Phase 1 Assessment of Potential Water Quality and Ecological Risk and Benefits From a Proposed Reintroduction of Mississippi River Water into the Maurepas Swamp

Prepared for
U.S. Environmental Protection Agency
Region 6
EPA/OCPD Contract No. 68-C-03-041
Work Assignment 2-32

October 2005

Prepared by

Battelle
The Business of Innovation

PHASE 1 ASSESSMENT OF POTENTIAL WATER QUALITY AND ECOLOGICAL RISK AND BENEFITS FROM A PROPOSED REINTRODUCTION OF MISSISSIPPI RIVER WATER INTO THE MAUREPAS SWAMP

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1.0 INTRODUCTION

The U.S. Environmental Protection Agency, Region 6 (EPA) and Louisiana Department of Natural Resources (LDNR) are developing plans for a proposed reintroduction of Mississippi River water into the Maurepas Swamp, a cypress-tupelo swamp south of Lake Maurepas (Figure 1). The project is funded through the Coastal Wetlands Planning, Protection, and Restoration Act (CWPPRA). It has been proposed that the future ecological sustainability of this coastal ecosystem is dependent upon the restoration of its natural connection with the Mississippi River.

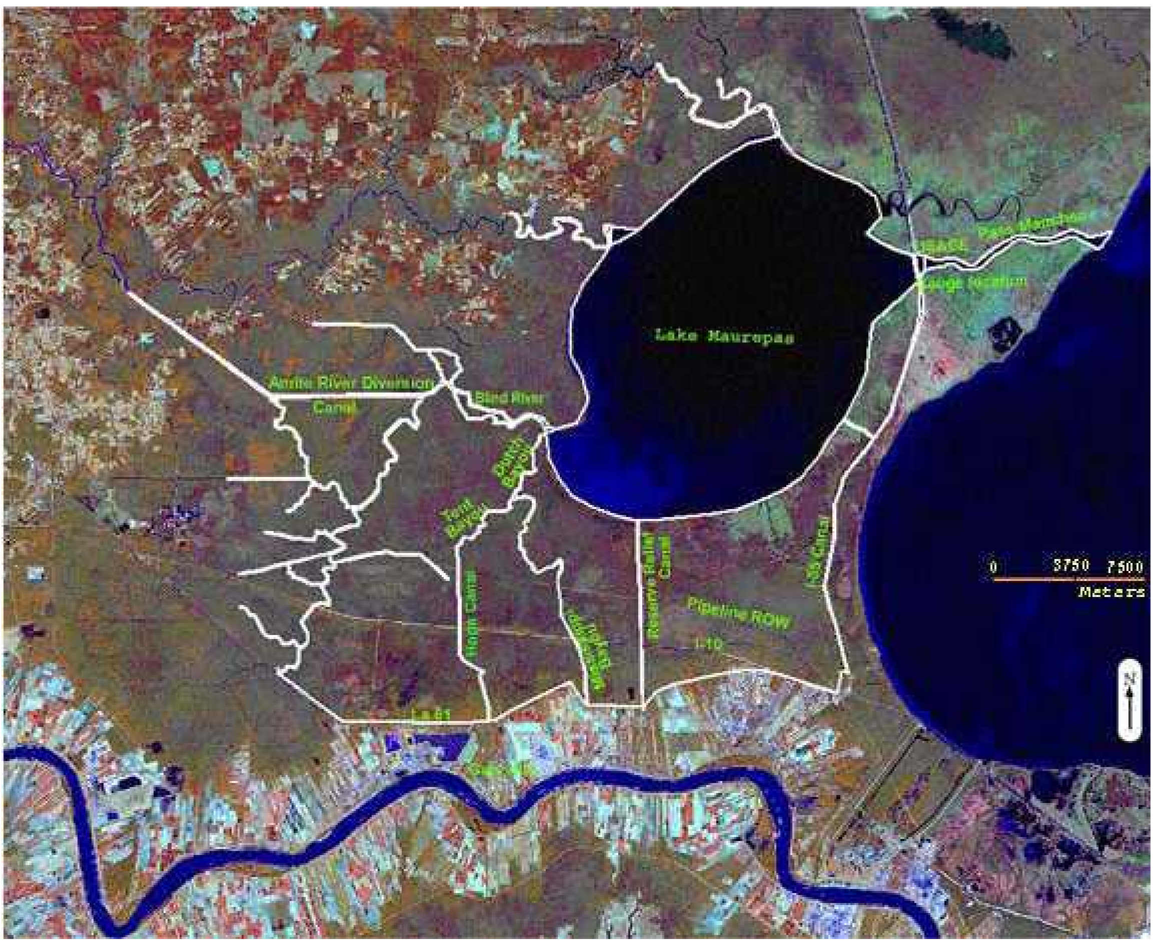

Figure 1. Maurepas Swamp Study Area. ***Source: Day et al. (2004).***

Maurepas Swamp is located in the northern Lake Pontchartrain basin of coastal Louisiana. It lies between the southern coastline of Lake Maurepas and the Mississippi River northwest of New Orleans. Plans are being developed for a freshwater diversion from the Mississippi River to the Maurepas Swamp to reintroduce nutrients, sediments, and freshwater for a series of beneficial ecological outcomes (Day *et al*., 2004, Shaffer *et al*., 2003). Increases in nutrients and sediments will reverse the existing declining state of subsidence in the swamp by (1) directly increasing short-term accretion rates through sediment transport to the swamp waters; and (2) by stimulating an increase in production of organic content of sediment which will augment long-term accretion and balance the sediment organic content necessary to support a healthy swamp ecosystem. The reversal of subsidence is critical to native vegetation species, such as cypress and tupelo, which cannot effectively recruit saplings in permanently flooded conditions. Thus, their propagation relies on periodically dry substrates. An increased rate of freshwater flow is also desired to decrease periodic saltwater intrusions that have been determined to significantly stress the swamp ecosystem.

This preliminary assessment is conducted to support EPA Region 6 in developing an environmental impact statement (EIS). This report focuses specifically on loads of nutrients, sediments, and toxic chemicals (contaminants) from the source of diverted freshwater (the Mississippi River) to the Maurepas Swamp and Lake Maurepas, as well as the potential for cascading effects in downstream locations (*e.g.*, Lake Pontchartrain and coastal waters).

1.1 Goals and Objectives

The objective of this Phase I evaluation is to characterize and evaluate the risks and benefits related to the ecology and human health associated with the reintroduction of Mississippi River water into the Maurepas Swamp and associated tributaries and downgradient areas. This preliminary assessment is based on available literature and data. It includes a discussion on uncertainty and provides recommendations for data collection necessary to reduce uncertainty. EPA plans to conduct separate supporting projects to assess risks related to any existing upland hazardous waste sites and any associated contribution of hazardous, toxic, or radiological waste sites in the project area.

The following specific needs are addressed in this report:

1. An assessment of potential risks of harmful, or nuisance, algal blooms that might occur in Lake Maurepas as a result of nutrient loadings from the Mississippi River reintroduction (diversion) project;
2. An assessment of potential risks, through a screening-level risk assessment of contaminants that might occur in Lake Maurepas, or the receiving swamps or associated hydrologic system, including:
    - Increased exceedance of water quality criteria for contaminants that may indicate a potential risks to finfish populations;
    - Increased exceedance of sediment screening values for contaminants that may indicate a potential risk to benthic invertebrate communities.
3. An assessment of potential risks, through a screening-level risk assessment, to bald eagles from exposure to chemical contaminants in the sediment, water column, and prey items as a result of the reintroduction (diversion) of the Mississippi River;
4. An assessment of the potential for positive water quality impacts of the project; and,
5. An assessment of solids/turbidity changes that can be expected to occur in the swamp and associated hydrologic systems and the southern portion of Lake Maurepas as a result of the proposed diversion project.

1.2 Document Organization

The remainder of the document is organized as follows:

Section 2.0 Site Description and History
This section provides the reader with a description of the study area. This section contains information on the proposed diversion, the existing conditions within the study area, and projections of future conditions if the diversion is implemented. Nutrient and contaminant loads and concentrations are summarized from previous studies.

Section 3.0 Summary of Screening-Level Ecological Risk Assessment
This section provides a summary of the screening-level risk assessment conducted to evaluate whether the potential risks associated with chemical contaminants carried in Mississippi River water and sediments could adversely affect wildlife species in Maurepas Swamp and Lake Maurepas if the diversion is implemented.

Section 4.0 Summary of Diversion Benefits and Risks
This section identifies the ecological benefits associated with the proposed diversion in contrast to the predicted future conditions if no action is taken to introduce Mississippi River water into the Maurepas Swamp. Potential risks associated with implementing the proposed diversion are also identified and summarized.

Section 5.0 Conclusions, Uncertainty, Data Gaps, and Recommendations
Uncertainty and information gaps are discussed and recommendations to reduce uncertainty are provided.

Section 6.0: References

Appendix A: Screening-Level Ecological Risk Assessment

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2.0 SITE DESCRIPTION AND HISTORY

2.1 Study Area

The study area associated with this evaluation extends from the Mississippi River, through the proposed diversion conduit (Hope Canal), Maurepas Swamp and Lake Maurepas. The specific swamp restoration area is shown in Figure 2 and includes approximately 122 km^2 of Maurepas Swamp from the mouth of the Blind River, eastward to the Reserve Canal.

Hope Canal is located in the southwestern area of Maurepas Swamp and extends from an area just south of Interstate 10 northward to its confluence with the Bayou Tent within the swamp. The remaining distance to Lake Maurepas is approximately 9 km through the sinusoidal channel of Dutch Bayou. Hope Canal is relatively narrow, roughly 25 meters (m) wide and has an average depth of 2 m. Its banks, once levied with dredge spoils, are now intermittently broken open to the surrounding swamp and, therefore, hydrologic communication between the canal and the swamp exists at various points. Hope Canal is hydraulically connected to Dutch Bayou which subsequently connects to Lake Maurepas near the mouth of Blind River.

Maurepas Swamp is a cypress (80%) and tupelo (20%) forested swamp that has a relatively long history of economic exploitation through logging and oil extraction activities. Therefore, in many areas the forest is second-growth and traversed by a number of abandoned canals and relict railroad beds. The swamp includes a recent State Wildlife Management Area and several privately-owned parcels that have been selectively logged and mined at different times resulting in a patchwork of vegetative cover. The primary area of the swamp that is targeted for restoration through the implementation of the proposed diversion is approximately 122 km^2 (Day *et al*., 2004) in size.

There are several existing canals and bayous within the swamp that are capable of providing hydraulic communication within the swamp and with the lake. Most natural bayous have been canalized or modified over time to accommodate human commercial activities in the area. Mississippi Bayou is the only remaining unaltered, natural bayou within the study area. Field investigations reported by Kemp *et al*. (2001) indicate that water levels within the swamp are governed by lake level and that salinities are positively correlated with lake level. Their initial conclusions are that high water level "events" are due to an influx of water from Lake Pontchartrain rather than to contributions from tributaries and rivers in the area. This influence from Lake Pontchartrain is associated with undesirable frequencies and durations of high salinity events which have been connected to salt stress and subsequent die-off of swamp vegetation, particularly cypress and tupelo trees (Shaffer *et al*., 2003). In many areas of the swamp there has been a measurable conversion to marsh and open water habitats and this trend is believed to be increasing over time due to the lack of riverine input (Barras *et al*., 1994) and salt stress (Shaffer *et al*., 2003).

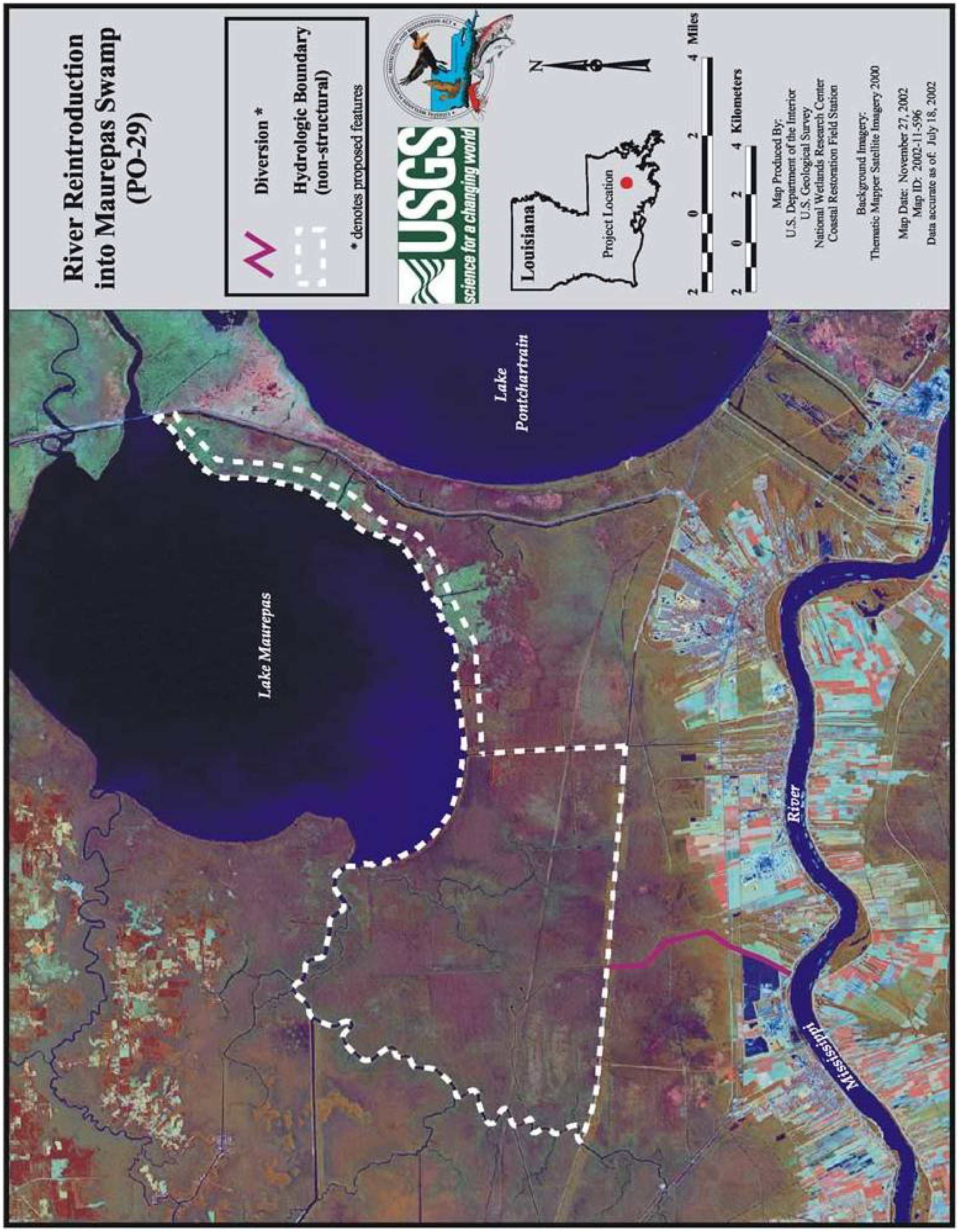

Figure 2. Maurepas Swamp Project Boundary. Proposed diversion originates at the Mississippi River, through Hope Canal (magenta line), to the receiving swamp (white outline). ***Source: EPA Region 6 (PO-29).***

Lake Maurepas is a round-shaped, shallow, brackish tidal estuarine system. It is approximately 240 km^2 in area and has a mean depth of about 3.0 m. The lake receives freshwater input through four river systems: Blind River, Amite River, Tickfaw River, and Natalbany River. The average freshwater input to Lake Maurepas from these rivers and other minor terrestrial sources is <3,400 cfs (CWPPRA Environmental Workgroup, 2001). At the northeast, Lake Maurepas is connected to Lake Pontchartrain by two passes: Pass Manchac and North Pass. The land between these two passes forms Jones Island and the passes converge on the eastern side of the island into one unified Manchac Pass. Tidal exchange with Lake Pontchartrain through Pass Manchac is a more significant influence on Lake Maurepas's volumetric and elevation characteristics than tributary freshwater discharge. The mean astronomical tide in Lake Maurepas is approximately 0.15 m (0.5 ft); however, greater tidal amplitudes are associated with meteorological events (*i.e*., winds) that influence both Lake Pontchartrain and Lake Maurepas. This results in interesting patterns of tidal exchange and, presumably, *in situ* mixing on weekly and fortnightly time scales. The lake's salinity is directly influenced by exchange with Lake Pontchartrain. Salinities in Lake Maurepas have been observed to range between 0 and 3 ppt (Day *et al*., 2004). Typically, salinities are higher along the eastern shore, near Pass Manchac. Due to Lake Maurepas's shallow depths, even relatively low energy wave action results in sediment resuspension and, therefore, relatively high turbidities and low transparencies which influence the degree to which primary production can occur in the water column and benthos.

Lake Pontchartrain is approximately 1,631 km^2 in area and has a mean depth of 3.7 m. This lake is considered a brackish estuarine system (mean salinity is 4 psu) and experiences tidal exchange with coastal waters through connections to Lake Borgne and western Mississippi Sound in the southeast. Lake Pontchartrain receives surface water from Lake Maurepas through Pass Manchac and from several additional small rivers and streams, including the Tangipahoa and Tchefuncta Rivers along the northern coast. The Bonnet Carré diversion is capable of providing a significant volume of Mississippi River water to Lake Pontchartrain and has been the focus of many studies. Lake Borgne and western Mississippi Sound extend immediately down gradient of Lake Pontchartrain. These estuarine systems have significantly higher salinities than Lake Pontchartrain and Lake Maurepas and are directly tidally connected to the Gulf of Mexico.

2.2 Existing Conditions

2.2.1 Climate

The climate in the Maurepas Swamp region is subtropical and strongly influenced by the thermal inertia of the Gulf of Mexico. Temperatures range from an average high of 27.2 ^oC (81 ^oF) in the summer to an average low of 10.6 ^oC (51 ^oF) in the winter. The climate is significantly humid due to its proximity to the Gulf of Mexico and the vast concentration of aquatic features within the coastal landscape. Winds typically prevail from the northeast from September through February and from the southeast from March through August.

The Maurepas region receives an average of 1.55 m (61.2 inches) of precipitation annually. The greatest rainfall occurs from June through September and the driest month is October. A net surplus of water is produced during the winter, a net balance during the summer, and occasional deficits from May through August, with an annual rainfall surplus of about 75 cm. This surplus is important for maintaining salinities well below seawater strength in the estuaries.

Tropical storms and hurricanes in the Gulf of Mexico during the summer and fall have been quite frequent in recent years and can be significant agents of change in the Mississippi delta area (most notably Hurricane Katrina in September 2005). Winter and spring weather can also be active, typically characterized by extratropical cyclones and associated fronts. These severe events can result in widespread changes in vegetation cover by decimating forests, killing large areas of vegetation through inundation with saltwater, and they typically are responsible for large scale transport of sediments.

The region's climate is influenced by El Niño Southern Oscillation (ENSO) events, which are associated with cyclic warming (El Niño) and cooling (La Niña) of the surface waters in the central and eastern Pacific Ocean. El Niño events typically result in wetter conditions in the southern U.S. while La Niña can result in drought conditions. The ENSO cycle occurs at irregular intervals of 2-7 years and usually lasts one or two years. In recent years, a swing from an extreme El Niño to an extreme La Niña event occurred in the region and resulted in a significant shift in Lake Pontchartrain salinities and water transparency (Cho and Porrier, 2005). The associated prolonged drought conditions increased salinity levels in Lake Maurepas and had measurable negative impacts on Maurepas Swamp vegetation which is largely salt-intolerant (Day *et al*., 2004). In Lake Pontchartrain, ENSO events are believed to control periodic species assemblages and spatial distributions in submerged aquatic vegetation (SAV) communities (Cho and Porrier, 2005).

2.2.2 Water Resources

Recent intensive field investigations reported in Lee Wilson & Associates (2001), Lane *et al*. (1999, 2003), and Day *et al*. (2004) provide the most comprehensive information on water resources within Maurepas Swamp and Lake Maurepas. Additional data provided by USGS (Amite River and Pass Manchac gaging stations) and Louisiana Department of Environmental Quality (LADEQ) monitoring stations further augment the following overview of existing conditions in the study area.

2.2.2.1 Hydrology

Maurepas Swamp is primarily hydraulically influenced by Lake Maurepas; however, freshwater discharge through the Blind/Amite River system and local runoff due to storm events has some impact on swamp hydrology (Lee Wilson & Associates, 2001; Lane *et al*., 2003, Day *et al*., 2004). As a result of human alterations, the periodic flow of Mississippi River water that historically occurred during flood events has not influenced swamp water in over 100 years. The resulting subsidence of the swamp, in concert with eustatic sea level rise, has increased the frequency and duration of surface water area within the swamp because subsidence has increased over accretion within most of the swamp. Relatively poor exchange between most of the swamp and Lake Maurepas, particularly in interior regions, often results in localized stagnant conditions where soil conditions (*e.g.*, low bulk density, limited nutrients, reduced environment) decreases rates of swamp productivity (Powell and Day, 1991; Shaffer *et al*., 2003). These extended flood conditions are believed to have doubled in duration over the past 50 years (Thomson *et al*., 2002) and are thought to be responsible for increased rates of subsidence and the conversion to open water environments in interior regions of the swamp (Shaffer *et al*., 2003).

Lake Maurepas hydrology is influenced by both freshwater input from its watershed and tidal exchange with Lake Pontchartrain. The lake is approximately 240 km^2 in area and has a volume of approximately 6.58 x 10^8 m^3. Freshwater discharge to the lake from the Blind, Amite, and Tickfaw Rivers has been estimated to account for an average annual discharge rate of <3,400 cfs to Lake Maurepas (Lee Wilson & Associates, 2001). Without accounting for precipitation and evaporation and transpiration, this annual influx of freshwater translates to a bulk freshwater replacement time for the lake of approximately 80 days (2.6 months).

Tidal exchange with Lake Pontchartrain varies considerably over weekly timescales due to meteorological effects but there is a measurable diurnal astronomical tidal signal (Figure 3). Diurnal astronomical tides are, on average, about 0.15 m (0.5 feet) while meteorological tides can be significantly greater; often resulting in over 0.6 m (2 feet) or more in elevational change over weekly periods (Figure 3).

Maurepas Swamp experiences flooded conditions more than 50% of the time. Mean annual water levels within the swamp are approximately 0.46 m (1.5 feet) while swamp ground elevations average are less than 0.40 m (1.3 feet) (Day *et al*., 2004). Shaffer *et al*. (2003) found no consistent pattern in elevation or flood duration among four different regions of the swamp, except that observations within “intermediate” marsh exhibited higher flood frequencies and depths than other regions.

Day *et al*. (2004) reported hydrologic characteristics of Maurepas Swamp among a series of field gaging stations (Table 1; Figure 4). Findings from this investigation indicate several things:

- All lake water levels, as measured with fixed gages, were consistent in phase and amplitude with the USGS gage at Pass Manchac;
- Tidal influence on Maurepas Swamp decreases with distance from shoreline;
- Evidence of diurnal tidal effects are filtered out at gages on small swamp channels such as the upper reaches of the Mississippi Bayou, and the swamp itself;
- During periods of high meteorological tides, the astronomic tidal signal is often absent from interior swamp areas, including Hope Canal, particularly during periods of water level recovery (drainage);
- The Reserve Relief Canal acts as an extension of Lake Maurepas due to the consistent nature of tidal propagation throughout its entire length.

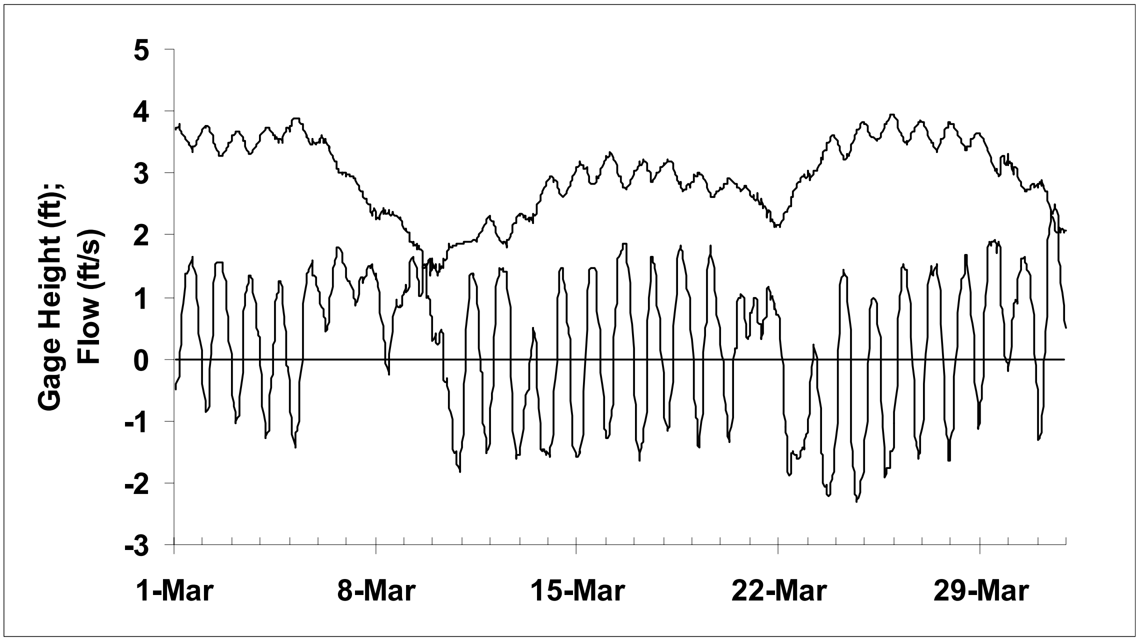

Figure 3. Water level and rate of flow as measured at USGS Station 301748090200900 at Pass Manchac during March, 2004. Top line is gage height (ft, NAVD88) and bottom line is flow (ft/s). Positive flow values (>0) represent flow from Lake Maurepas to Lake Pontchartrain and *vice versa*.

Summary statistics from this field observation are shown in Table 1.

Table 1. Maurepas Water Level Statistics: November 2002 to November 2003. Elevation units are in feet relative to NAVD 88 datum. *Source: Day et al. (2004)*.

Station	Manchac	S10	S4	S9	SLUA	S8	S6
Number of Observations	9081	4044	3919	4698	3639	4206	780
Maximum	4.15	3.35	3.64	2.85	2.93	2.82	2.16
Minimum	-0.24	0.13	-0.71	-0.68	0.56	-0.15	-0.13
Mean	1.39	1.56	1.54	1.46	1.70	1.53	1.31
Std. Dev.	0.62	0.66	0.63	0.63	0.43	0.60	0.68

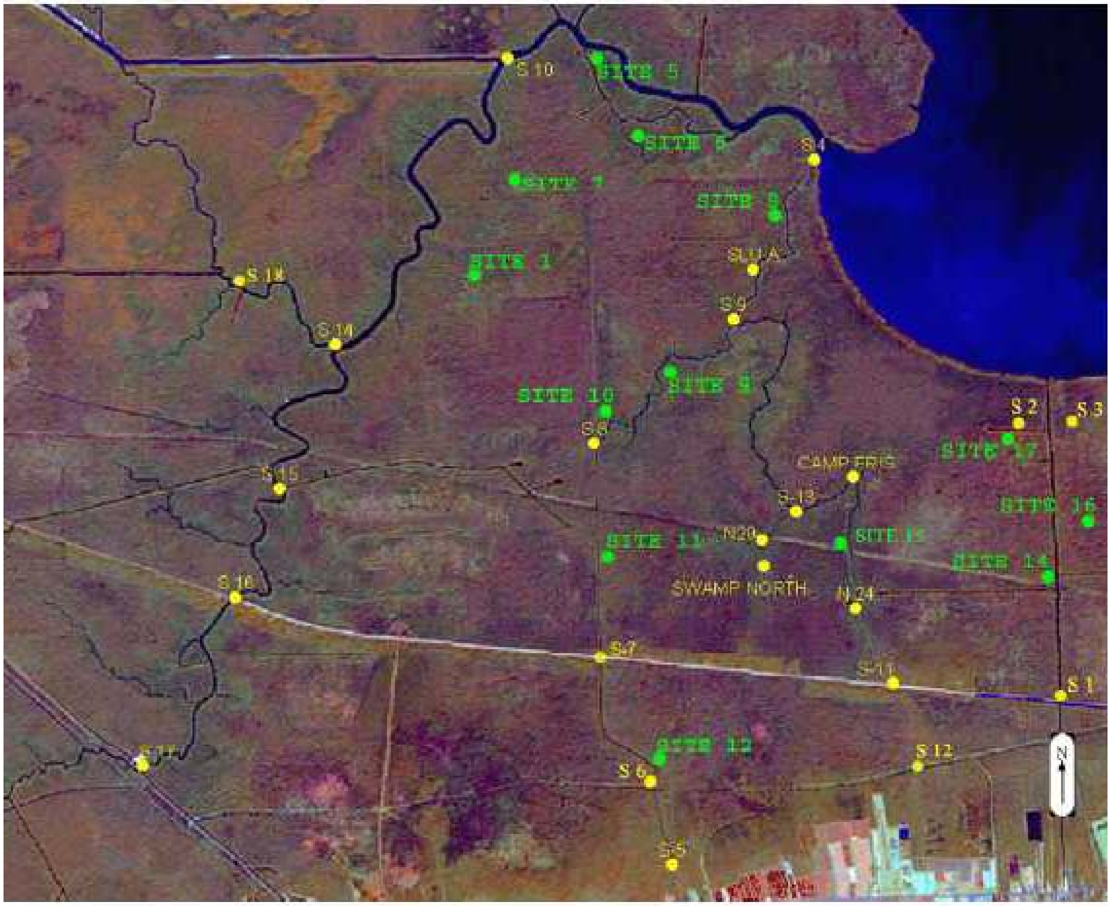

Figure 4. Maurepas Hydrologic Gages (yellow) and Shaffer *et al.* (2003) Forest Monitoring Stations (green). Swamp gages located at SLU A and URS N (Swamp North). *Source: Day et al. (2004).*

A series of hydrodynamic modeling analyses have been conducted to provide predictions of hydrologic and water quality changes in Maurepas Swamp and Lake Maurepas (Day *et al*., 2004) related to a series of diversion scenarios (see Section 2.3.1; Future Conditions). A 2-D hydrodynamic model (TABS-MD) was developed by Day *et al.* (2004) to simulate hydrologic flow and water quality. Future modification of this model development is intended to include sediment transport (Day *et al*., 2004). Three model modules of the TABS-MD method were applied in this study: GFEN, RMA2, and RMA4. The GFEN module is used to discretize a model grid (node locations). The RMA2 module simulates hydrodynamic conditions such as water elevation and movement over time among the spatial model nodes. The RMA4 module simulates mixing and transport of water column constituents based on the output of the RMA2 module. Figure 5 shows the model grid within the study area.

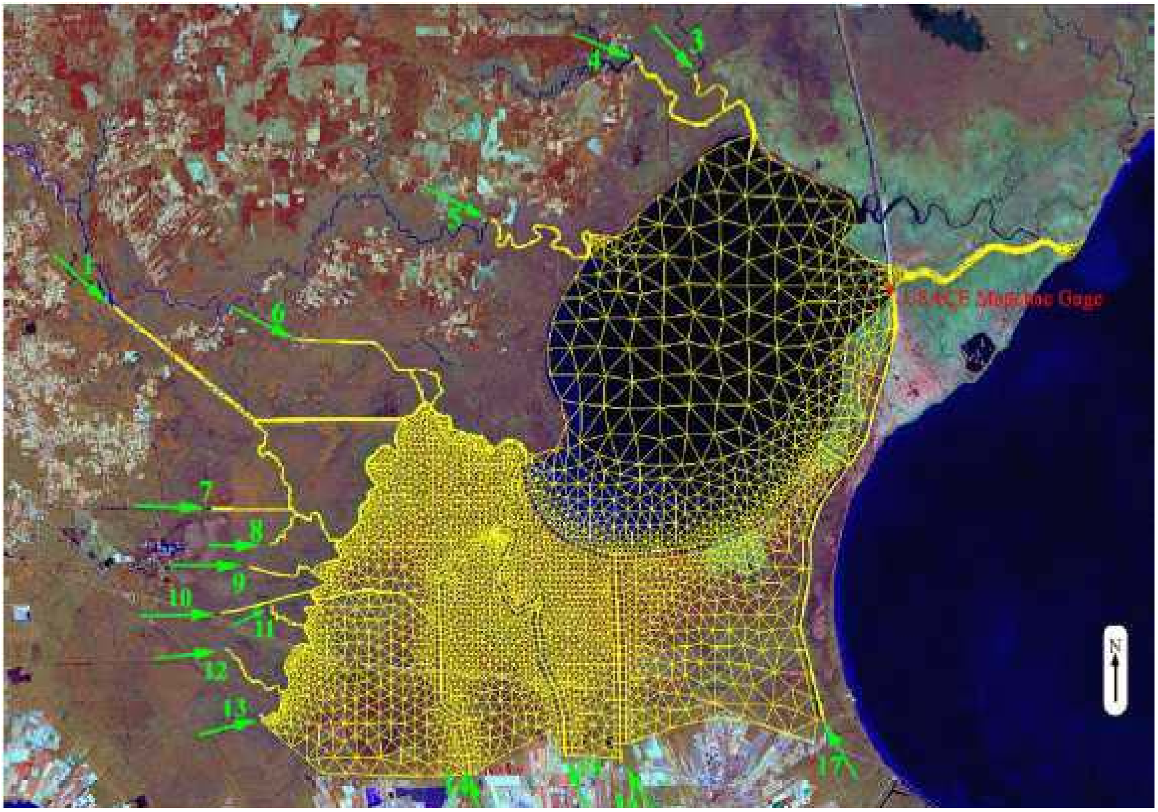

Figure 5. Maurepas Hydrodynamic Model Domain Showing FE Grid, Flow Boundaries, and the Stage Boundary at Pass Manchac. ***Source: Day et al. (2004)*****.**

The baseline "normal" (*i.e.*, existing) hydrodynamic modeling conditions reported by Day *et al*. (2004) were focused on Amite River discharge events and subsequent influences on Lake Maurepas elevations and salinities. The simulation of a conservative tracer, introduced in the Amite River and Amite River Diversion Canal, resulted in a consistent plume position along the western margin of the study area (Figure 6). Day *et al*. (2004) report that this same area experienced relatively high salinities during the 2000 drought and that this is likely due to the Blind River's tendency to provide an effective conduit for lake water during low base flow conditions. Also, due to the flashy nature of discharge in this area (i.e., high discharge for short durations), net water movement from western Lake Maurepas is currently limited, allowing for higher salinity water to persist.

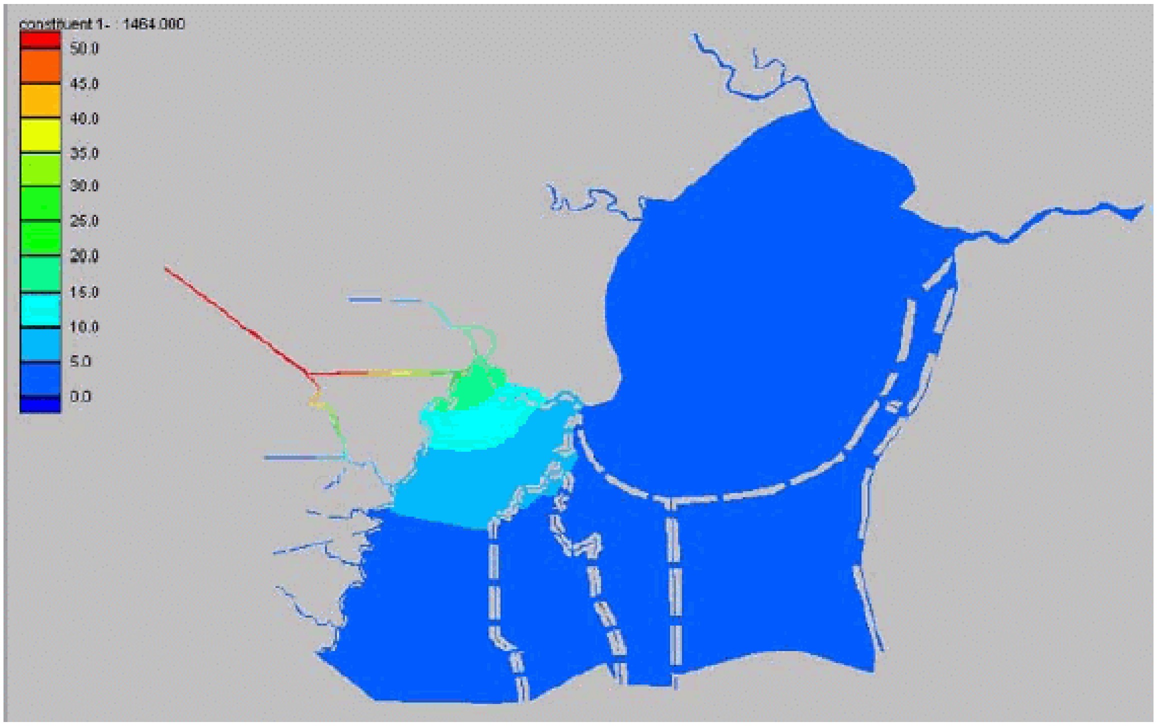

Figure 6. Predicted Influence of Amite River Discharge on Maurepas Swamp as Modeled by Day *et al*. (2004).

Further refinement of this modeling approach is underway (Bob Jacobsen [URS Corp.], personal communication) to provide a more comprehensive picture of water residence times, frequency and duration of stratified conditions, and overall movement and exchange of water within the swamp and the lake. These analyses are necessary to determine, with greater certainty, the influence of the proposed diversion on water quality and salinity within Lake Maurepas.

2.2.2.2 Temperature

Mean monthly water temperatures measured at Pass Manchac gage from March 2004 through February 2005 are shown in Table 2 and range from a low of 12.5 ^{o}C in February to a high of 29.7 ^{o}C in July. This gage measures water movement between Lake Maurepas and Lake Pontchartrain. Table 3 depicts the differences between inflowing and outflowing water between the two lakes and shows that water leaving Lake Maurepas was typically cooler from May through October and warmer in the other months. Additional, limited water temperature data collected from the LA DEQ at stations LR21, LR24, and LR29 in August and September of 1991 through 1994 (LA DEQ) are consistent with those in Tables 2 and 3 (data not shown).

Table 2. Monthly mean water temperatures (°C) for Pass Manchac for the period of March 2004 through February 2005 at USGS Station No. 301748090200900; Pass Manchac at Turtle Cove near Ponchatoula, LA.

Year	Month	Pass Manchac (°C)
2004	March	18.8
	April	19.5
	May	26.7
	June	29.1
	July	29.7
	August	29.5
	September	27.8
	October	25.5
	November	19.6
	December	12.6
2005	January	12.8
	February	12.5

Table 3. Monthly mean water temperatures (°C) for water moving (1) from Lake Pontchartrain to Lake Maurepas, and (2) from Lake Maurepas to Lake Pontchartrain. Also shown is the mean monthly difference in these values. Data from USGS Station No. 301748090200900; Pass Manchac at Turtle Cove near Ponchatoula, LA.

Year	Month	From Lake Pontchartrain to Lake Maurepas (°C)	From Lake Maurepas to Lake Pontchartrain (°C)	Δ T°
2004	March	18.5	19.0	0.5
	April	19.4	19.5	0.1
	May	27.6	26.5	-1.1
	June	29.5	28.8	-0.6
	July	30.4	29.4	-1.0
	August	29.7	29.3	-0.3
	September	27.9	27.7	-0.2
	October	25.8	25.3	-0.6
	November	19.5	19.7	0.2
	December	12.0	13.0	1.1
2005	January	12.5	13.1	0.6
	February	12.6	12.5	0.0

Water temperature data associated with sampling sites within Maurepas Swamp were not found in Day *et al.* (2003) or other primary literature reviewed.

2.2.2.3 Water Quality

Baseline water quality studies on Maurepas Swamp and Lake Maurepas were reported in Lee Wilson & Associates (2001) and Day *et al*. (2004). Two series of water quality sampling investigations occurred: (1) April 2000 through June 2001 at 19 stations covering all major bayous, river systems, and other water bodies associated with Maurepas Swamp (Day *et al*., 2001[1]; Lane *et al*., 2003) (Figure 7); and (2) April 2002 through May 2004 at the same 19 sampling sites (Day *et al*., 2004) (Figure 8). The first water quality investigation occurred during drought conditions associated with an extreme La Niña event. This event, coupled with two tropical storms, resulted in higher than average salinities across Lake Pontchartrain, Lake Maurepas, and within Maurepas Swamp (Lane *et al*., 2003; Day *et al.,* 2004; Cho and Porrier, 2005). The second period of study occurred during a more typical year and provides a good comparison of conditions. Water quality stations were grouped by region, as shown in Table 4.

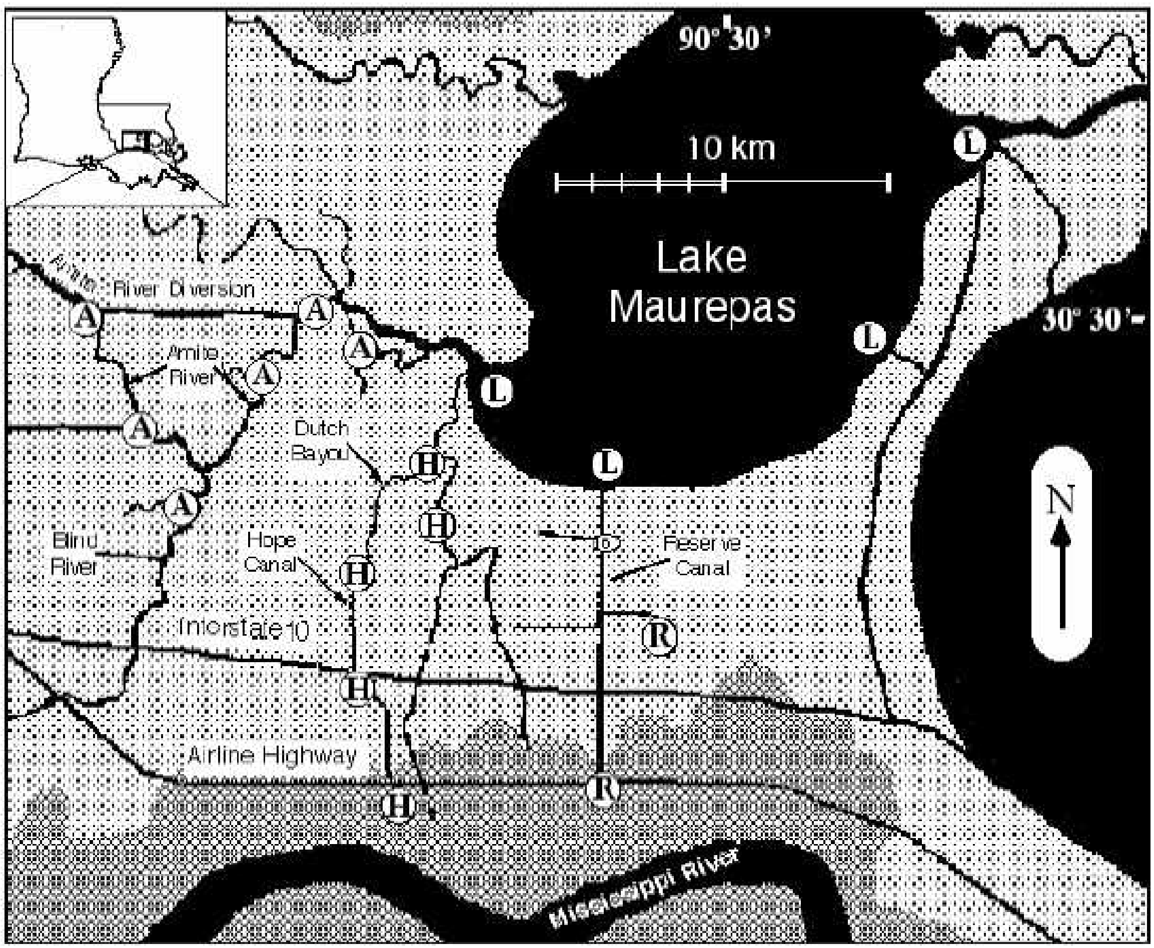

Figure 7. Lake (L), Amite (A), Hope (H) and Reserve (R) Water Quality Sampling Sites in 2000.
Source: Lane et al. (2003)

[1] Only results through October 2000 are presented.

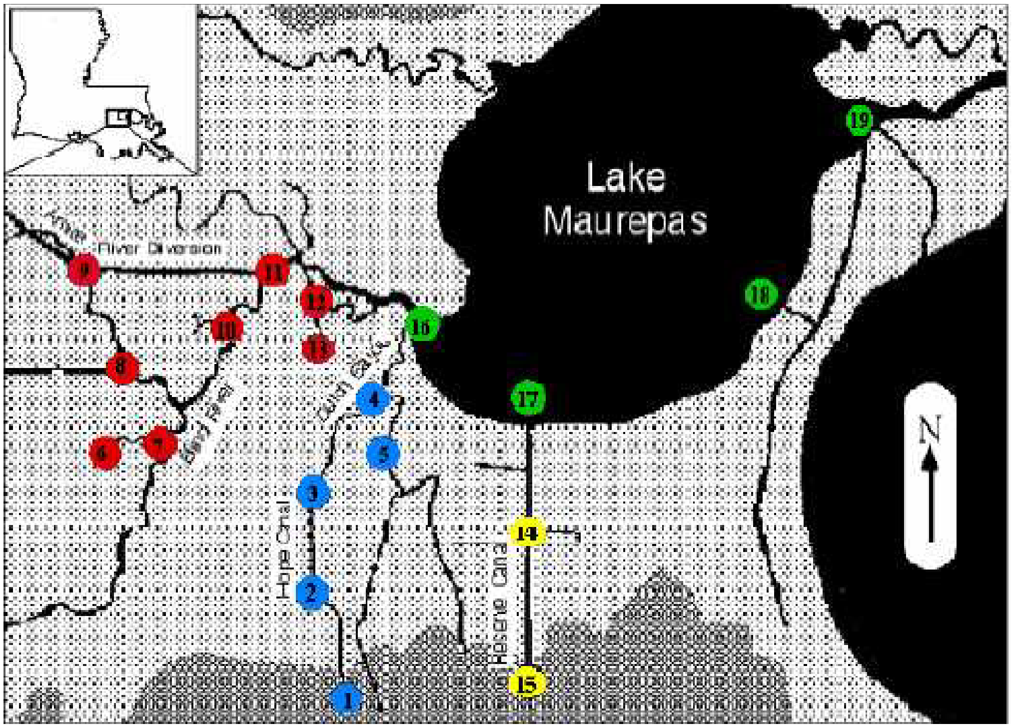

Figure 8. Water Quality Sampling Stations Sampled Monthly from April, 2002, to May, 2003. Lake (L) is Green; Reserve Canal (R) is Yellow; Hope Canal (H) System is Blue; Amite and Blind River (A) are Red. ***Source: Day et al. (2004).***

Table 4. Maurepas Region Water Quality Station Groupings.

Region	**Stations (see Figures 6 and 7)**
Amite/Blind River (A)	6 – 13
Hope Canal/Dutch Bayou (H)	1 - 5
Reserve Canal (R)	14-15
Lake Maurepas (L)	16-19

Water quality results from both publications cited above were synthesized and reported by Day *et al*. (2004). The following is a summary of this report's water quality findings.

Nitrogen

Nitrate ranged from below detection level (0.01 mg-N L^{-1}) to 0.32 mg-N L^{-1}. The mean of all measurements was 0.09 mg-N L^{-1}. The highest observed concentration was during the 2000 drought in the Amite/Blind River and Lake regions with means of 0.15 and 0.25 mg-N L^{-1}, respectively. These highest nitrate concentrations are still considerably lower than observed Mississippi River water concentrations (0.75 to 2.0 mg-N L^{-1}). In 2002 – 2003 ammonium concentrations was the dominant form of dissolved inorganic nitrogen (DIN), reaching mean concentrations of 0.9 mg-N L^{-1} in Lake and Reserve regions and high concentrations also in the vicinity of the I-55 bridge, presumably from runoff events originating from developed areas. Throughout the study ammonium ranged from below detection (0.02 mg-N L^{-1}) to a high of 1.2 mg-N L^{-1} and averaged 0.40 mg-N L^{-1}. In contrast, Mississippi River ammonium concentrations are generally below 0.1 mg-N L^{-1} (Lane *et al.*, 1999). Total nitrogen (TN) concentrations in the study area ranged from 0.18 to 1.75 mg-N L^{-1} and averaged 0.71 mg-N L^{-1}. Average TN concentrations were close and consistent across the region.

Day *et al.* (2004) note the contrast between TN:DIN and NO_3:NH_4 ratios in the study area among the drought and typical years within the study period. During typical rainfall conditions, approximately half of the TN is DIN and this is usually dominated by ammonium. During drought conditions, the majority of TN is composed of complex organic forms, such as humic substances, tannins, and phytoplankton.

Phosphorus
Phosphate concentrations ranged from below detection up to 411 µg-P L^{-1} with an average of 82 µg-P L^{-1}. Highest phosphate and total phosphorus (TP) concentrations were found in the vicinity of Airline Highway on Hope Canal where TP ranged from 12 to 1,077 µg-P L^{-1}, averaging 203 µg-P L^{-1}.

Silicate
Silicate (Si) concentrations ranged from 0.18 to 20.77 mg-Si L^{-1} and averaged 8.20 mg-Si L^{-1}. Highest concentrations were consistently observed in the Hope and Reserve Canals. Lake Maurepas concentrations were typically below 5.0 mg-Si L^{-1} and appear to be negatively correlated with salinity, which increased dramatically in the lake between May and September, 2002.

Nutrient Ratios
N:P ratios of 16:1 and greater were observed to be confined to the vicinity of the Amite and Blind Rivers. These rivers are influenced by development within their watersheds to the west. Si:N ratios were not observed to fall below 1:1. The low N:P and high Si:N ratios suggest that the study area is predominantly nitrogen limited.

Salinity
Salinity ranges from 0 to 3.3 psu and averaged 0.3 psu for the entire study area. These values are an order of magnitude lower than those observed during the drought conditions of 2000. The highest salinities were consistently measured on the eastern side of Lake Maurepas where Pass Manchac connects the lake to Lake Pontchartrain. The swamp was fresh for the entire period, and the Amite River salinities were lowest during spring and summer due to increased river flow during this period.

Suspended Sediment
Total suspended sediment (TSS) concentrations ranged from 1 to 58 mg L^{-1} and averaged 15 mg L^{-1}. These values were similar to those observed during the drought of 2000. Stations in Lake Maurepas had the highest TSS concentrations and the greatest variability in monthly observations. This is likely due to resuspension of bottom sediments during wind and storm

events. All TSS concentrations are considerably lower than those in the Mississippi River which range between 100 and 300 mg L^{-1}.

Chlorophyll a
Chlorophyll *a* ranged from 1 to 81 ppb (μg L^{-1}) and averaged 16 ppb. The highest observations occurred in the spring time in all regions except the lake. Lake Maurepas chlorophyll *a* concentrations typically averaged around 5 ppb and rarely exceeded 10 ppb.

The data are consistent with a common hypothesis that the Maurepas Swamp is generally nutrient limited and sediment starved. Lake Maurepas study locations were limited to shoreline areas, so whole-lake characteristics remain somewhat under evaluated. The results of the 2000 – 2003 surveys suggest that Lake Maurepas also exhibits poor light attenuation, presumably due to the significance of sediment resuspension. With poor light penetration, water column and benthic primary production is significantly limited and this is reflected in the chlorophyll *a* data.

No data associated with water column dissolved oxygen, primary productivity, or overall system metabolism have been reviewed.

2.2.3 Chemical Contaminants
The Mississippi River system traverses one of the most industrialized corridors in the world, draining 41% of the contiguous United States. Thus, there is likelihood that increased toxic contaminant loads, both historical and current, exist in both surface water and sediment beds of the river (USGS, 2001).

Sources of toxic contaminants to the water column include inputs from rivers such as the Ohio and Missouri, as well as other point and nonpoint sources such as effluent discharge and urban runoff, agricultural runoff, resuspension of sediments, and atmospheric depositions. The Maurepas Swamp study area is located in a highly industrial corridor of Louisiana, between Baton Rouge and New Orleans, where a large amount of chemical contaminants may be potentially released both directly and indirectly into the Mississippi River. The following sections discuss, in general, potential contaminants in three media: surface water, sediments, and fish tissue. More specific contaminant data were used in a screening-level ecological risk evaluation, which is presented in Appendix A.

2.2.3.1 Surface Water
The major direct contaminant inputs to surface water of the Mississippi River include various organic chemicals, pesticides, and inorganic contaminants (metals), which are discussed in the following sections.

Metals
Heavy metals in the Mississippi River originate from either natural processes or anthropogenic activities. Natural erosion and weathering of crustal materials occur over long periods of time and the amount of heavy metals released is generally small. However, the potential for contamination is increased when mining exposes metal-bearing ores. A significant amount of lead mining occurs in southeast Missouri adjacent to the Mississippi River downriver of St.

Louis (Meade, 1995). Furthermore cadmium, chromium, copper, lead, and mercury are used extensively in industries along the Mississippi River.

Data collected by USGS during 1991 and 1992 over a 2,900 km reach of the Mississippi River from Minneapolis, Minnesota to Belle Chasse, Louisiana indicate that the concentrations of toxic heavy metals dissolved in the water column were well below EPA guidelines for drinking water and criteria that supports aquatic life (Meade, 1995). The largest concentrations of heavy metals were measured downstream from tributaries such as the Des Moines, Illinois, and Missouri Rivers and near large metropolitan and industrial areas such as St. Louis, Missouri, Vicksburg, Mississippi, and south of Baton Rouge, Louisiana. Farther downstream of these areas, the concentrations of dissolved metals (especially mercury) appeared to decrease. This may be due to transformations from the inorganic form to the organic form or due to adsorption onto sediment rather than a decrease in the overall concentration of mercury in the river (Meade, 1995).

As of 2000, 26 facilities are currently included in LDEQ's Toxic Emission Data Inventory (TEDI) (LDEQ, 2000). Three of these facilities, all within the State of Louisiana, have reported mercury surface water discharges to the Toxic Release Inventory (TRI). The TRI facilities all discharge to the Mississippi River with the exception of PPG Industries which discharges to the Calcasieu River. Despite testing, none of the water bodies receiving mercury discharges have been found to require a fish consumption advisory (LDEQ, 2000). Table 5 summarizes the mercury releases to Louisiana surface water from 1987 to 1998.

Table 5. Mercury and Mercury Compounds Discharged Directly to Louisiana Surface Water. ***Source: LDEQ, 2000.***

	Annual Mercury Releases in Pounds												
Facility Name	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**Total**
Borden Chemicals & Plastics Operating L.P.	1	9	9	12	11	14	18	17	18	17	17	0	143
Pioneer Chlor-Alkali Co. Inc.	250	18	27	17	17	18	0	0	20	23	26	21	416
PPG Industries Inc.	12	15	0	12	11	24	10	5	4	22	0	0	115
Total	263	42	36	41	39	56	28	22	42	62	43	21	695

Pesticides

The Mississippi River Basin contains the largest and most intensely farmed region in the country (Meade, 1995). To increase crop yields, various pesticides are used to protect crops against weeds, insects, and other pests. Runoff of these pesticides to the Mississippi River presents potential impacts on the aquatic life and people who use the basin as a drinking water source. The majority of pesticides in the Mississippi River Basin are herbicides used for weed control. The most heavily applied are atrazine, alachlor, and metolachlor which are used in the production of corn and soybeans.

Pesticide loads in the Mississippi River were estimated at four stations along the Mississippi River based on data collected between April 1991 and March 1992 (Meade, 1995). The major pesticides in surface water include atrazine and its breakdown components, alachlor, cyanazine, and metolachlor. Estimated pesticide loads at the Baton Rouge station, which is located just north of the project area, are presented in Table 6.

Table 6. Estimated Pesticide Loads in the Mississippi River at Baton Rouge, LA (April 1991-March 1992). ***Source: Meade 1995.***

Pesticide	Load (kg)
Alachlor	33,700
Atrazine	321,000
Desethylatrazine	41,500
Desisopropylatrazine	3,200
Atrazine sum	365,700
Butylate	-
Carbaryl	-
Carbofuran	-
Chlorpyrifos	-
Cyanazine	127,000
Diazinon	-
Dieldrin	-
EPTC	-
Fonofos	-
Metolachlor	123,000
Metribuzin	6,810
Prometon	-
Propazine	-
Propachlor	-
Pendimethalin	-
Simazine	12,500
Trifluralin	-

\- no load estimate

Organic Contaminants

Sources of organic contaminants to the Mississippi River include industrial point sources (*e.g.*, PCBs and dioxins) and agricultural non-point source runoff (*e.g.*, pesticides). Once in the river, organic contaminants such as hexachlorobenzene and PCBs, are most concentrated in fractions of the sediment that contain the most organic carbon. Data from LDEQ from January of 1995 to October 2000 indicated that relatively few organic compounds were actually present at detectable concentrations in the water column. When these compounds did occur they were generally at concentrations of 1.0 µg/L or less (LDEQ, 2001a). Organic compound data, collected from January 1995 to October 2000 at six sites along the Mississippi River in Louisiana, revealed that the majority of 118 compounds were below analytical detection limits in all water samples. Only nine compounds or classes of compounds showed one or more detections. Criteria for drinking water were exceeded a total of five times: once for benzene at Lake Providence (located in the far northeastern corner of the State); twice for 1,2-dichloroethane (EDC) at Belle Chase (south of New Orleans) and twice for EDC at Pointe a la Hache (located downstream of New Orleans and Belle Chase on the Mississippi delta) (Table 7). No acute or chronic aquatic life criteria were exceeded in samples collected during this 5-year time period (LDEQ, 2001a).

LDEQ collected and analyzed water samples for PCBs and 2,3,7,8-Tetrachlorodibenzo-p-dioxin (TCDD) from four stations along the Mississippi River in 2001 (Piehler, 2002). Results from ambient river water showed no PCB or TCDD values detected above applicable standards.

Table 7. Organic Compounds Detected in Water Samples from Six Sites along the Mississippi River from January 1995 through October 2000. ***Source: LDEQ, 2001a***

Compound or Group	Number of Detections	Number of Criteria Exceedances
Phthalates	87	No criteria
Methylene chloride	7	0
1,2-dicloroethane (EDC)	4	4
Toluene	4	0
Benzene	1	1
Ethylbenzene	1	0
Pyrene	1	0
Chloroform	1	0
1,1,1-trichloroethane	1	0
Totals	107	5

2.2.3.2 Sediment

Sediment particles in the Mississippi River range in size from the very finest clays or colloids to coarse sand and gravel. Different sizes of particles are found in suspension and on the river bed. The interactions between these sediments are complex and variable: part of the suspended-sediment load interacts with the channel bed and part of it is independent from any such interaction. Sediments are typically stored in the channel bed during low discharge periods (<14,000 m^3/sec) and fine-grained particles are remobilized as suspended sediment during high discharge stages (>20,000 m^3/sec) (Demas and Curwick, 1988; Mossa, 1996).

Suspended sediment concentrations in the Mississippi River have been decreasing since the 1950s due to dam/reservoir construction and erosion-sensitive agricultural practices (Meade, 1995). Eventually, around 200 million metric tons of suspended sediment is discharged yearly to the Gulf of Mexico (USGS, 2001). These fine particles play the largest role in the transport and storage of toxic contaminants (Meade, 1995). Organic contaminants such as PCBs and some inorganic metals, such as lead, are more likely to adhere to sediment particles than to remain in the dissolved phase. Once adsorbed, these sediment particles may be transported downriver and eventually settle out onto the river bed.

Metals
A USGS survey from 1987 to 1992 sampled 12 stations along the Mississippi River and determined that concentrations of lead, cadmium, chromium, and copper were greater in the colloidal fraction than in the silt fraction of suspended sediments and decreased downriver (Meade, 1995). Trefry *et al*. (1985) indicate that inputs of lead to the Gulf of Mexico from the Mississippi River have declined by 40% since the 1970s. More than 90% of lead in the river is associated with suspended sediments in the inorganic form (Trefry *et al*., 1985).

Most of the mercury in the sediment phases is residual, likely as mercury sulfides, and the remainder is associated with the organic matter in suspension (Meade, 1995). According to the USGS survey, the percentage of mercury in the organic phase of the silt increased downriver of Thebes, Illinois (Meade, 1995). This has toxicological implications for humans and wildlife that absorb organic forms of mercury 14 times more readily than inorganic forms (Task Group on Metal Accumulation, 1973).

Organic Contaminants
Because organic contaminants are not water soluble, they often associate with sediment or are ingested by organisms and enter the food chain. Many organic contaminants are most concentrated in the fractions of the sediment that contain the most organic carbon. Contaminant data from 1987-1992 collected by USGS revealed that concentrations of hexachlorobenzene in sediments increased in the Lower Mississippi River between St. Francisville and Belle Chasse, LA. This may be due to the large number of halogenated hydrocarbon manufacturing industries along this part of the river (Meade, 1995).

In 2001, LDEQ collected sediment data for dioxins and PCBs from four stations along the Mississippi River in Louisiana. Both dioxins and PCBs were detected in all samples. However, only one sediment sample at Buras (near the Mississippi delta) contained elevated concentrations of the most toxic dioxins, 2,3,7,8-TCDD and 1,2,3,7,8-PeCDD (0.587 pg/g and 0.434 pg/g, respectively) (Piehler, 2002). The number of PCB congeners and the concentration of each individual homologue detected generally increased with distance downstream of Lake Maurepas. The concentration of PCB congeners in sediments ranged from 0.005 pg/g (PCB 77) at St. Francisville (north of Lake Maurepas) to 0.217 pg/g (PCB 118) at Buras (south of Lake Maurepas). The most toxic PCB homologue (PCB 126) was not detected in any sample.

Although the use and disposal of PCBs is no longer prevalent, the repeated deposition and resuspension of contaminated silt has resulted in a partial homogenization of PCB concentrations along the river. According to the USGS survey from 1987-1992, PCBs were detected in almost every sample analyzed (Meade, 1995). Some of the largest inputs of PCBs to the Lower Mississippi River appeared to be from the Ohio River, which confluences the Mississippi River, just south of Thebes, Illinois.

Polycyclic Aromatic Hydrocarbons (PAHs) were analyzed in sediments from the Lake Pontchartrain Basin, including Lake Maurepas, Lake Pontchartrain, and Lake Borgne. Results were included in the *Sediment Database and Geochemical Assessment of Lake Pontchartrain Basin* (Manheim and Hayes, 2002). Perylene is a common breakdown product of natural organic matter and was found in highest concentrations (up to 541 ppb) in sediments in Lake Maurepas (Figure 9). This may be due to the many swamps and marshes which surround the lake. On the other hand, pyrene is an anthropogenic PAH found mainly along the New Orleans shorefront (Figure 10) in close proximity of sources of urban waste products (Manheim and Hayes, 2002).

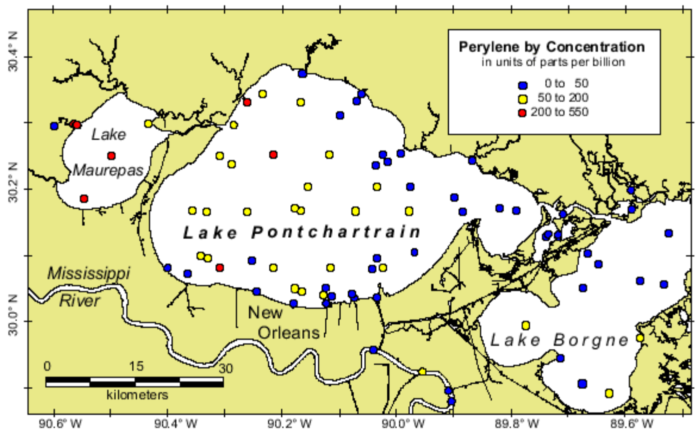

Figure 9. Perylene Concentrations in the Lake Pontchartrain Basin.

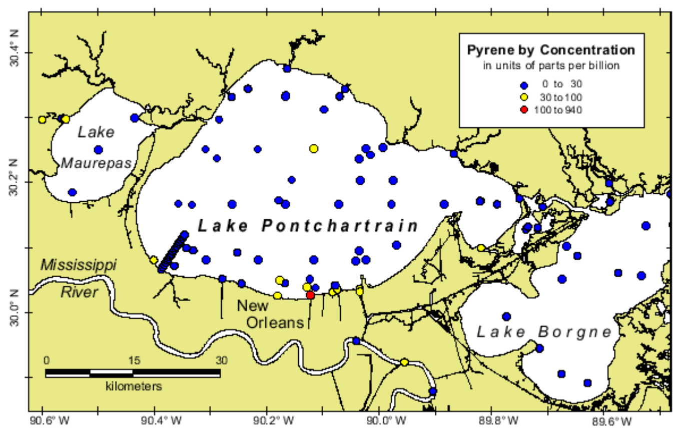

Figure 10. Pyrene Concentrations in the Lake Pontchartrain Basin.

2.2.3.3 Fish

Contaminant loads, particularly those in sediment, are of concern because of the potential for trophic transfer from producers or primary consumers (*e.g.*, benthic invertebrates) to higher-level consumers such as birds and mammals, including humans. As contaminants become incorporated into benthic habitats, they may be taken up by plants and benthic animals via contact with or the ingestion of contaminated substrates. The contaminants retained within the tissues of these organisms may be moved to other components of the ecosystem when higher-level consumers feed on the benthos. This trophic transfer through the marine food web may result in contaminant biomagnification as contaminants become more concentrated at higher trophic levels. Biomagnification has important human health implications because humans tend to consume organisms from higher trophic levels that are more likely to have high concentrations of contaminants (Battelle, 2004).

Due to the presence of contaminants found in fish tissue, fish consumption advisories have been issued at many sites along the Mississippi River. These warnings are based on high concentrations of contaminants in fish, such as PCBs, chlordane, hexachlorobenzene, and mercury, which are also generally found associated with the suspended sediments.

Metals
A study by USGS showed that, except for mercury and selenium, concentrations of metals in fish tissue along the Mississippi River were relatively low and stable or declining relative to past levels (USGS, 2002).

The State of Louisiana regularly samples fish tissue for concentrations of mercury because levels have been found to exceed the US Food and Drug Administration (FDA) action level of 1 ppm in several waterbodies throughout the State. As of June 2001, the State of Louisiana has issued 19 fish consumption advisories pertaining to mercury concentrations in fish tissue in various waterbodies or portions of waterbodies throughout the State (LDEQ, 2001b). One such advisory occurs along the entire 25 mile portion of the Blind River, which runs northeast through Maurepas Swamp into Lake Maurepas (Attachment 1). However, based on six samples of largemouth bass and one sample of freshwater drum that were collected from Lake Maurepas in 2003, concentrations of mercury in fish were not high enough to warrant an advisory (Attachment 2). In addition, despite testing, the Mississippi River has not been found to require a fish consumption advisory (LDEQ, 2001b).

Organic Contaminants
A USGS survey from 1987-1992 revealed that the highest fish tissue concentrations of hexachlorobenzene along the Mississippi River were located at Luling, LA, just south of Lake Pontchartrain (Meade, 1995). Along the entire Mississippi River, large numbers of external lesions were observed on various species of fish, including frayed and hemorrhagic fins and frayed gills (USGS, 2002).

In 2001 several species of fish, including bass, catfish, and crappie, were collected from four stations along the Mississippi River in Louisiana by LDEQ. Two stations, one at St. Francisville and one at Donaldsonville are located north of the Maurepas study area, such that contaminants from these areas could potentially reach Maurepas Swamp after completion of the diversion project. Tissue was analyzed for dioxins and PCBs, which were detected in all samples (Piehler, 2002). Concentrations of the most toxic dioxin, 2,3,7,8-TCDD, ranged from 0.1 to 0.9 pg/g at St. Francisville, located north of Baton Rouge; and from 0.07 to 0.53 pg/g at Donaldsonville, located just before the site of the proposed freshwater diversion (Table 8). Although there are no aquatic life standards for dioxins, results reveal no fish exceeded the federal standard of 50 pg/g of 2,3,7,8-TCDD for human consumption of fish tissue. In addition, none of the concentrations of PCBs in fish tissue exceeded the 2 ppm action level for total PCBs (Piehler, 2002).

Table 8. Concentrations of 2,3,7,8-TCDD (pg/g) in Mississippi River Fish. ***Source: Piehler, 2002.***

Location	Species	Result
St. Francisville	Flathead catfish	0.131
	Flathead catfish	0.231
	Flathead catfish	0.177
	White bass	0.85
	White bass	0.885
	White bass	0.746
Donaldsonville	Flathead catfish	0.492
	Flathead catfish	0.429
	Flathead catfish	0.22
	Flathead catfish	0.328
	Freshwater drum	0.068
	Big mouth buffalo	0.381
	Striped bass	0.53
	White crappie	0.199
	White bass	0.414

Pesticides
Although many currently used pesticides have been frequently detected in Mississippi River water (Meade, 1995), most of these pesticides are not believed to bioaccumulate into fish tissue. All fish tissue samples that were analyzed from Luling, LA by USGS (2002), however, contained some historical DDx compounds (*i.e.*, DDD, DDE, and/or DDT); chlordane, dieldrin, and nonachlor were also found in several samples. Specific data is provided in Attachment A.

2.2.4 Land Resources

Prehistoric History
The region surrounding Lakes Pontchartrain and Maurepas was formed 20,000 years ago in the Pleistocene Epoch, during the northward retreat of the continental glaciers. Sea level at that time was approximately 91 meters lower than today and as the glaciers began to retreat and melt, the sea level rose, flooding incised stream channels along the continental shelf. The retreating glacier also reworked and deposited sediments as it moved northward, leaving a collection of barrier landforms. Sediments transported by the Mississippi River eventually filled in the barriers, creating the boundaries of Lake Pontchartrain, Lake Borgne, and Lake Maurepas (Penland *et al.,* 2002a).

Soil/Sediment Quality and Subsidence
Coastal Louisiana has the highest land subsidence rate of anywhere in the United States, estimated at 1 cm annually, although the rate is quite variable along the coast. The southeastern coast in particular is subsiding more quickly than other areas, partially due to the thick layers of recently deposited sediments, which are more disposed to compaction than thin deposits (Gosselink *et al*., 1998). Although coastal Louisiana is more prone than other areas to subsidence and land loss, human activities have exacerbated the problem. The efforts beginning in the 1920s to control Mississippi River flooding by erecting levees and other control structures

have prevented the river from occasionally overflowing its banks and replenishing the surrounding land with nutrients and sediments. Research has indicated that oil and gas extraction activities may also intensify subsidence, due to the removal of massive quantities of fluids causing decreases in subterranean pressure and increasing stress on the lower layers. The drainage and clearing of wetland areas to make way for agricultural activities is another anthropogenic cause of subsidence.

Maurepas Swamp is also experiencing significant rates of subsidence due to sediment and nutrient starvation. Increased saltwater intrusions to the swamp, has resulted in deleterious conditions and subsequent decline in the swamp from the die-off of critical species such as the cypress. Erosion along the immediate coastline of the lake has also affected swamp decline at the local scale. A comprehensive soils and sediments characterization study was reported by Shaffer *et al*. (2003) in an effort to investigate the potential effects of the proposed diversion on the rate of local wetland subsidence. In this study, twenty study sites were selected to characterize swamp soils across a variety of different hydrological regimes. Figure 11 shows the locations of these sites. The sampling site names and their locations within the swamp complex are indicated in Table 9. Findings indicate that sediment quality, as indicated by bulk density, varies across the study area due to the heterogeneous influence of abiotic controls. Wetland subsidence could not be measured directly by feldspar marker zones due to the inability of the swamp soils to support them; Shaffer *et al*. (2003) failed to find any 2001 horizons following two tropical storms in 2002. Sediment elevation was measured by sediment elevation table (SET) methods. Net subsidence of 5.8 mm (s.e. ±5.2 mm) was reported at Intermediate sites (located intermediately between I-55 and Lake Maurepas). Net accretion of 12.0 mm (s.e. ±6 mm) was measured at marsh sites.

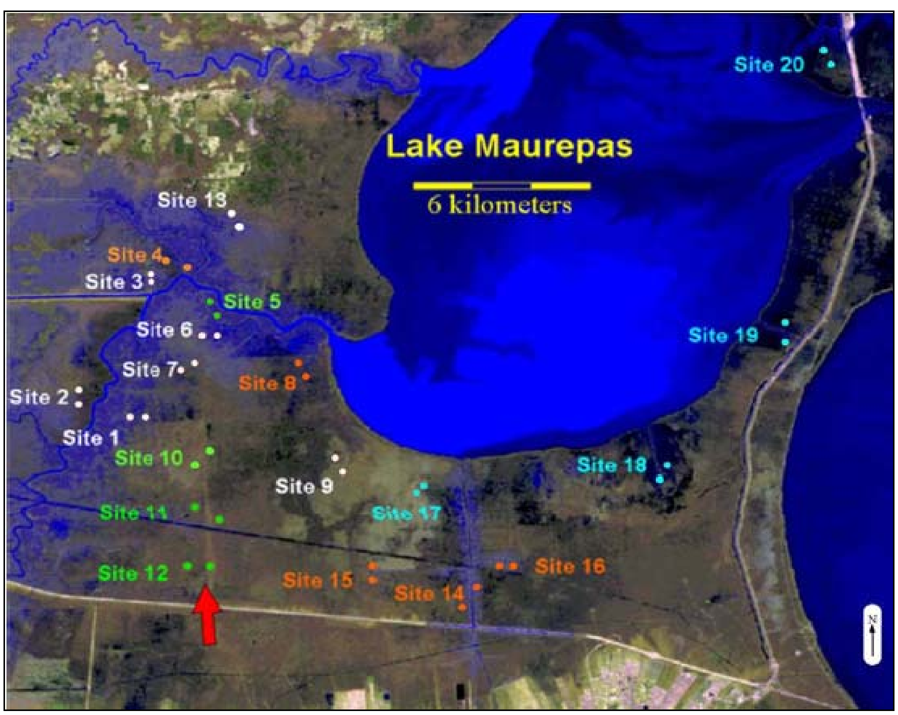

Figure 11. Locations and Names of Study Sites Associated with Shaffer *et al*. (2003).

Table 9. Summary of Sampling Sites in Shaffer *et al*. (2003).

Swamp Region	Site Number	Site Name
Interior	1	Red Top
	2	Cher Bayou
	3	Blind River/Amite Flood Relief Diversion Canal
	6	Potato Run
	7	Peter's Run
	9	Interior Mississippi Bayou
	13	Black Lake
Throughput	10	Tent Bayou/Hope Canal
	11	Middle of Hope Canal
	12	Top of Hope Canal
Intermediate	4	Lil' Chene Blanc
	8	Dutch Bayou
	14	Reserve Relief Canal, near I-55
	15	Reserve Relief Canal, west
	16	Reserve Relief Canal, east
Lake	17	Reserve Relief Canal, near Lake Maurepas
	18	Tobe Canal
	19	Ruddock
	20	Jones Island

A network of 20 wells was also placed throughout the study area to monitor salinity, pH, bulk density, redox potential (Eh); and concentrations of sulfide, nitrate, ammonia, and other elements. These measurements provide important baseline data that help explain the current and future health of this swamp ecosystem. Well salinities in the Lake sites were higher than the other sites with a mean of 4.15 psu during the drought year (2000) and a mean of 2.19 and 1.5 psu in 2001 and 2002, respectively. Well salinities were found to decrease with increasing distance from Lake Maurepas in areas along the lake's south coast toward Pass Manchac, but not within areas along Reserve Relief Canal and Blind River.

Bulk density of soils is an indication of the ratio between inorganic (*i.e.*, silt, clay, sand) and organic (*i.e.*, decomposing or decomposed plant matter) matter. Certain ranges of soil densities are necessary for different types of vegetation assemblages and their overall health. Bulk density also determines biochemical and physical properties of soils. In Maurepas Swamp bulk densities were found to range from a mean of 0.076 g cm^{-3} at interior sites to a mean of 0.103 g cm^{-3} at the Intermediate sites. The highest bulk densities were observed at Throughput sites (0.145 g cm^{-3}). The Lake sites had the lowest bulk densities (0.054 g cm^{-3}).

Wetland Loss
The loss of wetlands along coastal Louisiana has always been part of a natural evolutionary process involving the Mississippi and other rivers re-routing themselves over time, leaving the

delta lobes abandoned and sediment-starved. This process of land loss has, until recently, been balanced by land creation; where wetland is lost in one region, it is gained in another as the rivers shift their paths. However, recent research has shown that Louisiana's coastal wetlands are not replenishing themselves at the same rate as they are being lost, leading to a net loss of land along the Gulf of Mexico, particularly in the deltaic plain region. High subsidence rates along with comparatively low accretion rates and global sea level rise cause coastal Louisiana to lose approximately 62 km^2 of low-lying land every year (NOAA, 2003). Between 1978 and 2000, cumulative land loss along the entire Louisiana coast was estimated to be 1,704 km^2 (Barras *et al*., 2003). Like subsidence rates, land loss is felt in some regions more than others: Barataria basin (located just to the west of the birdfoot delta) loses approximately 29 km^2 of coastal land annually, while the Atchafalaya basin only loses about 0.25 km^2 (LCWCRTF, 1997). These large variations can be attributed to sediment thickness disparities, differences in river lobe patterns, vegetation type and salt water intrusion rates, and susceptibility to tidal surges, flooding, and strong winds.

Human activities have also played a large role in wetland loss along the Louisiana coast. The extensive levee systems erected in an attempt to protect agricultural land and cities has forced the Mississippi River to flow the way the people want it to, not the way it would naturally. Much of the sediment caught up in Mississippi River water is deposited off the continental shelf, leaving it unavailable to contribute to the building of new land. Dams constructed upriver and on important tributaries also act as sediment traps, preventing it from moving downstream toward the coast. Navigation, drainage, and mineral exploration canals around the edges of the coastline have altered water circulation patterns and increased salt water intrusion rates, effectively killing freshwater marshes before they can become established as salt marshes.

Shoreline erosion of Lake Maurepas has been measured by the USGS Coastal and Marine Geology Program since 1899. Transect research has shown that the average shoreline loss in Lake Maurepas between 1899 and 1995 was approximately 1 meter per year (Zganjar *et al*., 2002). The causes of this shoreline erosion are difficult to determine, although contributing factors may include storm surges, lack of sediment entering the area, and canal construction. Studies have found that the Maurepas Swamp area lost approximately 11.65 square kilometers of marsh habitat between 1932 and 1990, or 29% of its area (Penland *et al*., 2002b). Although this loss of swamp environment is not directly the cause for restoration planning, rates of erosion may be exacerbated by deteriorating conditions of the swamp due to nutrient and sediment starvation.

2.2.5 Biological Resources

The Maurepas Swamp area is typically categorized as a cypress-tupelo swamp and is dominated by trees, shrubs, and rooted herbaceous plants. Table 10 lists the flora species commonly found in the swamp area. In the southern section of Maurepas Swamp, alligator weed, smartweed, and arrow arum were found to be the most abundant herbaceous species (Shaffer *et al*., 2003). Research conducted by Shaffer *et al*. (2003) indicated that herbaceous species richness was highest in areas immediately south and east of Lake Maurepas and lowest in the areas surrounding the Hope Canal. They concluded that the number of herbaceous species in the Hope Canal area was likely related to the density of tree and shrub coverage and not related to nutrient availability.

Stem density was used as an indicator of tree abundance in the swamp. The greatest numbers of trees occurred at sites along the Hope Canal and the lowest numbers were found around Lake Maurepas. Approximately 25% of the trees along the Hope Canal and other canals in the swamp were water tupelo and 15% were found to be bald cypress. The remaining 60% of trees consisted of the other species listed in Table 10. Closer to Lake Maurepas, the dominant tree species became bald cypress, representing 60% of the trees present. Throughout the entire swamp, green ash and swamp red maple were the most abundant tree species and although water tupelo and bald cypress were present in less abundance, they did not much differ in abundance from each other (Shaffer *et al*., 2003). Between 2000 and 2002, the mortality of tree species other than bald cypress and water tupelo was found to be relatively high (~10%) in the areas surrounding Lake Maurepas and Pass Manchac. Water tupelo and bald cypress mortality rates near the lake and in other swamp areas were in the vicinity of 2-3%, with most of the die-off occurring in 2002 as a delayed result of drought conditions and salt water intrusion. Mortality rates since 2000 were lowest (< 1%) for those trees along the Hope Canal (Shaffer *et al*., 2003).

Shaffer *et al*. (2003) concluded that areas of the swamp dominated by herbaceous plants (around Lake Maurepas and in the interior areas of the swamp remote from freshwater exchange) were converting to marsh and open water, with the ultimate cause being the limited freshwater input entering those areas. The lack of freshwater is causing the trees at the sites close to Lake Maurepas to die primarily of salt stress, and trees at interior sites to succumb to nutrient deprivation. Because the Maurepas Swamp area is so continuously flooded, seed germination and recruitment is minimal, and therefore a new generation of vegetation is not establishing itself (Shaffer *et al*., 2003).

Table 11 lists the common wildlife species found in and around Lake Maurepas, Pass Manchac, and Lake Pontchartrain. For the Coast 2050 report, the status and trends of several important wildlife species populations in the Lake Pontchartrain and Pass Manchac regions were assessed. Numbers of brown shrimp are declining in both areas and white shrimp are declining in the southwestern area of Lake Pontchartrain. Populations of blue crab and largemouth bass have remained steady, as have channel catfish and red drum. Bald eagles have shown increasing or steady numbers in recent years, particularly in the southwestern Lake Pontchartrain area. Wading birds, in general, have been increasing in both Lake Pontchartrain areas and around Pass Manchac. Only migrant marsh birds have shown any sign of declining numbers in either of the two areas. Alligators have been increasing over the entire area and coastal mammals have demonstrated fairly steady numbers (LCWCRTF and the Wetlands Conservation and Restoration Authority, 1998).

Table 10. Common Vegetation Found in the Maurepas Swamp Area. ***Source: Shaffer et al., 2003***

Scientific Name	Common Name
Trees and Shrubs	
Cephalanthus occidentalis	Buttonbush
Fraxinus pennsylvanica	Green ash
Myrica cerifera	Southern wax myrtle
Nyssa aquatica	Water tupelo
Nyssa sylvatica var. *biflora*	Black gum
Quercus obtusa	Diamond oak
Salix nigra	Black willow
Sapium sebiferum	Chinese tallow
Taxodium distichum	Bald cypress
Herbaceous Plants	
Alternanthera philoxeroides	Alligator weed
Amaranthus australis	Pig weed
Apium lepiphyllum	Marsh parsley
Aster spp.	White and purple asters
Baccharis helimifolia	Eastern baccharis
Bacopa monnieri	Coastal water hyssop
Echinochloa walterii	Walter's millet
Eleocharis spp.	Spike rush
Galium tictorium	Marsh bedstraw
Hydrocotyle spp.	Dollar weed
Iris virginica	Blue flag
Ludwigia leptocarpa	False loostrife
Panicum dicotomiflorum	Fall panic grass
Panicum hemotomon	Maiden cane
Peltandra virginica	Arrow arum
Polygonum punctatum	Smartweed
Pontedaria chordata	Pickerel weed
Sable minor	Palmetto
Sagittaria lancifolia	Bulltongue
Vigna luteola	Deer pea

2.3 Future Conditions

The Maurepas Swamp diversion project will provide a source of nutrient and sediment-rich water from the Mississippi River to Maurepas Swamp via the existing Hope Canal. As described previously, Maurepas Swamp is among several wooded swamps in southern Louisiana that has been shown to be suffering from nutrient and sediment starvation (Shaffer *et al*., 2003; Day *et al*., 2004). The effects of this include subsidence and the inability for new growth to occur due to permanently flooded conditions. Additional effects of the cessation of periodic Mississippi

Table 11. Wildlife Species Commonly Found in and around Lake Maurepas, Pass Manchac, and Lake Pontchartrain. ***Source: Handley et al., 2002***

Common Names	
Wading Birds	**Shorebirds**
Great Blue Heron	Wilson's Phalarope
Little Blue Heron	Spotted Sandpiper
Great Egret	Pectoral Sandpiper
Snowy Egret	Least Sandpiper
Black-crowned Night-heron	Short-billed Dowitcher
Tricolored Heron	Western Sandpiper
White Ibis	Common Snipe
Clapper Rail	Solitary Sandpiper
White-faced Ibis	**Reptiles**
Least Bittern	American Alligator
American Bittern	**Mammals**
Virginia Rail	River Otter
Sora Rail	Muskrat
Common Moorhen	Mink
Waterfowl	Nutria
Canvasback	Northern Raccoon
Canada Goose	**Shellfish**
Snow Goose	Brackish Water Clam
Mallard	River Crayfish
Northern Pintail	Red Swamp Crayfish
Northern Shoveler	Blue Crab
Greater Scaup	White Shrimp
Lesser Scaup	Brown Shrimp
Bufflehead	**Marine and Freshwater Fish**
Red-breasted Merganser	Spotted Sea Trout
Redhead	Red Drum
Ruddy Duck*	Southern Flounder
Gadwall	Bay Anchovy
American Wigeon	Spot
Blue-winged Teal	Black Drum
Hooded Merganser	Atlantic Croaker
Mottled Duck	Southern Kingfish
Diving Birds	Sheepshead
Common Loon	Gizzard Shad
Horned Grebe	Largemouth Bass
Eared Grebe	Black Crapple
Double-created Cormorant	Bluegill

Table 11. Wildlife Species Commonly Found in and around Lake Maurepas, Pass Manchac, and Lake Pontchartrain. ***Source: Handley et al., 2002,*** **continued**

Common Names	
Diving Birds	**Marine and Freshwater Fish**
Anhinga	Blue Catfish
Pied-billed Grebe	Channel Catfish
Raptors	White Crappie
Bald Eagle*	Warmouth
Osprey*	Redear Sunfish
Peregrine Falcon*	Freshwater Drum
American Kestrel*	Spotted Sunfish
	Gulf Menhaden
	Gulf Kingfish

* indicates threatened or endangered status

River flooding into the Maurepas system are the greater propensity for saltwater intrusion via Pass Manchac, particularly during periods of drought.

The predictions of future conditions in the Maurepas study area are based on two scenarios. In the first scenario, no diversion of Mississippi River water is implemented. This is also called the "no action" alternative. Several reports reviewed have made estimates on what kinds of changes are likely in the Maurepas area if current trends continue. The second scenario is that of the implementation of a Mississippi River diversion through Hope Canal. Several reports and feasibility assessments reviewed to date have analyzed various discharge rates in terms of physical capabilities and capacities, net long-range benefits to the swamp ecosystem, and minimal impacts on Lake Maurepas water quality. The scenario that has been identified as optimal at this point is the Hope Canal diversion operating at an annual average of approximately 1,500 cfs. This section summarizes the anticipated conditions of water, land, and biological resources associated with the "no action" and 1,500 cfs diversion scenarios.

2.3.1 Water Resources

2.3.1.1 Hydrology

No Action
The "no action" alternative will likely result in increased loss of cypress/tupelo-dominated swamp habitat. This loss is expected to follow similar trends in habitat conversion as that experienced in eastern regions of Maurepas Swamp, in the vicinity of Pass Manchac and Jones Island (Shaffer *et al*., 2003; Gary Shaffer, personal communication). The loss of swamp elevation, and the associated vegetation, is expected to ultimately result in an increase of open water habitats. Areas of open water will be hydrologically different from wooded swamp and marsh habitats. Without the existence of swamp vegetation there is less physical resistance (surface roughness) to influence surface water movement. Therefore, as marginal areas of the swamp transition from cypress/tupelo swamp to marsh to open water environments, there is an

increased likelihood that tidal influence, and the transport of higher salinity water, may penetrate deeper into interior areas of the marsh. These interior regions, also experiencing the effects of continued subsidence, could be affected by salinity stress and, therefore, the process would be exacerbated. Subsequent erosion of former swamp land by turbulent energy embodied in Lake Maurepas and newly created open water environments would likely result in a larger, shallower lake which would certainly alter existing hydrodynamics of the system.

Proposed Diversion
Several potential diversion scenarios were analyzed in multiple studies (Kemp *et al*., 2001; Day *et al*., 2004). This report is focused on the diversion alternative that discharges an annual average of 1,500 cfs through the Hope Canal. One- and two-dimensional models were developed (Day *et al.*, 2004) to provide insight on potential fate and transport of water and constituents through the swamp and ultimately to Lake Maurepas.

The 1-D model (UNET; Kemp *et al*., 2001) was developed to examine the distribution of water through the study area for a fully-developed flow. This model was based on steady-state conditions and the study area was divided into a series of primary channels and swamp cells (Figure 12).

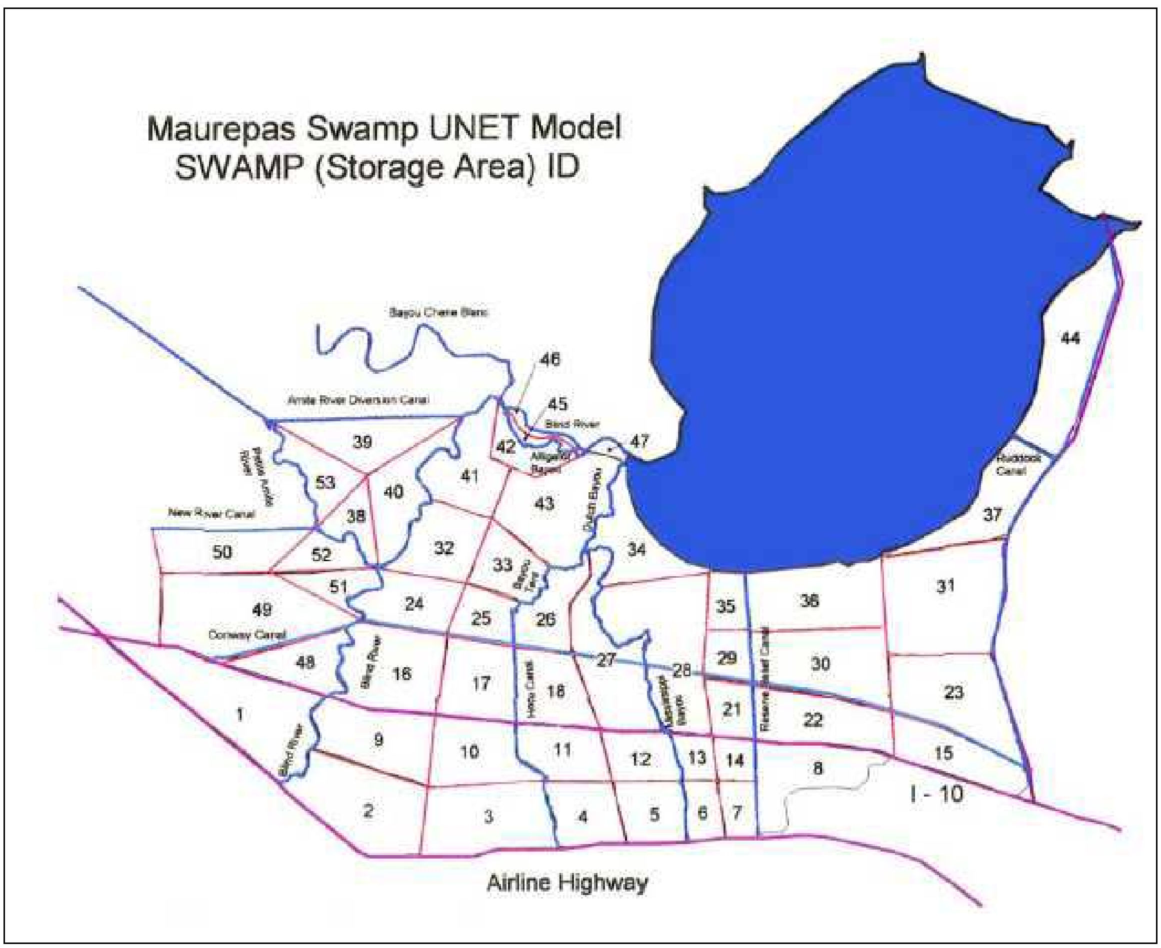

Figure 12. Spatial Arrangement of the Maurepas Swamp UNET Model Showing Swamp Model Cells, Canals, and Bayous.

Results of the UNET model predicted the following distribution of Hope Canal diversion water:

- Blind River System = 40%
- Tent/Dutch Bayou System = 53 %
- Reserve Canal = 7%

This UNET model did not apply evapotranspiration as a loss term for its hydrologic budget. Surface evaporation and transpiration through ground vegetation and tree canopies has the potential to influence swamp hydrologic budgets. However, based on an average annual potential evapotranspiration (PET) estimate of 9.4 cm m^{-1}, the resulting volumetric equivalent in Maurepas Swamp is approximately 137,616,000 m^3 which accounts for about 10% of the total annual diversion volume (1,339,501,061 m^3). This rate varies across seasons with times of net surplus (winter/spring) and deficits (summer/fall). This annual average loss of water to evapotranspiration may be significant enough to warrant further study.

In addition to UNET, a 2-D hydrodynamic model (TABS-MD) was developed to provide a more detailed analysis of hydrologic pathways and the transport of constituents in the water column (Day *et al*., 2004). This model is discussed in detail in Section 2.2.2.1. The results of this model suggest the following distributions of water through the swamp and to the receiving waters of Lake Maurepas based on an annual average discharge of 1,500 cfs:

- Blind River System = 53%
- Lake (not Blind River or Reserve Canal) = 16%
- Reserve Canal = 31%

A graphical representation of flow vectors through the swamp and to the lake based on the TABS-MD model results among three flow scenarios is shown in Figure 13.

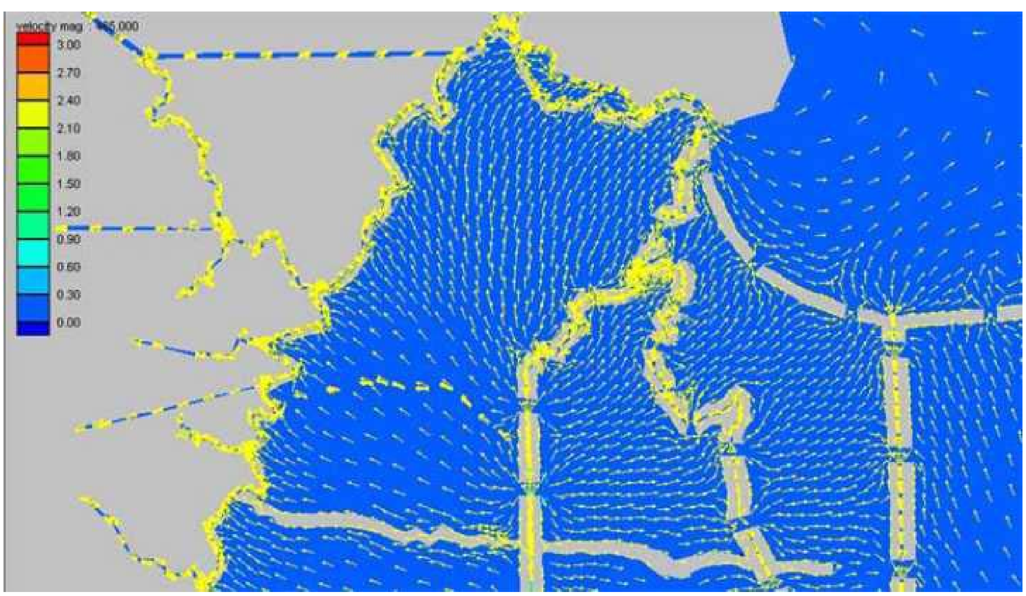

Figure 13. TABS-MS Predicted Flow Directions and Velocities for Maurepas Swamp Based On 1,500 CFS Diversion Discharge Rate. ***Source: Day et al. (2004).***

According to the CWPPRA Environmental Workgroup (2001), on average, Lake Maurepas receives <3,400 cfs of freshwater inflow (including the Amite/Comite system, the Tickfaw, and the Natalbany). A 1,500 cfs diversion capable of running year-round would translate into a 45% increase in average freshwater discharge to the lake. The summer-to-autumn low flow periods represent the time of most severe salinity problems since the majority of existing freshwater inputs come during spring runoff. The diversion running during these times would be contributing proportionately more freshwater inflows to the lake, and would thus have significant freshening capabilities (see Section 2.3.1.2).

The average volume of Lake Maurepas is about 658,359,829 m^3 (533,741 acre-feet) (CWPPRA Environmental Workgroup, 2001). Current freshwater replacement time (based on an annual average discharge rate of 3,400 cfs) is approximately 2.64 months. A 1,500 cfs diversion running year-round would contribute a maximum of approximately 1,339,501,061 m^3 (1,085,951acre-feet) of fresh water, which would effectively reduce the lake's freshwater replacement time to 1.83 months.

2.3.1.2 Temperature

The potential for changes in swamp and lake water temperatures due to the diversion is an important consideration with regard to critical thresholds associated with fish reproduction and habitat, rates of system respiration, and productivity. A comparison between mean water temperatures in the Mississippi River (LUMCON) and at Pass Manchac (USGS) from March 2004 through February 2005 is shown in Figure 14. Table 12 provides the actual monthly mean values and difference in temperature between the two water bodies. Compared to Lake Maurepas, Mississippi River water temperatures are typically cooler in the summer and similar, if not warmer, in the winter months.

A review of previous diversion studies in this region (*e.g.*, Bonnet Carré) has not resulted in any appreciable information about potential temperature changes due to diversion plumes in receiving waters. The only exception is for the Bonnet Carré diversion where the Reanalysis Team reported that during an experimental release in May 1994, cooler Mississippi River water flowed along the bottom of the warmer Lake Pontchartrain receiving waters out to a point in the lake where physical processes allowed for uniform mixing. The USGS (1996) reported that the diversion plume has distinct boundaries and extended out between four and five miles from the point of discharge along the shore. A four degree difference between river and lake water temperatures was reported. This caused the river water to move underneath the lake water. As the water temperatures equilibrated, mixing began." This temperature difference did result in limiting vertical mixing; however, the extent and nature of this thermocline (time and space) is not reported to an appreciable extent.

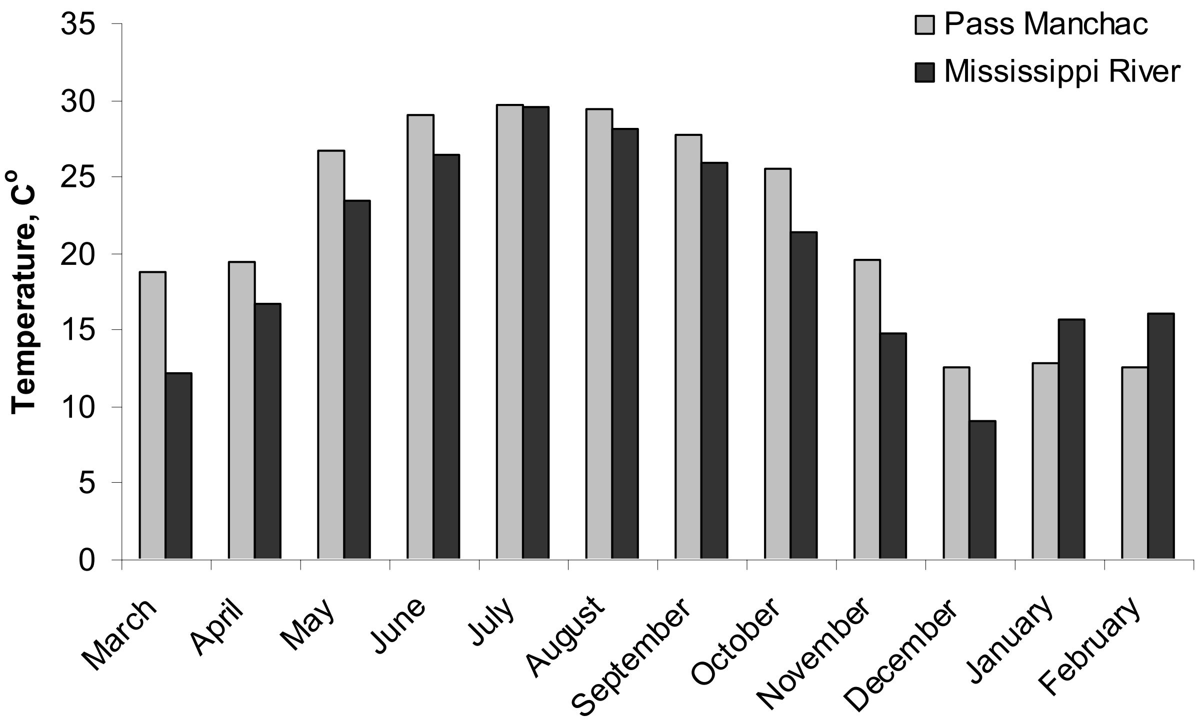

Figure 14. Comparison of water temperature between Pass Manchac (USGS Station No. 301748090200900; Pass Manchac at Turtle Cove near Ponchatoula, LA) and the Mississippi River (LUMCON Station). Values are monthly means from March 2004 through February 2005.

The potential for the occurrence of an isolated diversion plume in Lake Maurepas requires further study on the potential influence of Maurepas Swamp on temperatures of introduced Mississippi River water. Water residence times, flow directions, evapotranspiration, depth, and canopy are all important factors with regard to temperature effects to both the swamp and the receiving waters of the lake. The spatial degree of potential influence would likely be similar to that of modeled salinities and conservative tracers reported by Day *et al.* (2004) (Section 4). In these model scenarios, a 1,500 cfs diversion lowers salinities throughout the western sections of the swamp and along the southwestern third of the lake. The maximum spatial extent of potential temperature effects of the proposed diversion should be consistent with the simulated conservative tracer and salinity plumes reported by Day *et al.* (2004); however, specific meteorological conditions will govern the characteristics of any temperature plumes associated with the diversion.

Table 12. **Monthly mean water temperatures (°C) for Pass Manchac (USGS Station No. 301748090200900; Pass Manchac at Turtle Cove near Ponchatoula, LA) and the Mississippi River (LUMCON Station) for the period of March 2004 through February 2005.**

Year	Month	Pass Manchac (°C)	Mississippi River (°C)	Δ T°
2004	March	18.8	12.2	6.6
	April	19.5	16.8	2.7
	May	26.7	23.4	3.3
	June	29.1	26.5	2.6
	July	29.7	29.5	0.2
	August	29.5	28.2	1.3
	September	27.8	25.9	1.9
	October	25.5	21.4	4.1
	November	19.6	14.7	4.9
	December	12.6	9.1	3.5
2005	January	12.8	15.7	-2.8
	February	12.5	16.1	-3.6

It is probable that the potential degree of thermal stratification in the system, if it occurs, would vary seasonally. Furthermore, because of the relative shallowness of Lake Maurepas, wind-driven mixing would likely be more frequent compared to this process in Lake Pontchartrain. Predicting the effect of temperature on the coupled swamp-lake system requires the collection of site-specific data and conducting model simulations. Previous and existing water quality monitoring efforts as summarized by Day *et al.* (2004), Schaffer *et al.* (2003), and described by Bob Jacobsen ([URS Corp.], personal communication) coupled with future model development could provide sufficient information on the potential for significant thermal effects of the diversion. Model selection should be based on previous and existing efforts to assess hydrologic characteristics of the swamp and lake environments.

The potential for effects from temperature change on system biota include changes in primary productivity, system metabolism, and faunal behavior (both foraging and reproductive). One specific area of interest is the potential thermal effect on the Gulf sturgeon (*Acipenser oxyrhinchus de sotoi*). Although information is limited on whether populations of the Gulf sturgeon presently inhabit the Mississippi River, the historical range of the species included this waterway and many others along the Gulf Coast between Louisiana and Florida's Suwannee River. In 2003, the Final Rule for Designation of Critical Habitat for the Gulf Sturgeon (50 CFR Part 226) designated parts of Lake Pontchartrain, Lake Borgne, and the Mississippi Sound (along with other freshwater, estuarine, and marine water bodies) as critical habitat for Gulf sturgeon. In addition, the Gulf sturgeon is known to occur in Lake Maurepas and its northern tributaries- the Amite and Tickfaw Rivers (Howard Rogilio, Louisiana Department of Wildlife and Fisheries, personal communication). It is not known whether the Gulf sturgeon occurs in the bayous and canals along the southern shore of Lake Maurepas.

There has been an extensive amount of research done on the life history of Gulf sturgeon and its sensitivity to water temperatures. The Gulf sturgeon spawning study described in Fox *et al*. (2000) reported that water temperatures where sturgeon eggs were collected ranged from 18.3 to 22.0°C (64.9 to 71.6°F). Chapman and Carr (1995) conducted laboratory experiments indicating that Gulf sturgeon eggs, embryos, and larvae were most likely to survive in water temperatures between 15 and 20°C (59 to 68°F), with high mortality evident at temperatures of 25°C (77°F) and above. The most embryos (73.3%) survived at 15°C. Marchant and Shutters (1996) documented Gulf sturgeon eggs in water temperatures ranging from 18.3 to 20.0°C (64.9 to 68°F). Sulak and Clugston (1998) found that Gulf sturgeon begin spawning approximately four to seven days after the first new moon in March when water temperatures are above 17.0°C (62.6°F) and spawning will continue for several weeks, providing the water temperatures remain below 21 to 22°C (69.8 to 71.6°F). In the Suwannee River in Florida, sturgeon have been observed migrating into freshwater when water temperatures are between 17 and 21°C (62.6 to 69.8°F), typically beginning the migration in February and remaining upstream for eight to nine months (Carr *et al*., 1996). Some researchers have hypothesized that when the upstream water temperatures became too high for the spawning sturgeons, the fish seek out cool water aquifer-fed springs in the river, or "thermal refuges". Due to the often significant weight loss documented in Gulf sturgeon during their time upstream (Huff, 1975; Wooley and Crateau, 1985), it has been suggested that the fish rarely leave the river's thermal refuges and thus quickly over-exploit the food resources within them (Carr *et al*., 1996). This would suggest that water temperatures, particularly in river habitats, are significant not only for successful spawning and egg rearing, but also for the health of adult sturgeon.

2.3.1.3 Water Quality

No Action
Without the proposed diversion, Maurepas Swamp would likely continue to be nitrogen limited due to the lack of a consistent nitrate supply. The swamp is extremely effective at denitrification, particularly when water residence times are high. The lack of diversion water allows the swamp water column to become locally stagnant such that, in addition to denitrification, physical export of nutrients to adjacent regions or Lake Maurepas is limited to high meteorological tidal events and storm event precipitation.

Proposed Diversion
All models associated with this study area have assumed a mean Mississippi River nitrate concentration of 1.5 ppm (mg L^{-1}) (Lane *et al.* 1999). The attenuation of this nitrate as it travels through the Maurepas Swamp has been estimated to be quite significant (Day *et al*., 2001 and 2004). The UNET model predicts the flow distribution of diversion water throughout the swamp area. These flow distribution results, coupled with nitrate removal efficiencies calculated through comparative regression models (described by Day *et al.*, 2001 and 2004), provides predictions of a succession of nitrate losses, throughout its relatively coarse spatial network, as water travels from Hope Canal, downgradient to Blind River, Dutch Bayou, and Reserve Relief Canal. The shortest pathway to receiving waters was identified as Hope Canal to the Blind River. The coupled UNET-removal efficiency model predicted that between 94 and 99% of Mississippi River nitrate would be assimilated by the swamp. This would represent the most conservative loss rate as the remaining pathways are associated with longer water residence times and, therefore, greater nitrate reductions. In sum, with the total reduction rates of 94 and

99% applied to the loading rate, the expected net increase nitrate loads to Lake Maurepas would be about 0.50 and 0.08 g m^{-2} y^{-1}, respectively. Nitrogen reduction rates were also predicted by the 2-D TABS-MD model, as shown in Table 13. Both modeling analyses conclude that nitrate removal would exceed 90% between the Hope Canal diversion outfall and the receiving waters of Lake Maurepas. These rates suggest a net loading rate of between 0.50 and 0.84 g m^{-2} y^{-1} of NO_3-N, a relatively low value in comparison to other estuarine systems.

Most analyses related to Mississippi River diversions in wetland and estuarine environments have had a primary focus on nitrate due to its relatively high concentration in river water and the tendency for receiving environments to be highly nitrogen limited. Ammonium (NH_4) and organic nitrogen (measured through total Kjeldahl nitrogen [TKN]) are also of interest in terms of potential nutrient balances in the Maurepas system. Ammonium is about an order of magnitude lower than nitrate in Mississippi River water (Lane *et al*., 1999 and 2003). Internal

Table 13. Predicted nitrate removal for 1,500 cfs discharge. ***Source: Day et al. (2004).***

Input Characteristics	
Diversion Discharge (cfs)	1,500
Diversion Discharge (m^3s^{-1})	42
[NO_3-N] in River (mg L^{-1})	1.5
Output Routing	
Flow to Blind River (cfs)	795
Flow to Lake (cfs)	240
Flow to Reserve (cfs)	465
% Total flow to Blind River	53
% Total flow to Lake	16
% Total flow to Reserve	31
[NO_3-N] entering Blind River (mg L^{-1})	0.22
[NO_3-N] entering Lake (mg L^{-1})	0.20
[NO_3-N] entering Reserve Canal (mg L^{-1})	0.00
% Removal on Blind River Route	85
% Removal on Lake Route	87
% Removal on Reserve Canal Route	100
Overall Removal Efficiency	90
Nitrate Summary	
Total Nitrate to Swamp (kg d^{-1})	5,504
Active Area of Swamp (ha)	10,534
Total Nitrate Throughput to Waterbody (kg d^{-1})	550
Nitrate Retained or Removed in Swamp (kg d^{-1})	4,954
[NO_3-N] Entering Adjacent Waterbody (mg L^{-1})	0.15
Additional Areal Nitrate Load to Lake Maurepas (g m^{-2} y^{-1})	0.84

sources of ammonium include the decomposition of organic matter within the water column, but decomposition in benthic environments is often a more significant source. At the Caernarvon diversion, Lane *et al*. (1999) reported increases in ammonium concentrations from river values of 0.05 – 0.1 mg L^{-1} to receiving estuarine values of 0.1 – 0.2 mg L^{-1}, indicating a positive correlation between distance from the diversion and ammonium values. Likewise, similar distance-related increases, followed by decreases, in ammonium concentrations were observed in the Atchafalaya River (Lane *et al*., 2002). The decreases are likely due to assimilation by primary producers and perhaps nitrification (oxidation back to nitrite and nitrate). Day *et al*. (2001) predicted a similar fate for ammonium in the Maurepas system, with peak swamp concentrations between 0.1 and 0.2 mg L^{-1}. Similarly, total nitrogen (TN) would be expected to decrease significantly with distance from the diversion due to the same processes with greater ratios of refractory organic nitrogen with distance.

Phosphorus concentrations were measured in the study area and determined to be equivalent to ranges observed in Mississippi River water (Day *et al*., 2001). Lane *et al*. (1999) measured higher phosphate (PO_4) concentrations in receiving estuarine waters associated with the Caernarvon diversion and hypothesized that this was due to benthic remineralization in these waters. Yet concentrations remained relatively low (generally less than 0.15 mg L^{-1}). There are processes that result in both remineralization and burial of PO_4 in these types of aquatic environments due to several important factors such as flow rates, salinities, redox potential, and suspended sediment characteristics. Based on similar systems, Day *et al*. (2001) suggest that neither total phosphorous (TP) or PO_4 concentrations would be expected to change significantly in diverted Mississippi River water.

The diversion is expected to result in a net increase in suspended sediment delivery to Maurepas Swamp. Day *et al*. (2001) suggest that the swamp would be a significantly efficient trap for most of this new sediment supply (see Section 2.3.2). This would be due to physical settling as flow velocities decrease with distance (in most cases). Suspended sediment concentrations in Lake Maurepas have been observed to be relatively high, likely caused by wave action because the lake is quite shallow. It is expected that no net change in suspended sediment or turbidity will occur in Lake Maurepas as a result of a 1,500 cfs diversion at Hope Canal.

One intended benefit of the proposed diversion is a measurable decrease in the frequency and duration of high salinity events in the swamp and lake. The increased rate of diversion water (1,500 cfs) proposed to be annually discharged to the Maurepas system is roughly equivalent to introducing twice the volume of Lake Maurepas per year and about half of the existing freshwater input to the Lake. The introduction of this additional discharge would effectively reduce the freshwater turnover time (T_{fw}) from 2.64 to 1.83 months, or by 31%. This is a significant introduction of freshwater to the Maurepas system and will certainly have an effect on salinity levels. Hydrodynamic modeling results reported by Day *et al*. (2004) suggest that stronger head differential between Maurepas Swamp and the lake would significantly reduce salinities in the swamp. Day *et al*. (2004) illustrates salinity response to the diversion by reporting model results that indicate a reduction in lake salinities occurring primarily along the southern shore of the lake (Figures 15 and 16). This forcing of the salinity zone eastward would be particularly important during drought and tropical storm events when incursion of higher salinity waters to southern Lake Maurepas threatens the freshwater swamp environment.

Additional hydrodynamic modeling of solute transport through the swamp and lake are being conducted by URS Corp.

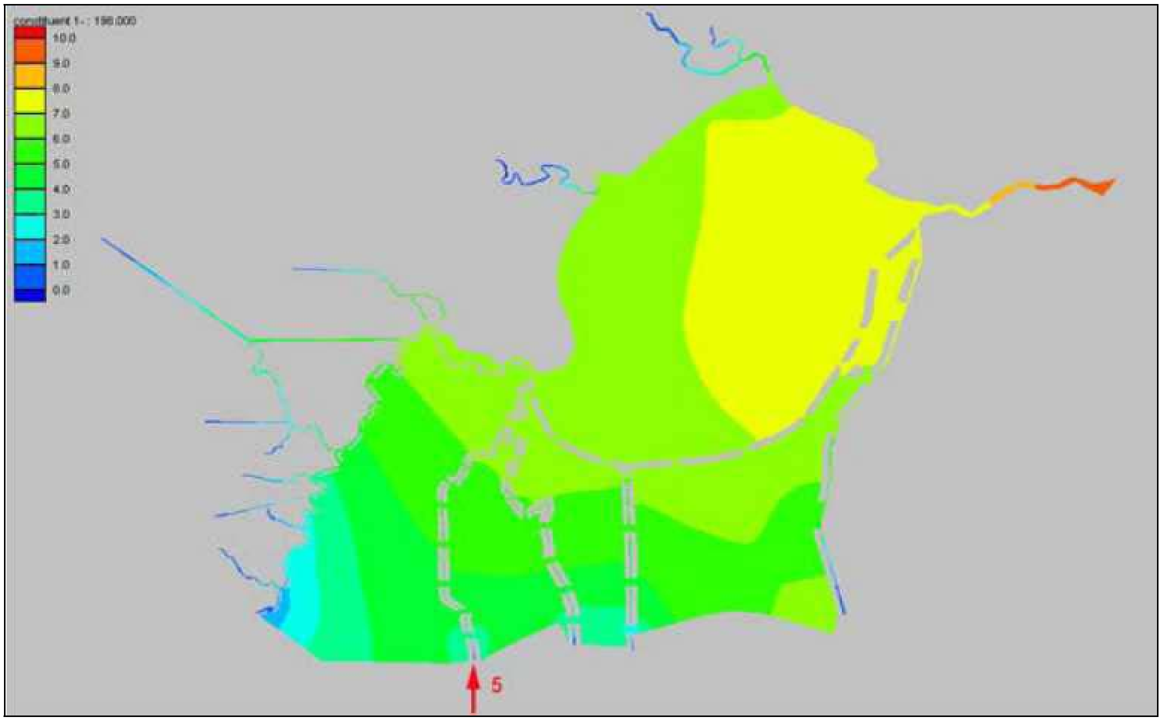

Figure 15. Baseline Transport of Conservative Constituent (a proxy for salinity) as Simulated by the TABS-MD Modeling Process. ***Source: Day et al. (2004).***

The diversion will result in measurable increases in nitrogen concentrations within the swamp. These concentrations would decrease with distance from Hope Canal to approximately 5 to 10% of initial concentration in surface water discharge areas. The increase of inorganic nitrogen to the nitrogen-limited Lake Maurepas may result in increased primary production (Day *et al*., 2001 and 2004; Lane *et al*., 2003). However, Lake Maurepas is notably turbid and, as a result, water column light attenuation is probably chronically limited[2]. Therefore, primary production is most likely light limited to such an extent that this too would decrease the likelihood of significant increases in productivity and in algal standing stock (Day *et al*., 2001 and 2004; Lane *et al*., 2003; Shaffer *et al*., 2003).

2.3.2 Land Resources

No Action

The restoration of Maurepas Swamp is dependent upon three Mississippi River water constituents: freshwater, sediments, and nutrients (particularly nitrate). Acting together to reverse net subsidence rates (about 6.0 mm y^{-1} in interior regions of the swamp), sediment

[2] Limited data from LA DEQ report a Lake Maurepas Secchi depth range of 0.5 to 1.2 m.

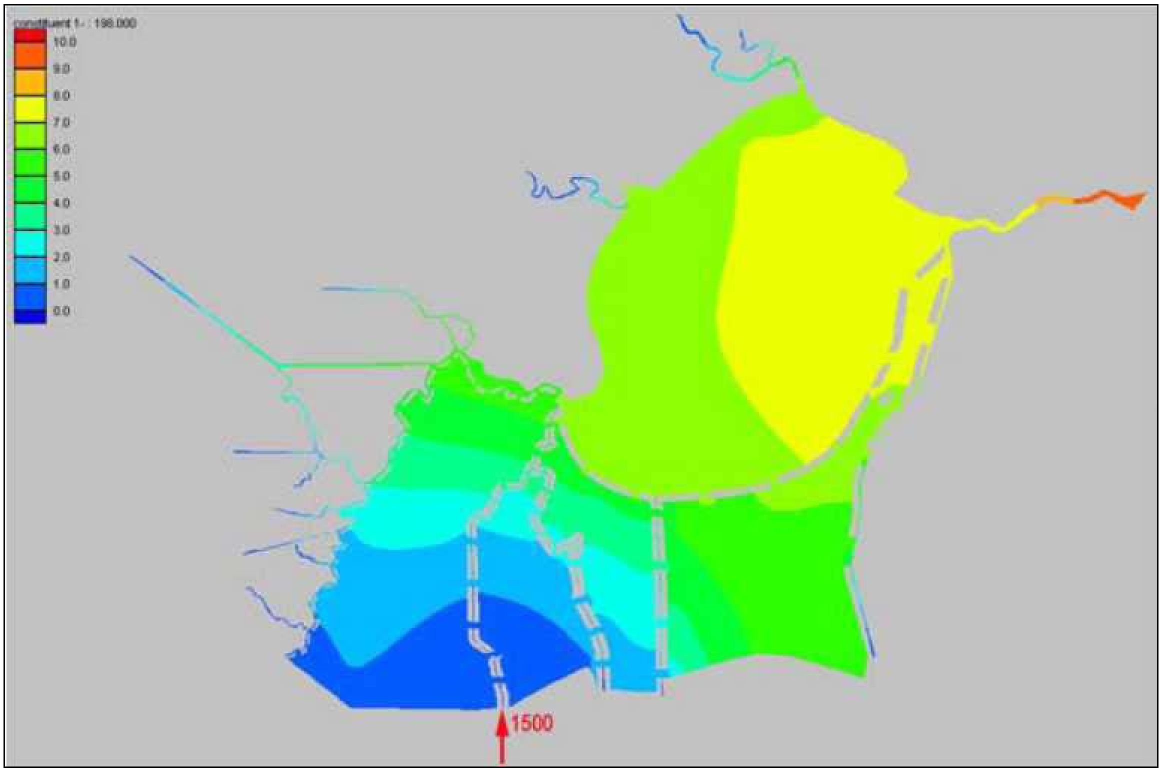

Figure 16. Signature of Conservative Tracer (a proxy for salinity) Resulting from 1,500 cfs After Two Months. Simulated by TABS-MD Model. ***Source: Day et al. 2004*.**

deposition and increased productivity is critical for long-term prevention of swamp dieback. Without sediment and nutrient subsidies, it is likely that continuing trends of subsidence and the associated conversion of habitat to marsh and open water will continue and cease to sustain a healthy swamp ecosystem (Shaffer *et al*., 2003). The restoration is also dependent upon the salinity-reducing effects of the fresh river water itself due to the deleterious effect of periodic and sometimes chronic intrusions of seawater on the existing swamp vegetation and other fauna. The feasibility study conducted by the U.S. Army Corps of Engineers for a freshwater diversion into the Lake Pontchartrain basin indicated that with no diverted flow, land in the basin area would be lost at the approximate rate of 6.5 square kilometers every year and subsidence would lead to 0.15 meters of lost elevation by the year 2040 (USACE, 1984). The feasibility study also estimated that without further action, about 91,000 acres of marshland and 86,000 acres of wooded swamp would be lost by 2040, mostly as the result of subsidence, erosion, human activity, and salt stress. Wind and wave action is also expected to continue eroding the shoreline of Lake Maurepas (USACE, 1984). Similar net loss is likely in the Maurepas Swamp under the no action alternative.

Proposed Diversion

Day *et al*. (2004) applied the swamp elevation model SWAMPSUSTAIN to estimate future trends in soil and sediment accretion rates based on a series of potential diversion scenarios. The model is based on the same spatial network as UNET (See Figure 12), which divided the swamp into cells, some that were bordering the Hope Canal (Tier 1 cells) and others that were one cell removed from the canal (Tier 2) or further away (Tiers 3 and 4). SWAMPSUSTAIN simulates swamp accretion within each cell based on sediment delivery and productivity rates on a monthly time step and provides long-term estimates of swamp dynamics across different regions. A threshold elevation (default value of 1.9 ft., NAVD 88) was determined as necessary to restore the historical cypress/tupelo tree ecosystem in the swamp. The model predicted that between 2,000 and 4,000 hectares of Tier 1 cells will reach the target elevation within 50 years, provided the average annual discharge rate was between 1,250 and 2,500 cfs. Two Tier 2 cells to the east of the Hope Canal would achieve the target elevation in less than 100 years, presuming a greater than 2,000 cfs discharge rate. Tier 3 and Tier 4 cells are never expected to achieve target elevations, given the sediment attenuation expected between the canal and these distant cells. The results from this model indicated that, although a significant portion of the Maurepas Swamp will not receive enough sediment deposits to achieve target elevation without further restoration initiatives, the benefits of increased nutrient inputs and decreased salinity will help to increase the health of those areas of the swamp (Day *et al*., 2004). Figure 17 depicts the response curves associated with SWAMPSUSTAIN across different diversion scenarios as a function of time.

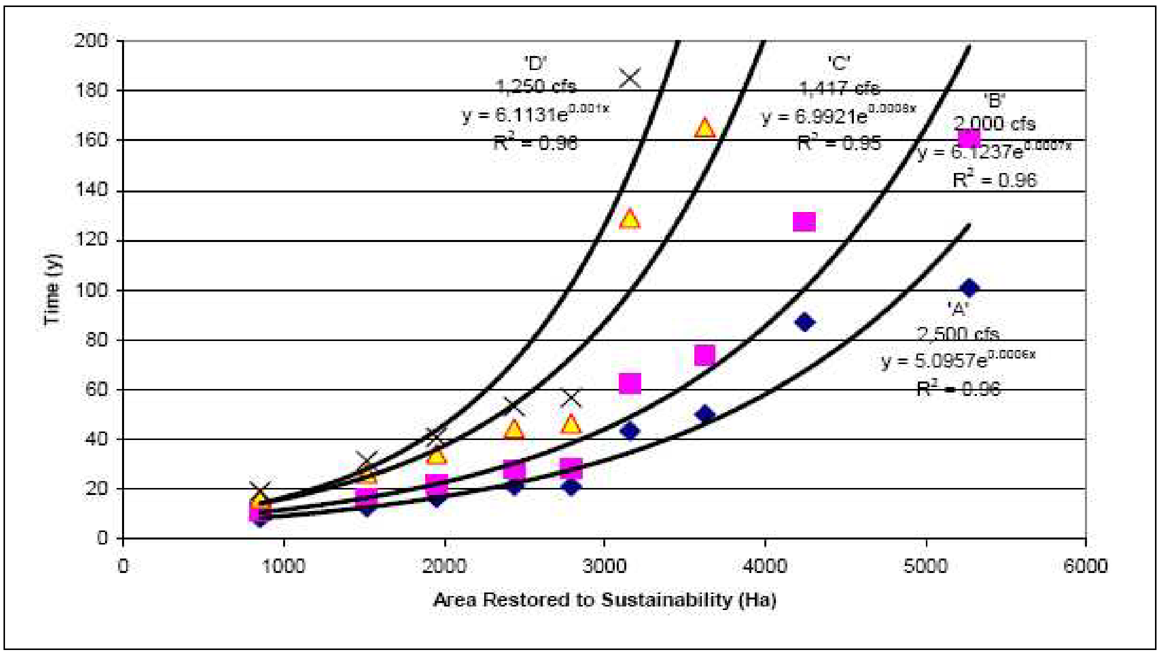

Figure 17. Response of potential swamp restoration over time based on SWAMPSUSTAIN model simulation results.

2.3.3 Biological Resources

No Action

The USACE feasibility study (1984) estimated that, due to continuing subsidence and land loss, vegetative diversity and species richness will continue to decrease if freshwater is not diverted into the area. For example, acreage of wooded swamp in the feasibility study area (which covers more than just Maurepas Swamp) is expected to decrease from 188,669 acres in 1978 to 102,687 in 2040, a loss of more than 45% (USACE, 1984). Without a freshwater diversion, high salinity levels would be expected to continue, causing tree mortality, habitat degradation, and decreases in fish productivity. Shaffer *et al*. (2003) estimated that tree mortality rates will continue without freshwater diversion and some study sites on the southern shore of Lake Maurepas may be completely deforested within 2-5 years. The Manchac land bridge, north of Lake Maurepas, experienced significant land loss during the mid to late 1900s, which may be useful for determining the future of Maurepas Swamp without freshwater diversion. The Manchac land bridge evolved from an area dominated by second-growth swamp to having large swaths of open water between 1956 and 1990. Since 1990, further open water conversion has been documented (Shaffer *et al*., 2003).

Proposed Diversion

Little research has been done on the potential effects on biological resources should a 1,500 cfs diversion be established. To imitate possible results from a freshwater diversion, Shaffer's team applied time-released fertilizer to selected areas of the swamp and found that there was almost a 300% increase in herbaceous crop levels. The amount of fertilizer applied was meant to mimic a 3000 cfs diversion (Shaffer *et al*., 2003). The proposed diversion is expected to not only increase nutrient levels but to decrease salinity levels in the swamp and in Lake Maurepas by diluting the ecosystem with freshwater. Given that high salinity levels can negatively affect vegetation health and increase mortality, lower salt concentrations in the swamp would likely lead to benefits for vegetative cover and prevent the conversion of wooded swamp to marsh and eventually to open water.

The proposed diversion would also have beneficial effects on the fisheries in the Maurepas Swamp area, particularly in Lake Maurepas itself and the tributaries surrounding the region. Healthy wetlands are critical to the productivity of many fish and shellfish species and wetland acreage would increase with a freshwater diversion. Results of the freshwater diversion at Caernarvon may provide an indication of how fisheries may respond to a diversion into the Maurepas Swamp. Operational since 1991, initial indications are that, by lowering the salinity levels in the marshes, the Caernarvon project may have expanded the critical nursery habitat for important commercial species such as brown shrimp, white shrimp, and blue crab. The economically-important largemouth bass fishery has also rebounded due partially to the diversion's expansion of marsh habitat (Caffey and Schexnayder, 2002).

3.0 SUMMARY OF SCREENING-LEVEL ECOLOGICAL RISK ASSESSMENT

A screening-level ecological risk assessment was conducted to evaluate the potential for increased exposure and risks associated with chemical contaminants that may be introduced to the study area as a result of the Maurepas Swamp diversion project. The details of this assessment are provided in Appendix A. The screening-level ecological risk assessment focused on identifying chemical contaminants of concern, ecological receptors that may be exposed to these contaminants, and an assessment of the potential adverse effects, or risks. The approach used follows EPA's ecological risk assessment guidance (EPA, 1997).

3.1 Conceptual Site Model (CSM)

The framework for the screening level ecological risk assessment is described through the conceptual site model (CSM). The CSM illustrates the relationships between contaminant sources, environmental transport mechanisms, contaminated media, and the ecological receptors that may be exposed. Figure 18 provides the CSM for this assessment.

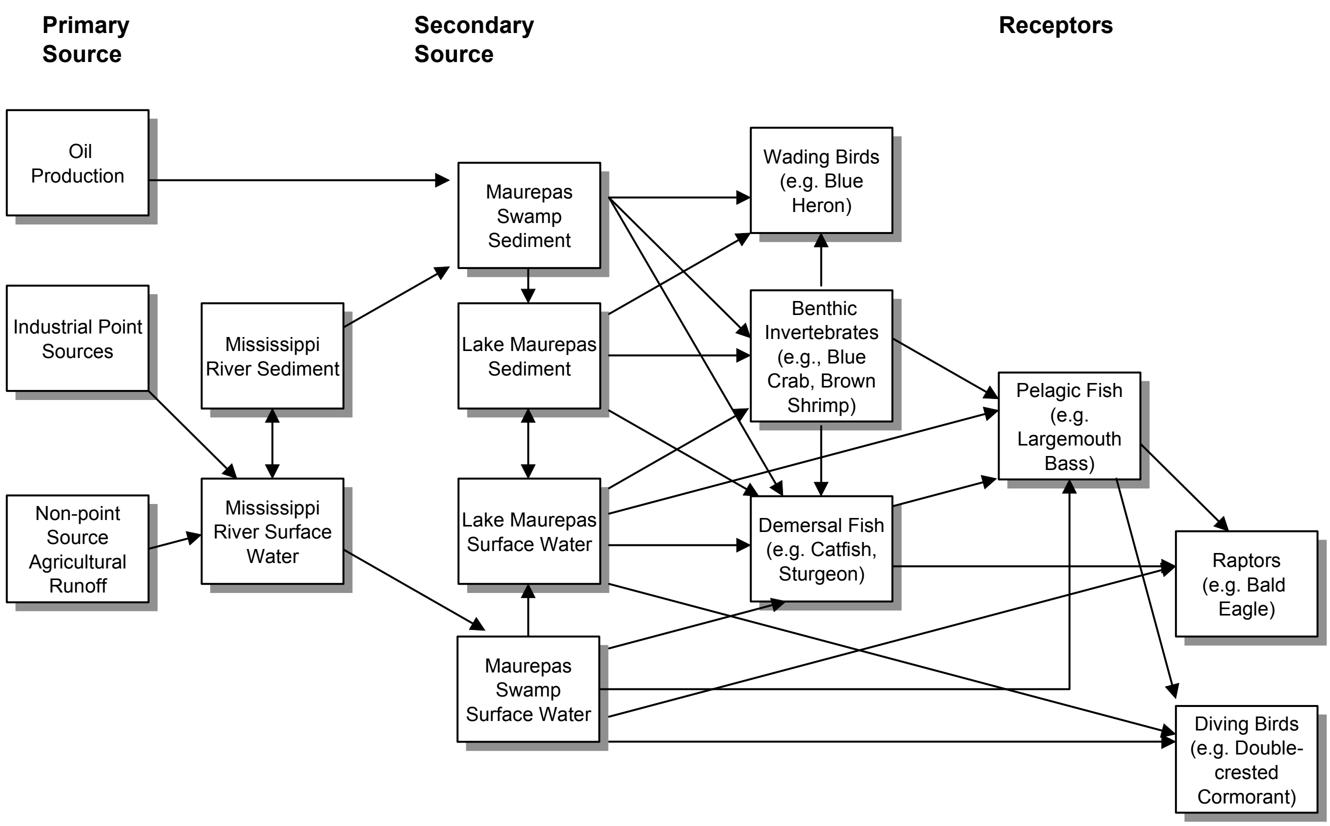

Figure 18. Conceptual Site Model for Screening-Level Risk Assessment of Maurepas Swamp Diversion Project.

3.2 Contaminants of Concern

The identified media of concern at the Maurepas Swamp and Lake Maurepas study area are surface water, sediment, and the tissues of prey items. For the screening-level assessment, it was assumed that chemicals carried in Mississippi River water and sediments (the source point for the diversion project) would represent future equilibrium conditions of contaminant in Maurepas Swamp and Lake Maurepas. A summary of these data and their sources are provided in Appendix A.

Water quality data was compiled from periodic monitoring conducted by LDEQ from 1995 to 2001 from six stations that were determined to be in the vicinity of the Maurepas study area including Amite River Diversion Canal north of Gramercy, Blind River near confluence with Lake Maurepas, Blind River near Gramercy, Lake Maurepas, Mississippi Bayou north of Reserve, and Mississippi River south of Lutcher.

Sediment data was compiled from Mississippi River locations sampled during EPA's Environmental Monitoring and Assessment Program (EMAP) and reported by Macauley and Summers (1998).

To assess potential exposures to upper-trophic level receptors, such as the bald eagle, chemical contaminant levels in prey items, such as fish tissue were compiled. Data collected by USGS (1995, 2002) and LDEQ (1997-2004) from Mississippi River, Lake Maurepas, Lake Pontchartrain, and at Luling were evaluated.

3.3 Selection of Receptors of Concern (ROCs)

The selection of receptors of concern (ROCs) provides an evaluation of ecological species that would be considered in the risk assessment. These factors include federally listed threatened and endangered (T&E) species; species of special concern within the State of Louisiana; the likelihood of the species expected to occur based on existing conditions in the swamp; significance of the species to ecosystem function; availability of toxicity and life history data; and species sensitivity to expected contaminants. Table 14 provides a summary of the ROCs selected; additional details are provided in Appendix A.

Table 14. Potential Receptors of Concern for the Maurepas Swamp Screening-Level Ecological Risk Assessment.

Receptor	Exposure Media	Rationale for selection of receptor and pathway
Benthic Invertebrates		
Blue crab	Sediment/surface water/biota	Epibenthic omnivorous invertebrate that consumes plankton and small fish and comes into direct contact with contaminated sediments

Table 14. Potential Receptors of Concern for the Maurepas Swamp Screening-Level Ecological Risk Assessment, continued.

Receptor	Exposure Media	Rationale for selection of receptor and pathway
Benthic macroinvertebrate community	Sediment/surface water/biota	Various benthic invertebrate populations representing different trophic levels which are in intimate contact with contaminated sediments
Fish		
Gulf sturgeon	Sediment/surface water/biota	Listed as a threatened anadromous species on both the State and Federal T&E list and feeds on benthic invertebrates and small fish
Pallid sturgeon	Sediment/surface water/biota	Listed as an endangered species on both the Federal and State T&E list and feeds on small benthic fish
Largemouth bass	Surface water/biota	Dominant predatory species that has sensitive early-life stages
Channel catfish	Sediment/surface water/biota	Freshwater demersal species that comes in direct contact with contaminated sediment as a result of foraging on benthic and epibenthic organisms and detritus
Birds		
Bald eagle	Sediment/surface water/biota	Listed as a threatened species on the Federal T&E list and endangered on the State list; observed nesting in the area and feeds on fish, waterfowl, and muskrats
Great blue heron	Sediment/surface water/biota	Wading bird that potentially consumes large amounts of sediment while feeding on benthic aquatic life
Double-crested cormorant	Sediment/surface water/biota	Piscivorous bird that has been observed foraging in the area.

3.4 Assessment and Measurement Endpoints

Assessment endpoints (AE) are defined by EPA (1997) as formal expressions of the actual environmental values that are to be protected at a site. AEs are defined based on anticipated exposure pathways, the presence of receptors, and a contaminants biotic transfer pathway. Selection of AEs would consider the ecosystem, communities, and species relevant to a particular site. For this screening-level ecological risk assessment the following three AEs and subsequent measurement endpoints (MEs) are proposed to represent the resources to be protected in Maurepas Swamp:

- AE(1): Protection and maintenance (*i.e.*, survival, growth, and reproduction) of benthic invertebrate communities that serve as a forage base for fish and wildlife populations.

  ME(1): AE(1) will be evaluated by comparing concentrations of contaminants in sediments to available freshwater sediment benchmarks from the National Oceanic and Atmospheric Administration (NOAA) (*e.g.*, PELs and TELs) which are protective of benthic organisms.

- AE(2): Protection and maintenance (*i.e.*, survival, growth, and reproduction) of benthic and pelagic fish populations that serve as a forage base for other fish and wildlife populations.

  ME(2): This will be evaluated by comparing concentrations of surface water contaminants to the National Recommended Ambient Water Quality Criteria (NRAWQC) developed by the USEPA and Canadian standards where US criteria are not available.

- AE(3): Protection and maintenance (*i.e.*, survival, growth, and reproduction) of the bald eagle.

  ME(3): This will be evaluated by modeling the daily dose of chemicals to the bald eagle from the ingestion of contaminated surface water, sediment, and prey items. Potential risk will be characterized by comparing the modeled dose estimate to toxicity reference values (TRVs).

3.5 Summary of Screening-Level Risk Assessment Results

The results of this screening-level risk evaluation support the conclusions of the Mississippi River Sediment, Nutrient, and Freshwater Redistribution Study (MRSNR) (as cited in Lee Wilson & Associates, 2001). In the MRSNR study, only a few compounds, mainly mercury and some organopesticides were found to occasionally exceed water or sediment benchmarks.

For the benthic invertebrate communities, exposure to the maximum concentration reported for nickel may pose a potential risk. In addition, the maximum concentration of three metals (cadmium, lead, and zinc), three PAHs (benz[a]pyrene, chrysene, and pyrene), and DDT isomers (4,4’-DDD, and 4-4’-DDE), and total DDx reported in sediment were slightly elevated and would be classified as presenting a low magnitude risk to benthic invertebrates.

The benthic and pelagic fish populations may be at risk from exposures to cadmium, and to a lesser extent, copper and nickel, which exceeded water quality criteria on at least one occasion between 1991 and 1997.

Exposures to maximum concentrations of mercury and total DDx reported in sediment and prey items pose a low magnitude level of risk to bald eagles.

In the absence of surface water and sediment data from the study area, it is difficult to quantitatively determine the increase or decrease in risks that the diversion project would have on ecological exposures to chemical contaminants. Qualitatively, the contaminants that exceed relevant ecological benchmarks are generally consistent with low magnitude levels of risk. These levels of risk are consistent with an industrialized area, and are likely consistent with regional conditions. As such, the diversion project may not result in any significant changes from regional conditions and risks to wildlife would not likely change. Additional investigations would be necessary to validate these assumptions.

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4.0 DIVERSION BENEFITS AND RISKS

This section provides a preliminary assessment of ecological benefits and risks associated with the proposed Maurepas Swamp diversion.

The Maurepas Swamp diversion project was conceived of with the intention to restore a significantly large area of swamp ecosystem through the reintroduction of Mississippi River water. Therefore, the focus has been on providing a suite of measurable, long-term benefits to the area. Summaries of anticipated benefits have been studied by several groups of scientists and widely reported (Day *et al*., 2001; Schaeffer *et al*., 2003; Lee Wilson & Associates, 2001; Day *et al*., 2004). These reports highlight the following benefits of the diversion project:

1. Retain (*i.e.*, minimize loss of) existing areas of swamp vegetation;
2. Retain and preferably increase overstory cover;
3. Decrease the morbidity rate of tupelo trees;
4. Increase the density of the dominant tree species;
5. Increase the primary productivity of trees;
6. Increase accretion of substrate in the swamp;
7. Restore and maintain characteristics of natural swamp hydrology (*e.g.*, flooding regime, drainage patterns, through-flow);
8. Reduce salinity levels in the swamp;
9. Increase sediment loading to the swamp;
10. Increase dissolved oxygen concentrations in the swamp water;
11. Maximize nutrient removal from river water diverted to the swamp;
12. Ensure that diversion of river water does not result in increased nuisance algal blooms in Lake Maurepas;
13. Reduce nutrient loading from the Mississippi River to the Gulf of Mexico;
14. Likely no increase in risk to ecological receptors from exposures to chemical contaminants; and,
15. Likely no increase in risk to bald eagles within the study area from consumption of contaminated prey.

The majority of these items (listed above) signify perceived, expected benefits associated with the proposed diversion project. However, the risk of deleterious effects associated with eutrophication is also of concern. Although the diversion is designed to provide relief to nutrient and sediment starvation existing in the swamp ecosystem, an increase of these to Lake Maurepas could promote increases in primary productivity (including nuisance/harmful algal blooms) and other undesirable conditions related to poor water quality. Given this, much effort has been spent on studying the relationship of diversion flow, distribution, and the capacity of the swamp to assimilate nutrients and sediments to the point where excess releases to Lake Maurepas would not pose a significant risk.

The following sections summarize potential benefits and risks to ecological receptors within Maurepas Swamp and Lake Maurepas.

4.1 Benefits

This section provides a preliminary assessment of anticipated project benefits based on previous studies, additional available data, and comparative analyses (*e.g.*, other diversion projects such as Bonnet Carré). A series of stressor-response matrices have been developed to illustrate the degree of association between potential agents-of-change and ecological receptors in the following ecosystems: Maurepas Swamp and Lake Maurepas. Additional downgradient (*i.e.*, Lake Borgne and Breton Sound estuaries) effects are also identified and discussed as necessary.

4.1.1 Mississippi River/Gulf Hypoxia Zone

The Maurepas Swamp diversion project will potentially divert approximately 1.34 trillion cubic meters of Mississippi River water per year. Based on the design of the diversion, approximately 90 to 99% of the nitrate within this water will be assimilated, retained, or lost prior to discharge to Lake Maurepas and down-estuarine waters (Day *et al*., 2004). Based on this rate of removal efficiency, it is likely that virtually all inorganic nitrogen within diverted river water (about 2 million kg) will be removed from the Mississippi River annually. However, this accounts for only a very small fraction of annual Mississippi River discharge to the Gulf of Mexico (about 0.5%). The benefit is cumulative; the Maurepas Swamp diversion contributes a small percentage of a larger, more significant reduction in nitrogen load to the Gulf of Mexico through additional existing and planned diversion projects. There is no immediate indication that alterations in nutrient ratios through this diversion will provide net benefits to Mississippi River discharge to the Gulf of Mexico. The diversion is not expected to alter the existing and future nutrient ratios within the Mississippi River.

4.1.2 Maurepas Swamp

This section summarizes the potential benefits to ecosystem receptors in Maurepas Swamp in response to the proposed diversion alternative. As it is stated earlier in this report, an overarching goal of this preliminary assessment is to identify potential benefits and risks associated with this diversion alternative in contrast to “no action”. A series of operational assumptions have been adopted in order to provide a distinct, consistent analysis of potential impacts to the study area. These are:

- The diversion delivers 1,500 cfs, on average, of Mississippi River water with nutrient and suspended concentrations consistent with those used as defaults in analyses and model simulations reported by Day *et al*. (2001), Lee Wilson & Associates (2001), Kemp *et al*. (2001), Lane *et al*. (2003), and Shaffer *et al*. (2003).
- The diversion outfall will possess discharge and distribution characteristics that are consistent with maximum distribution of Mississippi River water throughout the swamp.
- Nutrient assimilation and attenuation within the swamp is consistent with projections made by Day *et al*. (2004) and others (90 – 99% reduction in nitrate).

Based on these operational assumptions, and through an assessment of existing information, there are a suite of physical, biogeochemical, and ecological processes, associated with system-wide benefits that have been suggested by Shaffer *et al*. (2003) and summarized by Day *et al*. (2004). These include the following:

Retain (i.e., minimize loss of) existing areas of swamp vegetation
The reintroduction of nutrients and sediments are expected to reverse subsidence in critical interior areas of Maurepas Swamp through augmenting accretion rates.

Retain and preferably increase overstory cover
With increased swamp elevations, provided by increased accretion rates, the threshold for sustaining a healthy cypress/tupelo dominated swamp ecosystem will be reached and result in increased overstory cover.

Decrease the mortality rate of tupelo trees
Mortality rates are associated with prolonged periods of flooding, promoting stagnant conditions, and the recent increase in high salinity events. Both of these stressors have been shown to be strongly correlated with tupelo dieback. Increased flushing, substantially decreased salinities, and long-term accretion of swamp soils will provide greater likelihood of decreased mortality rates of tupelo and cypress trees.

Increase the density of the dominant tree species
Current densities of dominant tree species in Maurepas Swamp are declining due to the inability to reach sustainable fecundity rates. Prolonged flooding due to subsidence and stress associated with increased salinities prevent seed germination and growth of saplings. The increase in swamp elevations through accretion will provide increasingly more opportunity for seed germination and, therefore, increased density of dominant tree species.

Increase the primary productivity of trees
Maurepas Swamp has been determined to be significantly starved of nutrients that are essential for healthy growth and reproduction of dominant tree species. The introduction of nutrients in Mississippi River water, and sorbed to particulate matter within, will likely stimulate increased rates of productivity.

Increase accretion of substrate in the swamp
This process, already described above, is associated with conditions necessary to sustain a healthy cypress/tupelo swamp ecosystem.

Restore and maintain characteristics of natural swamp hydrology (e.g., flooding regime, drainage patterns, through-flow)
Natural swamp hydrology is based on historical periodic flood events that would provide freshwater (physical flushing), nutrients and sediments to Mississippi River delta swamp ecosystems. The restoration of these cycles, mimicked by diversion controls, would restore benefits associated with these hydrologic characteristics.

Reduce salinity levels in the swamp
Maurepas Swamp consists of an ecosystem that is sensitive and vulnerable to saltwater. Chronic and periodic high salinity events in recent years have resulted in measurable dieback of swamp vegetation, including dominant tree species. Increased delivery of freshwater, particularly during periods of low baseflow from swamp and lake tributaries, would effectively reduce salinities to tolerant levels.

Increase sediment loading to the swamp
Maurepas Swamp is sediment starved and currently receives sediment supply either from Lake Maurepas (but limited to coastal regions) during high tidal energy events, or at localized areas associated with Hope Canal, Amite River and Blind River where sediments in runoff events are readily deposited.

Increase dissolved oxygen concentrations in the swamp water
Stagnant water conditions, particularly in interior regions of Maurepas Swamp, are typically oxygen deprived due to poor horizontal exchange. A significant increase in volumetric exchange would occur under the proposed diversion alternative which would likely result in improved dissolved oxygen concentrations in areas of the swamp receiving increased flow.

Maximize nutrient removal from river water diverted to the swamp
The removal of nutrients from Mississippi River water within the swamp is important for two reasons. First, the swamp is nutrient limited and would benefit from increased productivity. Therefore, maximum distribution and residence time of nutrient rich river water is necessary for *in situ* assimilation. Perhaps more directly relevant is the desire to avoid eutrophication in the receiving estuarine waters of Lake Maurepas where too much nutrient enrichment can result in undesirable blooms of algae and low dissolved oxygen conditions.

Likely no increase in risk to ecological receptors from exposures to chemical contaminants
In the absence of surface water and sediment data from the study area, it is difficult to quantitatively determine the increase or decrease in risks that the diversion project would have on ecological exposures to chemical contaminants. Qualitatively, the contaminants that exceed relevant ecological benchmarks are generally consistent with low magnitude levels of risk (See Appendix A for details). These levels of risk are consistent with an industrialized area, and are likely consistent with regional conditions. As such, the diversion project may not result in any significant changes from regional conditions and risks to wildlife would not likely change. Additional investigations would be necessary to validate these assumptions.

Likely no increase in risk to bald eagles within the study area from consumption of contaminated prey
The screening-level risk assessment for the bald eagle evaluated exposures to mercury, nickel, and DDT (See Appendix A for details). The results indicate a low magnitude risk from exposures to mercury and total DDx. These exposures are primarily driven by contaminant levels in fish tissue, as the main source of contaminant exposure. Mercury levels in fish collected from Lake Maurepas and Lake Pontchartrain are generally higher than fish tissue concentrations sampled from the Mississippi River, therefore, the associated risk for mercury associated with the diversion, would be lower than or equal to present risk levels in the study area.

4.1.3 Lake Maurepas

The potential benefits in Lake Maurepas in response to the proposed diversion alternative are as follows:

Moderately increase the primary productivity within Lake Maurepas
Increased nitrate delivery to Lake Maurepas may result in stimulating water column and benthic productivity. Moderate increases in productivity are desirable to support organic carbon supplies to consumers. Increased organic matter provides a food source for higher trophic levels, including fish and shellfish. An estimated 0.50 to 0.84 g m^{-2} y^{-1} of additional nitrate supply to Lake Maurepas can be considered a comparatively low rate of increase. This, coupled with an almost certain significant decrease in water residence time, and typical shallow photic zone, will not likely result in significant algal blooms.

Reduce salinity levels in Lake Maurepas
As reported by Day *et al*. (2004), hydrodynamic modeling suggests moderate to significant reductions in salinities, particularly along the southern coast of Lake Maurepas, due to the Hope Canal diversion. A reduction in salinity levels within the lake will decrease stress on plant and animal species that are sensitive and vulnerable to fluctuations in salinity. In Lake Pontchartrain, improvements in oyster productivity in Lake Borgne have been attributed to decreased salinities associated with the Bonnet Carré spillway. Additional reductions in salinity due to Lake Maurepas discharges through Pass Manchac may contribute positively to downgradient ecosystem attributes.

4.2 Risks/Concerns

This section summarizes the potential risks and/or concerns that may occur in the Maurepas Swamp study area in response to the proposed diversion alternative.

Eutrophication
A major concern connected to the proposed diversion is possible eutrophication, and associated phytoplankton blooms in Lake Maurepas (Turner and Rabalais, 1991; Rabalais *et al*., 1994; Dortch *et al*., 1998). Among effects of eutrophication are decreased light penetration throughout the water column; increased phytoplankton and macroalgal production and biomass; and subsequent increases in system respiration that results in depressed dissolved oxygen concentrations (hypoxia and anoxia), particularly in bottom waters.

Rates of additional nitrate supply to Lake Maurepas are estimated to be between 0.05 and 0.84 g m^{-2} y^{-1}. This rate is somewhat low when compared to other estuarine systems around the world (Boynton *et al*., 1996; Nixon *et al*., 1996). Although current nitrogen loads and primary productivity with regard to Lake Maurepas require further research and analysis, preliminary estimates of the degree of increased productivity associated with the diversion can be made. Based on a comparative study, Nixon *et al*. (1996) produced a rather interesting relationship between dissolved inorganic nitrogen loads (mol m^{-2} y^{-1}) and primary production (g C m^{-2} y^{-1}). Based on this analysis, a 0.84 g DIN m^{-2} y^{-1} (0.06 mol DIN m^{-2} y^{-1}) translates into approximately 6.0 g C m^{-2} y^{-1} which is a comparatively low rate of production.

Concerns over eutrophication have been downplayed in most of the literature supporting this assessment. The prediction for such high rates of nitrogen reduction in Maurepas Swamp, coupled with the existing low rates of nitrogen load to the Maurepas system, provide the basis for this. It is important to evaluate the potential loading threshold that should be avoided to protect against eutrophic conditions. Further research on the nature of water column light extinction, system productivity, and water residence time would allow such an evaluation. This would increase certainty around system response to additional nitrate loads and define quantifiable thresholds. For example, if it were determined that the practical threshold was <4 g DIN m^{-2} y^{-1}, then Maurepas Swamp would need to adequately assimilate approximately 50% of the nitrate load (Figure 19).

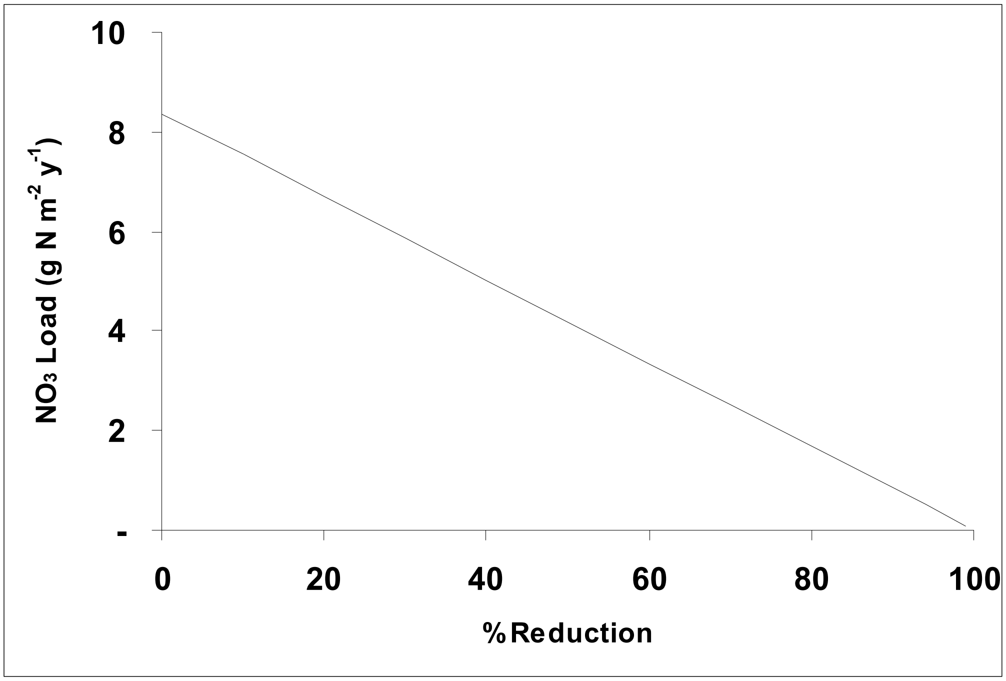

Figure 19. Nitrate load to Lake Maurepas as a Function of Nitrate Reduction Efficiency (%) of Maurepas Swamp.

Nuisance Algal Blooms
Nuisance algal blooms are associated with conditions favoring flagellate phytoplankton over diatoms. Diatom production is dependent upon an inorganic Si:N molar ratio of 1:1 or greater. Lower ratios increase the likelihood that flagellate plankton may increase in abundance over diatoms. Some flagellates are associated with the production of toxins that can result in undesirable and lethal conditions for consumers. In addition, the quality of flagellates as a food source for consumers is typically lower than that of diatoms. A significant blue-green algae bloom occurred in Lake Pontchartrain following a relatively large discharge event (up to 6,800 m^3 s^{-1}) (Day *et al*., 1999). This event raised awareness of the importance of controlling large discharge events that may increase the risk of nuisance blooms.

The proposed Hope Canal diversion would operate at least two orders of magnitude lower than that which stimulated the Lake Pontchartrain blue-green algal bloom. Also, the relative efficiency of nitrogen removal, and the predicted Si:N molar ratios from 1.5 up to 3.0 in exported Maurepas Swamp waters (Day *et al*., 2004), should mean that it is significantly less likely that undesirable, nuisance algal blooms will be of great frequency or magnitude. However, further research into this issue may be necessary.

Stratification

Water column stratification is an important controlling factor associated with DO and nutrient dynamics. Less-dense surface water can effectively "trap" bottom waters and create physical boundaries between water masses. Stratified water columns do not allow bottom water oxygen concentrations to be replenished by oxygen-rich surface waters. Higher rates of respiration in bottom waters can deplete existing pools of oxygen and result in anoxic conditions that are detrimental to benthic communities and fish which require aerobic conditions for survival. In shallow systems, stratification can rapidly result in anoxic conditions due to the relatively large ratio of sediment:water volume; respiration in sediments and bottom waters can rapidly deplete available oxygen.

Lake Maurepas is a notably shallow system with estimated low rates of productivity. The water column is mixed through wind events and suspended sediments from the lake bottom, which effectively reduce light penetration and, therefore, photic zone depth. It is uncertain whether there is sufficient system production to draw DO concentrations down to hypoxic or anoxic levels. However, thresholds in systems such as Maurepas are relatively low due to high water temperatures and small DO reservoirs (volume-limited). Hydrodynamic modeling has been 2-dimensional and, therefore, vertically integrated such that stratification events cannot be accurately depicted. Further evaluation of the degree and importance of water column stratification is probably warranted.

Atrazine

Although atrazine concentrations in the Mississippi River are of public concern due to the widespread use of this pesticide in the river basin, there is limited data for atrazine in surface water, sediments, or fish tissue in the Maurepas Swamp study area or effect levels to ecological receptors. Based on review of available data atrazine concentrations in the water column reported by LDEQ were below the Maximum Contaminant Level (MCL) for human health effects in drinking water. In addition, atrazine is not expected to bioaccumulate into fish tissue (EPA, 2005) and therefore, is not likely to significantly translocate through the food web to upper-tophic level receptors, such as the bald eagle. In general, it can be concluded that, although concentrations of atrazine may peak at times over the entire Mississippi River, concentrations in the river just north of the Maurepas Swamp study area in Louisiana are not likely to cause adverse effects to wildlife in the Maurepas Swamp or Lake Maurepas.

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5.0 CONCLUSIONS, UNCERTAINTY, DATA GAPS, AND RECOMMENDATIONS

The Hope Canal diversion would likely provide a balance of freshwater, nutrients, and sediments to effectively promote the reversal of swamp vegetation dieback and long-term restoration of the ecosystem that was present over 80 years ago. The primary benefits of this restoration effort would be realized within the wetland ecosystem of the Maurepas region with some potential additional, secondary benefits to Lake Maurepas. These benefits are directly associated with increasing rates of accretion and productivity of swamp vegetation such that long term survival and reproduction of cypress and tupelo trees can be realized. Related benefits include fending off salt water intrusion, which stresses the forest ecosystem, particularly during periods of drought. The reversal of forest dieback will slow or halt wetland loss and the subsequent conversion to open water environments. The risk of enhancing eutrophication through nutrient enrichment appears to be relatively low if wetland assimilation rates are to occur as predicted. Although the diversion would supply Lake Maurepas with a considerable increase of nutrients, the predicted areal loading rates pale in comparison to other nutrient enriched systems and would still be capable of limited *in situ* production, especially given the nature of water column transparency of this shallow lake. Silicate to nitrate ratios would likely continue to be great enough to support diatom production over flagellate species that are associated with nuisance algal blooms.

The emphasis of the recent, very comprehensive studies by Day *et al*. (2004), Shaffer *et al*. (2003), Lane *et al*. (2003), Kemp *et al*. (2001), Day *et al*. (2001) and others has been on the wetland and forested swamp ecosystems within the Maurepas region. Research programs focusing on Lake Maurepas have been limited and nowhere nearly as extensive as those associated with neighboring Lake Pontchartrain. Therefore, additional study within the estuarine environment of Lake Maurepas, including its interaction with Lake Pontchartrain, would complement the previous and ongoing rigorous baseline and modeling studies.

Data and information gaps exist with regard to fully supporting an Environmental Impact Statement (EIS). Valuable data and synthesis has been established through previous studies that will support EIS development. However, as in many cases, some key questions remain. Specific areas of uncertainty, data gaps and recommendations include the following:

- Most modeling, and related analyses, has assumed a constant nitrate concentration of 1.5 mg L^{-1}. It is likely that future efforts to reduce nitrogen loads to the Mississippi River in a basin-wide reduction strategy would influence this default value. A series of sensitivity analyses and necessary modifications to future implementation (diversion management) plans would be beneficial.
- Potential future variations in other Mississippi River constituents, including nutrients and contaminants, should be explored. The studies to date have focused extensively on inorganic nitrogen (nitrate) loads and have been forced to make a few broad assumptions about loading rates and trends of other nitrogen species and additional nutrients of concern. Although many of these assumptions are supported by comparative analysis (*e.g.*, Bonnet Carré, Caernarvon, Atchafalaya, and others), there remains uncertainty in the mass balances of Mississippi River constituents.

- All modeling efforts have been based on steady-state conditions and assumptions; however, meteorological events on weekly and fortnightly time intervals seem to influence water levels and constituents in Pass Manchac and at sampling stations throughout lake, tributary, and swamp locations. Sensitivity of the efficiency of nutrient and sediment distribution to the swamp and lake environments has not been evaluated. Net import and export of nutrients, salinity, and contaminants (if any) through Pass Manchac, in support of a system-wide series of budgets should be considered in future studies.
- The resulting DO concentrations in diversion water entering receiving tributaries and estuarine environments have not been formally addressed in the supporting literature. The potential role of the swamp environment to be a net sink of DO may influence DO concentrations in receiving waters, especially during critical periods.
- The influence of temperature gradients between diversion water and receiving waters has not been fully evaluated. This includes the relative contrasts in water mass temperatures over seasons and significant meteorological events (storms, droughts, heat waves). For instance, investigations in Lake Pontchartrain revealed that stratification occurred in the vicinity of the Bonnet Carré spillway due to temperature driven density gradients (USGS, 1996). Lake Maurepas is typically warmer than Lake Pontchartrain, but also not as deep. Further evaluation on the potential for thermal stratification may be necessary. Likewise, vertical density gradients due to salinity differences may need further analysis, particularly since the RMA2 model module is a 2-D and vertically integrates the water column.
- Existing net inputs of nitrogen, phosphorus, and silica are currently only inferred by observed concentrations in swamp, tributary, lake, and Pass Manchac waters. A watershed-scale analysis on nutrient loads, including atmospheric deposition, is necessary to contrast future estimates of loads due to the proposed diversion and to run comparative analyses against reference sites (*i.e.*, other similar estuarine systems). This would allow additional comparative approaches toward estimating net retention and export (*e.g.*, Dettmann, 2001).
- Nutrient balances between Lake Maurepas and Lake Pontchartrain could be calculated, or estimated, based on USGS real time water quality monitoring (USGS Gaging Station 301748090200900) of NO_3 + NO_2. Data from this station was attained for the development of this report; however, it was missing NO_3+NO_2 data and recent attempts to collect this failed due to *in situ* instrument malfunction. This information could be potentially significant, especially if it were to indicate that Lake Pontchartrain is a net exporter of inorganic nitrogen to Lake Maurepas.
- Potential evapotranspiration (PET) has not been considered in any of the diversion analyses. Preliminary estimates of the magnitude of PET on the hydrologic budget of Maurepas Swamp suggests that as much as 10% of the diversion water could be lost to evaporation and transpiration (J. Brawley, personal communication). An evaluation of this process and the sensitivity of the projected mass balances of water, salinity, and water column constituents are recommended.

- Further analysis of existing or future water temperature data would decrease present uncertainties related to the effect of a 1,500 cfs diversion of Mississippi River water through the system. The effect of canopy, water residence times, and the periodicity of pulsed events need to be considered to understand water temperature characteristics in both the swamp and receiving lake waters.
- Lake Maurepas water column properties and trends are considerably under represented in supporting literature. Water column light attenuation and stratification would elucidate current assumptions regarding the photic zone and net areal production within the lake. Additional phytoplankton standing stock and productivity measurements would be necessary to calculate total system production (baseline and future).
- It is unclear whether the existing benthic community would be influenced by increased nitrogen and freshwater. Additional studies on species assemblages and benthic habitat quality in Lake Maurepas are recommended.

The following recommendations are provided to fill in data gaps and reduce areas of uncertainty associated with understanding chemical contaminant exposures to ecological resources:

- Additional sediment and surface water samples should be collected in the Mississippi River to validate the chemical exposure data compiled for this screening-level risk assessment. These samples should be collected from areas near the proposed diversion such that it represents a source of inputs to the Maurepas Swamp. These data would reduce the temporal and spatial uncertainty in the current data set.

- Additional data collection should be considered within the study area. A limited number of sediment and surface water samples would allow for comparative risk/benefits to be assessed quantitatively.

- Available criterion for atrazine toxicity is based on values protective of aquatic organisms. Additional information on the toxicity of atrazine effects to upper trophic level organisms should be evaluated to address potential public concern and the seasonal spikes of this contaminant.

- The screening-level risk assessment assumes that the maximum concentration of contaminants in sediment and surface water samples in the Mississippi River will be present in the Maurepas Swamp, following the diversion. This is a highly conservative assumption and does not take into account any fate and transport processes, chemical degradation or transformation. To resolve this uncertainty, a fate and transport model should be incorporated into the hydrological model currently being developed for this project.

During the development of the final EIS, it will be necessary to research and address additional characteristics of the Maurepas Swamp, Lake Maurepas, and the Mississippi River. These points that will require further study were outside the formal scope of this project, but the National Environmental Policy Act (NEPA) guidelines require that the types of information and resources described below be considered. Important to include in the EIS, are the potential impacts resulting from the construction phases of the Hope Canal diversion as well as the operational phases.

Socioeconomic Information
Consideration will need to be given to the fishing economies (finfish and shellfish) in the Mississippi River, Lake Maurepas, and Lake Pontchartrain and how they will be impacted by both the construction and operation of the diversion project. Effects on subsistence fishermen as well as commercial fishermen and fishing support industries must be taken into account. Other socioeconomically important activities in the region may include tourism, recreational pursuits (*e.g.*, fishing, hunting, camping, kayaking), farming, energy generation and extraction, or lumbering and a final EIS will have to address potential impacts to these interests. Related to this topic is water navigation and how it will be affected (if at all) by both construction and operation.

Health and Safety Information
Although the risk assessment included with this report addresses the potential for humans and wildlife to be affected from any contaminant increases as a result of the diversion, an EIS will also often require an assessment of the atmospheric acoustic impacts (likely related to construction phases only) to humans and wildlife in the area. A related issue will be underwater noise associated with construction or operation and the effects on fish in the Mississippi River, Maurepas Swamp, and associated lakes. An assessment of how air resources may be affected during construction will likely need to be included in a final EIS, including the relevant air quality standards, the air quality changes that can be expected given the construction equipment, and the regional meteorological conditions.

Historical and Cultural Information
The applicable state and local historical preservation and mitigation policies will need to be determined and an archaeological assessment will likely need to be completed before construction can begin. A survey of power lines, underwater or underground cables, and other transmission lines will need to occur before construction can safely begin.

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