found.

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