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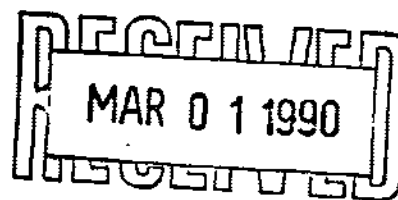
**THE ECOLOGY OF BARATARIA BASIN, LOUISIANA:
AN ESTUARINE PROFILE**

edited by
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CHAPTER 1

DESCRIPTION OF THE BASIN

by

W.H. Conner and J.W. Day, Jr.

1.1 INTRODUCTION AND PHYSICAL SETTING

Coastal Louisiana was formed as a result of sedimentation by the Mississippi River over the past several thousand years (Morgan 1967). Frequent channel changes by the Mississippi River have created broad areas of near sea level wetlands (Kolb and Van Lopik 1958; Figure 1). In an active delta sedimentation exceeds erosion, while in an abandoned delta the reverse is true. As channels extend into the shallow Gulf of Mexico waters, high ridges or natural levees form adjacent to the streams from the deposition of coarse suspended sediments. Lower elevations in the back of the natural levees contain much finer sediments and support wetland vegetation (Figure 2). Most estuarine systems of the Mississippi Deltaic Plain are thus located in an interdistributary position, that is, between the higher ridges of the Mississippi distributaries (Russell 1936).

The Barataria Basin is an example of such an interdistributary estuarine-wetland system. It is located between the natural levees of the active Mississippi River and the abandoned Bayou Lafourche distributary (Figure 3). The basin is roughly triangular in shape, with its apex at Donaldsonville. It is about 110 km long and 50 km wide at its largest point where it meets the Gulf of Mexico. Since the river occupied its present channel about 700 years ago, there has been little sedimentation in most of the basin (Morgan 1967). Since that time bays, lakes and, bayous have enlarged by subsidence and erosion to form an

extensive network of interconnecting waterbodies which allow transport of water, materials and migrating organisms throughout the basin (Fisk and McFarlan 1955; Coleman and Gagliano 1964; Morgan 1967, 1972).

Salient morphological features characterizing the area include natural and artificial levees, water bodies (such as bays, lakes, and bayous), coastal beaches and barrier islands, and swamp and marsh wetlands. The lower portion of the Barataria Basin is a typical bar-built estuary. It is shallow with bars at the mouth and a low-tide, low energy coast (Adams et al. 1976). The natural levees and barrier islands are the only high, well-drained ground in the basin, and thus have been the primary sites of human habitation. The coastline is primarily beach-dune systems with tidal flats and marshes in protected areas behind the barrier shores (Morgan 1967). Barrier islands protect the estuarine environment from waves and currents that would otherwise cause much more rapid erosion of wetlands.

The basin is still an extremely dynamic system undergoing constant change because of geologic and human processes. The basin has been closed to river flow since the leveeing of the Mississippi River in the 1930-40's and the closing of the Bayou Lafourche-Mississippi River connection in 1902. A small amount of water enters the basin through the Intercoastal Canal via the locks in New Orleans. Precipitation provides the main source of freshwater for the basin. During periods of high water on the Mississippi River and

← Lacune

still true?
Lafourche
1902

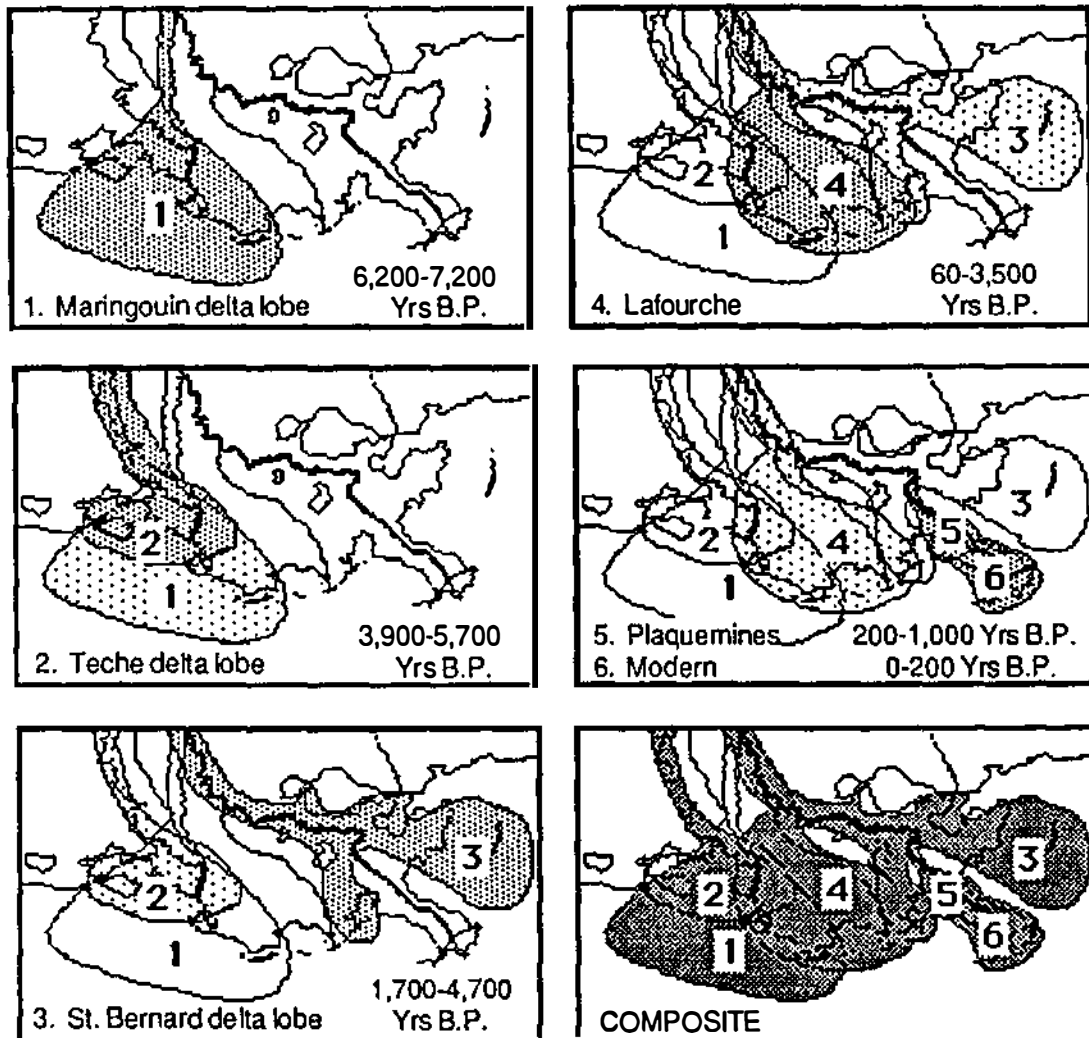


Figure 1. Historical sequence of major distributary delta lobes in the Mississippi Deltaic Plain (Baumann and Adams 1981).

given certain wind and sea conditions, freshwater from the river can exert some influence on the lower part of the basin.

1.2 HUMAN SETTLEMENT AND IMPACT ON THE BASIN

The first people to populate Louisiana in prehistoric times probably found that the coastal marshes provided an abundance of food. Gathering and hunting were the primary sources of food for these early settlers, and *Rangia* clam was probably one of the most dependable sources of food, as numerous shell middens are found throughout the coastal region of the state. Since there were no roads in the area, streams were ideal

highways for the early settlers. The floodplains of the major streams were also ideal areas for living and represented prime agricultural land when agriculture later became important.

The first European settlers to the basin arrived in the region in the 1700's and settled along the natural levees of the Mississippi River and Bayou Lafourche. Agriculture was important to the new arrivals and they planted indigo, tobacco, rice, and vegetable crops. Two of the most important groups of settlers to the area were the Germans and the Acadians. The Germans settled in St. Charles and St. John the Baptist Parishes, especially the area around Lac des Allemands (Figure 4). Most of these hard-working

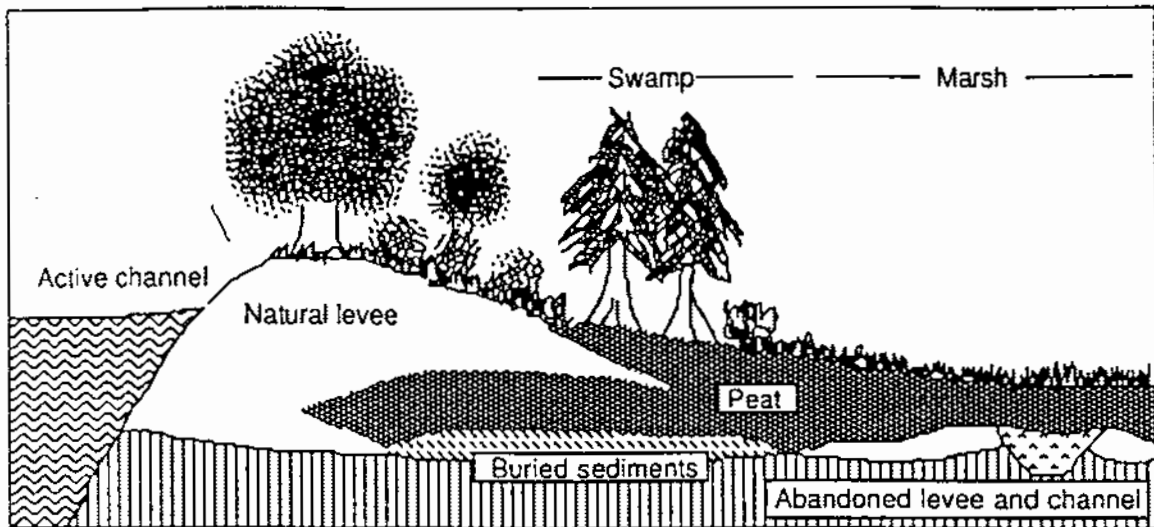


Figure 2. Generalized succession pattern in the delta area. With an active channel, there is maximum development of a natural levee. Behind the natural levee, swamp and marsh may form as the levee subsides.

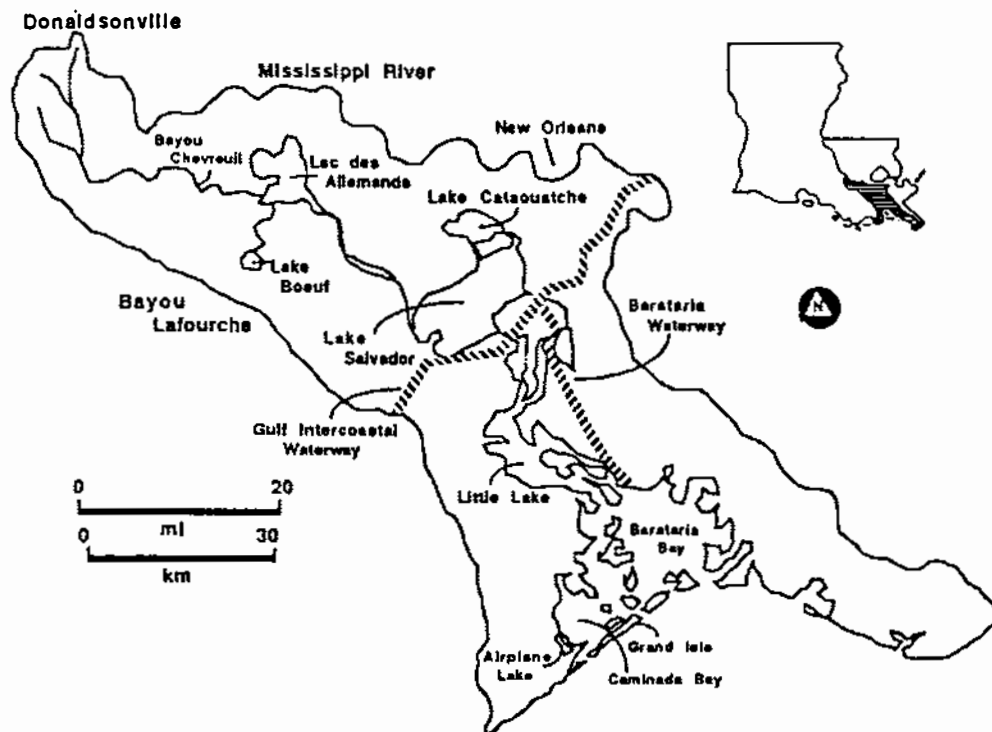


Figure 3. Location map of the Barataria Basin. The location and names of the most commonly referred to places in the text are shown.

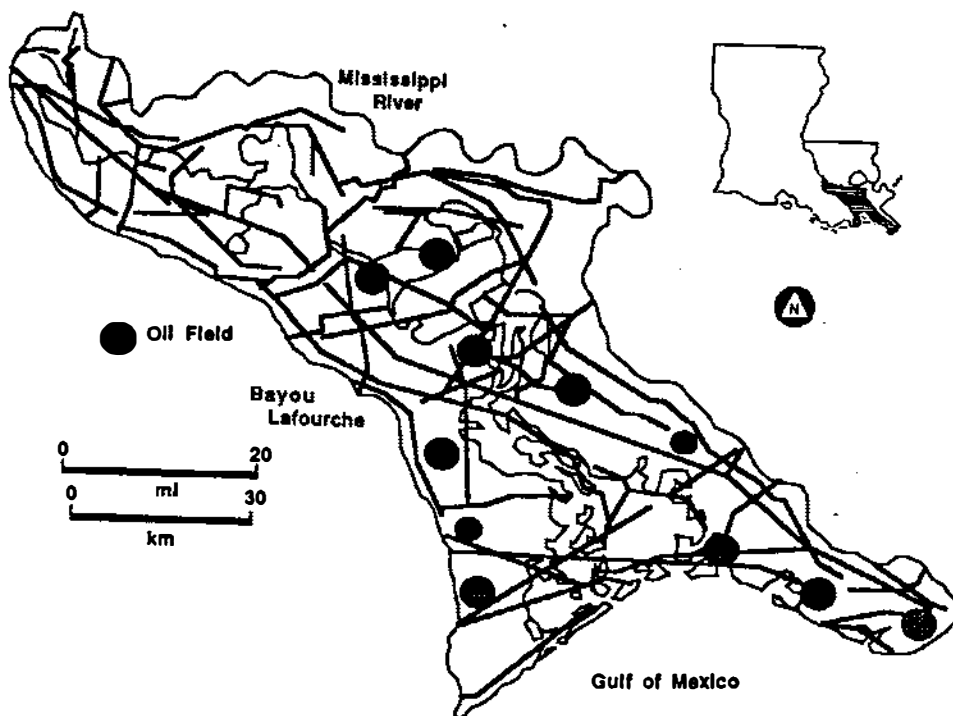


Figure 5. Major oil fields and pipelines within the Barataria Basin (modified from Adams et al. 1976). At this scale the intricate pattern of crisscrossing small canals within the basin cannot be shown.

1.4 BIOLOGICAL ZONES

The Barataria Basin is divided into five environmental units: levee and developed lands, swamp forest, fresh marsh, brackish marsh, and salt marsh (Figure 6). Some authors separate brackish and intermediate marshes, but for the purposes of this profile, the two units will be combined. These units are treated in order of increasing salinity since the flow of water occurs in this direction and water is considered the major integrative element of the system.

1.4.1 Levee and Developed Land

The highest and driest areas in the basin are found along the natural levee ridges of the Mississippi River and Bayou Lafourche. These levees were once covered with forests of hardwood trees. However, the majority of these forests have been cleared and are now used for agricultural, residential, and industrial purposes. Stands of American elm (*Ulmus americana*),

sweetgum (*Liquidambar styraciflua*), sugarberry (*Celtis laevigata*) and swamp red maple (*Acer rubrum* var. *drummondii*) can still be found in some areas.

1.4.2 Swamp Forest

Vegetation in the swamp forest is predominantly baldcypress (*Taxodium distichum*) and water tupelo (*Nyssa aquatica*). There are about 100,000 ha of swamp in the Barataria Basin (Table 1) representing 16% of the basin. The ratio of land to water is highest here, but decreases moving seaward as waterbodies become a more dominant feature of the landscape. Soil in this unit is composed largely of clay (38%) which is mainly Mississippi River sediment.

Waterbodies in the swamp forest are mainly bayous, which tend to serve as conduits of excess swamp forest production. During flooding episodes, excess water floods the entire system. As this water flows through the forest, it picks up

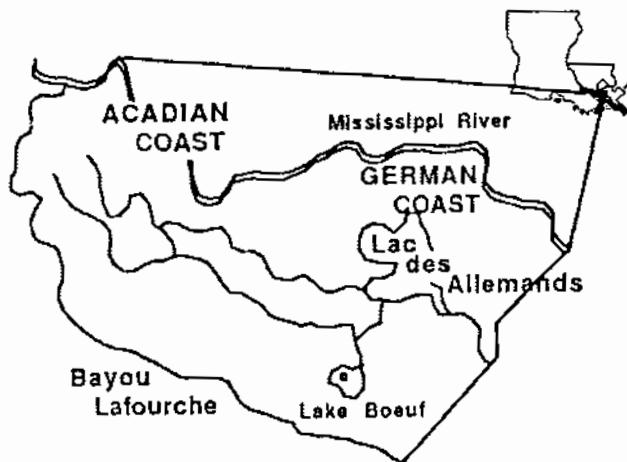


Figure 4. Map of the upper Barataria Basin showing the location of the Acadian and German coasts (reprinted, with permission, from Kniffen 1968, copyright LSU Press).

farmers raised produce to sell in New Orleans. These settlers lost their language and identity as they were absorbed by the French population. The Acadians first settled in the northern part of the basin and extended down the broad levees of Bayou Lafourche. These people were devout Catholics and held strongly to their traditions. They absorbed nearly every group with which they came in contact and still represent a significant portion of the population in the basin.

One of the most important factors that has influenced settlement in the basin has been flooding by the Mississippi River. Flooding has always occurred on the river. The Indians knew to live on the higher sections of land and plant their crops on the rich floodplains after the floodwaters receded. The European settlers, however, settled all along the natural levees, extended their fields back to the swamp, and built their towns right on the rivers. There was no way the settlers could escape flood damage. Thus began the fight to control the river by building levees. At first, each landowner was responsible for building and maintaining the levees along his property, but this did not work very well. In 1927, after a particularly destructive flood, the United States Corps of Engineers took over the planning and construc-

tion of the levees. By the 1940's, the entire Mississippi River was leveed and the Barataria Basin no longer received any overflow of the rich, sediment-laden waters.

The Barataria Basin is mainly composed of cypress-tupelo swamp in its upper headwater region. Lumbermen soon found that cypress was an excellent wood for building. Because of its location in the wettest parts of the state, however, it was difficult to harvest. This had changed by 1890, with the invention of steam equipment to pull the logs out of the swamps. Cypress lumbering began in earnest and peaked in 1913 with 755 million board ft being harvested in the state (Mattoon 1915). A large portion of the lumber came from the Barataria Basin area, and numerous cypress mills were located in the area. By 1925 all the virgin stands of cypress were logged and only a few individual virgin cypress exist today in the basin. The construction of canals and railroad lines in the swamp severely altered the natural hydrology of much of the basin.

Perhaps the greatest activity that has altered the entire basin is the search for, and extraction of, oil and gas. The greatest concentration of oil and gas in the state lies in the modern Mississippi delta and just to the west of the Mississippi River, especially in the Barataria Basin (Figure 5). Oil pipeline canals form an intricate network in the basin. Hydrologic patterns have been drastically altered and recent studies (Turner et al. 1982; Johnson and Gosselink 1982; Scaife et al. 1983) have shown that the large amount of land lost in the basin may be related directly and indirectly to the construction of these canals.

1.3 HYDROLOGY

Hydrology is an extremely important integrating factor in the basin. Water is the major transport mechanism among waterbodies, wetlands, and the gulf, carrying suspended silt and clays, nutrients, and organic material throughout the basin. The rate of water movement is a function of tide range (about 0.3 m at the coast), wind, precipitation, and the gradual slope of the land from the cypress swamps to the gulf (about 1.0 cm/km). These conditions create sluggish bayous and promote overland sheet flow through the wetlands. Hydrology is treated in detail in the next chapter, and its importance is discussed throughout this estuarine profile.

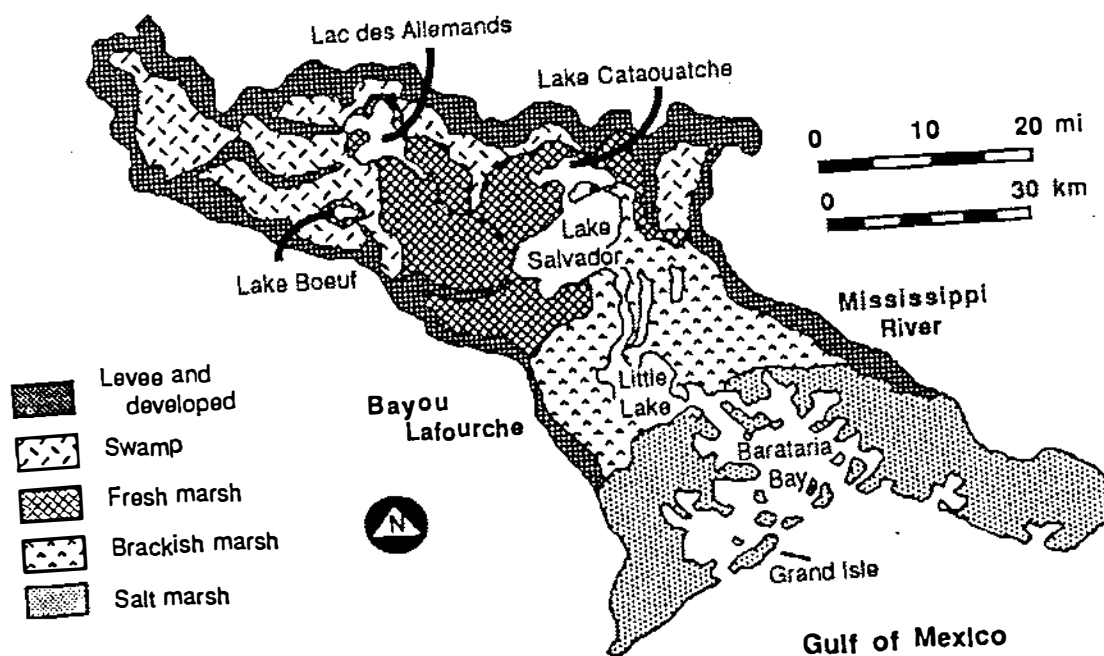


Figure 6. Habitat map of Barataria Basin.

detritus particles, organic decomposition products, and inorganic nutrients which are deposited in the bayous to be carried to units downstream.

1.4.3 Fresh Marsh

The fresh marsh portion of the basin lies immediately below the swamp forest and contains about 155,000 ha (25% of the basin). Salinity averages 1.8 ppt (Chabreck 1972). Much of the freshwater marsh environmental unit is composed of "flotant" or floating marsh. Flotant marsh consists of dense mats of vegetation supported by detritus several feet thick, all held together by a matrix of living roots. Maidencane (*Panicum hemitomon*) is the dominant plant species, covering over 41 % of the total area. This species is seldom found in other wetland habitats, and even in the fresh marsh there are areas where it is a minor component or absent. Spikerush (*Eleocharis* sp.) and bulltongue (*Sagittaria falcata*) are also important species in the freshwater areas.

One of the most obvious differences between swamp and fresh marsh areas is the increased thickness of the organic soils. Detritus

Table 1. Areal extent of the major ecological habitats in the Barataria Basin hydrologic unit (modified from Hopkins 1978).

Habitat	Area (ha)	Land:Water Ratio
<u>Levee and developed land</u>		
Land	122,352	54:1
Water	2,279	
<u>Swamp</u>		
Land	97,954	44:1
Water	2,202	
<u>Fresh marsh</u>		
Land	87,789	1.3:1
Water	67,240	
<u>Brackish marsh</u>		
Land	55,036	1.1:1
Water	48,263	
<u>Salt marsh</u>		
Land	63,356	0.8:1
Water	82,144	
<u>Total water</u>	202,128	
<u>Total marsh</u>	206,182	
<u>Total area</u>	628,619	

deposited in this environment remains partially undecomposed, resulting in the buildup of peat. The organic content of the soils in the fresh marsh is about 67%.

Waterbodies of importance in the fresh marsh include Lakes Cataouatche and Salvador and the surrounding bayous and canals. Primary production in these areas is overshadowed by the high concentration of organic material carried in from the surrounding swamps and marshes. The waterbodies are both highly eutrophic and heterotrophic.

1.4.4 Brackish Marsh

Between the upper freshwater end of the basin and the lower marine end of the basin lies the brackish marsh area, which covers about 137,000 ha (22% of the basin). Both of the previously discussed units are characterized by unidirectional water flow in response to rainfall. The brackish marsh area is the first system that is strongly influenced by tides and storm surges, which affect water level, frequency and duration of flooding, and salinity. This zone represents an area where fine particulate organic and inorganic matter are trapped. Fresh water flowing from the upper basin encounters higher salinity water, and the ionic components in the salt water cause the fine suspended particles in the fresh water to flocculate out; salinity ranges from 2 to 10 ppt (Chabreck 1972). Even though there is a net movement of water downstream, the inland flow of tidal waters determines the kinds of vegetation that occur in the wetland, aids in the recirculation of nutrients, and allows the inland migration of larval forms of estuarine species. Saltmarsh cordgrass (Spartina patens) is the dominant plant in this area.

1.4.5 Salt Marsh

More research has been done in this unit than in any of the others. The salt marsh is subject to modification by physical forces more than the other two types. There is one tidal cycle per day in the salt marsh, averaging 0.3 m in height, and salinity ranges from 6 to 22 ppt (Chabreck 1972). Storm surges and prolonged southerly winds can produce higher than average tides. There are approximately 145,000 ha of salt marsh in the basin, and the land to water ratio is the lowest of all the units in the basin. The major plant species in this unit is oyster grass (Spartina alterniflora), which covers 63% of the salt marsh area.

Interaction between wetland and waterbodies is more pronounced in the salt marsh than in any other unit. Because of the high proportion of water to land and the frequent flooding, it is difficult to distinguish between land and waterbody in many cases. The waterbodies are typically shallow and turbid with muddy substrate.

1.4.6 Offshore

The excess organic matter produced by the marshes of the Barataria Basin eventually finds its way to the Gulf of Mexico through the bayous and canals that drain the basin. There is considerable evidence to support the importance of "outwelling" from the Barataria Basin to the gulf (Day et al. 1982). One of the major factors influencing the offshore areas is the presence of the Mississippi River. Millions of cubic meters of freshwater and tons of sediments and nutrients are dumped each day into the Gulf of Mexico only 80 km to the east of the basin. Rather than mixing immediately, the freshwater forms a large gyre that impinges on the Barataria Basin offshore area.

CHAPTER 2

PHYSICAL VARIABLES

by

R. H. Baumann

2.1 INTRODUCTION

This chapter describes the major physical processes which are operative in the Barataria Basin. Emphasis is on water because it is the medium for material transport. Direct measurements of water flux through the basin are few, but analyses of various water level phenomena allow inferences regarding water movement and hence material transport. This chapter is concerned with identifying the water level change phenomena and discussing what regulates them and how they vary temporally and spatially. Humans have greatly affected the movement of water through the system and factors affecting physical processes also control, to varying extents, other components of the system. Several of these interrelationships are briefly mentioned to set the stage for the final chapter of this volume.

2.2 CLIMATE

Climatic conditions in the Barataria Basin are largely determined by its subtropical location and its proximity to the Gulf of Mexico (Sanders 1959, 1978). Two pressure ridges dominate weather conditions along coastal Louisiana. One is the "Bermuda high" centered over the Bermuda-Azores area of the Atlantic in the winter, and the other is the "Mexican heat low" centered over Texas during the summer (Stone 1972). These ridges produce winds with an easterly component. Northeasterly winds are prevalent in the fall and winter, and southeasterly winds are dominant in the spring and summer. Northwesterly winds occur most often in the winter months. Warmer temperatures and higher humidities are associated with the southeasterly winds in the spring and summer months, and cooler, drier weather

accompanies the northerly winds that occur predominantly in the fall and winter. Highly variable winter weather results from alternating exposure to cold dry continental air masses originating in the north or northwest and warm, humid tropical systems centered in the Gulf of Mexico. Summer weather is generally more stable, with prevailing south-southeast winds providing moist subtropical conditions. Local summertime heating causes convective updrafts, vertical development of cumulus clouds, and frequent, localized thundershowers. Occasional continental air masses from the north or west move over the basin bringing decreased temperatures and humidities during the summer.

Mean annual precipitation in coastal Louisiana is fairly high at about 160 cm. Long-term averages indicate that rainfall is fairly uniformly spread throughout the year, but the maximum usually occurs in July, and the minimum in October (Sanders 1959, Stone 1972). There are, however, exceptions in annual and seasonal totals. Annual totals have varied from 92 to 219 cm, while seasonal extremes have ranged from 0 to 46 cm during the period 1914-78 (Sklar 1983).

Using a climatic water budget developed by Thornthwaite (1948) in conjunction with synoptic weather types, Wax et al. (1978) were able to determine periods of water surplus and deficit in Barataria Basin. They found a water surplus in winter and early spring when precipitation was high and potential evapotranspiration was low. Deficits occurred in summer and autumn when south winds and increased salinities predominated. Effects of surplus precipitation are far more noticeable over the inland or upper end of the basin (above Lake Salvador), where runoff is

concentrated in streams or bayous, than in the lower basin where it is spread over the vast areas of marsh and open water (Wax et al. 1978). Sklar (1983) used long-term means to calculate a water budget for the upper part of the basin (Figure 7) and found that of the total annual precipitation, 61 cm was available for surface runoff and groundwater discharge.

Hurricanes and tropical storms with their high winds and heavy precipitation occasionally impinge upon the Louisiana coast, usually between June and November. Such storms can cause severe flooding as well as drastic alterations of normal hydrologic regimes in the basin (Day et al. 1977).

Mean annual temperature is 20.6 °C and varies seasonally from a mean monthly temperature of 13.0 °C in January to 27.5 °C in July. Occasional freezes occur in the basin during the coldest nights, but thawing occurs fairly rapidly after daybreak.

2.3 WATER LEVEL VARIATIONS

2.3.1 Tides

Tides in the Barataria Basin are generally diurnal and small. Mean tidal range at the coast (Bayou Rigaud) for 1951-70 was 32 cm, resulting

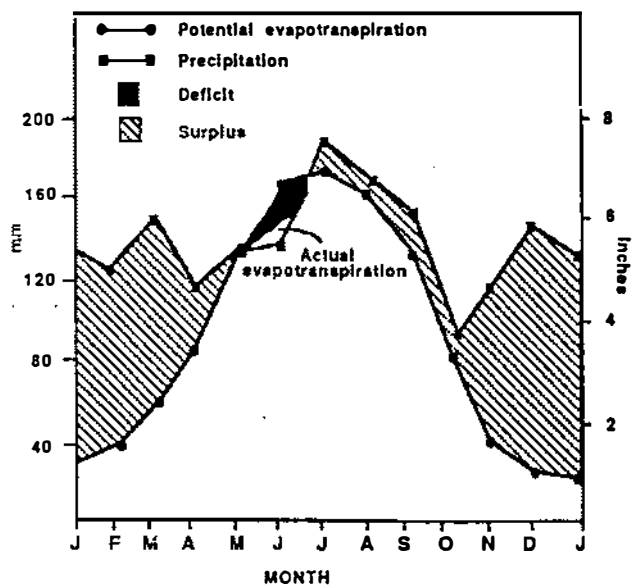


Figure 7. Average water budget for the upper Barataria Basin, 1914-78 (Sklar 1983).

in an estimated average gross turnover of lower Barataria Bay of 30% per tidal cycle (Marmer 1948). The tidal amplitude at Bayou Rigaud is attenuated by 68% at Lafitte, 78% at Barataria, and 90% at des Allemands (Figure 8; Byrne et al. 1976). Tidal range at Bayou Chevreuil is normally less than the accuracy limits of the water-level recorder (about 1.5cm).

Compared with a semidiurnal tide, a diurnal tide implies a lower frequency in inundation, longer turnover time, and a smaller volume of water available for material transport. Diurnal tides respond differently from semidiurnal tides to changes in the relative positions of the earth, moon, and sun.

In light of the expected differences in response, it is useful to indicate the relative degree of the diurnal nature of the tide. The ratio of the two principal semidiurnal components provides a simple classification of tidal type. According to work by Van der Stock (1897), and modified by Courtier (1938), a ratio of 0.25 or less is indicative of semidiurnal tides whereas a ratio of 3.00 or greater is characteristic of a diurnal tide. Values within a range of 0.25 to 3.00 provide a relative indication of the degree to which the tide is mixed. At Bayou Rigaud, the ratio is equivalent to 10.67 (Marmer 1954) indicating a diurnal dominance.

Three tidal range cycles--biweekly, seasonal, and 18.6 years--affect the inundation regime in the Barataria Basin. Periods of increasing tidal range result in greater frequency and depth of inundation. The effects diminish inland, corresponding with the overall decreasing importance of the tide. The following description of the tidal range cycles is based on information from the coastal station at Bayou Rigaud (Figure 8).

Although there is a slight difference in periodicity, equatorial and tropic tides are basically the diurnal analog to spring and neap tides. The biweekly change in diurnal tidal range is dominated by the changing declination of the moon with respect to the earth's ecliptic (approximately five degrees north and south), rather than the changing phase of the moon. During maximum semimonthly declination, tidal range is at its maximum (tropic tides). When the moon is aligned with the earth's equator, diurnal tidal range is at a minimum (equatorial tides). This latter period also

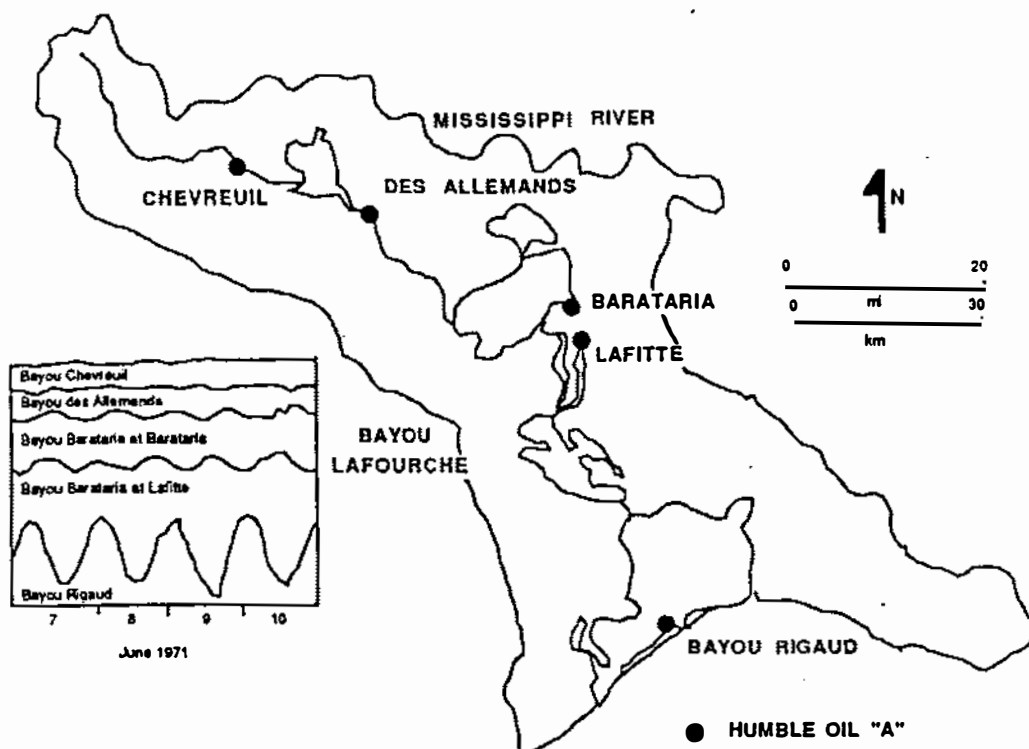


Figure 8. Tidal amplitude for five stations in the Barataria Basin. The location for Humble Oil "A" is shown because there is some discussion of this station in the text (modified from Byrne et al. 1976).

represents the time when mixed or semidiurnal tides may be present in the basin.

a. Biweekly tidal range cycle. The variation between equatorial and tropic tides represents the greatest magnitude in range of the tide in the Barataria Basin. This is apparently true for all areas dominated by diurnal tides (Grace 1932; Marmer 1954). During 1971, peak tropic tidal range averaged 45 % above, and peak equatorial tidal range averaged 45 % below, mean tidal range at Bayou Rigaud.

b. Seasonal tidal range cycle. Maximum tidal range occurs during the summer and winter solstices, and minimum tidal range occurs during the spring and fall equinoxes (Figure 9). The maximum seasonal variation occurs from September to December, the difference at Bayou

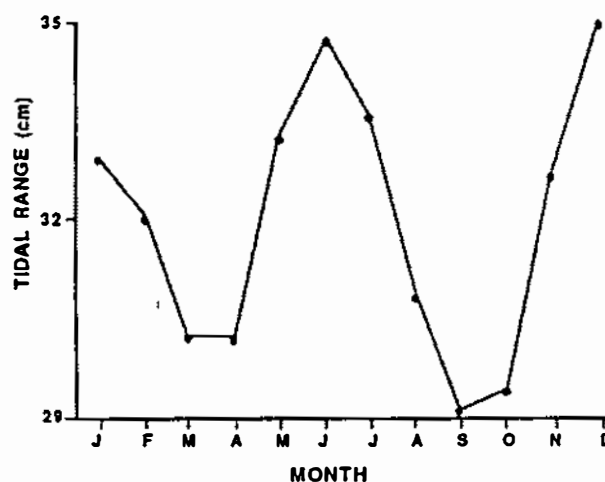


Figure 9. Mean seasonal variation in tidal range at Bayou Rigaud (Baumann 1980).

Rigaud being 6 cm, or $\pm 10\%$ of mean annual tidal range. The seasonal changes in tidal range modify the effects of the seasonal water level cycle on frequency of inundation (see Seasonal Inundation of Estuarine Wetlands).

c. The 18.6-year tidal range cycle. The variation in tidal range at Bayou Rigaud due to the 18.6-year cycle (Figure 10) is approximately 10 cm, or $\pm 16\%$ deviation from the long-term mean. This is somewhat greater than the seasonal change in tidal range ($\pm 10\%$) and considerably less than the biweekly change ($\pm 45\%$). Inundation frequency is positively related to the 18.6-year cycle (Figure 10), whereas there is no apparent relationship with duration (percent time). The latter is related more to the change in mean water level from year-to-year.

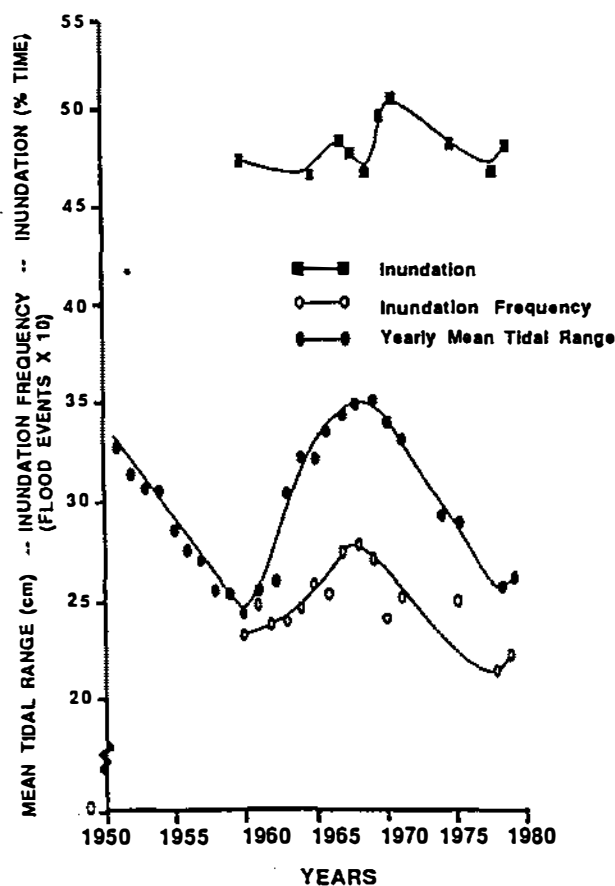


Figure 10. Variation in yearly range of tide at Bayou Rigaud and its effects on inundation of the saline marsh (Baumann 1980).

The gradual change in tidal range throughout this period is due to the change in the inclination of the moon's orbit to the earth's equator. During maximum inclination, diurnal tides exhibit maximum range. Semidiurnal tides exhibit an opposite and lesser magnitude response (Marmer 1954).

2.3.2 Nontidal Water Level Variations

Meteorological processes are another important mechanism controlling water level variation and flux in the Barataria Basin. The small tidal range increases the relative importance of such meteorological variables as wind stress and atmospheric pressure. Physical parameters that characterize the weather and, in the longer term, climate influence short- and long-term hydrologic responses. Significant increases in wind stress, lasting less than an hour and occurring approximately once every three days during the summer, minimize vertical stratification in the shallow lakes and bays (Hopkinson et al. 1985). At the other temporal extreme, a gradual change or long-term fluctuation in global climate has resulted in an eustatic rise in sea level.

2.3.3 Short-Term Impact of Weather Events

Water level variations within one to several days are governed by the combined effects of the change in the diurnal tide and climatic factors such as wind and precipitation. Wind stress is clearly the dominant factor in water level response to changing weather conditions at Bayou Rigaud, with precipitation (expressed as surplus) having little or no effect (Wax 1977). Water levels decrease significantly following a midlatitude cold front passage (Figure 11). The mean water level decrease at Bayou Rigaud, resulting from northerly winds, was 15 cm during one year of observation, and decreases of over 40 cm are not unusual (Wax 1977). The magnitude of the response of the water level to frontal passages and the frequency of this event during winter (5.7/mo) create an important mechanism for material transport in this low tidal energy environment. As a cold front approaches the area, southerly winds increase in speed, resulting in water set-up in the estuary (Figure 11). The relatively strong winds resuspend shallow bay bottom sediments, resulting in a seasonal peak in turbidity levels (Cruz-Orozco 1971) and net deposition of sediment as winds abruptly shift from the north, creating decreased

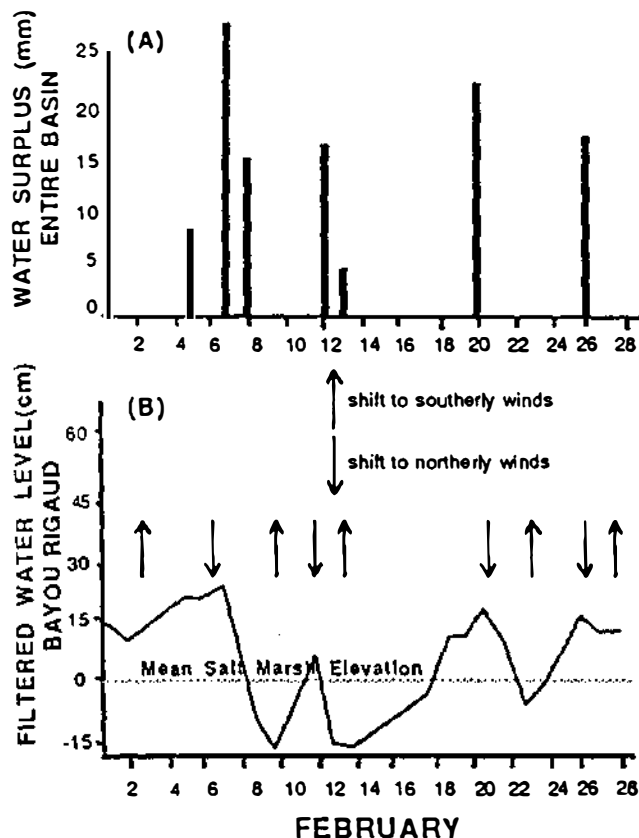


Figure 11. Water level and water surplus (excess precipitation) in the lower Barataria Basin during February 1971. Tidal pulses have been filtered out of the water level data (modified from Wax et al. 1978).

water levels (Figure 11) and strong ebb flows, which aid in the transport of particles from the marshes to the open bays and gulf (Happ et al. 1977). Water levels usually increase during all other weather events because of the dominance of southerly winds, although the response to tropical disturbances is variable (Wax 1977). Steady-state conditions of water level are generally achieved within 24 hrs regardless of the duration of the weather event, with the noteworthy exception of gulf tropical disturbances.

In the upper basin, the responses of water level to wind stress are similar to those at Bayou Rigaud. In cases where surplus rainfall is generated, water level response upstream in Bayou Chevreuil, unlike Bayou Rigaud, is initially independent of wind stress. Despite northerly winds, water levels typically rise at Bayou Chevreuil after the passage of a cold front because of

accompanying rains. Wax (1977) attributes Bayou Chevreuil's disparate (in comparison to nine Louisiana coastal stations) response to the altered hydrology of the upper basin. Numerous agricultural drainage and oil access canals facilitate rapid upland runoff into Bayou Chevreuil. Spoil embankments paralleling the canals retard overland sheet flow and alter the storage and release of flood waters. In essence, water level change at Bayou Chevreuil during periods of surplus rain is characterized by an abrupt rise (aided by canals) followed by a slow fall (release from semi-impoundments), a pattern similar to that of upland streams (Wax 1977).

In summary, wind stress results in a short-term water level response of a few hours throughout the basin. Water level responses to precipitation are very minor at the coast but increase substantially in the upper basin.

2.3.4 Seasonal Water Level Variation

A bimodal distribution of seasonal water level is fairly consistent throughout the basin (Figure 12); Marmer (1954) has shown this to be true throughout the northern Gulf of Mexico. Annually at all stations there is considerable variation in the magnitude of water level and in the months in which the maximas and minimas occur, but the bimodal distribution occurs with a high degree of regularity from year to year. Within the basin, there is a conspicuous increase in the spring maximum in an inland direction (Figure 12). This trend probably reflects increasing upland runoff influence as opposed to marine dominance at the coast (Wax 1977). No streamflow data are available for the area, but a long-term water budget for the upper Barataria Basin indicates that there is normally considerable surplus water generated for streamflow during this period (Figure 7).

Seasonal water level variation along the northern gulf coast is climatic in origin (Marmer 1954). Seasonal water level changes at high latitudes are primarily a result of barometric pressure changes, while at low latitudes, seasonal water level variations are largely changes in volume in response to seasonal heating and cooling of the water (Lisitzin and Pattullo 1961). Chew (1962) noted that the dominant feature of water level changes along the northern coast of the Gulf of Mexico is the semiannual rise and fall of sea level. Seasonal warming and cooling results in a

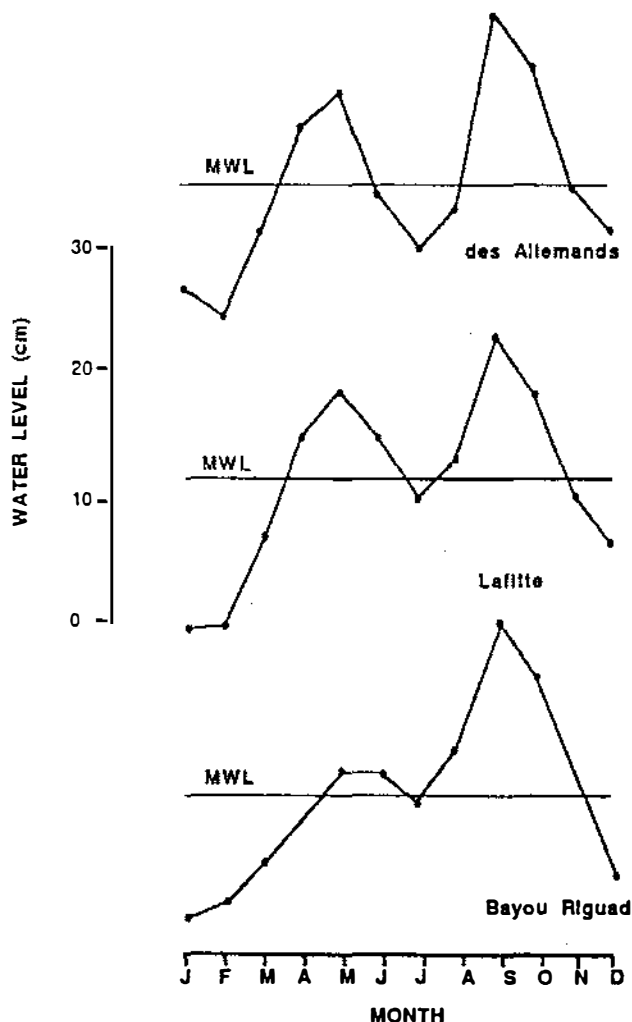


Figure 12. Mean seasonal water level for selected stations in the Barataria Basin (Baumann 1980).

maximum expansion and contraction of nearshore waters in September-October and January-February, respectively (Chew 1962; Whittaker 1971; Sturges and Blaha 1976). The secondary maximum in spring and secondary minimum in midsummer have been attributed to seasonal shifts in the wind regime over the Gulf of Mexico, resulting in alternating onshore and offshore transport of water (Chew 1962). The substantial difference from low wind stress in summer to higher values in fall accentuates the corresponding rise in water level, and the reversal in direction of high wind stress from fall to winter accentuates the corresponding decrease in water level (Sturges and Blaha 1976). Spring and fall correspond with maximum east and southeast

winds (Chew 1962), and an onshore transport of water results in a relaxation of an offshore gyre called the Mexican Current (Sturges and Blaha 1976). Winter and summer correspond with maximum westerly winds (southwest in summer, northwest in winter), which strengthen the Mexican Current, causing an offshore transport of water (Sturges and Blaha 1976).

Other factors that may contribute to the seasonal variability of water levels include barometric pressure and river and groundwater discharge and recharge. At New Orleans, the 30-year mean monthly range of barometric pressure is 6 mb. High barometric pressure during winter and low barometric pressure during fall inversely correspond with the seasonal water level cycle at Bayou Rigaud as shown in Figure 12. Several investigations have shown that water level decreases nearly 1 cm for each 1 mb increase in barometric pressure (e.g., Lisitzin and Pattullo 1961). Thus, the expected mean seasonal range in water level as a response to barometric pressure is approximately 6 cm, or 25% of the total mean seasonal water level change at Bayou Rigaud.

The proximity of the lower Barataria Basin to the mouth of the Mississippi River would seemingly have an effect on local water levels. Meade and Emery (1971) have shown that river discharge has a significant effect on year-to-year water level variability in the Gulf of Mexico. The seasonal relationship, however, does not appear to be strong. The spring rise in water level is somewhat out of phase with Mississippi River discharge, but this could be attributed to a lag factor. The more inland stations within the basin indicate that local streamflow and runoff has a greater effect on water levels within the basin than does Mississippi River flow.

The effects of groundwater discharge on estuarine and coastal water levels are unknown, but they are assumed to be minor. Groundwater discharge is probably fairly constant with no major fluctuations that could contribute to water level change.

2.3.5 Seasonal Inundation of Estuarine Wetlands

The duration of seasonal inundation of wetlands in both the upper and lower ends of the Barataria Basin (Figure 13) is largely a function of the seasonal water level cycle (Figure 12). A

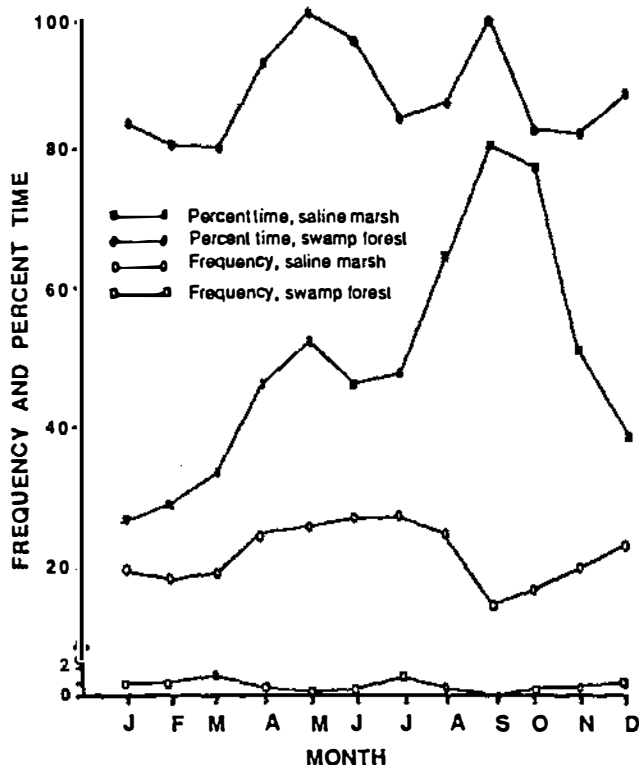


Figure 13. Comparison of the seasonal inundation regimes of the saline marsh and swamp forest, 5-year mean (Baumann 1980).

comparison of flooding duration (percent time) in the saline marsh with that in the swamp forest indicates that the duration of flooding increases as a function of distance inland from the coast (Figure 13). Annually, the saline marsh is inundated some 50% of the time, whereas the swamp forest is inundated in excess of 80% of the time.

The frequency of flooding is less variable seasonally than the duration of flooding, and frequency of flooding decreases inland (Figure 13). At the upper end of the Barataria Basin, in the swamp forest, there is no definitive seasonal pattern of frequency of inundation. The swamp forest is typically flooded for weeks at a time. On a mean annual basis, the swamp forest is flooded only ten times, but cumulatively these flood events represent 323 days/yr. This long-term flooding can present problems for the trees (see Chapter 4). In the saline marsh, the frequency of inundation is a function of the seasonal changes in water level due to tidal range and the sequences and aspects of weather events.

The relatively constant numbers of flooding events in the marsh over the year (average of 20/month) result from the additive, but out of phase, effects of tidal and weather-related factors. The seasonal change in tidal range (Figure 9) is out of phase with the seasonal water-level cycle (Figure 12). When water level is at a maximum in September, for example, tidal range is at a minimum, resulting in deep flooding of marshes for long periods of time. Thus, the seasonal low in frequency of flooding in September (approximately 15 events, Figure 13) is the result of high ambient water levels above the marsh surface.

On the other hand, frequency of flooding in the saline marsh during December (a mean of 23.4 events) is somewhat higher than the mean monthly rate (21.9 events), although water levels are below average (Figure 12). Two factors help to explain the increase in flooding frequency from September to December, despite a 21-cm fall in mean monthly water level at Bayou Rigaud. First, tidal range is at a semiannual maximum during December and represents a 6 cm (19 %) increase from the September minimum (Figure 9). Secondly, a seasonal change in the sequence of weather events helps to maintain both frequency and depth of inundation. During December and throughout the winter, winds are directionally more variable than during the other seasons, because of the higher frequency and greater intensity of midlatitude cold front passages (Wax et al. 1978). With the passage of a cold front, winds are northerly, resulting in water levels that fall below the marsh surface (Figure 11). As the next frontal passage approaches from the northwest, winds shift at the coast to southerly components. The continued approach of the front increases the strength of southerly winds that elevate water levels above the marsh surface (Figure 11). When the front arrives, the cycle is initiated once again. Thus, the combination of maximum tidal range and the passage of cold fronts results in salt marsh flooding during December that is frequent but of short duration.

Frequency of inundation in the saline marsh reaches a secondary minimum from January through March following the secondary maximum in December (Figure 13) because of the continued fall in mean monthly water level (Figure 12) partly due to steric effects and a decrease in tidal range (Figure 9). The abrupt rise in water level in April

caused by shifting winds results in more frequent flooding despite the concurrent secondary minimum in tidal range. The seasonal cycle is completed with a high flooding frequency maintained through the summer because of increasing tidal range. Climate has less influence on frequency of inundation in summer than in winter. Winds are generally less intense and are directionally less variable during summer than in winter. Tropical weather types dominate in summer; creating a dominance of southerly winds. A synoptic analysis of southeast Louisiana for 1971 (Muller 1977) indicated that tropical weather events occurred 98% of the time in June, 88% in July, and 67% in August. Because the wind regime is less variable both in terms of direction and velocity in summer than in winter, steady-state conditions are approached more frequently in summer and total water flux is correspondingly less.

In summary, water level variation in the Barataria Basin is governed by the combined effects of tides and weather events. Because tidal range is small, climatic events assume great importance. Wind regimes are directionally more variable and generally of greater intensity during winter. Thus, during winter, steady-state conditions are achieved less frequently and total water flux is greater.

2.3.6 Seasonal Salinity

The long-term mean salinity regime at the coast (Grand Terre) is characterized by a spring low followed by a rise peaking during early winter (Figure 14). Progressing inland, the seasonal salinity pattern becomes bimodal, with higher salinities occurring during spring and fall (Figures 14 and 15). These seasonal patterns and their spatial variability can be largely attributed to three factors: seasonal precipitation and evapotranspiration regime, Mississippi River discharge, and the seasonal water level cycle.

Rainfall is uniformly distributed throughout the year, on a monthly mean basis, with the noteworthy exception of a somewhat drier fall (Figure 7). Based only on precipitation and evapotranspiration, higher salinities should occur in summer and fall.

Mississippi River discharge may modify the timing of seasonal salinity patterns. The spring

decrease in salinity at Grand Terre is of greater magnitude and occurs later than that of the inland stations. Perret et al. (1971) attribute this to Grand Terre's proximity to the Mississippi River Delta, in

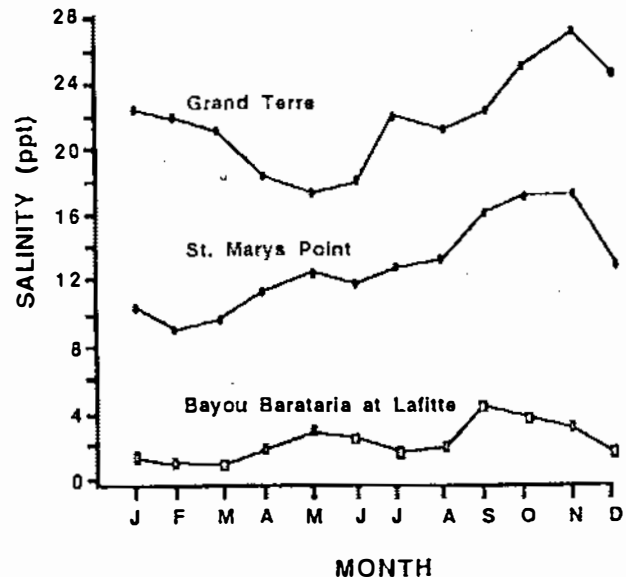


Figure 14. Long-term averaged monthly means of salinity, 1961-74 (Byrne et al. 1976).

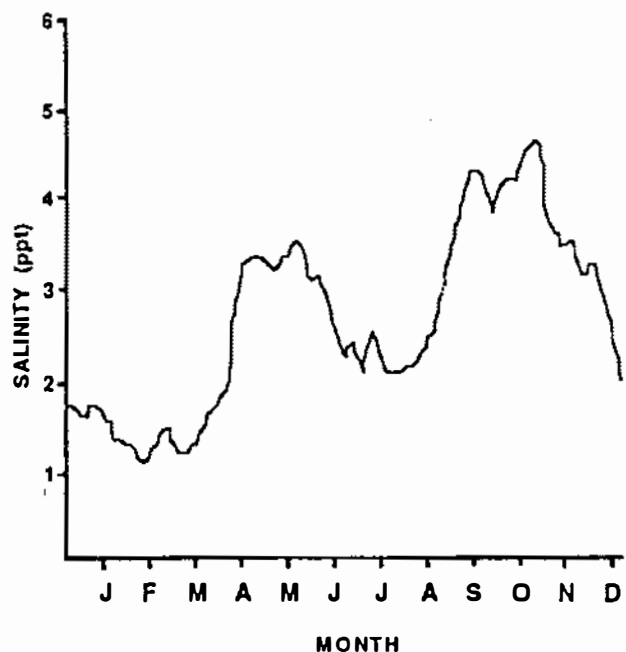


Figure 15. Mean weekly salinity at Lafitte, 1961-74. Data are the same as in Figure 14, but the salinity scale has been enlarged (modified from Byrne et al. 1976).

which maximum discharge occurs, on the average, one to two months later than local runoff.

Another apparently important but never substantiated factor in the seasonal salinity regime of the Barataria basin is the role of the seasonal water-level cycle (Figure 12). At Lafitte the two patterns closely resemble one another (Figures 12, 14, 15). There the abrupt decrease in salinity from early November to December is enhanced by a change in the wind regime, in addition to increased precipitation and decreased evapotranspiration. The increase in northerly wind components from fall to winter results in a seasonal net flow of water from estuary to gulf and a corresponding movement of fresh water from the upper to the lower basin. The abrupt rise in salinity at Lafitte in mid spring corresponds with a seasonal rise in water level (with waters flowing in from the gulf), as well as an increase in evapotranspiration rates. Despite high evapotranspiration rates during summer and low surplus rainfall, salinity falls to a secondary summer minimum at Lafitte. As in the winter, the secondary seasonal low salinity level corresponds with secondary seasonal low water level. Fresh water stored in the upper basin during winter and spring moves down the basin in response to the net outflow from the estuary.

2.3.7 Long-Term Water Level Variation

The one known long-term trend of water level is the apparent rise in sea level (Figure 16). The trends depicted in Figure 16 reflect the combined effects of subsidence and eustatic sea level rise. Global eustatic sea level rise has been estimated to account for about 0.14 cm/yr (Bloom 1977; Gornitz et al. 1982), a value in close agreement with tide gauge data from the relatively stable west Florida coast (Hicks 1981).

Subsidence is much more important. There was a significant, and as of yet unexplained, increase in the subsidence rate from 0.27 cm/yr during 1948-59 to 1.29 cm/yr for 1959-71 at Bayou Rigaud (Swanson and Thurlow 1973). The total apparent sea level rise for 1959-79 was 1.23 cm/yr at Bayou Rigaud (Baumann 1980). Differentiation between eustatic sea level rise and subsidence is functionally unimportant as they both have the same effect--the water appears to rise with respect to the land.

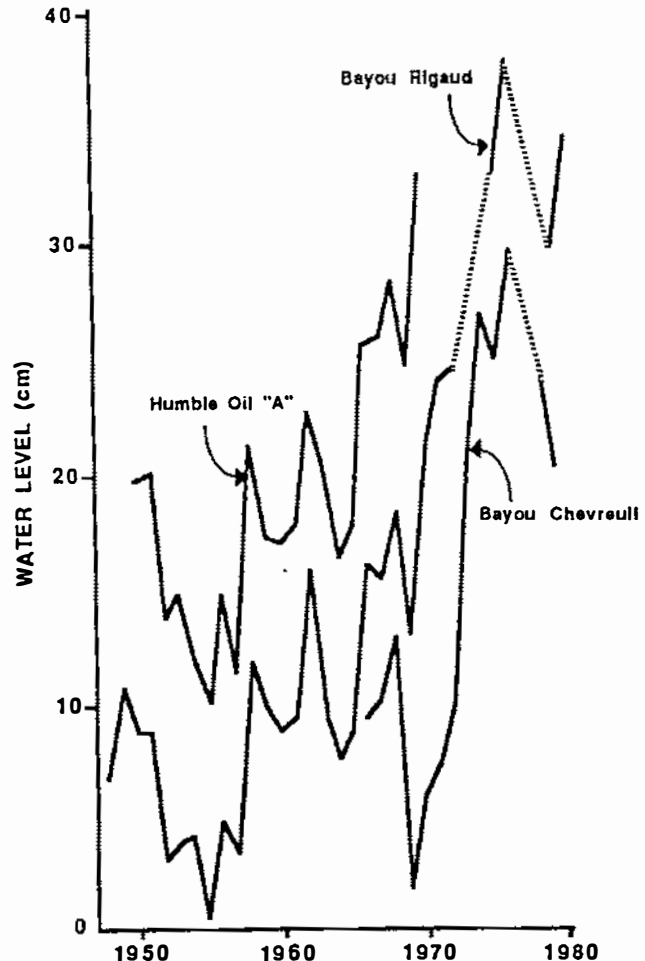


Figure 16. Variation in yearly mean water level at selected stations. Dashed lines indicate that an annual mean could not be determined for those periods (Baumann 1980).

Aberrations in the trend of sea level rise (Figure 16) have not received much attention and are typically attributed to climatic variability. One noteworthy exception is the work of Meade and Emery (1971), who showed that 21% of the year-to-year variation in water levels over the past several decades in the gulf is caused by river runoff.

2.4 SEDIMENTATION

Unless there are compensating factors, sea level rise could result in the die-off of emergent macrophytes. Known sedimentation rates on Barataria marshes are provided in Table 2. Streamside marshes are, in general, keeping pace with apparent sea level rise but streamside

Table 2. Mean annual sedimentation rates in various wetland environments in the Barataria Basin.

Marsh type	Method	Period	Mean annual sedimentation rate (cm)		Reference
			Streamside	Inland	
Fresh	RD ^a	1963-80	1.06	0.65	Hatton 1981
Intermediate	RD	1963-80	1.35	0.64	Hatton 1981
Brackish	RD	1963-80	1.40	0.59	Hatton 1981
Saline	RD	1963-77	1.35	0.75	DeLaune et al. 1978
Saline	VM ^b	1975-79	1.52	0.91	Baumann 1980
^a Radiometric dating with ¹³⁷ Cs.					
^b Visual marker -- white clay.					

marshes only represent a maximum of 25% of the wetland area in brackish and saline marshes and typically less than 5% in fresh marshes. The inland marshes that represent the bulk of the marsh area are not keeping pace, which is a contributing factor in the loss of 40,000 ha/yr of coastal wetlands in Louisiana (Gagliano 1981). The problems of sediment deficiency and wetland loss are the result of complex interactions between natural processes and man's modification of those processes.

Historically, the bulk of mineral sediments transported to and deposited on the marsh surface occurred during flood episodes of the Mississippi River with peak flows typically occurring between March and April. A 5-year study examining the seasonality of sedimentation in the lower Barataria Basin (Baumann et al. 1984) concluded that sediment input from the Mississippi River is no longer a viable process. Vertical accretion of the marsh is now largely a storm-related phenomena with sediments from other eroding marshes and bay bottoms being deposited.

2.5 HUMAN PERTURBATIONS

The change in the sedimentation regime of the salt marsh of the Barataria basin is a dramatic example of human intervention in natural

processes. Before the completion of the artificial levee system following the 1927 flood, riverine sediments were deposited in the Barataria Basin by overbank flow and crevasse formation. Thus, sedimentation primarily occurred during the spring floods of the Mississippi River. During the present deterioration phase of the basin, sedimentation of the salt marsh occurs primarily during winter storm and hurricane conditions (Baumann 1980). These latter processes are not sufficient to maintain the elevation of the marsh with respect to the sea. The wetland loss problem is intensified by other human activities, e.g., canals (Craig et al. 1979), and if the trend continues, the present salt marsh will be converted to openwater within the next several decades.

Canals and the spoil banks that frequently accompany them contribute to land loss directly by their creation, and indirectly by their alteration of natural flow. Spoil banks retard the exchange of water, sediments, nutrients, and other materials between the marsh and open water areas. Canals accelerate both the intrusion of salt water and runoff of fresh water. Northern Barataria Bay has experienced a significant annual increase in salinity of 0.108 ppt from 1961-74 (Van Sickle et al. 1976). Ultimately, the entire basin is expected to become an open-water brackish bay or sound unless Mississippi River flow is reintroduced to the area.

CHAPTER 3

CHEMISTRY AND NUTRIENT DYNAMICS

by

C. J. Madden and R. D. DeLaune

3.1 INTRODUCTION

Nutrient dynamics in Barataria Basin are controlled by the amount of allochthonous materials entering the basin, hydrology, and biological and chemical processes acting within the basin. The hydrologic flow from the upper basin to the Gulf of Mexico carries nutrients entering from the heavily populated uplands surrounding the upper basin to the upper, middle, and lower basins. The nutrients undergo a series of transformations as they move through the basin.

Upper Barataria Basin is composed of fresh swamp forest, marsh, and lake. Around the upland perimeter, increasing urban, agricultural, and industrial pollution has introduced nutrient-rich runoff to the basin. The middle basin grades into brackish marsh surrounding a complex of lakes which act as receiving basins for upland and upper basin runoff. In lower Barataria Basin, two large saline bays, Barataria Bay, and Caminada Bay, which open into the Gulf of Mexico, are bordered by tidal salt marshes. The distinct upper, middle, and lower basin habitats of Barataria Basin are distinguished by their salinity and nutrient regimes and by the amount of production they sustain.

Historically, regular inundation of the basin by floodwaters topping the natural levees introduced riverine water and nutrients to the swamp and marsh. As cultural development occurred along the river and basin, artificial levees were constructed, eliminating all riverine input to the basin. Today, the sole hydrologic input is precipitation, which averages 160 cm/yr (Sklar 1983). Nevertheless, the hydrologic transport of sediments and nutrients remains the major mechanism of nutrient supply in the Barataria

system. Fertilizer and dead organic material which accumulate in the uplands during the summer months are flushed through the basin during the fall in freshwater pulses. Biological processes allow nutrient exchange among atmosphere, biosphere, and sediments and also make nutrients available for hydrologic transport. A number of biological processes important to nutrient dynamics have been studied in the basin and will be discussed. These include nitrogen fixation, nitrification, denitrification, ammonification, photosynthesis, respiration, and mineralization.

Salinity fluctuations are important in determining the chemical properties of the water as well as the distribution of biota in the wetlands. By monitoring the conservative property of salinity, investigators have traced long-term changes in hydrologic inputs and flows through the basin. The seasonal salinity regime of Barataria Basin is a complex one controlled by precipitation, winds, and the proportion of Mississippi River and gulf water imported through the bay mouths. Strong northwest frontal passages drive water from the upper basin to the gulf, freshening the entire basin during winter. At this time of year, the gulf water level is at its lowest, assisting the southward flow. In summer, predominantly southeasterly winds and a high gulf water level push salt water into Barataria Basin from the gulf. High evapotranspiration:precipitation (ET:P) ratios coupled with the gulf backpressure generally cause freshwater flow downbasin to cease in July and August, raising basin salinity. Precipitation in autumn exceeds evapotranspiration and freshwater again feeds the lower basin.

The upper basin swamp forest never experiences salinity. Middle basin salinities range

between 0 and 5 ppt depending on precipitation and the amount of gulf water driven inland by southeasterly winds. The lower basin-bay area experiences salinities of 18-30 ppt throughout the year. Studies have shown salinity in the middle basin to be increasing by almost 0.11 ppt/yr (Van Sickle et al. 1976). At the turn of the century, the middle basin was fresh. Encroachment by saline water has increased middle basin salinity to 5 ppt. Toward the gulf, salinity in upper Barataria Bay has increased to 11 ppt where 75 years ago it was only 6 ppt. Predictive models indicate that overall salinity will increase about 30% by the year 2000 (Van Sickle et al. 1976).

Increases in salinity are directly and indirectly related to human activity. The construction of artificial levees has stopped the inflow of fresh river water to the basin. The dredging of linear canals has given saline gulf water direct access far upbasin (Craig and Day 1977). Marsh subsidence has converted much of the marsh area to open water, allowing saltwater intrusion. Natural subsidence is a consequence of sediment consolidation and eustatic sea level rise. The indiscriminate dredging of canals and construction of artificial levees that block the influx of important marsh-building sediments from the river has unnaturally increased land loss rates to more than 100 km²/yr (Gagliano et al. 1981).

Salinity increases are also affecting the production of marsh macrophytes within the basin. Recent studies (Pezeshki et al. in press) show that salinity increases currently occurring in brackish marshes are altering normal physiological functions of *Spartina patens*, the dominant species in the Barataria brackish marshes. Reduction in primary production of marsh macrophytes will affect estuarine carbon cycling and organic carbon pools which are important to vertical marsh accretion. Organic carbon accumulation is important in maintaining marsh elevations in rapidly subsiding environments such as the Barataria Basin.

3.2 UPPER BASIN NUTRIENT PROFILE AND TROPHIC STATE

The upper Barataria Basin is dominated by swamp forests of baldcypress and water tupelo and, in better drained areas, by bottomland hardwoods. Lac des Allemands, the major water body in this section, is always fresh and serves as

the catchment for all upper basin drainage. It is fed by upland runoff through Bayou Chevreuil and Grand Bayou. Fresh marsh borders the lake to the south and east.

The natural chemistry of the upper basin has been disturbed by urban and agricultural activity on the surrounding natural levees. The development of population centers has introduced high levels of nutrients and sediments into upland runoff. Impervious urban land areas and highly channelled drainage networks in farm fields have increased upland runoff volumes and changed the natural hydrology of the upper basin. These impacts are compounded by canalization of the swamp and marsh by oil and gas interests. In short, the burgeoning development of the area is increasing nutrient input and reducing the capacity of the wetlands to process these inputs. The result is eutrophication of the basin's waters, a disturbed swamp system chemistry, and reduced swamp productivity (Day et al. 1982).

Annual loadings of 1.2 million kg nitrogen (N) and 130,000 kg phosphorus (P) are estimated to enter the upper basin from all upland sources (Kemp 1978). Runoff from agricultural land adds more N and P per area than any other land use, comprising an estimated 75% of all N and 95% of P entering the basin. Seventy-one percent of the upland Barataria watershed is now devoted to agriculture (Hopkinson 1978) and cropland erosion accounts for over 80% of the 63 million kg or 63,000 metric tons of sediment lost annually from the watershed. Based on predictions of land use, N loads are expected to increase by 28% and P loads by 16% before 1995 (Hopkinson and Day 1980b).

As a means of quantitatively assessing the water quality of Barataria Basin, Seaton and Day (1979) modified a statistical technique developed by Brezonik and Shannon (1971) which yields an index of the degree of eutrophication in a water body. The Trophic State Index (TSI) ranks bodies of water based on a multivariate statistical formulation including total N, total P, secchi depth, and chlorophyll *a* data (Table 3). By ranking all water bodies in Barataria Basin from most negative TSI (oligotrophic) to most positive (hypereutrophic) it was shown that all waterways in the upper basin clustered together in the eutrophic to hypereutrophic range. Poor water quality characterized by high nutrient levels, high algal

Table 3. Average yearly nutrient and chlorophyll *a* concentrations and secchi depths at several sites in Barataria Basin. GIWW = Gulf Intracoastal Waterway. Nutrient data are in mg/l; chlorophyll data in mg/m³ and secchi in cm.^a

Area/Location	NH ₄ ⁺	NO ₃ ⁻	Inorg N	PO ₄ ⁻³	TON	TP	Secchi	CHL <i>a</i>
Upper/swamp	0.13	0.08	0.21		1.17	0.22	50	2
Upper/St. James Canal	0.10	1.88	1.98		2.01	0.19	8	53
Middle/Lake Salvador	0.09	0.11	0.20		0.73	0.11	46	3
Middle/Lake Salvador ^b	0.06	0.95	1.01	0.06			53	8
Middle/Lake Cataouatche	0.06	0.27	0.33		1.59	0.15	32	27
Middle/Lake Cataouatche ^b	0.08	0.15	0.23	0.09			53	47
Lower/GIWW	0.10	0.48	0.58		0.95	0.89	11	7
Lower/Little Lake	0.15	0.12	0.27		0.71	0.07	65	5
Lower/Little Lake ^b	0.10	0.21	0.31	0.06			54	10
Lower/Airplane Lake ^c			0.06	0.04				

^a Data from Seaton and Day (1979) unless otherwise noted.
^b From Hopkinson and Day (1979)
^c From Ho and Lane (1973)

standing crop, and low water clarity persisted throughout the upper basin. Downbasin, waters gradually improved in quality. Caminada and Barataria Bays had negative TSI, indicating mesotrophy to meso-oligotrophy (Table 4).

3.2.1 Drainage Density and Trophic State

Oil access canals and agricultural drainage ditches cutting through the basin (Figure 17) have been cited as having exacerbated the problem of nutrient enrichment. In the swamp's natural condition, before the dredging of linear canals, runoff was distributed as sheet flow over the swamp forest. Now, hydraulically efficient canals guide water and nutrients directly to receiving waterbodies, bypassing the swamp forest. Studies have shown that the Barataria swamps had been acting as effective nutrient filters, removing inorganic nutrients from percolating floodwaters (Meo et al. 1975; Kemp 1978). But in the current situation, nutrient removal and uptake processes occurring in the canals alone are insufficient to

reduce the runoff nutrient loads, resulting in the high loading to Lac des Allemands (Butler 1975).

By constraining canal flow, spoil banks restrict the natural lateral transport of water necessary for the removal of wastes, the replenishment of marsh sediments, and the import of new nutrients to the swamp forest. Obstruction of overbank flooding by levees can result in nutrient starvation and the blocking of swamp substrate accretion. As the density of canals increases, there is a concomitant reduction in overland flow and basin water storage capacity.

Horton (1945) developed a means of quantifying the impact of canals on wetlands. The Drainage Density Index (DDI) reflects the degree of canal development in a wetland and is defined as the total length of the drainage network per square unit of drainage basin. A total of 37.2 linear mi of canals criss-cross the upper Barataria Basin representing a DDI of 40.0 mi/mi² in uplands (Gael and Hopkinson 1979). When upland DDI is

Table 4. Trophic state index (TSI) classification of Barataria Basin, Louisiana. LB = lower basin, MB = middle basin, UB = upper basin, O = oligotrophic, M = mesotrophic, E = eutrophic, and H = hypereutrophic (modified from Witzig and Day 1983a, b).

Station	Location	TSI score	Trophic group
Caminada Pass	LB	-4.8	M-O
Bayou Rigolettes	LB	-4.3	M
Barataria Bay	LB	-3.8	M
Lake Salvador	MB	-3.3	M
Bayou Perot	LB	-2.8	M
Little Lake	LB	-2.7	M
Bayou Barataria	LB	-1.8	M
Barataria Waterway	LB	-1.6	M
Natural swamp stream	UB	-1.4	M
John-the-Fool Bayou	LB	-0.6	M
Little Lake oil and gas field	LB	-0.4	M
Bayou Chevreuil 1	UB	6.0	E
Lake Cataouatche	UB	0.7	E
Bayou des Allemands	MB	2.6	E
Burtchell Canal	MB	2.7	E
Bayou Citamon	UB	3.7	E-H
Lac des Allemands	UB	3.8	E-H
Bayou Chevreuil 2	UB	4.0	E-H
St. James Canal	UB	6.4	H

recalculated to include all split and quarter ditches in sugarcane fields, the index rises to 800 mi of canal/mi².

A strong correlation has been noted between drainage canal density and the condition of receiving water bodies. In the Gael and Hopkinson study, Barataria Basin was divided into 24 subcatchment areas, including water quality stations that had been previously sampled by Seaton and Day (1979). Within subcatchments, a direct relationship between DDI and the deterioration of water quality was found indicating that eutrophication in the upper basin is a function of the density of drainage canals. In regions of low canal density, the upper basin is generally oligotrophic to mesotrophic (Craig and Day 1977; Seaton and Day 1979). In regions of extensive channelization and agricultural development, the upper basin has become eutrophic to hypereutrophic. Large percentages of agricultural land included in two of the subcatchments with a

large number of canals contributed to the high total N loads of 2.0-2.2 mg/l. Catchments consisting of underdeveloped natural swamp exhibited good water quality and had lower total N values averaging 0.67 to 1.1 mg/l.

Most of the canal development has occurred in the last two decades. The nutrient-concentrating effect of canals can be illustrated by recalculating loading rates to the swamp as they would have been without the presence of canals and levees. If the 1.2 million kg of N entering the basin from upland sources were allowed to move as sheetflow over the entire upper basin, the annual N load would total about 1.27 g/m², a twenty-fold reduction from current levels of 30.1 g/m² to Lac des Allemands. Likewise, the 132,283 kg of P entering from uplands, distributed over the basin floor, would add 0.14 g/m² annually, instead of the 4.3 g/m² loaded to Lac des Allemands by canal-directed flow (Hopkinson and Day 1980a, b).

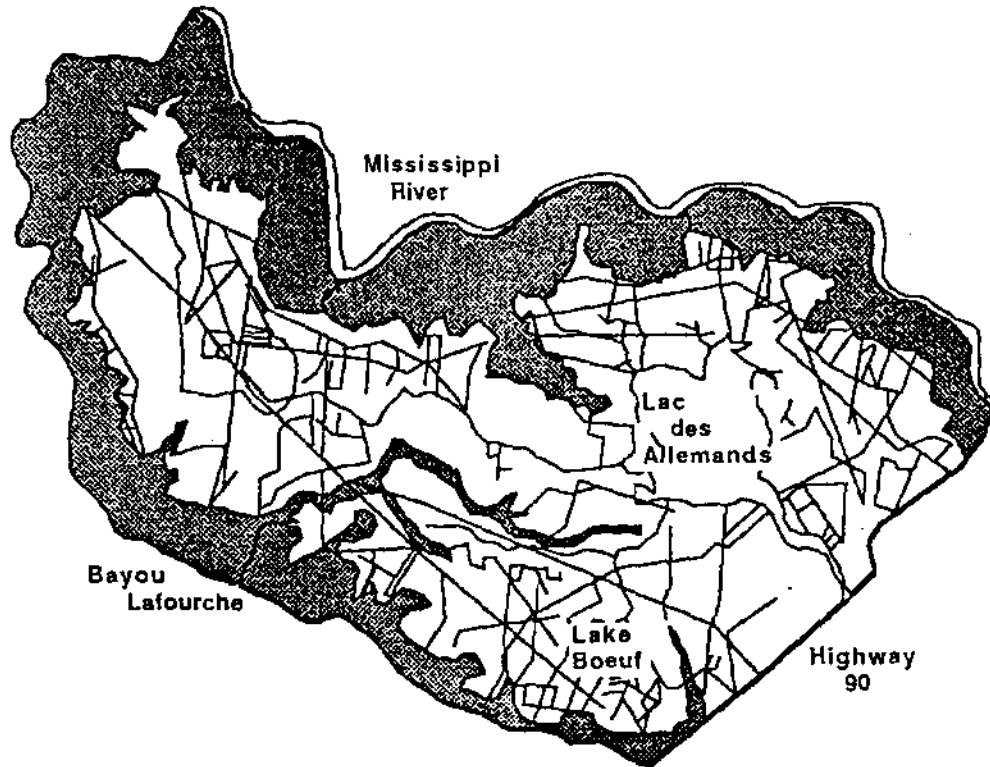


Figure 17. Drainage network of the upper Barataria Basin. Stippled areas are intensively drained natural levees (modified and used with permission, from Gael and Hopkinson 1979, copyright LSU Division of Continuing Education).

3.2.2 Nutrient Uptake, Productivity, and Export

The disruption of basin hydrology by canals and the increasing inputs of pollution have resulted in high nutrient concentrations in water bodies of the upper basin (Stow et al. 1985). However, a number of studies (Seaton and Day 1979; Hopkinson and Day 1979; Kemp 1978; Butler 1975) have shown striking differences between the nutrient levels in impacted lakes and natural swamps in the upper basin. While bayous and lakes receiving large inputs of upland runoff have N:P ratios of 6:1 (Kemp 1978) to 9.2:1 (Gael and Hopkinson 1979), natural swamp waters exhibit ratios of 2:1 (Kemp 1978). Inorganic N is removed from swamp floodwaters through denitrification and the sedimentation of ammonium-bearing clays (Kemp 1978; Engler and Patrick 1974). Although the sedimented clays remain in the system, the end product of denitrification is N_2 gas which is released to the atmosphere.

Ten percent of ammonium inputs to swamps is removed through plant uptake. Another

large percentage is adsorbed to sediments. Swamp sediment pore water ammonium concentrations are 15 times the concentrations in overlying waters (Kemp 1978). In passing through the swamps, water column nitrate levels in bayou inlets are reduced by one-half and N is exported from the swamps largely in organic form, as detritus and leachates. Thus, nitrate concentrations in swamp streams are kept low throughout the year, averaging 0.05 to 0.14 mg/l (Kemp 1978; Butler 1975), while bayou and lake sites always exhibit high concentrations of nitrate (0.28 to 0.32 mg/l). The high levels of nitrate and ammonium found in Bayou Chevreuil and other receiving waters draining the uplands show a seasonality that coincides in spring with peak fertilizer application and peak hydrologic flushing, and in late summer with the decomposition of large blooms of N-fixing algae (Figure 18).

Nitrogen-limited freshwater marshes in the upper basin can improve water quality by removing nutrients from inflowing waters. In one uptake study (DeLaune et al. 1986), eight percent of the labelled N applied to the freshwater marshes

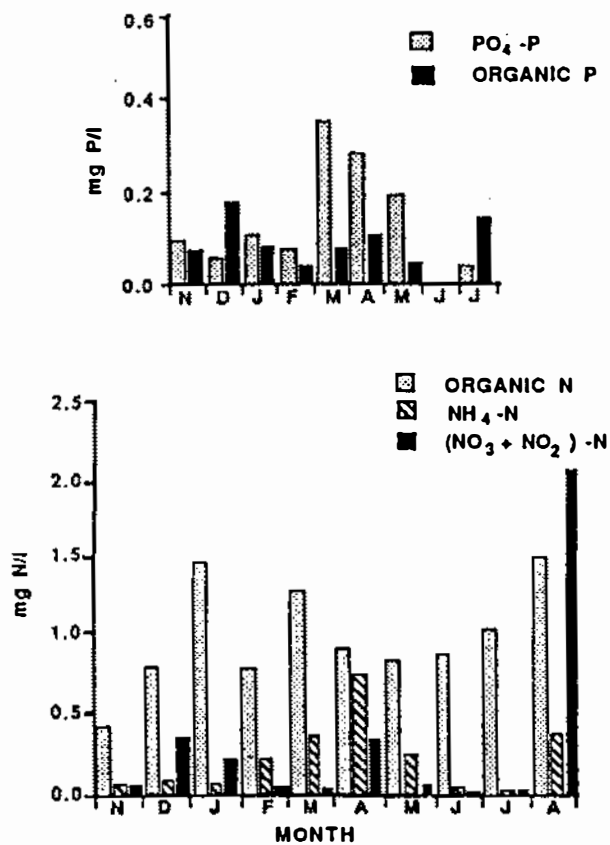


Figure 18. Phosphorus (P) and nitrogen (N) levels in bayous of the upper Barataria Basin (Kemp 1978).

remained in the plant-soil system, indicating efficient N use.

Kemp (1978) speculates that originally the entire upper basin aquatic system was N-limited. Although this condition persists in the lower Barataria Basin (Sklar 1976), the upper basin has recently been described as P-limited by Day et al. (1977) and Seaton and Day (1979). Lantz (1970) reported that increases in eutrophication have paralleled accelerated P loading while N loading has remained constant indicating limitation by P. Nitrogen fixation rather than upland drainage is reported to be the primary source of N to Lac des Allemands (Stow et al. 1985). This is attributed to the fixation of atmospheric N by massive algae blooms in the P-enriched lake. Annual P loading of 4.3 g/m²/yr to Lac des Allemands has risen to ten times the critical specific loading level discussed by Vollenweider (1968) and 30 times that calculated by Brezonik and Shannon (1971)

as being the threshold for eutrophic conditions in lakes. Fresh upper reaches of Barataria Basin are especially susceptible to eutrophication because of the lack of tidal flushing.

Studies (Butler 1975; Craig and Day 1977) concur that the P retention capacity of Lac des Allemands is approximately 55% and while the lake acts as a strong sink for P, almost half of the P load is exported to water bodies downstream. A considerable portion of the P in Lac des Allemands is tied up in plant material, and on average, there is three times more P in particulate than in dissolved form. The high water column productivity (net daytime productivity = 611 g C/m²/yr; Day et al. 1977) incorporates 10%-15% of the P imported into organic matter, but by far the largest fraction of the des Allemands P load is bound in lake sediments (Stow et al. 1985). Equilibrium studies show bottom sediments in Lac des Allemands are a major sink for incoming dissolved ortho-phosphate (Stow et al. 1985). Well-oxygenated waters and the presence of an oxidized sediment microzone encourage the trapping of precipitated ferric-phosphates. These compounds, plus phosphate adsorbed to clay particles are trapped in reduced sediments below the oxidized zone. Day et al. (1977), using a mass balance model, estimated that 45% of the P in the lake flows to the sediments, adding 2.0 g P/m²/yr to the sediment pool. The lake bottom, in reducing dissolved P concentrations, significantly reduces the potential for eutrophication and buffers the impact of upper basin P loads on middle basin waters. Sedimentation in the lake, ranging from 0.44 cm/yr to 0.81 cm/yr, also removes large amounts of C, N, and P. Carbon, nitrogen, and phosphorus were found to accumulate in the sediment at the rate of 60, 7.1, and 1.1 g/m²/yr, respectively (Stow et al. 1985).

3.3 MIDDLE BASIN NUTRIENTS

Lake Salvador lies at what is considered the interface of the upper and middle basins and serves to filter out much of the high nutrient load delivered from the upper basin. Much dissolved organic and inorganic material is removed by flocculation in Salvador's brackish waters. The process of flocculation is common in estuaries, occurring where salinity is 2-3 ppt. The ionic environment at this salinity encourages the clumping of clays, silts, and organic particulates into larger particles which readily settle out.

The middle basin, in contrast to the upper basin, experiences gulf tidal effects and alternate seasonal inundations of fresh and salt water, flushing the marshes more efficiently than those in the non-tidal upper basin. As in the upper basin, canals have altered the chemistry and sheet flow hydrology in the middle basin by causing flow to bypass swamp and marsh. Furthermore, canals have altered the circulation and flow patterns within the lake complex itself. Whereas Lake Cataouatche once emptied into Lake Salvador, the creation of the Barataria Waterway, a linear navigation canal, has proved an efficient alternate drainage for Lake Cataouatche, which now empties directly into lower Barataria Bay, effectively isolating Lake Salvador from the middle basin lake system. As a result, nutrient and chlorophyll *a* levels in Lake Salvador are much lower than in the other middle basin lakes. In Lake Cataouatche, the Barataria Waterway, and Barataria Bay, nutrients and chlorophyll *a* concentrations are similarly high (Seaton and Day 1979), indicating that these enriched water bodies form a tightly integrated complex with free circulation among them (Day et al. 1982).

The uncoupling of Lake Salvador from the circulation of the middle basin has resulted in an uneven distribution of nutrients and sediments in the water bodies and a less stable hydrologic regime. Because of its isolation, Lake Salvador, the largest body of water in both the upper and middle basins, can no longer serve as a runoff nutrient processor, and the other lakes are overloaded. Slow moving bayous that once tended to damp the movement of fresh and salt water are now replaced by channels which move water rapidly through the basin. Water level and salinity variations are rapid and extreme, tied closely to precipitation or tidal fluctuations. Salt water now intrudes farther upbasin, and has altered the species composition of the wetland biota.

Land use in the middle basin differs from that in the agriculturally-dominated upper basin. Hopkinson (1978) reported that 40% of the middle basin upland is woodland or open, while only 6% is agricultural (as compared to 71% agricultural in the upper basin). However, much of the input to the middle basin is nutrient-rich urban runoff draining the populated eastern levees near New Orleans. Nitrate concentrations (3.91 mg/l) in the runoff are

quadruple the average runoff concentration in other parts of the basin. Through Bayous Verret and Segnette, 935,000 kg N and 134,000 kg P are imported to the middle basin annually in runoff from the uplands surrounding the middle basin. Additionally, a substantial loading of nutrients is imported to the middle basin through Bayou des Allemands from the upper basin. Butler (1975) calculated this annual export from the upper Barataria Basin to be 8,016,000 kg organic carbon (C), 1,047,000 kg N, and 154,000 kg P. Added to this huge unprocessed export from the upper basin, middle basin upland runoff raises the total loading on the middle basin system to almost 2 million kg N and 228,000 kg P annually, or nearly twice the loading on the upper basin.

Import of C, N and P from the upper basin to Lake Salvador peaks in February with the surge of wet season runoff (Figure 19). Phosphorus loading to Lake Salvador from the upper basin totals 176,000 kg or 0.97 g/m²/yr, nearly 100% of which is retained in the lake (Craig and Day 1977). Despite such high nutrient loads, the lake is not eutrophic because the sediments and denitrification act as effective sinks for P and N.

The net daytime productivity (402 g O₂/m²/yr GPP) and chlorophyll *a* concentration (7-12 mg/m³) of clear Lake Salvador are low relative to other middle basin waters, and with a community respiration uptake of 602 g O₂/m²/yr this lake displays a moderate degree of heterotrophy (-198 g O₂/m²/yr net community productivity). Heterotrophy is a condition whereby a greater amount of organic material (and oxygen) is consumed than is produced by a system. This indicates that the system is not autosufficient; that is, it requires the import of organic material from outside the system. Lake Cataouatche, although contiguous with Lake Salvador, differs greatly from Salvador in nutrient character. Net daytime productivity (876 g O₂/m²/yr) is double that of Salvador, and the resulting organic material when decomposed by bacteria fuels a strong heterotrophic demand for oxygen. Net respiration in Lake Cataouatche is -1,205 g O₂/m²/yr, resulting in a net community oxygen consumption of -350 g O₂/m²/yr, approaching the heterotrophy of Lac des Allemands (-450 g O₂/m²/yr) and far exceeding that of Lake Salvador and of Little Lake (-117 g O₂/m²/yr NCP; Hopkinson and Day 1979).

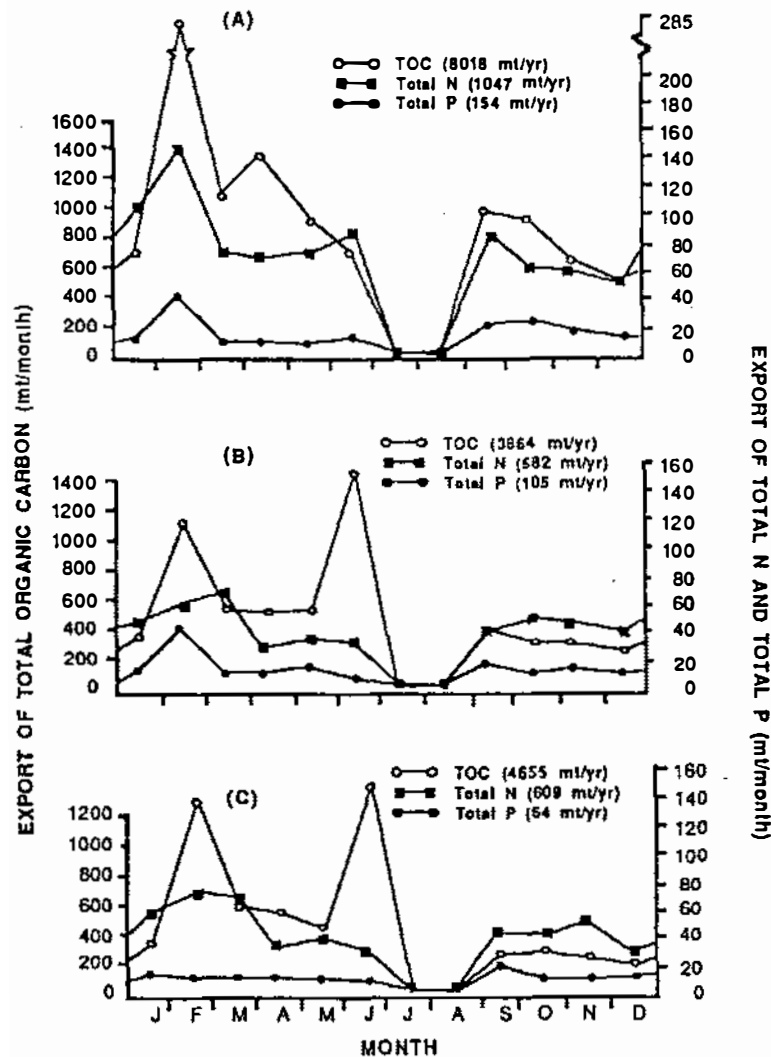


Figure 19. Monthly material export (in metric tons) from the upper Barataria Basin to the lower basin as measured in Bayou des Allemands (A), Bayou Chevreuil (B), and Bayou Boeuf (C) (Butler 1975).

The P loading rates for Lake Cataouatche and Lake Salvador are similar (1.6 and 0.97 g/m²/yr), but surprisingly Salvador displays none of the eutrophy plaguing Lake Cataouatche. Several factors in addition to the 40% lower P loading rate account for the high water quality in Lake Salvador:

1. Lake Salvador, with more than four times the volume of Cataouatche, effectively dilutes the nutrient load.
2. Circulation patterns in Lake Salvador tend to hold nutrient inputs along the western shore,

leaving the majority of the lake unimpacted.

3. Bayou des Allemands began carrying large nutrient surpluses into Lake Salvador only recently and the sediments in Lake Salvador still possess a great capacity to store nutrients. In contrast, Lake Cataouatche has drained an urban center for over three hundred years. Continuous inputs during that period have exhausted the sediment buffer.
4. Whereas Lake Cataouatche's reduced sediments release phosphorus to the overlying water column, Lake Salvador is oxygenated

throughout the water column and into the sediments trapping phosphorus in the form of ferric-phosphates and adsorbed phosphates below the oxidized zone (Craig and Day 1977).

Like Lake Salvador, Lake Cataouatche retains 95% of its P input, but in Lake Cataouatche sediment sink processes are not sufficient to prevent continuous algal blooms. The dissolved nitrate level (0.58 mg/l) in Cataouatche is three times Lake Salvador's and particulate organic nitrate (PON) is six times that of Lake Salvador. The mean chlorophyll *a* value in Cataouatche of 55 mg/m³ is five times the concentration in Lake Salvador. The average basin-wide chlorophyll *a* concentration is 11 mg/m³.

Bayou Perot and Bayou Rigolettes are parallel, elongated lakes draining Lakes Salvador and Cataouatche, respectively. Although the waterbodies they drain are of very different quality, these bayous are similarly high in water quality and low in nutrient and chlorophyll concentrations. This is of interest considering the very eutrophic character of the Lake Cataouatche source water for Bayou Rigolettes. The 95% P retention capacity of Cataouatche effectively reduces the nutrient levels in its outflow, so at this point in the basin, nutrients are reduced to near-natural levels through biological and chemical processes and from this point on, the basin system shifts from a heterotrophic to an autotrophic state.

Nutrient levels in Bayou Chevreuil in the upper basin exhibit rapid increases in inorganic nutrients during the days following storms (Figure 20; Kemp 1978). This suggests that accumulated nutrients are mobilized quickly by storms and concentrated in the bayous. These precipitation events play an important part in the chemistry of the middle basin; seasonal variations in the nutrient regime are linked to precipitation patterns. In summer, gulf backpressure and high evapotranspiration relative to precipitation combine to stall hydrologic flow, also shutting down the export of nutrients from the upper to the middle basin (Butler 1975). In autumn, when precipitation increases, accumulated nutrients are flushed into the estuary. High concentrations of total P and dissolved organic N are pulsed through the system from the flushing of leachates and detritus.

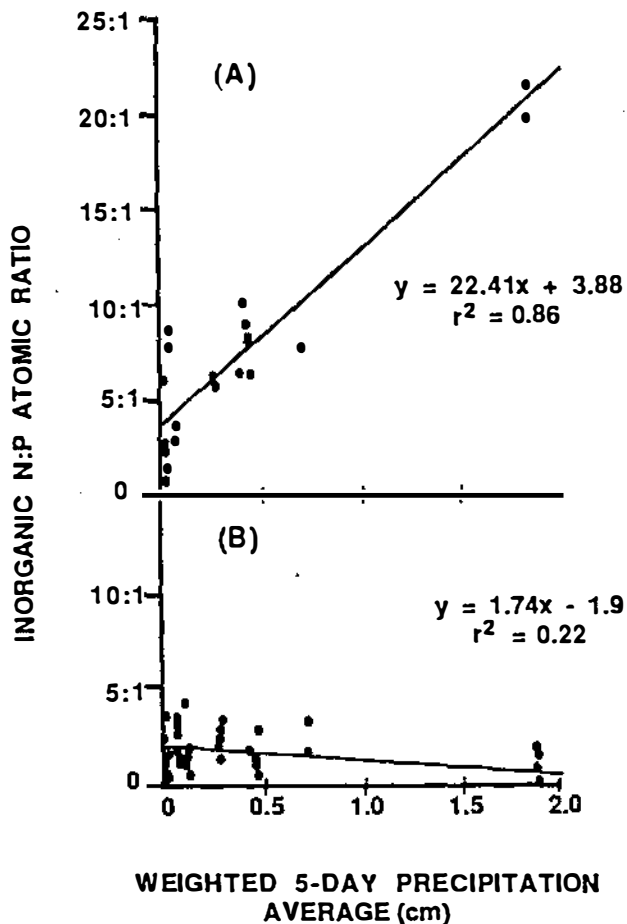


Figure 20. Relationship of precipitation to N:P ratios in Bayou Chevreuil (A) and swamp floodwater (B) (reprinted, with permission, from Kemp and Day 1984, copyright University Presses of Florida).

Hopkinson et al. (1978) described yet another mechanism of nutrient enrichment important in the middle basin. High rates of benthic bacterial respiration have been measured in lake sediments, largely driven by the large organic input from upstream. Bacteria decompose organic material and release N and P in their mineral ammonium and phosphate forms to the environment. Theoretically, this source of liberated "remineralized" P could add another 27 g/m²/yr inorganic P to the water column annually.

3.4 LOWER BASIN NUTRIENT DYNAMICS

Most of the water reaching the lower basin at Barataria and Caminada Bays is imported from

Little Lake and is of good quality with low chlorophyll *a* of about 9 mg/m³, total P of 0.18 mg/l, nitrate of 0.39 mg/l, and ammonium of 0.12 mg/l. The artificially dredged Barataria Waterway serves as a conduit, discharging enriched upper basin water directly into Barataria Bay. However, in the down-basin direction, freshwater runoff becomes less influential to basin chemistry. The Gulf of Mexico, laden with Mississippi River water, becomes increasingly important toward the lower basin and the proportion of Mississippi and Gulf of Mexico water mixing and entering the mouth of the Barataria estuary is controlled by wind, current, tide, sea level, discharge, and precipitation. While the river plume can flow directly into the basin for sustained intervals during spring flood, during periods of low flow, the river does not impact the lower estuary at all. The seasonal importance of the Mississippi River to lower basin nutrient chemistry is evident in the high correlation between river discharge and nutrient levels in the lower Barataria estuary.

In 1973, the Mississippi River flood peaked at its greatest discharge in several years. Ho and Barrett (1977) took this opportunity to make detailed measurements of nutrients along

the Mississippi River plume westward past the Barataria estuary throughout the year. Their objective was to determine the influence of the river on nearshore gulf and estuarine waters under various discharge conditions.

Salinity transects in January 1973 from the upper estuary in Caminada Bay to the gulf crossed a number of distinct water masses. The upper region of Caminada Bay draining freshwater marshes was characterized by low salinities. At Caminada Pass, salinities increased in a gulf water mass trapped by the river plume, but again dropped farther offshore where stations lay in the turbid river plume itself (Figure 21). Silicate, phosphate, ammonium, and nitrate levels had a strong negative correlation with salinity, rising sharply in the riverine water mass, indicating the importance of the river as a source of inorganic nutrients to the lower basin during high-flow periods. In contrast, marsh-drained upper estuary waters were an order of magnitude higher in organic N than gulf or riverine levels.

When river flow is adequate and currents are favorable for directing the plume into the bay, the increased input of nutrients stimulate

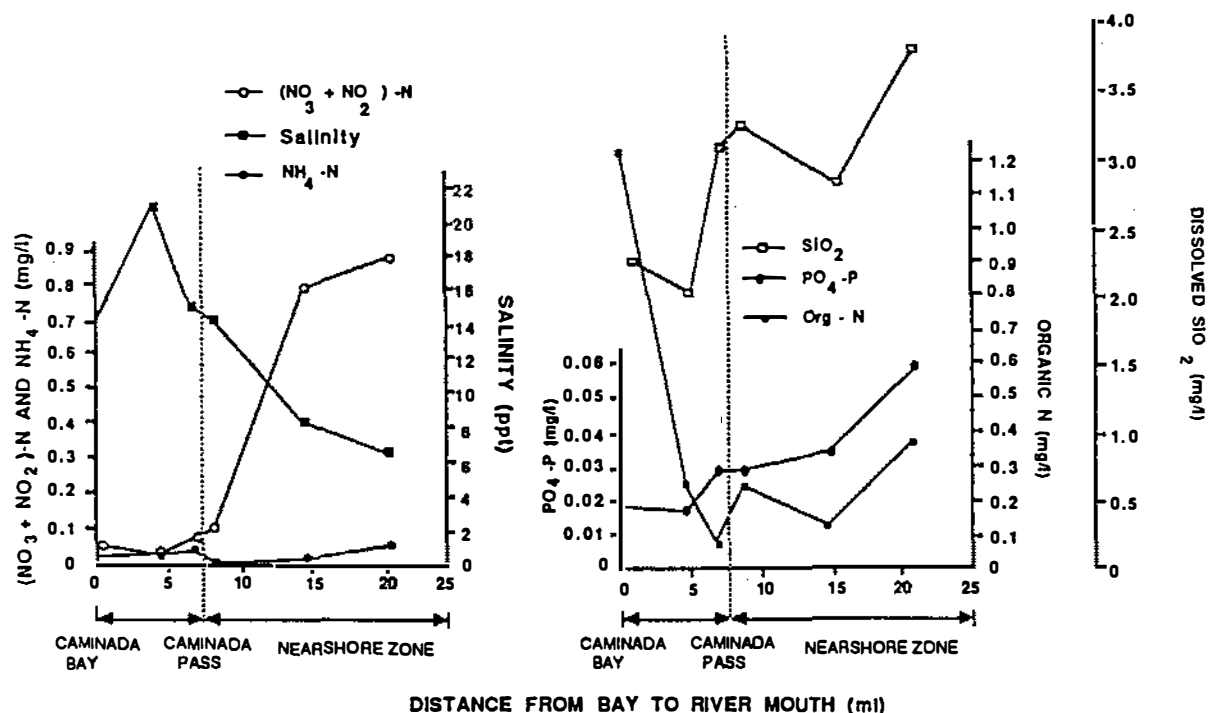


Figure 21. Nutrient profile for Caminada Bay and nearshore Gulf of Mexico during spring flood, 1973 (reprinted, with permission, from Ho and Barrett 1975).

productivity in lower Barataria Basin. During the months of spring flood, Barataria and Caminada Bays often experience an inverted spatial nutrient pattern opposite that of the upper and middle basin pattern of decreasing concentrations downbay. Instead of decreasing at these times, downstream concentrations of inorganic nutrients in the lower basin increase toward the gulf because of the effect of the river. During these periods of high river flow, organic N levels also increase toward the gulf due to increased incorporation into organic matter by phytoplankton production. During periods of low river flow, concentrations of inorganic nutrients and chlorophyll *a* are low and further decrease into the gulf.

The marshes in the lower saline portion of the Barataria estuary are highly productive. Annual marsh net production of 1,176 g organic matter/m² measured by Kirby and Gosselink (1976) is equivalent to 590 g C/m²/yr. The salt marshes play an active role in the nutrient cycling of the basin. In general, salt marshes are perceived to be a major source of carbon to estuaries and the nearshore zone, and many investigators (Day et al. 1973; Happ et al. 1977; Craig et al. 1979), in estimating high rates of export of C from Barataria Basin, have linked the productivity of the vast Louisiana fishery to the high primary productivity of Louisiana salt marshes. Carbon, in its particulate organic form (POC) and its dissolved form (DOC) is produced in salt marshes as a result of the breakdown of dead organic material and leaching. Day et al. (1973) created a budget to estimate the total community productivity and carbon flow through the estuary. Total marsh aboveground net primary production was estimated to equal 759 g C/m² annually. Consumption of the vascular plant and algal production by primary consumers was calculated to approximate 50% of the NPP, leaving 382 g C/m²/yr available as detritus for sedimentation in the lower basin, as food, or for export from the estuary. Combined with phytoplankton and benthic algal production, the input of marsh detritus to the waters of the lower basin was calculated to be 750 g C/m²/yr for water surface (i.e. not including marsh) of which 432 g C/m²/yr was consumed in the water. The fate of the remaining 318 g C/m²/yr input to the estuary is the subject of some debate, specifically concerning whether the carbon is exported or sedimented within the basin. Converted to mass per unit of the entire estuary surface in the lower Barataria Basin

(including marsh surface), the surplus available is 178 g C/m²/yr.

Day et al. (1973) expected that the entire amount of the surplus was exported from the estuary to the nearshore zone and very little was sedimented. Although no flux measurements were available on which to base this estimate, they find support in the fact that there is no net gain of sediment level in the basin and not more than 0.81 cm of sediment can accumulate each year based on the rate of subsidence. Mineral sediments from resuspension in the basin and Mississippi River inputs contribute to sedimentation, and the organic content of the basin sediment is only about 13%. Day et al. (1973) calculated that 1,053 g/m²/yr organic matter or 527 g C/m²/yr would account for this input, most of which would be available from root and belowground production. Although there are no root production measurements for these marshes, their argument that most of the organic material withheld from export would come from biomass already emplaced in the ground is reasonable. One may expect that belowground production is greater than aboveground production. Furthermore, since much of the lower basin is not keeping up with subsidence, somewhat less than the 527 g C/m²/yr is required to account for annual peat accumulation.

Happ et al. (1977) measured concentrations and fluxes of DOC, TOC, and chlorophyll *a* in the lower basin as a means of determining the fate of C and found evidence for the export of carbon from the Barataria estuary. A gradient of TOC from a high of 8.5 mg/l in waters of fringing marshes to 5.9 mg/l in the lower bay to 2.8 mg/l in the nearshore gulf indicated that marshes are a source of carbon and that there is movement into the gulf. Based on calculations of mixing rates in the estuary by Kjerfve (1972) and a flushing time of 23 days (Austin 1955), Happ et al. concluded that outwelling exports 140-190 g C/m²/yr from the estuary, which is near the value calculated by Day et al. (1973).

DeLaune et al. (1978), Hatton (1981), and DeLaune and Smith (1984) measured vertical accretion rates in Barataria Basin marshes using ¹³⁷Cs profiles and determined that streamside and inland salt marshes are accreting at the rate of 1.35 cm/yr and 0.75 cm/yr, respectively, from the accumulation of organic detritus and tidally

imported clays and silts. The organic content measured in these soils is about 20%, representing an accumulation of about 240-390 g of organic C/m²/yr of marsh surface in the form of peat (Smith et al. 1983), indicating that 50%-75% of annual marsh production must remain on the marsh. Another large percentage is lost as CO₂ and CH₄ gas, leaving much less net carbon to be exported than other studies would indicate (Feijtel 1985). Smith et al. (1983) calculated that an equivalent of approximately 400 g C/m²/yr is evolved from the marsh surface as CO₂ and CH₄. While some CO₂ is recycled back into the marsh through uptake by photosynthesis, most of it is lost to the atmosphere and combined with the carbon accumulated as peat; very little of the production remains to be exported. However, the contribution of belowground production by salt marsh vegetation has yet to be determined, and this fraction may supply much of the accumulated peat, as suggested by Day et al. (1973). The amount of belowground macro-organic matter (MOM) is several times the organic material in aboveground production. Buresh et al. (1980) measured a ratio of MOM fractions to aboveground matter of 5.7 in Barataria salt marshes; however, little is known of turnover rates of belowground production.

Feijtel et al. (1983) synthesized existing carbon flux data and estimated carbon flow along a salinity gradient in Barataria Basin. Using a mass balance approach, they found an estuarine carbon surplus of 130-230 g/m²/yr which originated primarily in the tidal salt marsh. Carbon export from marshes to adjacent water bodies decreased with distance upbasin from the Gulf of Mexico.

In contrast to upper basin marshes, which receive almost no mineral sediment, the influx of Mississippi River water through the lower basin mouth provides mineral sediments for salt marshes, augmenting the nutrient supply and enhancing sedimentation. The sediments making up the wetland soils of the basin are largely unweathered recent Mississippi River alluvium. For this reason the marshes usually contain adequate supplies of most of the major plant nutrients such as phosphorus, potassium, calcium, and magnesium as well as essential micronutrients. Barataria Basin salt marshes have been shown to serve as great nutrient sinks (DeLaune et al. 1981), accumulating N and P at rates of 21 g/m² and 1.79 g/m² annually. The bulk of active plant

roots are found above 30 cm depth and as the marsh accretes, the N and P below this depth become unavailable as a source of nutrients to the plants and are lost from the system.

Enrichment experiments (Patrick and DeLaune 1976; Buresh et al. 1980; DeLaune et al. 1983) have shown N to be limiting to the growth of the *Spartina* salt marshes. Despite the large reservoir of organic N in marsh soils, the short term supply of N to plants is governed by the rate of mineralization of organic N to the ammonium form. In these marshes this occurs at a rate of 25 g N/m²/yr and represents 60% of total inputs (DeLaune et al. 1979). Increases of up to 25%-30% in plant biomass and height have been stimulated by the application of supplemental ammonium N to marsh sites. While supplemental P was rapidly taken up by marsh plants, there was no increase in growth response, although luxury consumption increased tissue P concentrations by 20%.

Organic enriched mineral sediments provide the greatest source of N to the lower basin marshes, but a significant part of the N input is contributed by the fixation of atmospheric N by heterotrophic bacteria associated with the marsh plants (Casselman et al. 1981). Partitioning experiments by Casselman et al. (1981) indicate that negligible fixation occurs in open water or on the plants themselves (only up to 0.2 g N/m²/yr) while marsh soil adjacent to plant roots is the site of intense fixation: 4.5 g N/m²/yr in inland marshes and 15.4 g N/m²/yr in streamside marsh. In the case of streamside marsh this represents almost 40% of the total N budget of the *Spartina* plants.

Tidal fluxes provide the important link between lower basin marshes and the open waters of the lower Barataria Basin, Caminada Bay, and Barataria Bay. Denitrification rates are low in the marsh (approximately 3-4 g N/m²/yr; DeLaune et al. 1983) and thus by far the major N loss from the marshes (and consequently the important inputs to open waters) is due to tidal export of detritus. It is estimated that approximately 40% of the net aboveground *Spartina* N production (10-12 g N/m²/yr) is lost in this fashion. Because P is not transformed into a gaseous phase in its nutrient cycle, all P export from the salt marsh (1.0 g P/m²/yr or about 36% of production) is via tidal export as well. Marsh vegetation is thus pumping N, P, and C from sediment and atmospheric

reservoirs into the lower estuary in the form of leachates and detritus. However, nutrient inputs from the accretion of mineral sediments, nitrogen fixation, rainfall, and the import of organic material from the upper Barataria Basin far exceed the export and loss of nutrients in the lower basin, making the Barataria salt marsh a net importer of N and P.

3.5 SUMMARY

The Barataria Basin is a dynamic chemical link between land and sea in coastal Louisiana. In recent years, its hydrology and chemistry have been altered by the natural abandonment of the river channel and by human activity, and what once was a flow-through estuary dominated by riverine processes is now a swamp-lake system whose chemistry is largely controlled by precipitation and tides. Levees have isolated the basin. Canal dredging and increased pollution are creating a steep biological and chemical gradient along the basin characterized by eutrophy and heterotrophy in the upper end and autotrophy in the saline end. Upper basin photosynthesis:respiration ratios (P:R) of 0.71-0.76 (Day et al. 1977) contrast sharply with lower basin P:R ratios of approximately 1 (Allen 1975).

The upper basin may be experiencing problems because natural controls of nutrient fluxes and primary production have been

compromised. Productivity and nutrient levels in the upper basin are tied to the seasonal pattern of precipitation, upland nutrient runoff, and fertilizer application (Stow et al. 1985). Productivity in the middle basin follows a more erratic, aseasonal pattern, and is dependent on water clarity and depth (Day et al. 1982). Winds, river discharge, and tides control nutrient flux and primary productivity in the lower basin.

Sealing of the basin borders with levees has robbed the upper basin of its sediment source, essential to maintaining the wetland against continuous loss to subsidence. In the lower basin, organic accumulation is supplemented by Mississippi River sediment, deposited by tidal inundation. The salt marshes experience an average of 160 major inundations per year, while fresh marshes experience only 20. With a lack of new mineral sediment input, marshes throughout the basin are deteriorating rapidly.

New nutrient inputs each year total only one-fifth to one-half the nutrients regenerated within the basin. The effect of these new inputs is to stimulate higher productivity and also higher recycling rates as more organic material is supplied to benthic remineralizers. High nutrient loads have created an immensely productive heterotrophic upper basin, but the natural buffering capacity in the middle basin has thus far protected downstream waters from eutrophy.