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# Using Geostatistics to Track Areas Affected by Oilfield Brine

by Merle Grabhorn, University of Tulsa

The link between brine disposal operations in Hendrick Field, Texas, and water quality decline has long been suspected but not documented. A cost-effective way to map groundwater conditions and provide for future modeling was needed.

## Previous Disposal Practices

Winkler County in West Texas (Fig. 1) is in a water-short region. Residents rely on the Cenozoic alluvium as their only water source. Oil field brine-disposal pits have contributed to the decline of water quality in the area. Records show that Winkler County's Hendrick Field, one of the giant oil fields of Texas, has had water encroachment and disposal problems since its discovery.

Although no exact records were kept concerning the disposal of produced water, enough data existed to allow an estimate of brine production from Hendrick Field. The field produced over 10 billion bbl of water, and most of it was placed in unlined evaporation pits for disposal from 1920 to 1969.

The disposal of oil field brine in unlined pits was considered an acceptable practice until 1969. However, evidence began to mount that leakage from unlined pits was affecting the groundwater. After 1969, Texas prohibited the disposal of produced water in unlined evaporation pits.

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This newsletter features oil- and gas-related projects implemented through DOE's oil and gas environmental research program. BDM-Oklahoma, Inc., as management and operating contractor of the National Oil Program, assists DOE in reaching its objectives.

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## Assessment of Disposal Practices

To understand the impact of brine disposal operations on the Cenozoic alluvium, an assessment was made to determine:

(1) *What impact on groundwater was caused by brine disposal from Hendrick Field operations before the "no unlined pit" order in 1969.*

(2) *What, if any, effects or changes have occurred to groundwater since the "no pit" order was issued.*

Because of the size of the area affected, estimated at the start of the project to be more than 50 square miles, it was necessary to locate areas for further investigation before any field work to minimize possible field expenses. This was accomplished using public domain reports, maps, and historical aerial photography.

A summary of operational practices and the petroleum geology of Hendrick Field was obtained by reviewing industry journal articles from the 1920s, published field maps from the 1930s, and other published data ranging from the late 1920s through the 1990s. Aerial photographs taken from before the Second World War to the present were used to document pit locations and other field activities.

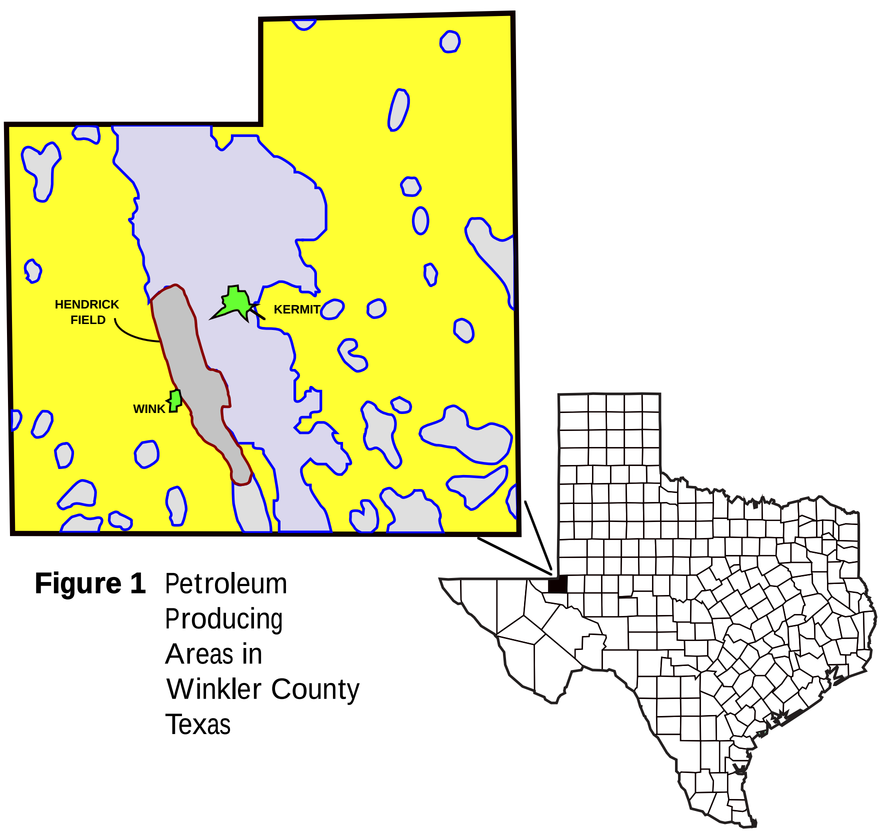


**Figure 1** Petroleum Producing Areas in Winkler County Texas

## Data Gathering and Inputting

Although groundwater data for Winkler County were sparse, two published reports were found to contain sufficient data for analysis purposes. Data from more than 130 wells were obtained from two reports from the 1950s and 1970s. Data included depth of well or sampled interval, water levels, and chemical analyses of the water samples.

All applicable data were input into a geographic information system (GIS). The GIS was used to enhance and accelerate the analysis process. Data sets could be combined, correlated, and viewed. Displays could be created and viewed interactively on a computer workstation screen or by hard copy plots made by plotter or printer.

Several types of data were selected for analysis, including groundwater elevations and geochemical data. Three groundwater characteristics selected for detailed analysis were total dissolved solids (TDS), chloride ($Cl^-$) and sulfate ($SO_4^=$). These ionic species were selected because they would give the best representation of oil field brine contamination.

These characteristics were subjected to geostatistical analysis and kriged (defined on page 3), producing brine contamination maps with error variance maps. Geostatistical analysis was used to determine the similarity or dissimilarity between the groundwater samples and the distance between well locations.

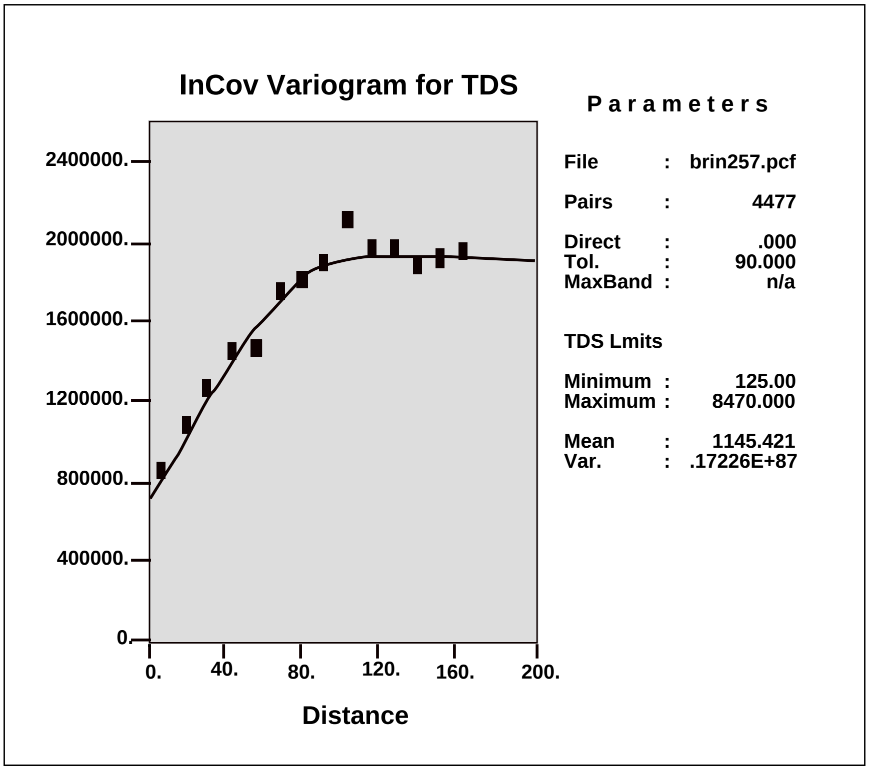


**Figure 2** TDS Variogram, Nuget 70000
Sill 1200000, Range 99
Spherical Model

The differences in similarity or dissimilarity over distance were calculated and plotted in a semi-variogram (Fig. 2). A mathematical model was fitted to the variogram (the solid line in the semi-variogram of Fig. 2).

## Estimating Ionic Values Through Kriging

The mathematical model was used to estimate values of ionic species at unsampled areas by kriging. Kriging estimates a value and a range of probable values or confidence levels for unsampled areas. The actual value of an unsampled location may not be precisely what was estimated, but will have a high probability of being in the range of expected values.

Because of the mathematical nature of the kriging process, the estimations derived are considered unbiased. The unbiased nature of the estimation and the ability to obtain confidence values make the method extremely useful. The estimation variance can be used to locate areas of high or low certainty reliably in the map. The variance can also be used for conditional simulation when performing ground water modeling. This is particularly important in mapping contamination of any sort.

## Using Stiff Diagrams to Visualize Ionic Concentrations

Additional ionic species were used to construct Stiff diagrams. Stiff diagrams convert ionic concentrations into visual shapes or

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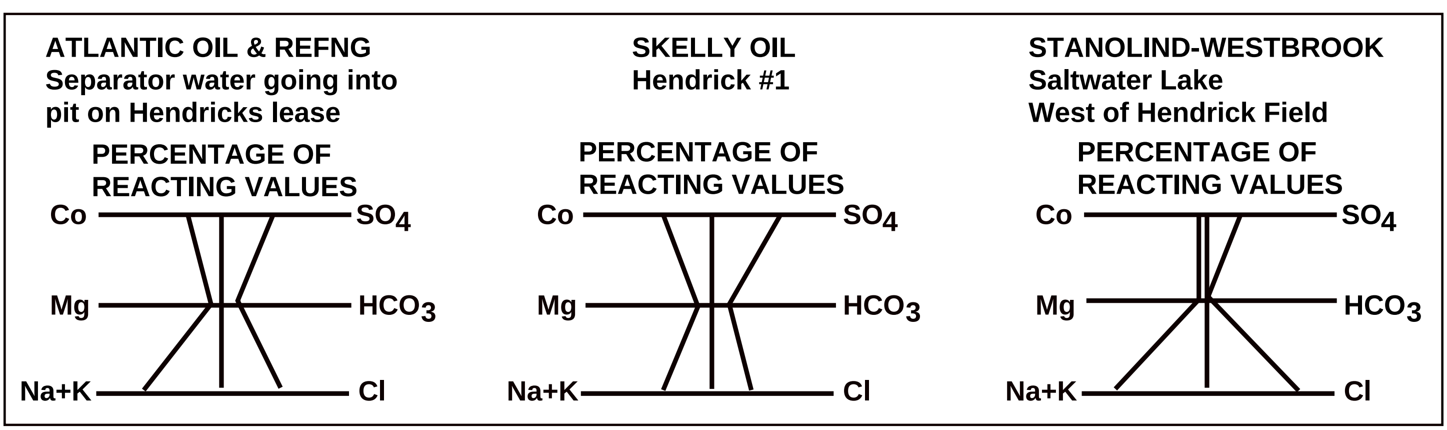


**Figure 3** Stiff Diagrams Derived from Study

*Continued from page 3*

patterns as shown in Figure 3. By visually comparing the shapes one can quickly "see" similarities and differences between the ground water samples. Produced water from Hendrick Field has a particular "hourglass" shape, distinct from that of the groundwater.

The GIS allowed the overlaying or combining the Stiff diagrams and the kriged groundwater maps for interpretation purposes (Fig. 4). By viewing the data at different time periods, one could see the changes in concentration and the movement of brine in the Cenozoic alluvium through time.

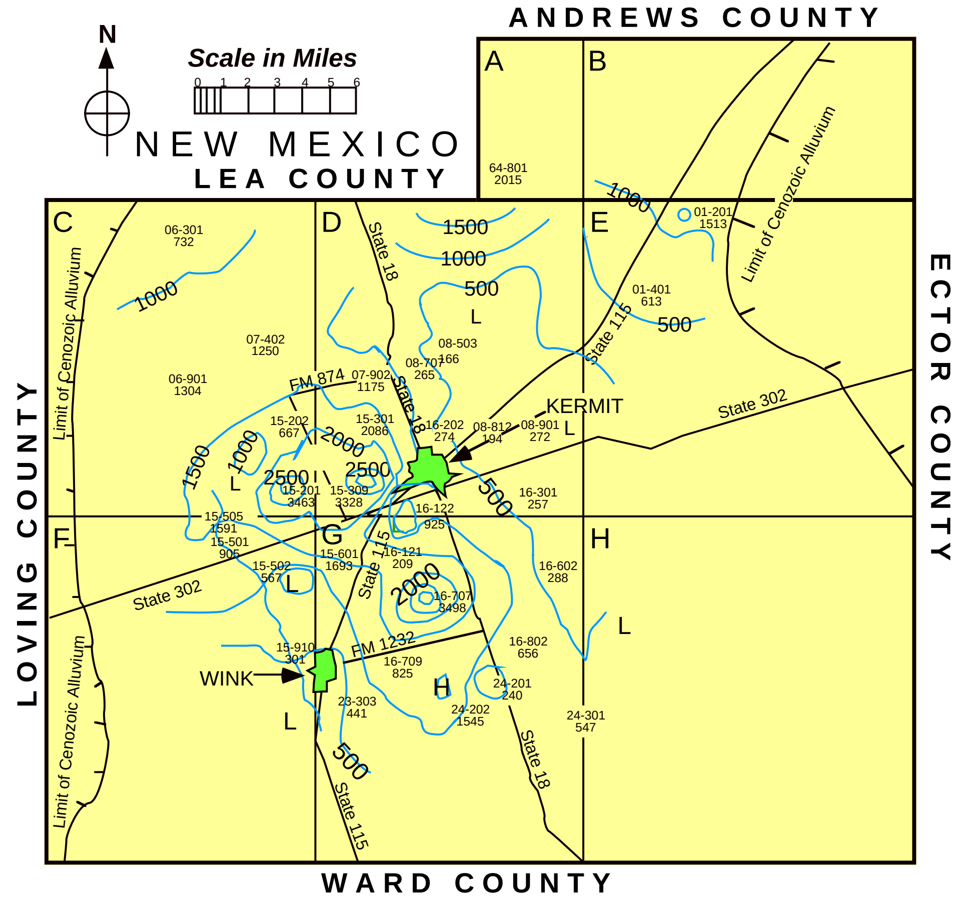


**Figure 4** Brine-Contaminated Water

## Contamination Confirmed

The map shown in Figure 4, taken from 1979 data, shows a plume of brine-contaminated water as much as 6 miles wide and 12 miles long with TDS levels as high as 2,500 mg/liter. The Stiff diagrams confirm that water in the Cenozoic alluvium aquifer has been contaminated by brine from Hendrick Field. The plume has been migrating to the south and has been reducing in concentration since the "no pit" order.

The combination of using public domain data and performing geostatistical analysis to create ground water maps allows one to obtain an overview of groundwater conditions for a minimal expenditure. The statistical nature of the data allows one to perform other analysis such as modeling and helps focus future data gathering programs.

Presentation of this article at the 3rd International Petroleum Environmental Conference, September 24-27, 1996, Albuquerque, NM, was sponsored by the U.S. Department of Energy.

# Produced Water Treatment by Hydrocyclones Looks Promising

by Steve Jones, BDM-Petroleum Technologies

More than 15 billion barrels of produced water are estimated to be generated as by-products of oil and gas operations in the United States annually. Enhancing liquid/liquid separation technology called hydrocyclone may help reduce what presently is the largest volume waste in the oil and gas production business.

The treatment and disposal of produced water is regulated primarily under the Clean Water Act.

The composition of produced water varies significantly with the production zone and time, but it is usually a highly saline water containing significant amounts of metals and organic substances. The common contaminant of concern in produced water is oil and grease.

## Research on Hydrocyclones

The Hydrocyclone Development Consortium (HDC) at Michigan State University has conducted a multi-year research program on "The Further Development of a Novel Hydrocyclone for Liquid/Liquid Separation." The research investigated the fundamental properties of hydrocyclones and evaluated hydrocyclones as treatment options for produced water from oil and gas production operations.

Hydrocyclones are devices that separate dispersed oil in water on the basis of density through the application of large centrifugal forces (Fig. 5). Hydrocyclones' relatively compact size and simplicity of operation make them a produced water treatment technology that is well suited to offshore production operations.

## Evaluating 20 Different Designs

The fundamental properties and the ability of 20 different hydrocyclone designs to separate the light phase (dispersed oil and grease) from the heavy continuous phase (water) were investigated. In all cases, drop breakup prevented the hydrocyclones from attaining their theoretical limits of separation.

Improved performance of hydrocyclones was obtained by the injection of auxiliary control flows.

The major recommendation of the research is to redesign and increase the cross-sectional feed area of hydrocyclones, relative to the area of the swirl chamber, and to optimize the control flow nozzle of the swirl chamber.

The research also identified the need for studies on:

- Hydrodynamic stability of reverse-flow deoiling hydrocyclones
- Development of small separation cut-size mini-hydrocyclones
- Low stable split-ratio characteristics of large, high-capacity hydrocyclones with upper tailpipe control flow

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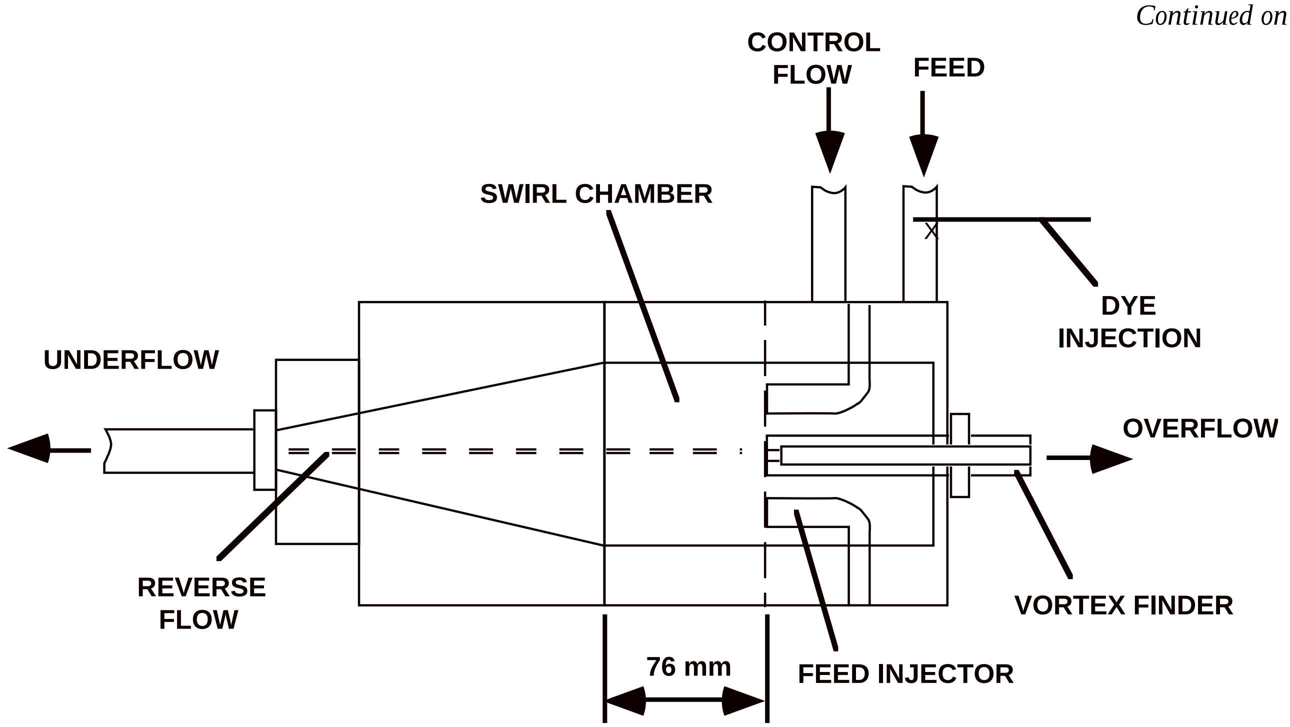


**Figure 5** Hydrocyclone Design

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The Hydrocyclone Development Consortium includes Michigan State Univ., Amoco, ARCO, Chevron, Exxon, Marathon, Krebs Engineers, Monosep Corporation, Texaco, U.S. Navy, and DOE.

The research was funded by DOE, the member companies, the Exxon Foundation, the National Science Foundation, the Office of Naval Research, and DuPont.

This article is based on a report submitted to BPO: "The Further Development on a Novel Hydrocyclone for Liquid/Liquid Separation" by C. A. Petty, S. K. Ali, and J. F. Foss, College of Engineering, Michigan State University, East Lansing, MI 48824.

# Economic Impact of Recent Effluent Guidelines

by Viola Rawn-Schatzinger, BDM-Oklahoma

New federal and state environmental acts setting guidelines for effluent discharge in the Gulf of Mexico may have severe effects on the economics of oil and gas production. A DOE-sponsored study by Continental Shelf Associates and ICF Resources (March 1996) assessed the economic impact of present and future environmental rulings for the Gulf of Mexico. The research was done primarily in the fall of 1993, but note was taken of proposed legislation going into effect between 1994 and 1997.

The technologies for the treatment and disposal of produced water and sand discharge currently in practice and those being developed to meet new guidelines were analyzed. The economic impact on both existing production and the potential for exploration and development in the Gulf of Mexico (Fig. 6) was included in the assessment. The economic impact of regulatory requirements were considered for the following:

- Incremental costs to the petroleum industry
- Current and future reductions in offshore oil and gas production
- Potentially recoverable oil and gas reserves that could become uneconomic to develop
- Lost revenues to federal and state treasuries
- Lost government revenues from offshore lease sales

Economic evaluations were performed on three levels or three future price scenarios:

- Oil prices (West Texas Intermediate) remain constant at $20, gas at $2.00 per million Btu
- Oil prices remain constant at $16, gas at $1.50 per million Btu
- Escalating oil and gas prices based on the 1994 Energy Information Administration Annual Energy Outlook

Differences in regulations, water discharge, injection technologies, platform characteristics, and environmental effects were studied in six parts of the Gulf of Mexico: Texas Coastal, Texas State waters, Louisiana Coastal, Louisiana State waters, Central Federal Outer Continental Shelf (OCS), and Western Federal OCS.

Related DOE-sponsored studies have analyzed scientific data on (1) the fate of trace metals, organics, and naturally occurring radioactive materials in water, sediment, and marine biota (2) the recovery of the seabed near terminated water discharge sites in the wetlands and open bays of Louisiana, and (3) the catch, consumption, and use of seafood collected from coastal and offshore waters. These factors were taken into account when studying the economics of effluent regulations.

A number of technologies are in use or are being developed to meet the environmental guidelines. The technologies were analyzed in different sections of the Gulf of Mexico for applicability, availability, effectiveness, cost, and effect on marine life. Produced water treatment and disposal technologies considered were:

**Gas Flotation –** Involves injection of small gas bubbles below the surface of produced water. The bubbles carry the oil to the surface where it is trapped in a foam that can be skimmed.

**Plate Coalescer –** Uses gravity separation to remove oil and grease. The oil clings to the plate surfaces and rises upward, as the water is forced downward.

**Media Filtration –** Produced water is forced through a bed of sand or granular media. The filters tend to plug and are not used much in offshore areas.

**Hydrocyclone –** A new technology which uses centrifugal force to separate oil and grease particles from produced water. Hydroclones are not a standalone treatment and are expensive, but may be very effective for offshore applications.

**Centrifuge –** Produces six to ten times the centrifugal force of a hydrocyclone and is capable of removing very fine particles of oil and grease. Upstream chemicals do not affect its performance, but the rotating equipment requires significant maintenance.

**Membrane Filtration –** A produced water treatment technology using a cross-flow membrane filtration which is still in the experimental stage. At present the filters clog badly and are very expensive to operate.

**Reinjection –** Has been used primarily onshore. It is expensive and requires balance between injected waters and formation water, but may prove the most effective technology to meet stricter effluent standards.

Other experimental technologies being developed are air stripping and reverse osmosis.

Which technologies will prove the most economic for fulfilling the requirements of the federal and state guidelines will depend on the price of oil, the cost of operation, and ultimately the effluent standards imposed. Costs of disposal and loss of revenue must be balanced to justify the environmental benefits.

For details, see: ICF Resources, Inc. and Continental Shelf Associates, Inc. 1996. Assessment of Economic Impacts of Offshore and Coastal Discharge Requirements on Present and Future Operations in the Gulf of Mexico. Final Report. DOE Contract No. DE-AC22-92MT92001. Washington, DC; Department of Energy.

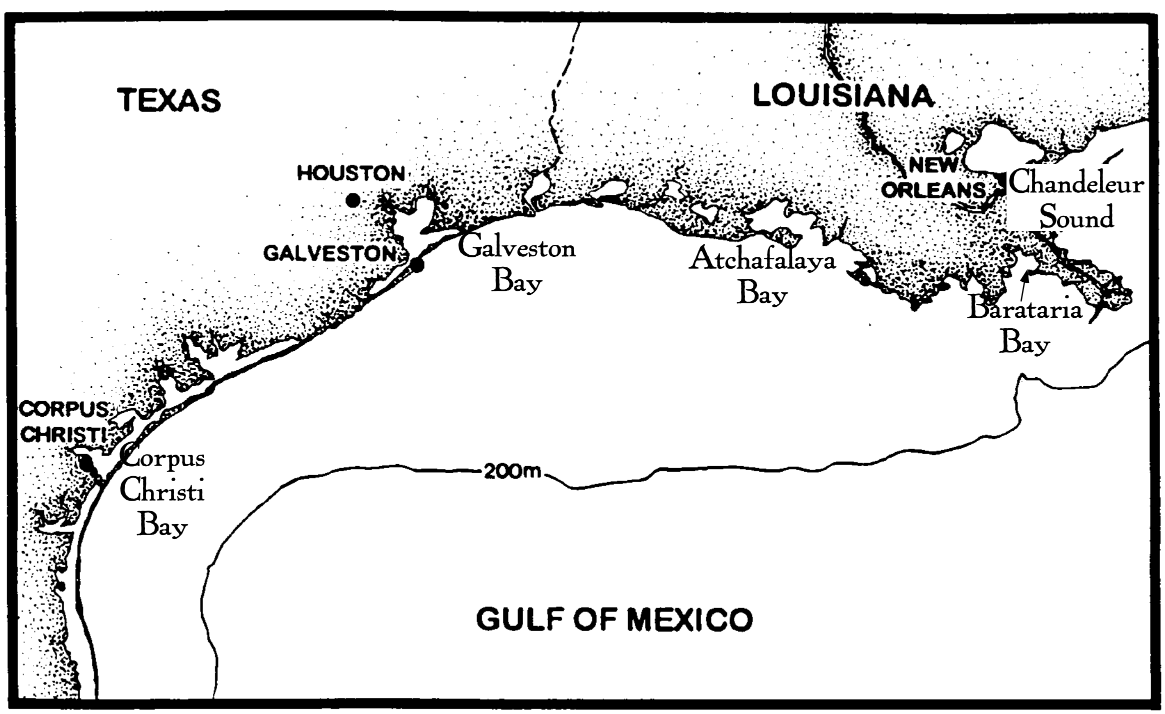


**Figure 6** Map of Coastal Areas of the Gulf of Mexico

# CALENDAR

**MARCH 3-5, 1997**

*SPE/EPA Exploration & Production Environmental Conference*, Wyndham Anatole Hotel, Dallas, TX.

**MARCH 24-27, 1997**

*DOE Morgantown Energy Technology Center*, Wyndham Greenpoint Hotel, Houston, TX. For information call 304-285-4108.

**APRIL 8-9, 1997**

*AAPG Annual Technical Conference*, Division of Environmental Geoscience Sessions: Dallas Convention Center, Dallas, Texas.

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