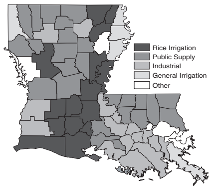

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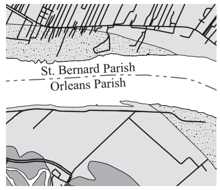

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Louisiana Geological Survey

NewsInsights

December 2005 • Volume 15, Number 3

Louisiana Geological Survey Staff Assist in Hurricane Katrina Effort

Members of the Louisiana Geological Survey (LGS) staff participated in preparations, emergency response, and recovery efforts for Hurricane Katrina. The LGS was cited by the Louisiana Department of Wildlife and Fisheries (LDWF) for its efforts and for "helping to save numerous lives."

LGS assistant director John E. Johnston III, the department's regular representative to the Louisiana Office of Emergency Preparedness, carried out scientific and liaison work with the LDWF, the U.S. Coast Guard, both the federal and state Departments of Homeland Security, the Federal Bureau of Investigation, and the Federal Emergency Management Agency. Along with Reed Bourgeois, LGS computer analyst, Johnston provided scientific input, housing and office space (after obtaining the necessary approvals from the LSU administration), Internet connections, printing and plotting support, computers, and software for search and rescue, law enforcement, and mapping operations. Johnston also helped to plan and coordinate early scientific missions into New Orleans to gather post-Katrina scientific data, which included obtaining clearances for water sampling for the LSU School of the Coast and Environment's Dean Edward Laws and the staff of the LSU Department of Environmental Studies and the LGS. Johnston was commended by the Louisiana National Guard for "outstanding effort."

Assistant professor Thomas van Biersel and accounting specialist Jeanne Johnson prepared a 911 phone call registry and also did mapping and database work in cooperation with the U.S. Geological Survey (USGS) and the National Wetland Research Center personnel in support of the LDWF's search and rescue operations. They prepared an emergency call database which was used to compile search and rescue maps of the location and time of emergency calls made in the New Orleans area during and after Hurricane Katrina by the USGS and LGS geographer Hampton Peele. These maps, multiple copies of which were printed by the LGS and the USGS and supplied to the agencies involved in search and rescue efforts, aided rescue teams in locating people trapped by the storm and saved lives. Van Biersel, Bourgeois, Johnson and Peele were all commended by the LDWF for their efforts.

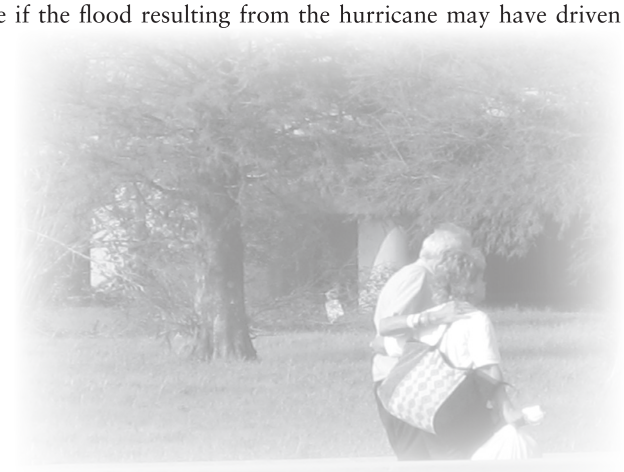
Peele and two other LGS cartographers, Robert Paulsell and John Snead, also worked in association with other LSU GIS labs to provide important GIS and mapping support for state and federal agencies by manning GIS workstations at the Louisianan Emergancy Operations Center as well as their on-campus laboratory. Many hardcopy maps and digital data were prepared for distribution to rescue and relief operations. Oversized provisional base maps were produced for the Katrina and Rita impact areas.

Other LGS staff providing various forms of assistance during and after Hurricane Katrina included the director, Chacko John, research associates Brian Harder and Byron Miller, and office coordinator Ann Tircuit.

Subsequent to Hurricane Katrina, LGS assistant professors Thomas van Biersel, Douglas Carlson, and research associate Riley Milner took part in a joint study with the USGS and the Louisiana Department of Environmental Quality to determine the effects of Hurricane Katrina's storm surge on water wells on the north shore of Lake Pontchartrain. Ongoing efforts are underway to see if the flood resulting from the hurricane may have driven saline water down existing water wells or directly invaded shallow aquifers in the vicinity of Lake Pontchartrain.

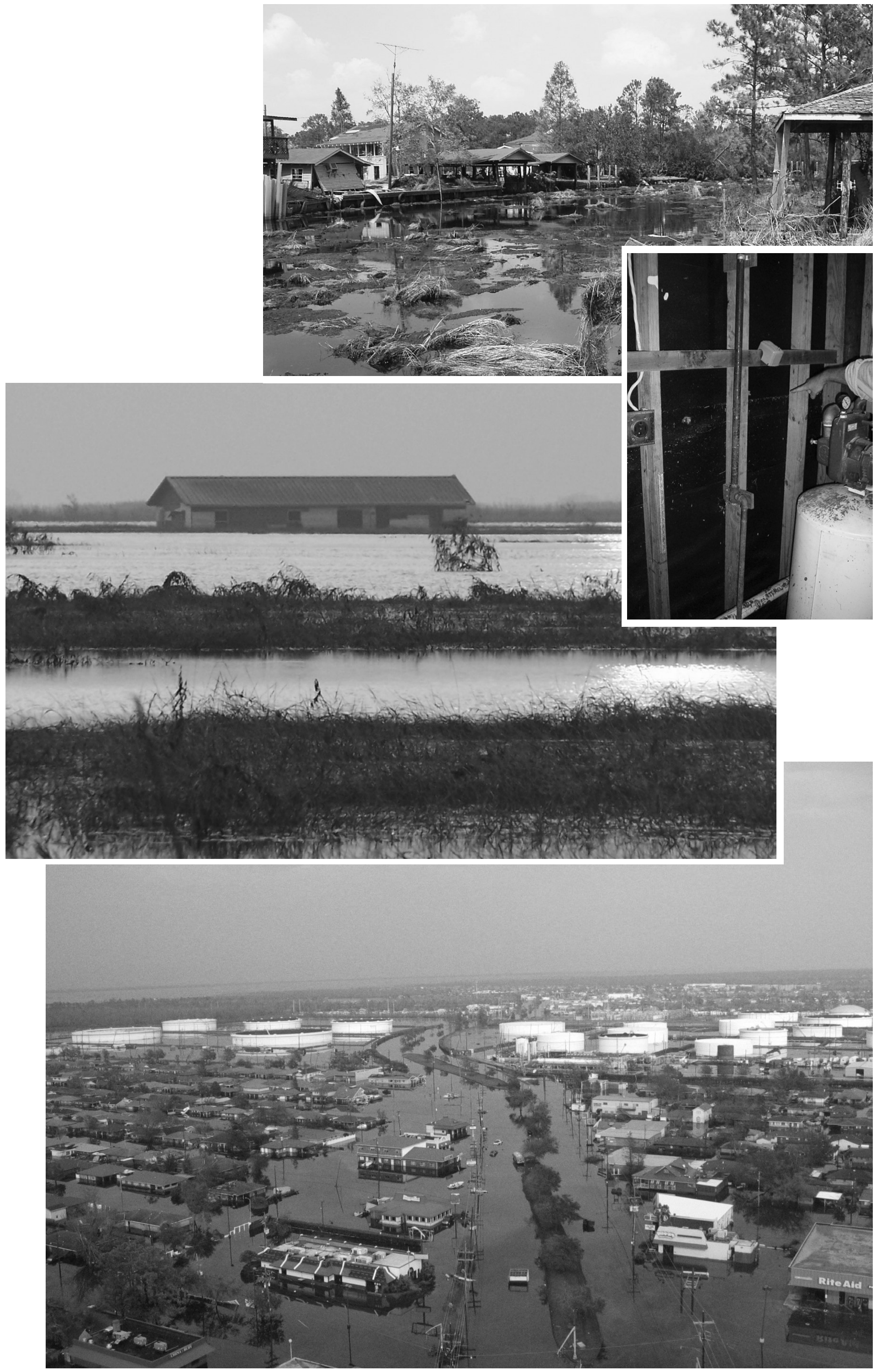
Search and Rescue Mapping for Hurricane Rita

On September 22, 2005 the Louisiana Department of Wildlife and Fisheries (LDWF), requested LGS mapping assistance for the anticipated search and rescue effort that they would be leading in response to Hurricane Rita.



Before Rita had made landfall on Sept. 24th, R. Hampton Peele had developed a new statewide search and rescue reference system. For the next five days LGS produced newly designed small scale planning maps and large scale responder maps for the LDWF, the Louisiana State Police, Louisiana Air National Guard, the United States Coast Guard, the USGS and FEMA, until the search and rescue effort had ended.

Hurricane images



The Louisiana Geological Survey

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LGS Mission Statement

The goals of the Geological Survey are to perform geological investigations that benefit the state of Louisiana by:

(1) encouraging the economic development of the natural resources of the state (energy, mineral, water, and environmental);

(2) providing unbiased geologic information on natural and environmental hazards; and

(3) ensuring the effective transfer of geological information.

The Louisiana Geological Survey was created by Act 131 of the Louisiana Legislature in 1934 to investigate the geology and resources of the State. LGS is presently a research unit affiliated with the Louisiana State University and reports through the Executive Director of the Center for Energy Studies to the Vice Chancellor for Research and Graduate Studies.

Louisiana Historic Use of Groundwater: 1950 to 2000

Douglas Carlson

Introduction

Groundwater found within aquifers is a small share of the world's water supply. Approximately 97.5% of all the water in the world is saltwater in the oceans. Only 2.5% of the world's water is freshwater, most of which lies in polar ice caps. Fresh groundwater accounts for only 0.3% of all water on earth and 12% of all freshwater (Vandas et al., 2002). However, within the conterminous United States groundwater comprises approximately 86% of all freshwater. By comparison lakes account for approximately 14%, which includes the United State's share of the Great Lakes (Driscoll, 1986).

Because groundwater is the most abundant source of freshwater that is easily available for human use, it has been used for centuries. As early as 2000 B.C. the Persians, Chinese and Egyptians dug the first water wells (Glennon, 2002). The drilling of wells to find water began about 4,000 years ago by the Chinese. They developed cable- tool-percussion drilling which was used to drill wells to depth of 3,000 feet (Driscoll, 1986). Prior to the 1890s wind driven or reciprocal pumps could lift water only 70 to 80 feet (Glennon, 2002). The development of centrifugal or rotary pumps allows access to water at depths of 100s to 1,000s of feet below the earth's surface (Glennon, 2002). The power source for lifting water from these great depths arrived in the early 20 th century, the gasoline internal combustion engine often a modified Ford Motor Company Model T engine (Glennon, 2002).

For the past fifty years the U.S. Geological Survey (USGS) every five years determined estimates of water use in the United States. In 1950 approximately 34 billion gallons per day (bgd) of groundwater was used in the United States and by 2000 groundwater use increased to 83.3 bgd (Hutson et al., 2004). This increase of groundwater use in the fifty years between 1950 and 2000 is 145%, which is greater than the population increase in the same period of time which is 89%. The share of freshwater supplied by groundwater has also increase from 19.5% in 1950 to 24.1% in 2000 (Hutson et al., 2004).

Groundwater is especially important source of public and private supply of drinking water. In the United States groundwater supplies drinking water for over 50% of the population for 29 states, one of which is Louisiana. In Louisiana 61% of the population has its drinking water supplied by groundwater (Vandas et al., 2002).

Historical Groundwater Use 1950 to 2000

Category of Use

Over the past fifty years as Louisiana's population grew from 2.7 million to 4.5 million people, resulting in an increased groundwater usage from 850 million gallons per day (mgd) to 1,600 mgd (Urban Systems Associates Inc., 1982; Sargent, 2002, World Almanac Books, 2005). During the past fifty years, rice irrigation has been the leading user of groundwater, except in 1955 when industrial use surpassed it briefly (Figure 1). While general use of groundwater has increased through the past fifty years, this is not always the case for every category of water use. Rice irrigation, industry, rural domestic, and power generation are groundwater use categories that have remained roughly constant throughout the past fifty years. On the other hand, groundwater use for livestock has declined significantly. The typical yearly decline for livestock use of groundwater is 1.7%. Public supply, aquaculture and general irrigation are categories where the use of groundwater has increased. In the past fifty years, public supply groundwater use has increased from 55 mgd to 350 mgd (Urban Systems Associates Inc., 1982; and Sargent, 2002). That is an average yearly increase of 3.8% for public supply use of groundwater. Aquaculture groundwater use has increased from 50 mgd to 150 mgd over the past twenty years (Walter, 1982; and Sargent, 2002), which is an average yearly increase of groundwater used of 6%. Aquaculture use of water includes alligator, crawfish and fish farming (Sargent, 2002), which is an average yearly increase of groundwater used of 6%. General irrigation groundwater use has increased from 10 mgd to100 mgd over the past forty years (Snider and Forbes, 1961; and Sargent, 2002). General irrigation is for crops other than rice such as corn, cotton, sod, sorghum, soybeans, strawberries and sweet potatoes (Sargent, 2002).

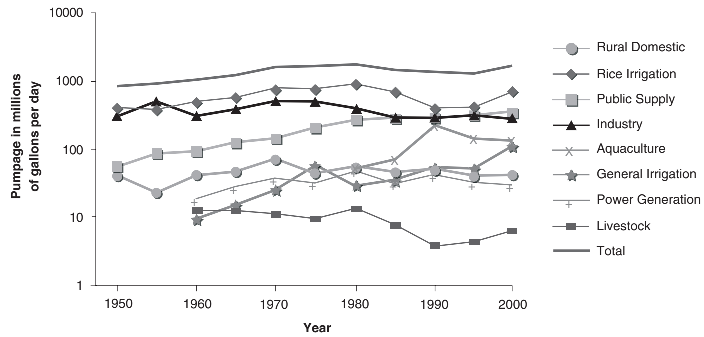


Figure 1. Groundwater use in Louisiana by category from 1950 to 2000 (sources of information are: Urban Systems Associates Inc., 1982; Walter, 1982; Lurry, 1987; Lovelace, 1991; Lovelace and Johnson, 1996; and Sargent, 2002).

Three categories (rice irrigation, industrial and public supply) of groundwater users have accounted for between 80% and 95% of groundwater use for the past fifty years. There has been a general decline in these three uses of groundwater in terms of their share of the state's total groundwater use, which has fallen from about 95% in 1950 to about 80% in 2000 (Figure 2). Among the major uses of groundwater, rice irrigation's share has remained fairly constant at 40-45% of all groundwater used. Industry's share of all groundwater used has decreased from 40% in 1950 to 20% in 2000. However, this decrease may be due to industry shifting from self reliance to relying on public water supply for their needs. Public supply's share of all groundwater used has increased from 7% in 1950 to 20% in 2000. Smaller category uses have increased more rapidly than general groundwater use in Louisiana. This increase is largely a result from the expansion of aquaculture and general irrigation usage, whose share of all groundwater use changed from under a few percent in 1960 to 15% in 2000 (Figure 2).

Although the amount of groundwater used by industries has remained fairly constant between 1960 and 2000 (Figure 1), groundwater used by the four categories of industries has changed. For the same period of time chemical, paper products, petroleum refining and food products account for about 90% of all groundwater used by Louisiana's industries (Figure 3) (Lovelace, 1991; Lovelace and Johnson, 1996; Sargent, 2002, and U.S Geological Survey, 2005). In general, groundwater used by chemical and paper product industries has remained fairly constant from 1960 to 2000 (Figure 4), while groundwater use by petroleum refining and food products industries has decreased during the same time period (Figure 4).

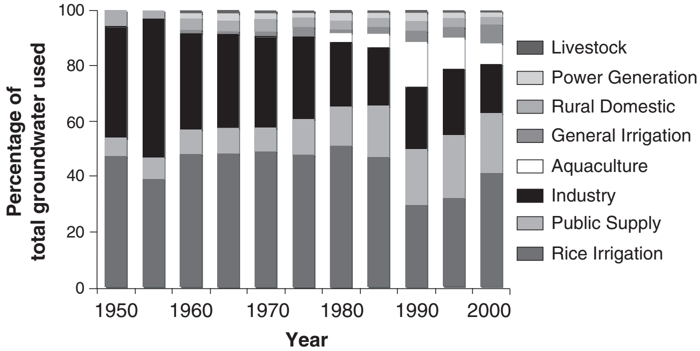


Figure 2. Share of groundwater use in Louisiana by category from 1950 to 2000 (sources of information are: Urban Systems Associates Inc., 1982; Walter, 1982; Lurry, 1987; Lovelace, 1991; Lovelace and Johnson, 1996; and Sargent, 2002).

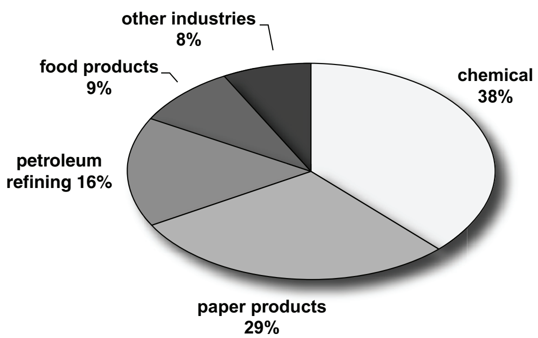


Figure 3. The average share of groundwater used by various categories of Louisiana industries between 1960 and 2000. Sources of data are Lovelace (1991); Lovelace and Johnson (1996); Sargent (2002); and U.S Geological Survey (2005).

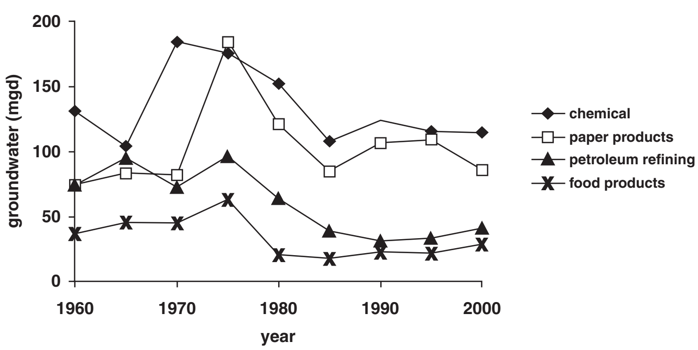
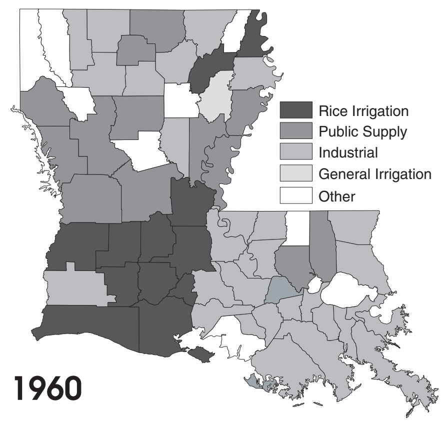


Figure 4. Industrial category use of groundwater in Louisiana between 1960 and 2000. Sources of data are Lovelace (1991); Lovelace and Johnson (1996); Sargent (2002); and U.S Geological Survey (2005).

There has been a major change in leading users of groundwater by parish between 1960 and 2000 (Figure 5). There have been an increasing number of parishes that have public supply as their leading category of groundwater use: 13 parishes in 1960 (Snider and Forbes, 1961), 19 parishes in 1980 (Walter, 1982); and 26 parishes in 2000 (Sargent, 2002). By comparison there have been a decreasing number of parishes that have industry as their leading category of groundwater use: 30 parishes in 1960 (Snider and Forbes, 1961), and 16 parishes in 2000 (Sargent, 2002).

Source of Groundwater

It appears that except for the Chicot Aquifer there are no detailed records indicating what groundwater use is for the other aquifers for the past fifty years. The Capital Area Ground Water Conservation Commission District has detailed records of groundwater use, but they are for 1975 to the present (Capital Area Ground Water Conservation Districut, 2005). Louisiana's 13 leading aquifers (Carrizo-Wilcox, Catahoula, Chicot, Chicot Equivalent, Cockfield, Evangeline, Evangeline Equivalent, Jasper, Jasper Equivalent, Mississippi River Alluvial, Red River Alluvial, Sparta, Upland Terrace) have values of groundwater use noted for 1990, 1995 and 2000 (Lovelace, 1991; Lovelace and Johnson, 1996; and Sargent, 2002). During the 1990s the vast majority of groundwater used in Louisiana is pumped from two aquifers: the Chicot and Mississippi River Alluvial Aquifers (Figure 6), which are located in mainly agricultural districts. The 1990s appear to be typical of groundwater use for the past fifty years in that approximately half of all groundwater used in Louisiana is pumped from the Chicot Aquifer (Figure 7).



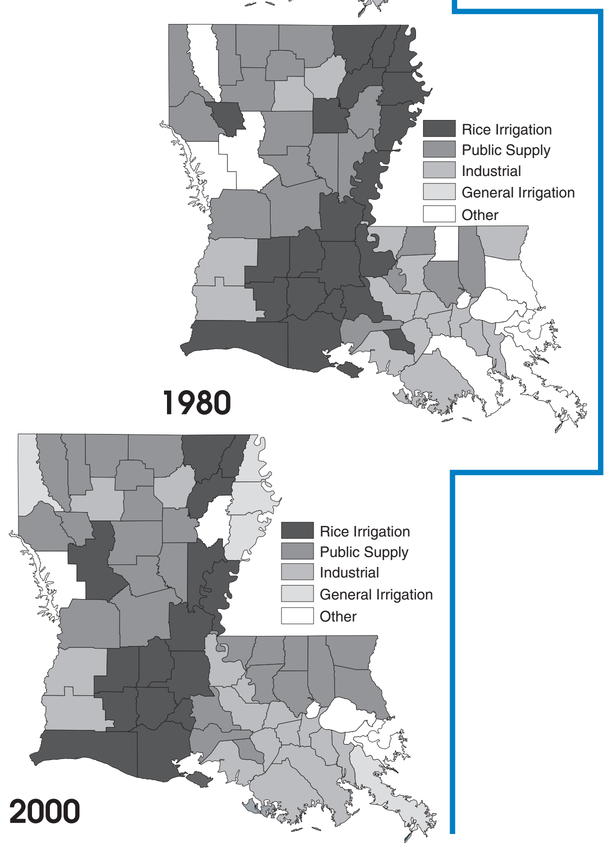


Figure 5. The maps of Louisiana are a display of what is the leading category of groundwater use by parish in 1960, 1980 and 2000 (Sniders and Forbes, 1961; Walter, 1982; Sargent, 2002).

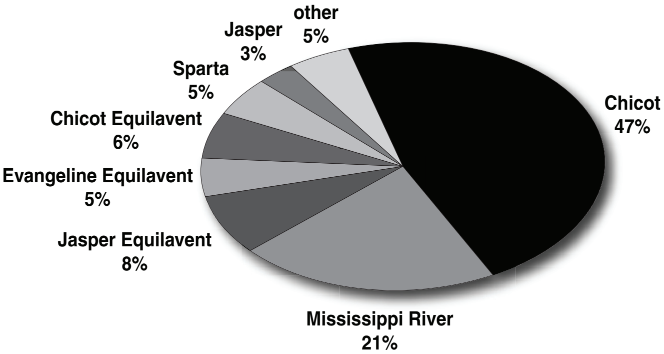


Figure 6. Distribution of groundwater used in Louisiana by aquifer for the average of 1990, 1995 and 2000. Sources of data are Lovelace (1991); Lovelace and Johnson (1996); and Sargent (2002).

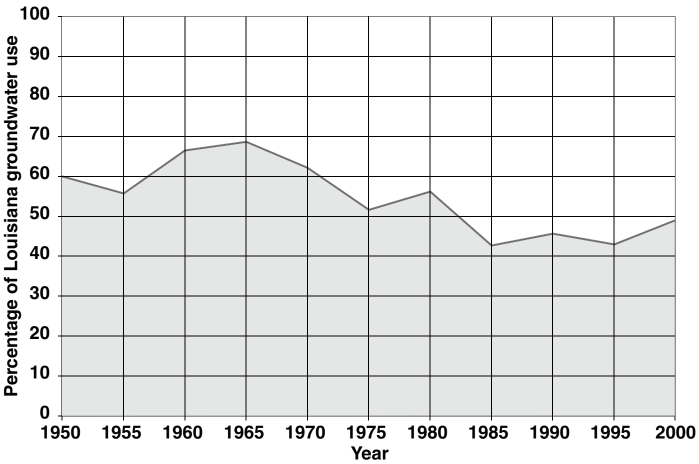


Figure 7. The above display is of the Chicot Aquifer's percentage of all groundwater that is used in 1950 to 2000 in Louisiana. Sources of data are Harder (1961); Kilburn and Whitman (1962); Whitman and Kilburn (1963); Zack (1971); Urban Systems Associates Inc., (1982); Walter (1982); Lurry (1987); Lovelace (1991); Lovelace and Johnson (1996); and Sargent (2002).

Summary

Although fresh potable groundwater is a tiny share of all water on earth it has been an important source of freshwater for thousands of years. In the United States groundwater is the main source of freshwater and groundwater is an increasingly important source of potable water especially for public supply. In Louisiana detailed collection of groundwater use has been completed only since 1950. In general, three categories of users have dominated groundwater use in Louisiana: industry, public supply and rice irrigation. However, two categories of groundwater users are rapidly increasing their demand of groundwater: aquaculture and general irrigation. Lastly it appears that two aquifers, Chicot and Mississippi River Alluvial, supply the majority of groundwater used in Louisiana.

Acknowledgements

I would like to thank Charles Demas and Pierre Sargent for access to the U.S. Geological Survey records of groundwater used by industries from 1960 to 2000. In addition Pierre Sargent preformed several data sorts of his computer records of industrial use of groundwater which made analysis of water use within industrial categories far easier.

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Review of the Engineering Geology of St. Bernard Parish, Louisiana

Paul V. Heinrich

Introduction

St. Bernard Parish has a total area of 1,330 square miles (3,445 square km). Of this area, about 465 square miles (1,200 square km) is land. The remaining 865 square miles (2,240 square km), 65 percent, of St. Bernard Parish consists of open water in the form of streams, lakes, and bays. This area lies entirely within the St. Bernard delta lobe of the Mississippi delta, which was created by the Mississippi River when its main channel occupied Bayou La Loutre (Figure 1)(Frazier, 1967; Wiseman et al., 1979; Saucier, 1994). The engineering properties of these deltaic sediments, as summarized and discussed in this article, provide guidance for the reconstruction of St. Bernard Parish.

The elevation of St. Bernard Parish varies from 6 ft (1.8 m) below sea level to 12 ft (3.6 m) above sea level. The portion of St. Bernard Parish, which lies below sea level, was marsh and swamp, which have been drained and protected by dikes. The highest natural parts of St. Bernard Parish are the natural levees, locally called "finger ridges", of the Mississippi River, its distributaries, and a former channel of it now occupied by Bayou La Loutre. The portion of these natural levees lying sufficiently above sea level that are suitable for agriculture and urban development without the use of dikes comprise only about 58 square miles (150 square km), of the land within St. Bernard Parish. In the northern part of St. Bernard Parish, near Arabia, a large man-made pile rises over 35 ft (11 m) above sea level.

Prior to being devastated by Hurricane Katrina, St. Bernard Parish had been a prosperous, populated, and culturally distinct part of the New Orleans metropolitan area. The U.S. Census Bureau estimated the population of St. Bernard Parish was 65,554 people in 2004 comprising 25,123 households in 2000 (U.S. Census Bureau 2004). This was a population density of about 141 persons per square mile. Given that the vast majority of the population was concentrated on only 58 square miles of high ground within St. Bernard Parish, the actual population density of its urban areas is several times higher than this figure. A significant part of this population comprised suburbs containing people who worked within various parts of Orleans Parish. Associated with these suburbs were well-developed wholesale, retail and service business sectors. In 2000, there were an estimated 27,078 housing units and 1,191 private, nonfarm businesses within St. Bernard Parish (U.S. Census Bureau, 2004). Not reflected in any of the published statistics was the closely-knit and

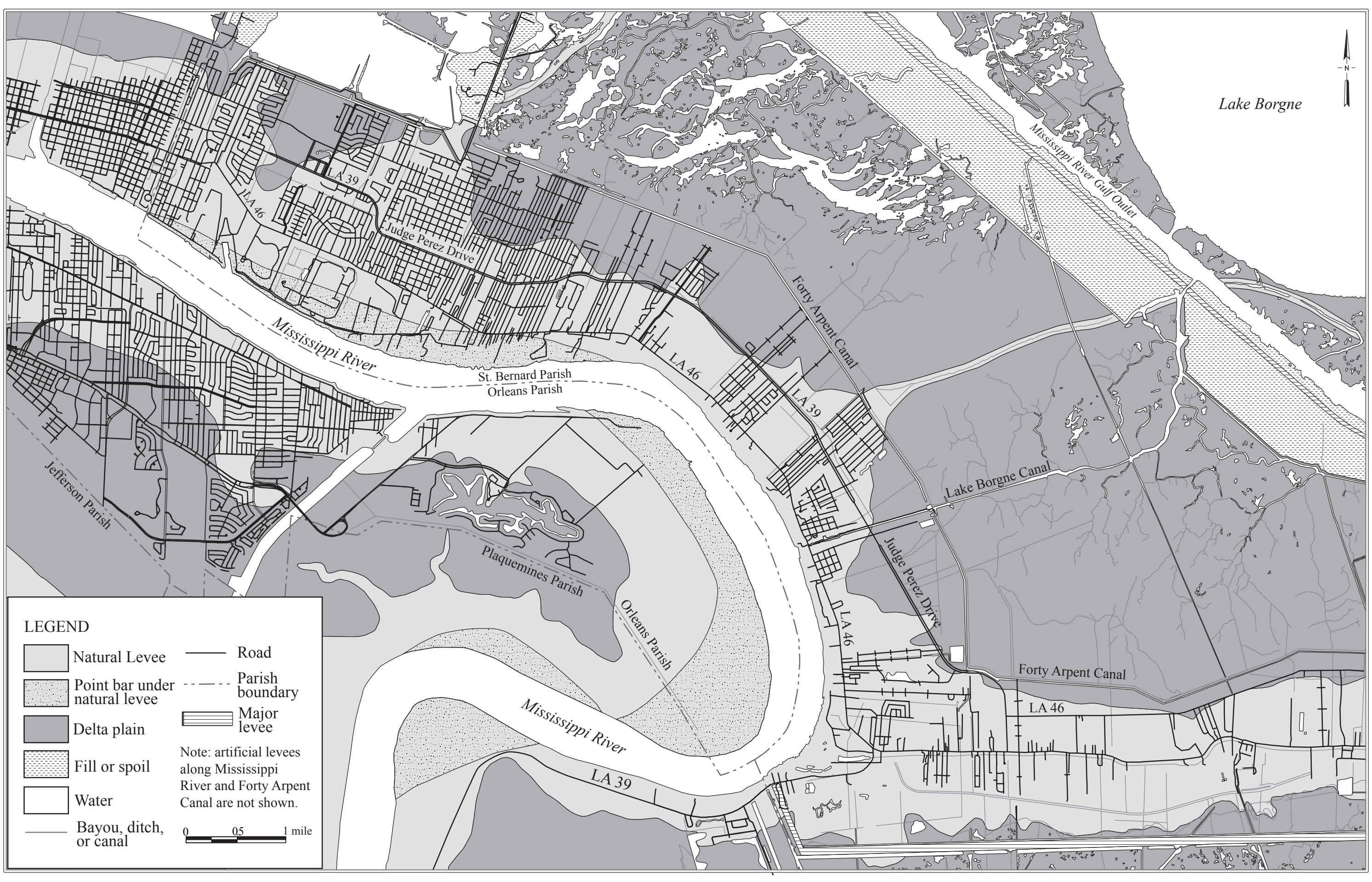

Figure 1. Surficial geologic map of the urban corridor within northwest St. Bernard Parish.

often culturally distinctive nature of many of the numerous communities that had developed within St. Bernard Parish since 1780, when it was first settled.

Before the devastation wrought by Hurricane Katrina, St. Bernard Parish possessed a diverse industrial base. Along the east bank of the Mississippi River, mostly between Arabia and Chalmette, the industrial base included sugar (American Sugar and Domino Sugar refineries) and petrochemical (Murphy Oil and Tenneco Oil refineries) refineries. Further south, the industrial base consisted mainly of seafood processing plants and some shipbuilding. The population within lowermost part of St. Bernard Parish depended almost entirely upon shrimping, fishing, and oyster farming.

The effort by the citizens of St. Bernard Parish to return to what is their home, rebuild their communities and livelihoods, and remain to lead productive lives will require an understanding of the nature and physical properties of the deltaic sediments that underlie St. Bernard Parish. The physical (engineering) properties of these sediments have been described and summarized in a number of published studies, i.e. Kolb and Van Lopik (1958), Dunbar et al. (1994), Kolb (1962), and Montgomery (1974). Additional geotechnical data is available from a study, U.S. Army Corps of Engineers (1958), conducted for the construction of the Mississippi River-Gulf Outlet (MRGO) channel. These reports, their plates, and 1:62,500 scale geologic maps are currently available online at U.S. Army Corps of Engineers (2004).

A summary of the information available from the above sources in relationship to a preliminary geologic map of the urban core of St. Bernard Parish will be presented in this report. This map was prepared from an examination of LIDAR (LIght Detecting And Ranging) digital elevation models, soil surveys by Trahan et al. (1989, 2000), 1:24,000 scale topographic mapping, and various historic and contemporary aerial imagery. The compilation and analysis of data from geotechnical investigations produced for various Louisiana Department of Transportation and Development, U.S. Army Corps of Engineers, local refineries, and local government projects would provide an even more detailed picture of the engineering geology of St. Bernard Parish.

Natural Levees

Within St. Bernard Parish, urban centers and industrial complexes occupy alluvial ridges, called natural levees, which flank both sides of river and distributary channels (Figure 1). Natural levees are asymmetric ridges, which are highest adjacent to their associated channel and slope gently away and downward in elevation from it until they merge with marshes and swamps of lower elevation (Shaw and Moresi 1936; Fisk and McFarlan, 1955, 1966).

Distributaries are channels that branch off of the modern and relict courses, i.e. Bayou La Loutre, of the Mississippi River. They are called “distributaries” because when active, they distributed floodwaters away from the Mississippi River into the surrounding deltaic plain. The channels of these distributaries and their natural levees radiate outward in a fan-like network from either the modern Mississippi River or its former St. Bernard delta lobe trunk channel (Shaw and Moresi 1936; Fisk and McFarlan, 1955, 1966; Kolb and Van Lopik, 1958, 1966; Saucier, 1994).

Within St. Bernard Parish, natural levees flank the active channel of the modern Mississippi River and the relict trunk channel and associated relict distributary channels of the St. Bernard delta lobe. Besides the Mississippi River, the relict trunk channel, now occupied by Bayou La Loutre, and a large relict distributary channel, now occupied by Bayou Terre Aux Boeufs, has large, well-developed natural levees (Fisk and McFarlan, 1955; Kolb and Van Lopik, 1958, 1966; Saucier, 1994; Shaw and Moresi, 1936).

As previously noted, the natural levees constitute the high ground within St. Bernard Parish. The highest part of this parish consists of the natural levee of Mississippi River, which forms its east, left-descending, bank. It is as much as 12 ft (3.6 m) above sea level. The towns of Arabia, Chalmette, Meaux, Poydras, and Violet along with major industrial complexes, i.e. the sugar refineries of American Sugar and Domino Sugar and petrochemical refineries of Murphy Oil and Tenneco Oil, occupied the natural levee along the east bank of the Mississippi River. Chalmette and Poydras occupy segments, which are wider than normal, where it joins respectively the natural levees of either an unnamed distributary or Bayou La Loutre (Shaw and Moresi, 1936; Kolb and Van Lopik, 1958, 1966).

These natural levees typically consist of equal proportions of high plasticity, fat clay, (CH, in the Unified Soil Classification System) and low plasticity, lean clay (CL, in the Unified Soil Classification System)(figure 2). The natural levees of the Mississippi River and Bayou La Loutre also consist of as much as 30 percent silt and sandy silty, which is ML in the Unified Soil Classification System. The silt and sandy silt comprise the crests of these natural levees. Typically, both the grain size and thickness of natural levee sediments decrease away from it crests towards where they merges with the surrounding delta plain (U.S. Army Corps of Engineers, 1958; Kolb and Van Lopik, 1958; Kolb, 1962).

Because of prolonged subaerial exposure, the sediments comprising natural levees are typically preconsolidated by desiccation and cementation. As a result, the cohesive clayey sediments found within natural levees typically possess high cohesive shear strength, 800 to 1200 lbs per square foot, and low water contents, 20 to 40 percent of dry weight. Their Liquid Limits range from 35 to 75. The water contents of sandy silt and silt are correspondingly low and typically range from 20 to 30 percent of dry weight (U.S. Army Corps of Engineers, 1958; Kolb and Van Lopik, 1958; Kolb, 1962).

Along short segments of the Mississippi River and its abandoned trunk channel, Bayou La Loutre, lateral migration of the channel created narrow, but thick, sequence of point bar sediments (Figure 1). These point bar deposits consist of 70 to 110 ft (21 to 34 m) thick sequence of sandy sediments, which locally underlie a narrow belt of natural levee sediments adjacent to their associated channel (Figure 2). Typically, the upper two-thirds to one-half of the point bar deposits consists of interstratified mixture of silty clay, silt, and sand (respectively CL, ML, and SP, in the Unified Soil Classification System). The remaining lower part of the point bar deposits consists of well-sorted (poorly graded) fine sand. Minor amounts of organic matter, either as fragments of either driftwood or ground up debris, occur within these sediments (U.S. Army Corps of Engineers, 1958; Kolb and Van Lopik, 1958; Kolb, 1962).

Deltaic Plain

The delta plain of the St. Bernard delta lobe within St. Bernard Parish consists of low tracts of periodically inundated land that is covered by a carpet of herbaceous plants. Depending on the degree of salinity, fresh, brackish, or saltwater marsh covers its surface. Adjacent to the natural levees of the major distributaries and major channels, cypress-tupelo swamps occupy portions of the delta plain, which are not permanently covered with water. The surface of the delta plain typically approximates mean high tide level, which is less than a foot (0.3 m) higher than mean sea level. Numerous lakes and interdistributary bays of various sizes and tidal channels break the surface of the delta plain.

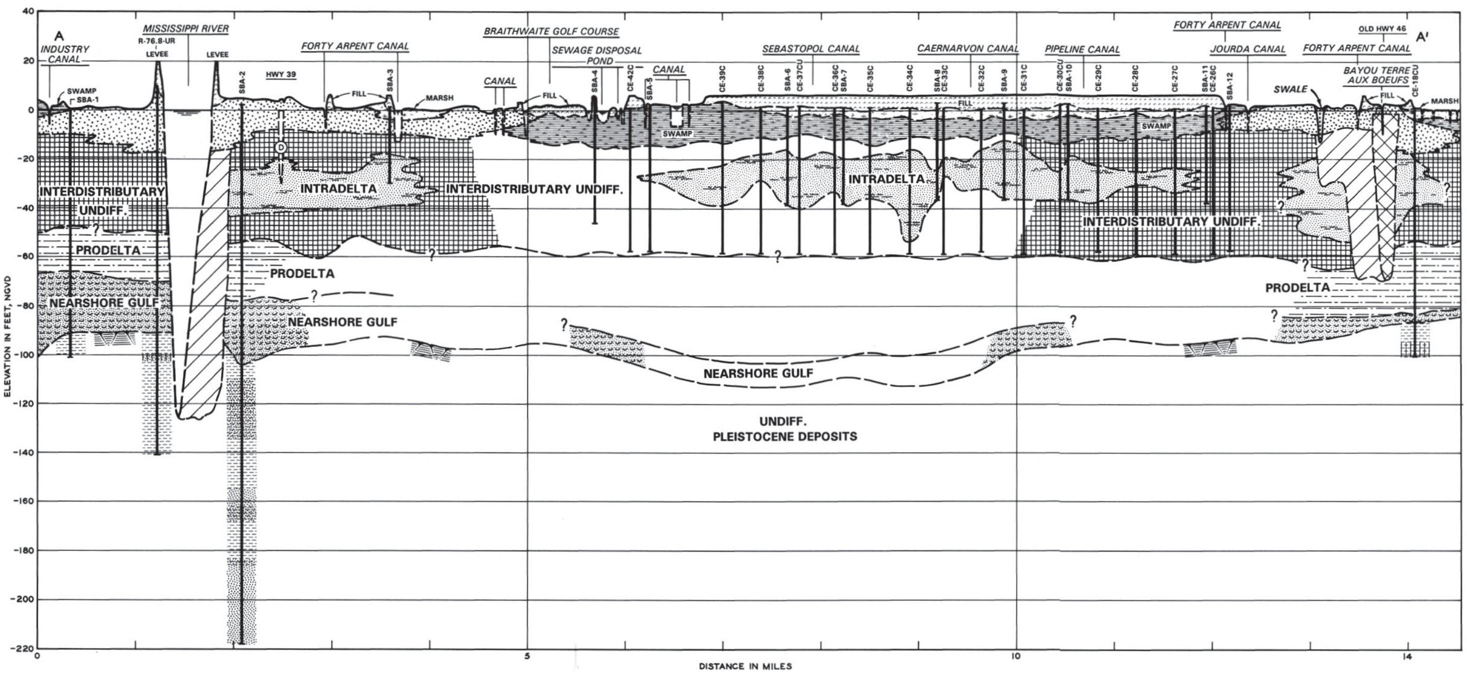

Figure 2. Cross Section of natural levees and delta plain within the urbanized part of St. Bernard Parish. (Reprinted from Dunbar et al. 1994)

The delta plain within St. Bernard Parish is the surface of a sequence of deltaic sediments deposited by the Mississippi River between 1,800 to 4,800 BP as it built out the St. Bernard delta lobe. From bottom to top, this sequence of deltaic sediments consists of (1) prodelta, (2) mixed intradelta and interdistributary, and (3) marsh and swamp deposits. Within St. Bernard Parish, the basal prodelta deposits lie upon a thin layer of shelly marine sands. These sands, in turn, lie upon the often deeply eroded surface of older Pleistocene sediments, which once was subaerially exposed as the Louisiana continental shelf. The total thickness of deltaic deposits within St. Bernard Parish ranges from less than 50 (15m) to over 150 ft (46 m) in thickness (Fisk and McFarlan, 1955; Kolb and Van Lopik, 1958; U.S. Army Corps of Engineers, 1958; Frazier, 1967).

Prodelta Deposits

The lowermost layer of deltaic sediments of the St. Bernard delta lobe consists of a gulfward thickening blanket of clay (Figure 2). This layer accumulated within the Gulf of Mexico as clay carried by currents out of the delta mouth and into the Gulf of Mexico settled from suspension on its bottom. Visually, these clays appear massive although they show laminations when x-rayed (Kolb and Van Lopik, 1958; U.S. Army Corps of Engineers, 1958; Coleman, 1981).

These prodelta sediments consist of homogeneous, normally consolidated fat clay (CH). These sediments decrease in grain size with depth from silty clay to fine clay. Their water content typically ranges from 40 to 80 percent of dry weight. Their Liquid Limit ranges from 70 to 120 and their Plasticity Index ranges from 30 to 35. The cohesive strength of the prodelta sediments gradually increases with depth typically within the range of 200 to 600 lbs per square feet. In deeper borings, the cohesive strength of these sediments has been found to be as high as 900 to 1300 lbs per square feet (Kolb and Van Lopik, 1958; U.S. Army Corps of Engineers, 1958).

Intradelta and Interdistributary Deposits

The sediments underlying and composing the bulk of the delta plain within St. Bernard Parish consist of a mixture of interfingering and interlayered intradelta and interdistributary sediments overlying the prodelta sediments (figure 2). The intradelta deposits consist of silts and clayey silts deposited as a mixture of the delta front and as crevasse splays and sandy sediments deposited as distributary mouth bars. The interdistributary deposits consist of laminated clay, typically with silt laminae or partings, which accumulated within interdistributary bays from the settling of fine-grained sediments brought into them by floodwaters (Kolb and Van Lopik, 1958; U.S. Army Corps of Engineers, 1958; Coleman, 1981).

Intradelta deposits typically consist of a heterogeneous mixture of normally consolidated silt and clayey silt (ML), silty clay (CL), fat clay (CH), and about one-fourth fine-grained well-sorted (poorly-graded) sand (SP). The water content ranges from 30 to 40 percent of dry weight for the fat clay and 15 to 30 percent for the silt and clayey silt. The Liquid Limit of the clays range from 35 to 110 and of the silt and clayey silt is as much as to 30. The Plasticity Index of the clays ranges from 15 to 60 and for the silt and clayey silt it is as much as 10. These sediments have a moderate cohesive strength (Kolb and Van Lopik, 1958; U.S. Army Corps of Engineers, 1958).

Interdistributary deposits consist largely of underconsolidated fat clay (CH). Its water content typically ranges from 50 to 160 percent of dry weight. Its Liquid Limit ranges from 60 to 160 and their Plasticity Index ranges from 30 to 75. The cohesive strength of the fat clay erratically increases with depth and generally ranges from of 150 to 300 lbs per square feet with an observed maximum around 500 lbs per square feet (Kolb and Van Lopik, 1958; U.S. Army Corps of Engineers, 1958; Coleman, 1981).

Marsh and Swamp Deposits

A layer composed of swamp and marsh deposits overlies the intradelta and interdistributary deposits and forms the surface of the delta plain. Swamp sediments occupy a narrow strip of delta plain adjacent to the natural levees of major channels. Marsh sediments underlie the remaining majority of the delta plain. These sediments typically range in thickness from 5 to 10 ft (1.5 to 3 m)(Figure 2). Marsh deposits consist typically more than 60 percent of herbaceous plant material, which has largely accumulated in place. The high productivity of plant material and the permanently waterlogged nature of the delta plain provide an ideal environment for the preservation and accumulation of organic matter. Adjacent to the natural levees, where prior to the construction of artificial levees, floodwaters once regularly flushed sediment into the adjacent delta plains along with freshwater. In this belt, sediments composed primarily of silt and clay accumulated in freshwater swamps (Kolb and Van Lopik, 1958; U.S. Army Corps of Engineers, 1958; Coleman, 1981).

The swamp sediments, which border the natural levees of the Mississippi River and Bayou La Loutre, consist typically of clay (OH) containing less than 30 percent organic matter in the form of logs, roots, stumps, thin peat beds, and disseminated material. The water content of these sediments typically ranges from 60 to 200 percent of dry weight. Their Liquid Limit ranges from 60 to 150 and their Plasticity Index ranges from 30 to 60. The typical cohesive strength of these sediments ranges from 200 to 700 lbs per square foot. Typically, the cohesive strength of swamp sediments is very low (Kolb and Van Lopik, 1958; U.S. Army Corps of Engineers, 1958; Coleman, 1981).

Marsh sediments typically consist largely of peat (PT) and organic-rich clay (OH). The water content of these sediments ranges from 80 to 800 percent of dry weight. Their Liquid Limit ranges from 70 to 250. These sediments have a low cohesive strength and are readily compressible (Kolb and Van Lopik, 1958; U.S. Army Corps of Engineers, 1958). Within the St. Bernard delta lobe, marsh sediments average about 10 ft (3 m) thick. Within the delta plain between Lake Borgne and the natural levees of the Mississippi River and Bayou La Loutre, the peat comprising these sediments thickens towards Lake Borgne to a maximum thickness of 8 to 12 ft (2.4 to 3.6 m) (Snowden et al., 1980).

Discussion

In terms of engineering geology, the principle engineering concerns are (1) foundations, specifically for heavy structures, (2) settlement of the ground, and (3) subsidence. Of lesser concern is the corrosive nature of the surface sediments within St. Bernard Parish.

Foundation Conditions

The best conditions for foundations within St. Bernard Parish occur within the natural levees. Because of their preconsolidated nature and low plasticity, they provide relatively favorable foundation conditions for light structures and roads. Since these sediments are relatively thin and rest on more compressible and lower strength intradelta and interdistributary sediments, the construction of heavy structures will likely require the use of pilings, floating foundations or other engineering techniques. Where the natural levees overlie thick, sandy point bar sediments, the point bar deposits provide relatively favorable foundation conditions for heavy structures. Otherwise, where they are enough to the surface, pilings will likely need to be driven down to preconsolidated Pleistocene sediments, on which the sediments of the St. Bernard delta lobe lie. The shrink-swell potential of natural levees is low, except for a belt of moderate-to-high shrink-swell potential where these sediments grade into the adjacent swamp sediments of the delta plain.

In sharp contrast, the organic-rich sediments that underlie the delta plain are unsuited for foundations of all but the lightest structures. Their high water contents, low shear strength, and high compressibility result in an inadequate bearing capacity for the foundations of most structures. The porous nature of the peat makes seepage beneath levees a significant problem requiring specific design mitigation. The shrink-swell potential of the organic delta plain sediments is low to nonexistent. However, swamp deposits have a low-to-high shrink-swell potential where drained for development.

Settlement

Within St. Bernard Parish, settlement of the ground on which structures are built due to their weight is a significant concern. The settlement occurs because of two processes, primary and secondary consolidation. In case of primary consolidation, settlement occurs as the result of the reduction in the volume of the sediment as water is squeezed out of it by the weight of a sustained load. In case of secondary consolidation, the reduction in volume of the sediments results from the adjustment of the internal structure of the sediment in response to a sustained load after the water is squeezed out of it (Kolb and Van Lopik, 1958; Snowden et al., 1977, 1980).

The sediments underlying the natural levees within St. Bernard Parish are least affected by consolidation. Within the higher parts of the natural levees, these sediments are only partially saturated and have little water to be removed by primary consolidation. Also, even when they are saturated, the sandy and silty natural levee sediments have a grain-supported internal structure, which resists secondary consolidation to a limited extent. As a result, such sediments are only slightly affected by the dewatering of pore spaces. The presence of fine-grained, cohesive sediments within upper point bar deposits makes them susceptible to some consolidation, which results in relatively minor settlement. However, because of the interstratified nature of these sediments, which allows fine-grained layers to readily drain into coarse-grain layers, whatever settlement occurs is rapid. Where underlain by intradelta, interdistributary, and prodelta sediments, consolidation within these sediments can result in some settlement (U.S. Army Corps of Engineers, 1954; Snowden et al., 1977, 1980).

Because of their high water content, high plasticity, and the presence of compressible organic matter, marsh and swamp sediments are quite prone to significant, often severe, settlement resulting from loading. Loading often causes high rates of initial settlement as a result of the expulsion of water, the compression of organic matter, and adjustment of the internal structure of fine-grained sediments comprising these sediments. Typically, consolidation of these sediments continues for long period of time after the sediments have been loaded (U.S. Army Corps of Engineers, 1954, 1958; Snowden et al., 1977, 1980).

As documented by Snowden et al. (1977, 1980) both organic-rich swamp and marsh deposits, i.e. peat, can be especially treacherous because of settlement due to the destruction of organic matter by oxidation. When such sediments are drained for urban, agricultural, or other development, the organic sediments lying above the water table essentially disappear as they oxidize. This type of settlement will rapidly continue as long as organic deposits remain above the water table. Lake Big Mar, a failed agricultural reclamation project just over the parish boundary in Plaquemines Parish, demonstrates what the ultimate result of this process can be.

Subsidence

Subsidence, settlement on both semi-regional and regional scales, is the result of a number of processes. The natural levees within St. Bernard Parish and adjacent strips of the delta plain are subsiding relative to the adjacent delta plain. This is happening because of the load placed on the underlying intradelta, distributary, and prodelta deposits by the weight of the natural levees is causing these sediments to consolidate (Kolb and Van Lopik, 1958). The portions of the natural levee sediments overlying less compressible point bar sands and silts cut into preconsolidated Pleistocene deposits, and the parts overlying point bars are likely not experiencing this process. Also, removal of underground fluids by oil and gas production can locally cause subsidence within the delta plain as summarized by Morton et al. (2005).

On a much larger scale, St. Bernard Parish along with the entire Mississippi River Delta is subsiding. This subsidence is the result of compaction of the thousands of feet of sediments underlying the Mississippi River Delta, downwarping of the underlying crust, and salt tectonics caused by the enormous weight of these sediments overlying them. Such subsidence is a significant concern in that with time it increases the vulnerability of St. Bernard Parish to storm surges by lowering the land surface and the height of existing levees.

Corrosion

In general, the surface sediments within St. Bernard Parish are corrosive to both uncoated steel and concrete. There exists a uniform risk of corrosion for uncoated steel buried within the surface sediments comprising both the natural levees and delta plain. For concrete buried within the surface of the natural levees, swamps, and brackish marshes of St. Bernard Parish, there is the general, but not universal, moderate risk of corrosion. For concrete buried within the surface of the saline marshes, the risk of corrosion is low (Trahan et al., 1989).

Summary

As previously discussed, sediments with very different engineering properties underlie St. Bernard Parish. As decades of practical experience have demonstrated, the natural levee deposits provide the best conditions for development within St. Bernard Parish. The portions of the natural levees underlain by point bar deposits provide the most stable locations for the construction of large structures and reconstruction of critical infrastructure. In sharp contrast, organic-rich swamp and marsh sediments, characterized by high water content, high plasticity, and the presence of compressible organic matter, underlie the delta plain. These physical characteristics make the delta plain very poorly suited for development without special and expensive remediation. Most types of conventional development will ultimately result in irrevocable subsidence to subsea elevations. Continued settling of levees built within this area over a period of decades will compromise their effectiveness as protection against storm surge.

Ongoing regional and semi-regional subsidence also has implications for St. Bernard Parish. Subsidence not only accentuates the magnitude of flooding created by hurricane storm surge by physically lowering the land's surface with time, it also reduces the effectiveness of existing levees and other flood control structures by reducing their height. In addition, subsidence further exacerbates the damage caused by storm surges by significantly contributing to land loss that reduces the moderating affect that marshes have on them.

Acknowledgements

I thank Richard P. McCulloh and Bill Good of the Louisiana Geological Survey for reviewing a draft of this paper.

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Louisiana Parish Well Reference Cartographic, Production and Well Information Reference 1900 - 2004

Brian Harder

The Louisiana Geological Survey in cooperation with the Center for Energy Studies through the PTTC program have created the Louisiana Parish Well Reference Cartographic, Production and Well Information Reference 1900 - 2004. Modeled after the Louisiana Desktop Well Reference it is a Geographic Information System (GIS) for the Louisiana oil and gas industry emphasizing the historical field and LUW production at the parish. Developed using ESRI's Arcview software, the program is easy to use, allowing large amounts of data to be evaluated by combining geographical, image and well information. Included is a parish map with all well locations, parish boundaries, section, township and range boundaries, primary, secondary and tertiary roads, permanent and intermittent streams and water polygons. It contains production data from 1900 through 2005 and current well status information. The historical production data, including that prior to 1977, was compiled from two sources from the Louisiana Department of Natural Resources Office of Conservation. Monthly LUW production was taken from the Production Audit Cards and annual field production was taken from the Annual Oil and Gas Reports. Currently St Bernard Parish and Cameron Parish are complete and for sale for $75 on the PTTC web site (www.cgrpttc.lsu.edu). We are currently working on Vernon and Rapides parishes combined which should be available in early 2006.

New Publications

Educational Series

Douglas Carlson - ***Louisiana Ground Water Resources:*** Louisiana Geological Survey, Educational Series #4, 27 p. (2005). A general interest publication providing basic information on ground water in Louisiana including aquifers, aquifer properties and definitions, ground water flow, usage and interesting water facts in the appendix.

Port Arthur 30 X 60 Minute Geologic Quadrangle Map (2005). Scale 1:100,000. Geology by Paul Heinrich, GIS compilation by R. Hampton Peele and P. Vijaiamernath and Cartography by John Snead and Lisa Pond. Multicolored, sheet size 20" X 46" with descriptions of map units.

Contact Patrick O'Neill to order LGS publications at 225/578-8590 or email at poneil2@lsu.edu.

Modeling the Burial and Thermal History, Organic Maturation, and Oil Expulsion of the North Louisiana Petroleum System

Roger Barnaby

More than 2.5 billion barrels of oil have been produced from Jurassic through Tertiary reservoirs in north Louisiana. Organic–rich Smackover (Late Jurassic) lime mudstones are considered to be the primary source rocks. Smackover source rocks accumulated in a marine environment, the dominant organic material is oil-prone algal kerogen. The objective of this study is to apply geochemical analysis and basin modeling to evaluate the source rock organic maturity; assess the timing and depth of hydrocarbon generation and expulsion; estimate the volumes of expulsed hydrocarbons; and identify key controls influencing hydrocarbon reservoir distribution.

Zimmerman (1999) was the first to model the north Louisiana petroleum system, although his effort was hampered by the paucity of geochemical data and by limitations in the computer software used to model the processes of burial, thermal maturation, and hydrocarbon expulsion. Organic maturity data collected by this study, based on kerogen color, indicate that the Smackover is mature for oil and gas. Although total organic carbon contents are low (average = 0.5%), cores are confined to the updip portion of the Smackover; distal facies that extend downdip beneath the reach of well penetrations are considered to be more prolific source rocks.

BasinMod® software was used to generate a 4–dimensional basin model of the Mesozoic through Cenozoic succession in north Louisiana. Geological interpretations and petrophysical data for lithologic determinations were provided by 140 control wells and 42 sample wells. The 160 m.y. succession was subdivided into 30 time slices represented by 26 depositional events and 4 unconformities. Figure 1 is a stratigraphic cross section through the model, extending from north to central Louisiana. On the Monroe Uplift in north Louisiana, an angular unconformity occurs above the Early Cretaceous, with up to 4500 ft of erosion. Burial history analysis indicates that Smackover source rocks on the Monroe Uplift attained maximum burial during the Early Cretaceous, prior to uplift and erosion. Further downdip, the Smackover underwent continuous subsidence and present-day depths represent maximum burial.

The thermal history was modeled based on basement heat flow; a more fundamental approach than previous efforts that assumed a constant geothermal gradient throughout north Louisiana for the past 160 m.y. Present–day heat flow was calculated using well bottomhole temperatures; paleoheat flow was modeled based on the amount of lithospheric stretching that occurred during Late Triassic to Early Jurassic rifting. Modeled paleotemperatures were compared with temperatures derived from thermal maturity and fluid inclusion data. Kerogen maturation was calculated using a kinetic model; oil generation from kerogen is a function of temperature and time. The present-day updip Smackover is mature for petroleum; thermal maturity increases with depth downdip (Figure 2). Modeling indicates that the source rocks began to generate oil by the Early Cretaceous, at burial depths of 8,000 to 9,000 ft.

Oil expulsion was modeled by assuming that the source rock expelled oil when the oil saturation in the pore space exceeded the critical saturation threshold, above which the relative permeability of oil is greater than that of water. Modeling suggests that peak oil expulsion occurred during the Early Cretaceous at burial depths of 9,000 to 12,000 ft (Figure 3). Estimated expulsed oil volumes are 250 billion to 2500 billion barrels; cumulative production thus accounts for less than 1 percent of the total oil. Assuming typical reservoir recovery efficiencies of 25 to 50 percent, the original oil in place accounts for less than 4 percent of the total volumes of oil that were generated and expulsed in the north Louisiana petroleum system.

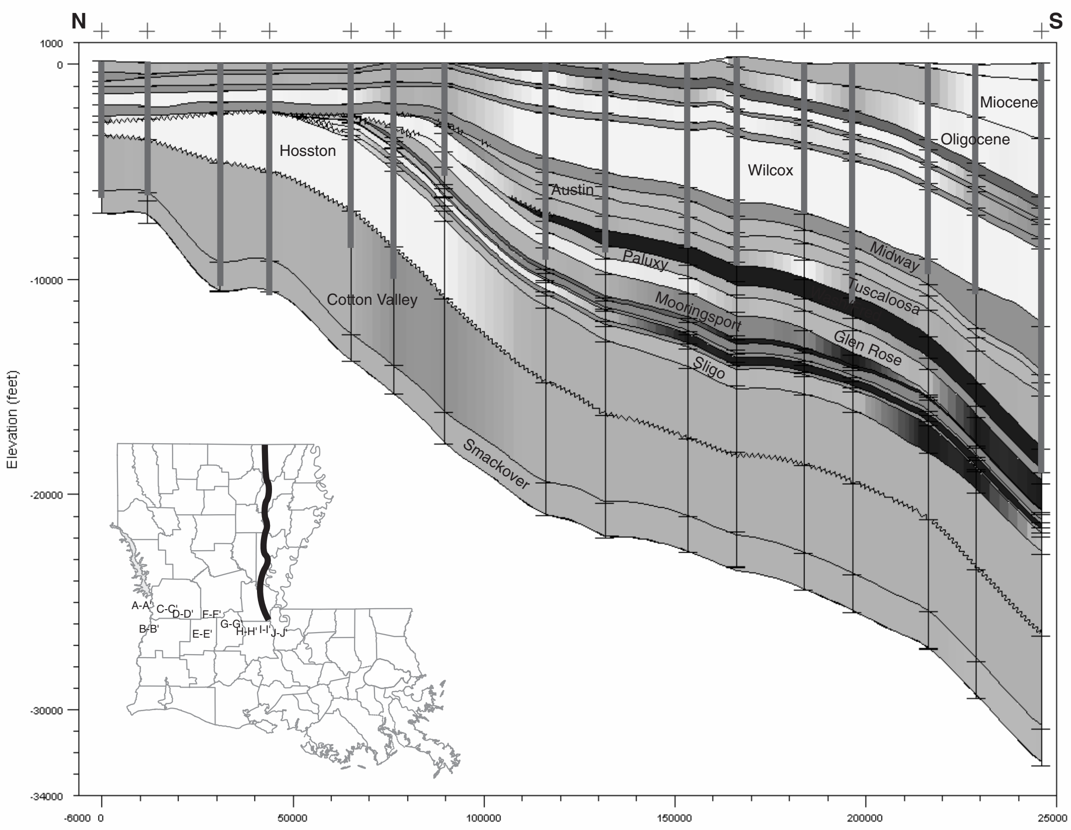


Figure 1. Stratigraphic cross section of Late Jurassic through Tertiary strata from north Louisiana Monroe Uplift to central Louisiana. Vertical lines indicate well control.

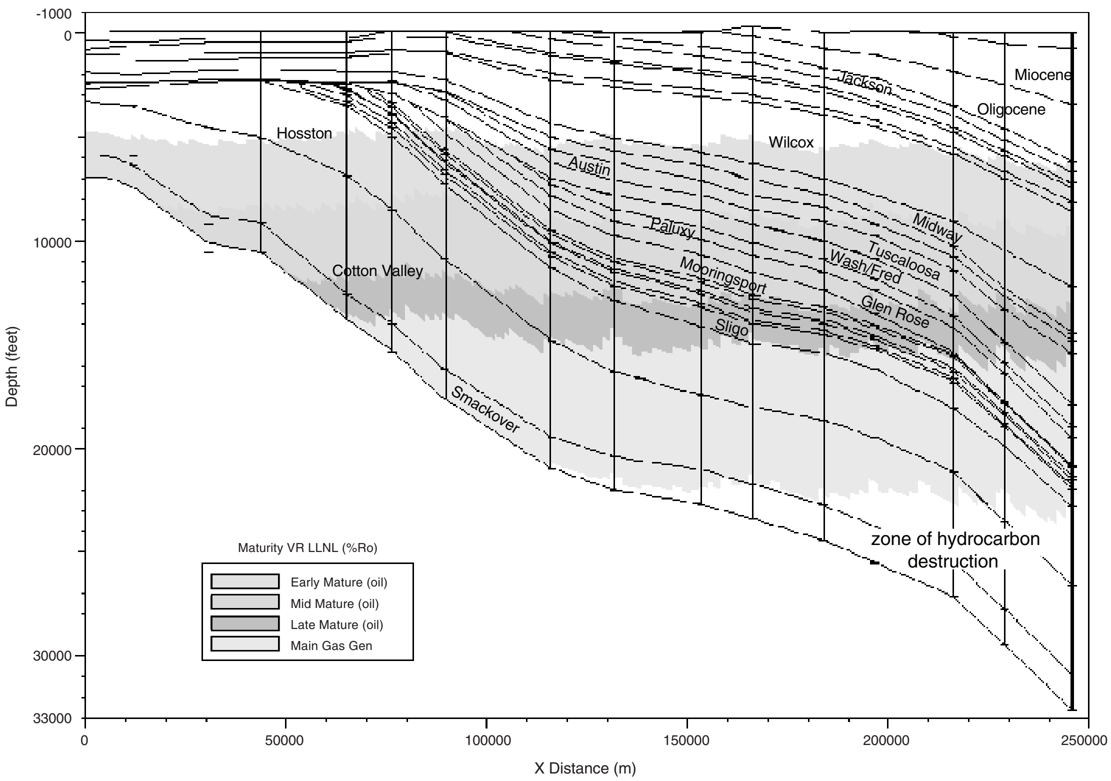


Figure 2. Present-day maturity windows, same cross section as Figure 1. Updip Smackover is in the oil window, thermal maturity increases basinward to zone of main gas generation, the downdip Smackover is thermally overmature for oil or gas.

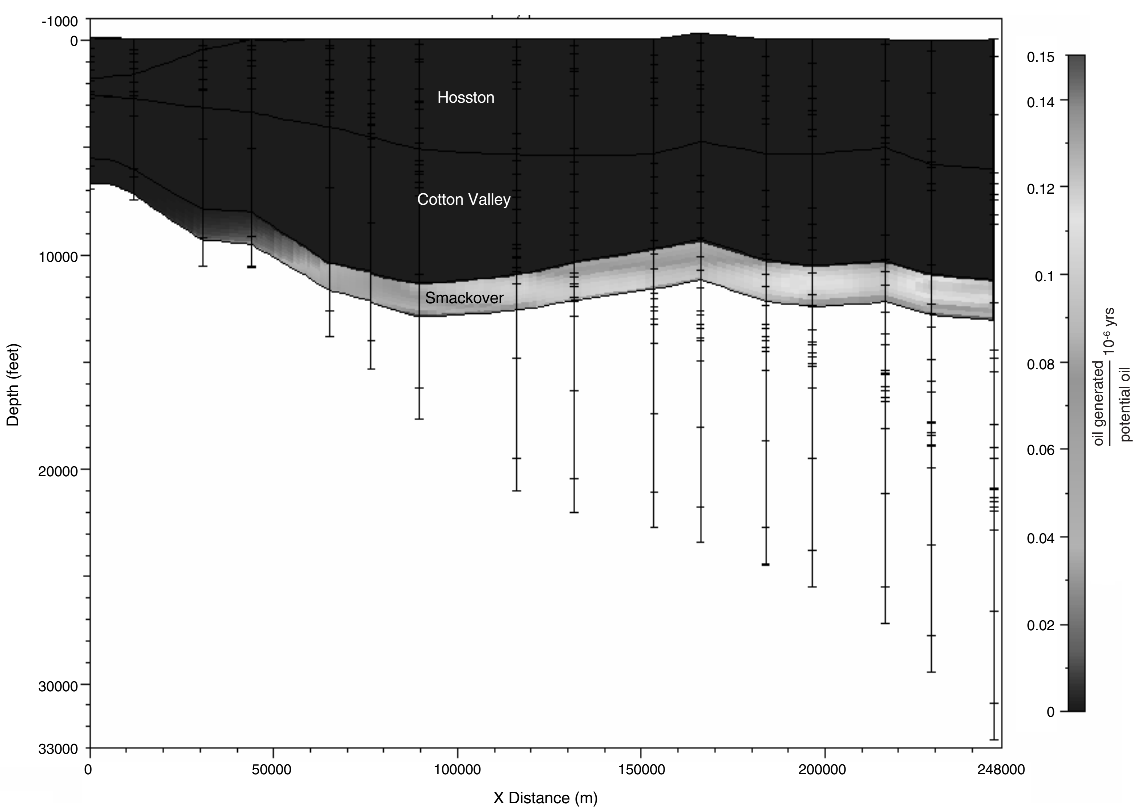
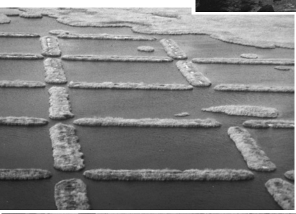


Figure 3. Modeled Smackover oil generation, same cross section as Figure 1. 110 million years before present, oil generation reached a maximum during the Early Cretaceous, with conversion rates up to 15 percent/m.y. Maximum generation and expulsion were coeval.

Review of Recent Activities of the Coastal Processes Section

Bill Good

Monitoring data and reports of the Gulf Intracoastal Waterway (GIWW) to Clovelly (BA-02) and the Jonathan Davis (BA-20) hydrologic restoration (HR) projects were reviewed in order to identify key research and monitoring needs. Based on this review, it is suggested that a quantification of the degree to which these HR projects actually control water exchange is critically needed. It is important to understand the dynamics of water exchange both at the level of the individual structure and of the entire project perimeter, considering storms and other events during which high water levels and high salinities co-occur.



A conceptual model was presented that is based on the description of HR projects that characterizes them as a means to mitigate ecosystem degradation resulting from increased hydrologic interconnections. An alternative conceptual model is also proposed that assumes that increasing relative sea level rise (RSLR) is the principle factor driving ecosystem degradation. The implications of these two viewpoints are briefly discussed. A shift in emphasis of the monitoring efforts for these projects would logically follow if the alternative model were accepted: accretion rates, anaerobic stress indicators, and RSLR rates would warrant additional emphasis.

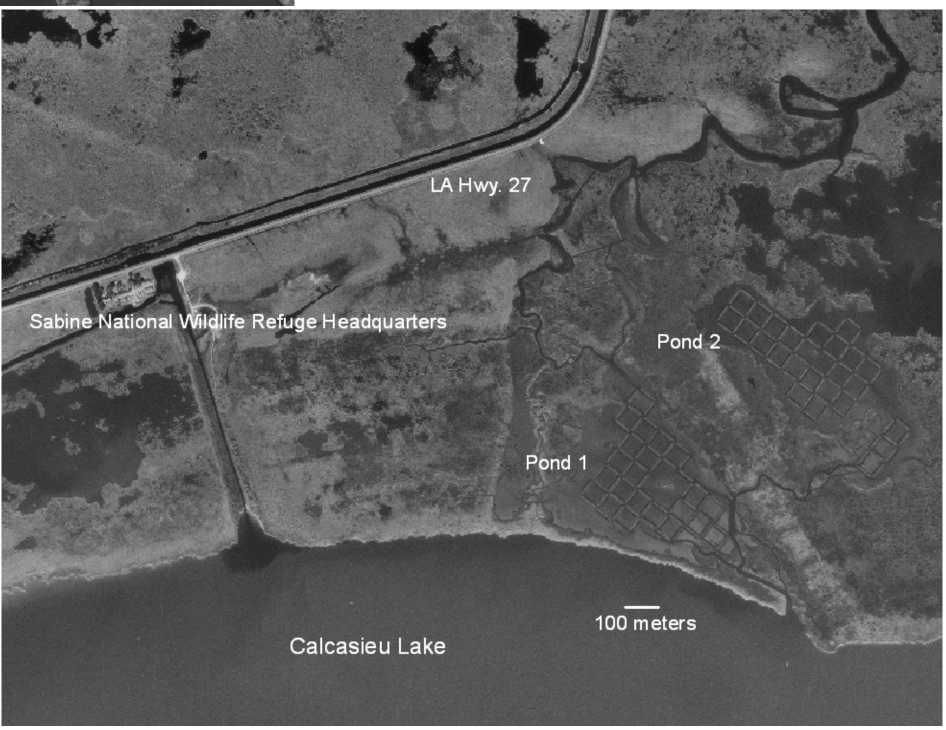


Figure 1. The first marsh terracing project, completed at the Sabine National Wildlife Refuge in Cameron Parish, Louisiana

Additionally, a GIS study is underway of the first marsh terracing project, which was completed at the Sabine National Wildlife Refuge in Cameron Parish, Louisiana in 1990 (figure 1). This study is based on a GIS-assisted comparison of a low-altitude, high-resolution color infrared aerial photograph of the project immediately after construction in November of 1990 with a comparable image taken in 2000. Terracing is a fairly new restoration technique in which a series of ridges are constructed to marsh elevation in shallow coastal ponds or bay bottoms. This analysis indicates that during the ten-year interval, marsh vegetation spread laterally from the terraces into the adjacent open-water areas (figure 2). Expansions of up to four or five meters were not uncommon. Additionally, the shorelines adjacent to the terrace fields showed comparable lateral expansion rates in some areas. The pattern of marsh expansion suggests that proximity to sediment supply is a key factor in the degree of terrace expansion and shoreline advancement, and that some interactive effects of the terraces facilitated the shoreline advancement by reduction in wave-induced water velocities in the immediate area.

The present investigation indicated that the total increase of the 130 terraces was 22,192 square meters (5.5 acres), and was on average 171 square meters per terrace (0.1 acres) from the time period 1990-2000.

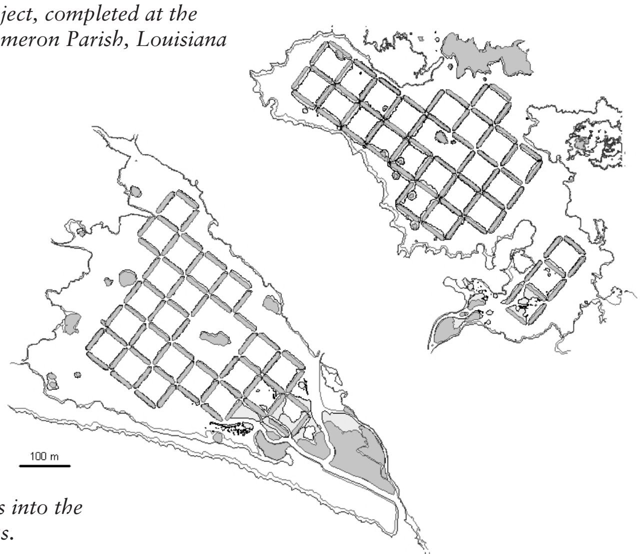


Figure 2. During the ten-year interval, marsh vegetation spread laterally from the terraces into the adjacent open-water areas.

Conferences

Gulf Coast Association of Geological Societies (GCAGS)

This meeting scheduled for September 25-27, 2005 at New Orleans was cancelled due to Hurricane Katrina. However, the GCAGS has informed us that the papers scheduled to be presented at this conference will be published in the Transactions. The following papers were submitted by LGS Faculty and Staff for this meeting:

- ***A New Look at the Chicot Aquifer of Southwestern Louisiana*** by Douglas Carlson and Riley Milner. (2005).
- ***Exploratory Progress Towards Proving the Billion Barrel Potential of the Tuscaloosa Marine Shale*** by Chacko J. John, Bobby L. Jones, Brian J. Harder and Reed J. Bourgeois (2005).

LGS Advisory Board Meeting for 2005

The LGS Advisory Board Meeting, scheduled for September 16, 2005, was cancelled as a result of Board members and LGS Faculty and Staff being involved in Hurricane Katrina related activities. The meeting will be rescheduled in early 2006.

American Institute of Hydrogeology (AIH)

The 25th Anniversary meeting of the AIH will be held from May 21-24, 2006 at the Holiday Inn Select, 4728 Constitution Avenue in Baton Rouge, Louisiana. The titles of abstracts of the papers submitted by LGS Faculty and Staff which have been accepted for presentation are as follows:

- ***How Falling Groundwater Levels Influences the Water Budget of Lake Pontchartrain Watershed*** by Douglas Carlson.
- ***Updated Geology and Saltwater Intrusion for the Chicot Aquifer of Southwestern Louisiana*** by L. Riley Milner and Thomas P. Van Biersel.
- ***Saltwater Encroachment in Regional Drainage Basins of Southern Louisiana: an update*** by Thomas P. Van Biersel and L. Riley Milner.

Baton Rouge Geologic Society (BRGS)

Bill Good presented a talk titled *"An Overview of Marsh Terraces in Louisiana with Emphasis on the 1991 Sabine Project"* at the first meeting of the BRGS for the year 2005-2006 on September 9, 2005.

Personnel News

Weiwen Feng, Research Associate 3 in the Cartographic Section resigned from LGS to take a position with an environmental firm.

Ms. Asheka Rahman has been hired as his replacement. She has just completed a doctorate degree in civil and environmental engineering and will be mainly involved in GIS work on LGS contract projects with the LSU Center for Public Health Impact of Hurricanes and the Oil Spill Research and Development Program.

Robert Paulsell

Robert Paulsell, Research Associate 4, was presented with an LSU 15 year Service Award by the LGS Director Chacko John.

Douglas Carlson, Asst. Professor–Research, was elected as the Gulf Coast representative for the Division of Environmental Geology (DEG) of the American Association of Petroleum Geologists (AAPG).

Clayton Breland, Asst. Professor–Research was elected as the Vice President of the Baton Rouge Geological Society (BRGS) for the 2005-2006 term.

Chacko John, LGS Director, was elected as the Vice President of the Association of American State Geologists for the 2005-2006 term.

Dr. Bill Good, Manager, Coastal Processes Section will be retiring on December 31, 2005. LGS thanks Bill for his service here and we wish him the best of luck.

Renewed Interest in Alternative Sources of Energy

With gas prices projected to remain relatively high for the foreseeable future, people in the energy business have begun to scour the landscape for alternative sources of energy. The state's budding Coalbed Methane (CBM) exploration and production effort might fit the bill for many in the industry. Dr. F. Clayton Breland, Jr. with the Basin Research Energy Section at LGS has studied the potential of CBM in Louisiana for the past five years. Recently, Dr. Breland was invited to be guest speaker at the Southwest Louisiana Geophysical Society's November 11 meeting and luncheon. The title of Dr. Breland's presentation was *"A Discussion of Coalbed Methane and Its Occurrence in Louisiana"*. Dr. Breland has also been recently asked, along Dr. Gary Kinsland with the University of Louisiana at Lafayette, to co-chair the Coalbed Methane session at the upcoming 2006 GCAGS in Lafayette. Kinsland and Breland have worked in a collaborative effort to study CBM the last few years, most recently with a USGS funded project.

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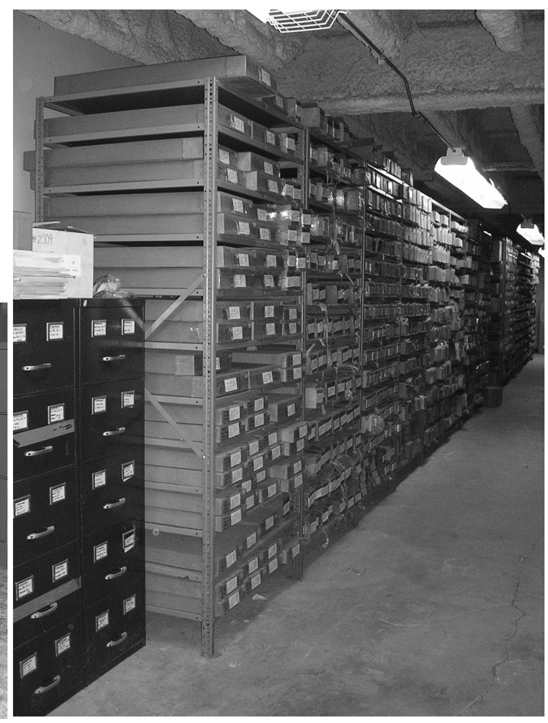
LGS RESOURCE CENTER

The LGS Resource Center is located on the LSU Campus and consists of a core repository and well log library. The core facility has over 30,000 feet of core from wells in Louisiana, Alabama, Arkansas, Florida, Mississippi, and Texas. The well log library contains over 50,000 well logs, most of them from Louisiana. The LGS Resource Center is available for use by industry, academia, government agencies and those who may be interested. Details of current holdings are posted on the LGS website www.lgs.lsu.edu under Publications and Data. For more information contact Patrick O'Neill at 225/578-8590 or by email at poneil2@lsu.edu.



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