MISSISSIPPI RIVER DIVERSION INTO THE MAUREPAS SWAMP

Water Quality Analysis – Draft Final Report

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EXECUTIVE SUMMARY

The objectives of this study were 1) to carry out a baseline study of water quality parameters in the Maurepas basin that is proposed to receive diverted water from the Mississippi River and 2) to to estimate nutrient uptake in diverted river water based on patterns of water flow determined using a UNET hydrologic model and nutrient loading-uptake relationships. Water sampling trips were carried out monthly from April 2000 to June 2001 at 19 stations covering all of the major bayous and water bodies in the Maurepas swamp, as well as some of the side channels to the main bayous. Nitrate concentrations ranged from non-detecable to 0.143 ppm, with a mean of 0.008 ppm. These levels are much lower than the Mississippi River. Ammonium concentrations ranged from non-detectable to 0.048 ppm, with an average concentration of 0.007 ppm. Total nitrogen concentrations ranged from 0.193 ppm to 1.285 ppm, with an average of 0.577 ppm. Ammonium and TN levels were somewhat lower than the river. Phosphate and total phosphorus concentrations ranged from non-detectable to 0.369 ppm, with an average of 0.034 ppm and 0.022 ppm to 0.424 ppm, averaging 0.055 ppm, respectively. These levels were similar to the river. Total suspended sediment concentrations ranged from 4 to 101 mg L^{-1}, averaging 16 mg L^{-1}, and Chlorophyll a ranged from 1 to 31 ug/l. Because the

sampling took place during an extreme drought period, a second year of sampling should determine water quality parameters during more typical climatic conditions.

The hydrodynamic model indicated that water would flow sequentially through different cells representing different sub-basins of the study area. Because of the low capacity of Hope Canal, most of the water flows overland through the swamp. Nitrate loading is high in the initial cells and removal efficiencies are on the order of 40-70%. Loading in subsequent cells is much lower and simulated nitrate retention is greater than 90%. Outfall management is extremely important in the Maurepas diversion project to ensure maximum contact of the diverted water with the wetland surface and high nutrient retention. Based on experience in other estuarine wetland areas receiving river water, concentrations of ammonium, phosphate, total phosphorus should not change significantly from those measured in the baseline study. There should be a high uptake of total suspended sediments which will lead to significant increases in accretion rates. Because most nutrients will be retained in the swamp, the diversion should not cause adverse water quality conditions or extreme or persistent algal blooms in the Lake Maurepas.

INTRODUCTION

Since the early 1900's the Maurepas wetlands have been hydrologically isolated from the Mississippi River by the construction of flood control levees (Mossa 1996). These levees prevent seasonal flooding and thus introduction of sediments and nutrients into nearby wetlands. These floods provided a source of mineral sediments, which contributed directly to vertical accretion; nutrients associated with these sediments promoted further vertical accretion through organic soil formation from wetland plant production (Delaune et al. 1983). These increases in vertical accretion helped maintain wetland elevation above relative sea-level rise (RSLR), the combined effect of eustatic sea-level rise (1-2 mm yr^{-1}, Gornitz et al. 1982) and coastal subsidence. Subsidence in the Maurepas wetlands is classified as intermediate, at about 1.1 to 2.0 feet/century, but has resulted in a net decrease in ground surface elevation and continuous flooding of most of the swamp. This has led to a lack of regeneration since seedlings need a period of no flooding to survive. Occasional intrusion of saltwater is another factor that probably contributes to stress on the swamp forest. These intrusions are apparently associated with drought conditions combined with meteorological events that produce excessively high tides. Such salinity levels are damaging to freshwater swamps; tupelo trees are especially sensitive to salinity as low as 2 practical salinity units (PSU).

As a restoration effort, the State of Louisiana has proposed a freshwater diversion into the Maurepas wetlands that will mimic flooding events of the Mississippi River (Chatry and Chew 1985). Though increases in the catch of oysters, saltwater finfishes and penaeid shrimp have been attributed to other Mississippi River diversions (Gunter 1953, Chew and Cali 1981), there has been controversy about the effects of diverting Mississippi River water into Lake Maurepas. A major concern is possible eutrophication, and associated phytoplankton blooms, as currently observed in Louisiana's offshore waters (Turner and Rabalais 1991; Rabalais et al. 1994, Dortch et al. 1998) and other estuaries throughout the world (Justic et al. 1995, Rosenberg 1985). On death, bacterial decomposition of excess algal cells may deplete oxygen levels in the lower water column, leading to disruption of the benthic community and other deleterious affects. Phytoplankton blooms can lead to anoxic conditions that can cause widespread mortality of commercial fish populations.

Phytoplankton production in coastal wetland systems is most likely to be nitrogen limited relative to phosphorus due to denitrification, the preferential sedimentation of nitrogen in zooplankton fecal pellets, and the more rapid recycling of phosphorus (Nixon et al. 1980, Howarth 1988). Phytoplankton can generally assimilate only inorganic nitrogen, which exists in two forms, nitrate (NO_3^-) and ammonium (NH_4^+). Other forms of nitrogen are usually in a recalcitrant, non-labile form, that are not available for phytoplankton assimilation or growth. The inorganic nitrogen fraction in Mississippi River water is predominantly in the form of nitrate (Figure 1).

Various studies have reported reduction of NO_3^- in estuarine environments with much of the reduction due to denitrification (Khalid and Patrick 1988, Lindau and DeLaune 1991, Nowicki et al. 1997). Denitrification of NO_3^-, and the subsequent release of nitrogen to the atmosphere, has been found to occur at high rates (Smith et al. 1983, Khalid and

Patrick 1988, Lindau and DeLaune 1991, Nowicki et al. 1997). Jenkins and Kemp (1984) reported that up to 50% of NO_3^- introduced into the Patuxent River estuary underwent denitrification. This process is carried out by denitrifying bacteria that use nitrate as an electron acceptor to oxidize organic matter anaerobically (Koike and Hattori 1978). Another transformation pathway of NO_3^- is assimilation into particulate organic matter by autotrophic photosynthetic organisms and vascular plants. There is often a permanent loss of nitrogen due to the burial of organic material in the coastal zone due to the high subsidence rate. DeLaune et al. (1981) studied wetlands in Barataria Bay found nitrogen was buried in the interior marsh at a rate of 13.4 g m^{-2} yr^{-1}.

The rate of nitrogen removal is dependent on the loading rate and the form of nitrogen (e.g., NO_3^- vs. NH_4^+). It is also essential that to assure maximum efficiency of nitrogen removal, diverted water be spread over the swamp as much as possible (Blahnik and Day 2000). There have been several studies of the relationship between the nutrient loading rate into wetlands and associated removal efficiency (Spieles and Mitsch 2000, Boustany et al. 1997, Faulkner and Richardson 1989, Richardson and Nichols 1985). The most comprehensive studies have been of wetland wastewater treatment systems, where the predominant form of nitrogen is NH_4^+. Mississippi River water contains predominantly NO_3^-, that is much more reactive than NH_4^+, because of the potential for denitrification. Therefore Mississippi River water entering wetlands will have a much higher removal efficiency than wetland wastewater studies indicate. There was a 88 to 97 percent reduction of NO_3^- in Mississippi River water flowing into the Caernarvon receiving basin with a loading rate that ranged from 5.6 to 13.4 g m^{-2} yr^{-1} at Caernarvon, Louisiana (Lane et al. 1999, Table 3). During the 1997 opening of the Bonnet Carre Spillway, Lake Pontchartrain received Mississippi River water at a NO_3^- loading rate of 8.6 g m^{-2} yr^{-1}, and 92 to 98% reduction of NO_3^- was calculated (Day et al. 1999). In a wetland treatment system at Thibodaux where NO_3^- was the dominant form of inorganic nitrogen due to a high rate trickling filter, NO_3^- removal was 100% within 200-800 m of the input (Zhang et al. 2000), with most of the reduction due to denitrification (Boustany et al. 1997).

These studies indicate very high removal efficiencies for NO_3^-, but at high loading rates, removal efficiencies decrease (Spieles and Mitsch 2000, Boustany et al. 1997, Faulkner and Richardson 1989, Richardson and Nichols 1985). For example, Spieles and Mitsch (2000, Table 1) found only a 37 to 40% reduction in NO_3^- in wetlands receiving Olentangy River water at loading rates of 4.6 to 4.7 kg ha^{-2} day^{-1} (equivalent to 168 to 172 g m^{-2} yr^{-1}). In 1997, the Atchafalaya River estuarine complex had a loading rate of 66 to 136 g m^{-2} yr^{-1}, with a 41 to 47% decrease in NO_3^- (Lane et al. 2001b, Table 2). These studies suggest (Table 1), that the NO_3^- removal efficiency for the Maurepas forested wetlands will be greater than 90% if yearly loading to the system does not exceed 10 g m^{-2} yr^{-1} (Figure 2), and daily loading is less than 0.1 g m^{-2} day^{-1} (Figure 3). These loading rates are average rates calculated for total receiving systems. In the next paragraph, we point out that the way water flows through a system is very important to determining actual nutrient retention rates.

There are several things to consider when using these curves. First, the curves are based on total loading to the different systems and assume that the water inputs are spread evenly over the receiving area. However, it is known that water flowing into a wetland often forms small channels and the actual contact area is much lower. At a treatment wetland at Breaux Bridge, LA for example, Blahnik and Day (2000) found that about 60% of the surface water flow was concentrated in only 10-12% of the area. Similarly, at the fresh water diversion at Caernarvon Louisiana (Lane et al. 1999), the actual contact area of the inflowing water was considerably less than the area used to calculate the loading rates. Therefore, the loading rates-retention estimates are conservative. Second, the shape of the loading-uptake curve shows that uptake decreases rapidly with increasing loading at low loading rates (e.g., less than 10 g $m^{-2}y^{-1}$ or 0.1 g $m^{-2}d^{-1}$), but changes very little at higher loading rates (e.g., greater than 10 g $m^{-2}y^{-1}$ or 0.1 g $m^{-2}d^{-1}$). Thus, proportionally much more total quantity of material will be removed at higher loading rates even if the % removal is lower. This indicates that river water flowing sequentially through a series of wetland cells (as is discussed in the hydrologic model later in the paper) will have a higher removal rate than if the water was applied equally at the same time over the whole area. Therefore, this suggests that loading rates calculated for the entire Maurepas receiving area will be conservative compared to loading rates calculated for a sequence of cells. This will be discussed in more detail later in the paper.

Suspended sediments introduced from Mississippi River freshwater diversions are rapidly trapped in the receiving wetlands (Lane et al. 1999, 2001a,b). This is due to decreasing water velocity when entering the estuary, allowing suspended sediment to drop out of the water column. DeLaune et al. (1979) found the mineral fraction in coastal Louisiana soils to range from 0.2 to 0.4 g cm^{-3}, with the remainder of the soil matrix, and the vast majority of soil volume, consisting of locally generated organic material from root growth and void space. Thus, a minimum of about 0.2 grams of mineral sediment must be supplied for each cm^2 (or 2 kg of sediment per m^2) of wetland area (Suhayda et al. 1991).

In this study, we had several objectives. The first was to carry out a baseline study of water quality parameters in the Maurepas basin that is proposed to receive diverted water from the Mississippi River. Sampling stations were established in the proposed receiving area and in control areas that will not be affected by the diversion. This sampling serves to characterize current water quality conditions in the basin and thus provides a comparison for expected conditions resulting from the diversion. The extreme drought conditions over the last year means that the values for these water quality parameters are not likely to be typical for the area under normal precipitation levels. The second major objective was to estimate nutrient uptake in diverted river water. To accomplish this, we used a hydrologic model to estimate water routing through the system. The system was divided into different cells and loading and uptake was estimated for each cell based on loading-uptake curves.

METHODS

Water Quality Analysis

Water sampling trips were carried out monthly from April 2000 to June 2001 in order to characterize current conditions in the Maurepas swamp, but only results through October 2000 are presented. The sampling trips were conducted on April 25, May 23, June 29, July 26, August 22, September 19, and October 23, 2000. Additional sampling has continued monthly, however, but the analytical results were not available when this report was prepared. These results will be included in the final report. Water samples were taken at 18 locations on May 23, and 19 locations during the rest of the sampling (Figure 4). Station 7 was the sampling station added. Station locations were determined with the intention of covering all of the major bayous and water bodies in the Maurepas swamp, as well as some of the side channels to the main bayous. Side channels within the swamp were sampled to determine if there were differences between the main channel and interior areas. It was felt that this would provide a first estimate of the ability of the wetland to lower nutrient concentrations. When this study was first conceived, the location of the proposed diversion was unknown. Because of this, the three main alternatives, Blind River, Hope Canal, Reserve Canal, were sampled extensively.

Water samples were collected in 500 mL acid-washed polyethylene bottles, stored on ice and taken to the laboratory for processing. Within 24 hours, 60 ml from each water sample were filtered through pre-rinsed 25 mm 0.45 μm Millipore filters. The filtered water samples, and filters, were frozen until nutrient and chlorophyll analysis, respectively. Within one week of sample collection, total suspended sediment (TSS) was determined by filtering 100-200 mL of sample water through pre-rinsed, dried and weighed 47 mm glass microfiber filters. Filters were then dried for 1 hr at 105°C, weighed, dried for another hour, and reweighed for quality assurance (Standard Methods 1992). Salinity was also determined within a week of sample collection using a Atago© S-10 hand held refractometer (accuracy: ±2 practical salinity units (PSU)). Within one month of sample collection filtered samples were analyzed for chlorophyll a. Nitrate (NO_3-N) and nitrite (NO_2-N) were determined separately using the automated cadmium reduction method with an Alpkem© autoanalyzer (Standard Methods 1992). NO_3^- was the predominant form (>90%) of total oxidized nitrogen (NO_3^-+NO_2^-), and therefore NO_3^-+NO_2^- was reported as NO_3^-. Ammonium (NH_4^+-N) was determined by the automated phenate method, and phosphate (PO_4^{3-}) by the automated ascorbic acid reduction method, both with an Alpkem © autoanalyzer (Standard Methods 1992). The accuracy of the nutrient analysis was checked every 20 samples with a known standard, and the samples were redone if the QC was off by 5%. Chlorophyll a was determined by a modified version of the technique suggested by Strickland and Parsons (1972). Chlorophyll pigments were extracted with a 40:60 ratio of dimethyl sulfoxide (DMSO):90% acetone as described by Burnison (1980). The extract was measured fluorometrically with a Turner Designs model 10-AU fluorometer (Standard Methods 1992).

Hydrodynamic model of Nitrate Loading to the Maurepas Swamp

An important goal of the Maurepas diversion project is to supply as much nutrients to the swamp as it could assimilate without adversely affecting water quality. Conversely, the goal is to limit direct nutrient input to Lake Maurepas. Not all of the 122 km^2 of swamp receiving flow from the diversion is equally benefited or effectively engaged in nutrient assimilation. It was appropriate then to use a hydrodynamical model, referred to as a UNET model, to examine the actual distribution of water through the study area for a fully developed flow. Fully developed flow is that which occurs at steady state conditions. The study area was divided into labeled channels and numbered swamp cells and the UNET model allowed quantification of flow rates between cells (see Figure 12, in Kemp et al. 2001). The report by Kemp et al. (2001) gives details of this model.

In order to develop an initial estimate of nitrate uptake by the system, the results of the UNET model and Mississippi River concentrations of nitrate were used to calculate nitrate uptake. Mississippi River water quality was obtained from a previous study of the Caernarvon Mississippi River diversion (Lane et al. 1999). Water samples were taken monthly from January 1988 to December 1994 at Caernarvon, Louisiana, located at river mile 81.5 and analyzed for nitrate, ammonium, total nitrogen, and total suspended sediments, as well as several other constituents. These seven years of data were averaged by month (Figure 1), and these averaged values were used as initial concentrations with the results of the (UNET) hydrodynamic model that has been developed for this study to estimate distribution of water. Nutrient uptake in each cell was estimated from the loading-uptake curves (Figures 2 and 3). This is explained in more detail below.

RESULTS & DISCUSSION

Water Quality Analysis

In order to simplify such a large data set, consisting of over 900 values, the stations were grouped by region as defined below, delineated by hydrological boundaries. The Amite/Blind River region consisted of stations 9, 10, 11, 13, and 15; the Hope/Dutch Bayou region of stations 1, 2, 4, 6, and 7; the Reserve Canal region of stations 16, 17 and 20; and the Lake Maurepas region of stations 3, 6, and 18. Values for each station during each month are given in Figures 6-9, and averaged data for each region during each month are given in Figure 5.

Nitrate concentrations ranged from non-detectable to 0.143 ppm, with a mean of 0.008 ppm. The highest concentration occurred in April at station 10, located in the Amite River (Figure 6). It should be noted that these nitrate concentrations are very low compared to the Mississippi River that has an approximate average concentration of 1.5 ppm and generally ranges between 0.75 and 2.0 ppm. Ammonium concentrations ranged from non-detectable to 0.048 ppm, with an average concentration of 0.007 ppm. The highest concentrations occurred during September in the Amite/Blind River and Lake Maurepas regions (Figures 6,9). These values are somewhat lower than ammonium levels in the Mississippi River which generally are less than 0.1 ppm. Total nitrogen concentrations ranged from 0.193 ppm to 1.285 ppm, with an average of 0.577 ppm. The highest levels were in the Hope /Dutch Bayou region, but all other regions had average TN concentrations above 0.4 ppm (Figure 5). River concentrations of TN in the river generally are between 1.0 and 2.0 ppm. The high total nitrogen and low inorganic nitrogen concentrations indicate the presence of high concentrations of nitrogen in the organic form, such as humic substances, tannins, and phytoplankton.

Phosphate concentrations ranged from non-detectable to 0.369 ppm, with an average of 0.034 ppm. The highest concentrations were consistently found at station 1, the most southern station on Hope Canal (Figure 7). Total phosphorus concentrations ranged from 0.022 ppm to 0.424 ppm, averaging 0.055 ppm. The peaks of PO_4 found at station 1 were also evident in high TP concentrations during the same periods. These concentrations for phosphate and TP are similar to concentrations in the river.

Total suspended sediment concentrations ranged from 4 to 101 mg L^{-1}, averaging 16 mg L^{-1}. Stations located around Lake Maurepas had the highest TSS concentrations (Figure 9), probably due to high wave energy that resuspended bottom sediments. The TSS concentrations were considerably less than those in the Mississippi River which generally range between 200 and 300 mg/l. Conversely, Lake Maurepas had the lowest chlorophyll a concentrations of any of the other regions in this study (Figure 5). Chlorophyll a ranged from 1 to 31 ppb, with the highest concentrations in the Blind/Amite River and Hope Canal/Dutch Bayou regions.

Salinity ranged from 0 to 12 PSU, with an average of 3 PSU for the entire study. The highest levels were at the two stations located at the eastern side of Lake Maurepas, but substantial salinities (above 5 PSU) were found at all regions during some time during this study. The Amite/Blind River region had the lowest salinities in the study area during spring and summer, coinciding with high river flow in the Amite basin, but salinities in all regions averaged above 4.5 PSU during September and October (Figure 6). Such high salinities are detrimental to the freshwater wetland plant communities.

Comparisons of main channel versus side channel constituent concentrations revealed several trends. The main and side channel station pairs included stations 9 and 8 (Figure 10), 11 and 12 (Figure 11), and 13 and 14 (Figure 12), respectively. There tended to be lower nitrate concentrations in the side channels compared to the main channels, but the very low ambient nitrate levels make this conclusion tenuous. There were generally higher total nitrogen concentrations in the side channels compared to the main bayous. The side channels also had generally lower chlorophyll *a* concentrations than the main channels. These results support the idea that significant nitrate reductions will occur in interior swamp areas.

Hydrodynamic model of Nitrate Loading to the Maurepas Swamp

The project area that can be potentially flooded from a Mississippi diversion from Hope Canal was delineated as the region north of I-10, bound to the west by Blind River, to the east by Reserve Canal, and the north by Alligator Bayou, an area of 122 km^2. As has been discussed, nitrate nitrogen is the nutrient form that occurs in Mississippi River water at high concentrations relative to background in the swamp or Lake Maurepas. Processing of nitrate by the swamp must be effective if nutrient, and specifically nitrate, loading to the Lake is to be reduced to acceptable levels.

When the diversion is initiated, water first flows into storage in the swamp and little reaches Blind River or the Lake. Residence time for water entering the swamp at this time is long, allowing for more effective nutrient assimilation. After the diversion is shut down, the head driving transport is removed and, again, residence time rises. The critical design condition with respect to nitrate uptake is most closely approached when the swamp has reached its full storage capacity and Mississippi River water is flowing continuously in something of a steady-state. The model indicates that these conditions are reached after about 1 month of operation at 1500 cfs, and after longer periods for lower volume or discontinuous discharges.

In the proposed diversion, Mississippi River water will be conveyed by a large leveed channel to the I-10 bridge. At this point it will enter the Hope Canal channel. The unimproved Hope Canal channel downstream of the I-10 bridge has a capacity to convey about 100 cfs at bank-full. A longitudinal section of this channel showing discharge at various points shows that most of the 1,500 cfs that reaches the I-10 bridge will be lost from the channel within 1 mile of this point. The water that is lost from the channel will be discharged into the adjacent swamp through natural and artificial breaks in the banks.

Five miles downstream from the I-10 bridge, discharge increases again when Hope Canal joins Dutch Bayou. This added water has traversed the swamp for up to 5 miles. About 800 cfs -- of the original 1,500 -- reaches the Lake via this route. About 600 cfs enters the Lake after moving west and reaching Blind River, while only 100 cfs reaches the eastern study area boundary at Reserve Relief Canal. The shortest route that the water can take through the swamp is the route to Blind River, a distance of about 3 miles.

The most conservative approach to estimating nitrate assimilation and throughput assumes that all water in the swamp is derived from the Mississippi River. In reality, water in the swamp comes from a variety of sources that are likely to contribute little nitrate. With this caveat, it can be assumed that the water leaving the channel cascades from one swamp cell into the next adjacent down-gradient cell until it reaches a boundary, whether Blind River, Lake Maurepas or the Reserve Relief Canal. Mississippi Bayou, between Hope and Reserve Relief, also intercepts flow. Steady-state discharges from one cell to the next were determined (Table 2).

Table 2 contains information on flow distribution, nutrient concentrations and loading. The first column shows the swamp cell number (see Figure 12 in Kemp et al., 2001, Attachment C). The area of that cell in acres and square meters is given in the two columns to the right. The discharge in cubic feet per second (cfs) and cubic meters per day (cmd) received by the referenced swamp cell is given in the next two columns. Table 2 is separated into sections grouping primary cells that receive water directly from Hope Canal (Q1), secondary cells that receive water leaving the primary cells (Q2), and so on through the cascade.

Water leaves the Mississippi River and Hope Canal with an assumed nitrate concentration of 1.5 parts per million (ppm or grams per cubic meter), but the entering concentration for cells receiving water indirectly must be determined based on loading and processing by the up gradient swamp cell. Loading is a function of the input concentration, the volume of water introduced and area of the receiving swamp cell. Because denitrification occurs so rapidly, and this is the most significant transformation process in the swamp, all loading calculations are made on a daily basis (grams per square meter per day, g m^{-2} d^{-1}). The capacity of the surface area of the swamp for removal of nitrate is known and has been plotted for a range of daily loadings (Figure 3). As has been discussed, removal efficiency (% removal) decreases in a non-linear fashion as loading increases.

The sixth column in Table 2 gives the input nitrate concentration (grams per cubic meter) and the loading in the next column to the right. The loading rate is found on the X-axis in Figure 3, and the approximate removal efficiency is read from the Y-axis. This removal efficiency is listed in the eighth column. A nitrate concentration for water exiting the cell is given in the last column. This then becomes the input concentration to the next receiving cell.

As can be seen, nitrate loadings in the swamp cells adjacent to Hope Canal range from .09 to .24 g m^{-2} day^{-1}, relatively high values that will ensure significant swamp benefits. Removal efficiencies for these cells are relatively low (40 to 70 percent) as would be expected. Concentrations of nitrate entering the next swamp cells are calculated at between 0.45 and 0.9 ppm. Loadings at the next tier of cells in the swamp cascade range from 0.03 to 0.06 g m^{-2} day^{-1}, levels that assure reductions of 90 to 95 percent, resulting in calculated exit concentrations ranging from 0.02 to 0.09 ppm. The minimal reduction in nitrate from Mississippi River concentrations (1.5 ppm) would be 94 to 99 percent along the shortest path to Blind River. Calculated resulting concentrations for this path are on the high end of the range measured in the channels to this point, but effects of dilution have not been considered. Reductions for the longer paths that most water will follow will, of course, be greater. The effect of rainfall, mixing and other diluting factors may be assessed in the next phase of work when 2-dimensional modeling is planned. In the absence of more detailed information on flow paths, these preliminary calculations give confidence that little Mississippi River derived nitrate will reach Lake Maurepas, even if a 1,500 cfs diversion were operated continuously at full capacity.

Importance of Outfall Management

The calculations in the previous section assume that the diverted water flows over the entire surface area of the receiving swamp. The small capacity of Hope Canal will ensure that most diverted water will move as overland sheet flow. It is known, however, that water flowing in wetlands often tends to move in shallow channels which limits the contact area (e.g., Blahnik and Day 2000). Therefore, outfall management is extremely important in the Maurepas diversion project to ensure maximum contact of the diverted water with the wetland surface. Care should be taken in the next phases of the project to identify any possible short circuits and to develop an outfall management plan that eliminates these short circuits. If short circuits do take place and wetland contact is reduced, then the actual nutrient uptake rates will be lower than those discussed here.

Behavior of Other Nutrients in the Proposed Diversion

This report has focused maily on nitrate because it is the inorganic nutrient with the highest concentration in river water and therefore of most interest in terms of potential for offshore hypoxia and river diversions. However, the other forms of nitorgen (ammonium and organic nitrogen) and phosphorus (total phosphorus and phosphate) are also of interest. In this section, we review the expected behavior of these forms in the proposed river diversion.

Ammonium concentrations in river water are less than a tenth of nitrate, so that loading of ammonium from the river is not significant when compared to nitrate. Ammonium can also be added to the water column by regeneration during the decomposition of organic matter. This generally leads to an increase in ammonium concentrations downstream from an introduction of water into a wetland/estuarine system. This has been observed in both river diversions and wetland treatment systems. At the Caernarvon diversion, ammonium increased with distance from the structure, from between 0.05-0.1 mg/l in the river to values of between 0.1 and 0.2 mg/l (Lane et al. 1999). Similarly, ammonium increased from an average of 0.05 in the Atchafalalya River to a mean of about 0.1 with distance from the river (Lane et al. 2001b). In both of these cases, ammonium first increased and then decreased. Similar patterns of ammonium increases and then decreases also have been reported for wetland treatment systems in Louisiana (Blahnik and Day 2000, Zhang et al. 2000). Thus, it is expected that ammonium concentrations and spatial patterns in the Maurepas diversion will likely be very similar to that reported for other diversions in Louisiana with peak ammonium concentratons generally between 0.1 and 0.2 mg/l.

Such ammonium dynamics are primarily caused by the regeneration of NH_4 by the decomposition of organic matter (Kemp and Boynton 1984), as well as reduction of NO_3 to NH_4 (Sorenson 1978). Bacteria and fungi decompose organic material to obtain energy and in the process release nutrients in dissolved organic form (Day et al. 1989). Numerous studies have shown the net mobilization of NH_4 by benthic sediments (Koike and Hattori 1978; Callender and Hammond 1982; Teague et al. 1988). The relatively shallow water depths, rapid settling rates and rapid bacterial utilization result in fairly short residence times for organic material in estuarine and wetland waters (Moran and Hodson 1989). Therefore, much of the regeneration of nutrients probably takes place on or in the bottom sediments, which is where NH_4 regeneration is highest (Blackburn 1979).

Total nitrogen (TN) in the study area generally ranged from 0.5 to 1.5 mg/l. Several studies have shown that TN decreased with distance where river water flows into coastal wetland/estuarine systems in the Mississippi Delta (Lane et al. 1999, 2001 a,b, Perez 2000). Lane et al. (1999) reported that at the Caernarvon diversion, mean TKN concentration were higher in the upper estuary (1.2-1.6 mg/l) than in the river (0.9-1.1 mg/l) but decreased further into the system. They concluded that the estuary was a source of organic nitrogen that then decomposed down estuary. We expect that the Maurepas system will respond in a similar manner and that TN concentrations will decrease significantly with distance from the diversion.

PO_4^{3-} concentrations in the study area were in the same range as the Mississippi River and in other areas receiving Mississippi River water (Atchafalaya, Lane et al. 2001b; Bonnet Carre, Lane et al. 2001a; Caernarvon, Lane et al. 1999). Lane et al. (2001b) reported that PO_4 was often higher in the estuarine regions compared to the Atchafalaya River, suggesting benthic remineralization to be a major source of PO_4 to the water column. But values were generally less than 0.15 mg/l. Estuarine and wetland sediments have been found to be net sources of PO_4, with flux rates highly correlated with temperature (Nixon et al. 1980), but cases of estuaries acting as net sinks for PO_4 have also been reported (Callender and Hammond 1982, Froelich 1988, Teague et al. 1988). These contradictory findings may be because PO_4 is readily sorbed by clay and detrital organic particles at high concentrations, while at lower concentrations PO_4 is released into the water, thus maintaining moderate ambient concentrations (Jitts 1959, Patrick and Khalid 1974). Also, cyclic aerobic and anaerobic conditions in the top several millimeters to centimeters of the wetland soil effect the sorption and release of PO_4, with PO_4 being released during anaerobic conditions (Patrick and DeLaune 1977), possibly exasperating hypoxic events. Sharp et al. (1982) found these sorption-desorption processes provide a buffering mechanism for phosphorus in the Delaware estuary. Madden et al. (1988) showed that TP behaved similarly in Fourleague Bay, Louisiana, with little change in concentration throughout the year. These findings suggest that neither TP nor PO_4 concentrations will likely change much with diverted river water.

Summary of the Expected Effects of the Proposed Diversion on Nutrient Levels

The forgoing analysis provides a first estimate of the impact of the proposed diversion on the Maurepas system. The results of sampling of water quality parameters shows that for some nutrient forms, the Maruepas basin has relatively low nutrient concentrations compared to the Mississippi River and other systems studied. However, most of the sampling occurred during one of the most prolonged droughts in the history of south Louisiana. So it is likely that during more normal rainfall periods, concentrations of some constituents would be higher. For this reason, sampling during the second year of the study is necessary to document more normal conditions.

The mean concentration of nitrate in the Maurepas study area of 0.008 ppm (range undetectable to 0.14 ppm) is much lower than than what is found in the Mississippi River (reported values range from 0.75 to 1.6 ppm). Results of studies from other areas where river water is entering shallow wetland and estuarine systems show rapid declines of nitrate generally to values of 0.1 ppm and lower. With proper outfall management, similar reductions of nitrate are to be expected in the Maurepas system. Ammonium concentrations in the Maurepas system are in the low range of values reported for the Mississippi River and for systems that presently receive river water. We feel that under normal rainfall conditions, ammonium levels would be somewhat higher. TN and organic nitrogen levels in the Maurepas system are similar to those in the Mississippi River and systems receiving river water. These results suggest that the low rainfall resulted in a low input of inorganic N and that most N is tied up in organic forms. The proposed diversion should not significantly change TN levels.

Concentrations of phosphate and TP in the Maurepas system are similar to levels in the Mississippi River and to systems which receive river water. We expect that the diversion will not significantly change the concentrations of these parameters. The buffering mechanisms for phosphorus discussed earlier will serve to generally maintain concentrations within the existing range.

TSS levels in the Maurepas system are significantly lower than in the Mississippi River but similar to wetland dominated coastal systems receiving river water. An outfall management plan designed to maximize wetland overflow and contact will result in highly efficient trapping of sediments. This sediment deposition will also carry sorbed nutrients. Chlorophyll levels in the Maurepas system are in the range for other systems receiving river water. The outfall management plan will lower nutrient concentrations and reduce the probability of extensive phytoplankton blooms.

Sediment loading to the Maurepas Swamp

The Mississippi River will be the primary source of sediments to most of the study area in the proposed Maurepas diversion. In estuarine waters, additional TSS is formed by flocculation of dissolved organic and inorganic matter during the mixing of river and sea water (Sholkovitz 1976). Turbidity maximums due to this process have been reported for rivers such as the Amazon, where suspended sediment concentrations a few meters from the bottom were as high as 500 mg L^{-1} (Gibbs 1976). Uncles and Stephens (1993) found the turbidity maximum in the Tamar estuary to be associated with the freshwater-saltwater interface, where there was considerable resuspension of near-bed sediment by relatively strong currents. In the Maurepas study area, physical settling will be the most important mechanism for decreased sediment concnetrations because almost all of the sediment will be deposited in the swamp before any salt water is encountered. Lane et al. (1999) reported that there was very rapid decrease of TSS in the Caernarvon outfall area within a short distance of the diversion structure. Since this is an actively subsiding area, burial will be an important mechanism for permanent uptake of mineral sediments as well as nutrients either sorbed to sediments or taken up by biological activity.

A diversion of 1500 cfs run all year would deliver about 1.6 km3 of river water to the Maurepas system. This discharge would introduce approximately 3.6 x 108 kg of mineral sediment into the Maurepas wetlands each year. If it is assumed that sediments would be evenly distributed over the entire wetland area (122 km2), the loading rate per m2 would be 2.8 kg. Assuming that mineral sediments have a bulk density of about one, then this would yield an elevation gain of 0.28 mm. Since the sediments will be deposited in water and because the majority of vertical accretion in a wetland is due to organic soil formation, the deposited sediment will generate considerably more elevation gain. It is unlikely that suspended sediments would be evenly distributed. It is more likely that sediments will be deposited very rapidly after leaving channelized flow, and as initial areas are filled in, sediment deposition will move further into the wetland complex. The expected rise in elevation in the initial UNET cells will most likely produce a hydrological gradient that will convey sediment-laden water to more distant cells where further deposition would take place.

Potential Diversion Impacts in Lake Maurepas

Our analysis suggests that nitrate introduced in the proposed diversion will be mostly retained in the swamp wetland system. Nitrate flowing into the lake can be taken up by phytoplankton as well as undergoing the same dynamics (e.g., denitrification, reduction to ammonia) as in the wetland system. Rapid reductions in nitrate in Mississippi River water flowing into shallow estuarine waters in the Mississippi delta have been reported, with much of the decrease due to denitrification (Lane et al. 1999, 2001 a,b, Perez 2000, Madden et al. 1988, Teague et al. 1988). The shallow, well-mixed water column and anaerobic sediments in Lake Maurepas are highly conducive to denitrification.

Dugdale and Goering (1967) defined nitrogen available to phytoplankton to be in either ‘new’ or ‘regenerated’ form. They defined NO_3^- as new nitrogen derived from autochthonous sources, such as riverine, whereas NH_4^+ was defined as regenerated nitrogen resulting from remineralization within the benthos or the water column. Using this definition, it is likely that phytoplankton growth in Lake Maurepas will be supported mainly by regenerated nitrogen since most nitrate will be taken up in the swamp system.

Coastal estuarine systems are more likely to be nitrogen limited relative to phosphorus due to denitrification, the preferential sedimentation of nitrogen in zooplankton fecal pellets, and the more rapid recycling of phosphorus (Nixon et al. 1980, Howarth 1988). Thus the N:P ratio is high in Mississippi River water, but low in the Atchafalaya plume area (Lane et al. 2001b), Fourleague Bay and the western Terrebonne marshes (Madden et al. 1988, Perez 2000), the Bonnet Carre spillway (Lane et al. 2001a), and Caernarvon (Lane et al. 1999). The expected rapid loss of nitrate will shift the N:P ratio of potential N limitation in river water to potential P limitation after water filters through the swamp. Lane et al. (2001a). For example, Madden et al. (1988) and Perez (2000) reported rapid declines of the N:P ratio in the Atchafalaya outfall area. Passage of the water through the swamp system will also affect the Si:N ratio. Lane et al. (2001a) reported that the Si:N ratio increased from around 1.4 in river water to 2.5 to 3.0 after diversion through the Bonnet Carre Spillway. A high Si:N ratio favors the growth of diatoms (Officer and Ryther 1980). Thus, passage of river water through the swamp system will likely reduce conditions for noxious algal blooms both due to lowered nutrient concentrations and to shifts in nutrient ratios.

The response of phytoplankton, as measured by chlorophyll a concentration, in these systems generally indicates a lack of extensive and persistent blooms (Madden et al. 1988, Perez 2000). This is probably due to phytoplankton productivity in highly turbid waters being limited by light, rather than nutrient, availability. In addition, the rapid uptake of nutrients, especially nitrate, lowered nutrient levels. At very high loadings, such as occurred in Lake Pontchartrain following the 1997 opening of the Bonnet Carre Spillway, blooms of nitrogen fixing bluegreen alage can be stimulated (Dortch et al. 1998). This is the reason that it is imperative that loading rates not be excessive so that that wetland assimilation can take place.

The effect of the Maurepas diversion on Louisiana's off-shore hypoxic zone

Diversion of Mississippi River water into the Maurepas swamp will have the effect of buffering the impact that NO_3^- and other nutrients have on the Louisiana coastal shelf zone. This zone is currently experiencing summer hypoxia due to direct introduction of nutrient laden water from the Mississippi River without benefit of processing by a shallow water wetland ecosystem (Turner and Rabalais 1994). The area of low oxygen bottom waters is now widespread during the summer and has been linked to fish kills and other deleterious effects (Turner and Rabalais 1991). Forested wetlands have been shown to be effective sinks for nutrients (Ewel and Odum, 1979 Faulkner and Richardson 1989, Breaux and Day 1994, Boustany et al., 1997). Lane et al. (2001b) found that the Atchafalaya River Delta estuarine complex had the effect of buffering the impact of the Atchafalaya River, and the introduction of NO_3^-, on the Louisiana coastal shelf zone. Based on the results of this study, we estimate that 90 to 100% of diverted Mississippi River NO_3^- will be either transformed or lost before reaching stratified Gulf waters. Similar reductions in nitrogen have been reported to occur in wetland wastewater treatment systems (Nichols 1983, Breaux and Day 1994), as well as in other areas where Mississippi River water flows into shallow inshore areas (Lane et al. 1999, Perez 2000, Lane et al. 2001a,b). The dynamics and impacts of nutrients other than nitrate will be treated in the next section. The use of coastal wetlands and shallow water bodies to process Mississippi River water before entering the Gulf of Mexico has been proposed to help reduce the hypoxic zone, as well as restore and maintain rapidly degrading wetlands (Boesch et al. 1994). Because of the small volume of the Maurepas diversion, it will in itself have a negligible impact on offshore hypoxia since only about 0.5% of the river discharge will diverted. But as part of a larger program of diversions, it is possible that there could be significant reductions of nitrogen reaching the nearshore Gulf of Mexico. Additional studies should further investigate this question.

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Table 1. Nitrate (NO_3^-) loading rates and removal efficiencies for various studies.

Reference	NO_3 LR (g/m2/yr)	NO_3 LR (g/m2/day)	Removal (%)	Influent
Lane et al. '99	5.6		97	Mississippi
	7.3		95	River Water
	13.4		88	
Day et al. '99	8.6		92	
	8.6		98	
Lane et al. '01	66		47	
	136		40	
Reilly et al. '00		1.244	80	Santa Ana
Table 3		2.691	23	River water
pg. 41		5.746	14	
		0.121	82	
		0.893	54	
		2.033	27	
		0.006	67	
		0.373	81	
		2.282	47	
		0.247	100	
		0.389	84	
		1.432	45	
Phipps &	21.6		78	Des Plaines
Crumpton '94	3.2		95	River water
Table 1, pg. 405	20.2		84	
Spieles & Mitsch '00		0.46	39.8	Olentangy
Table 1, pg. 83		0.47	36.7	River water
		1.23	29.3	Wastewater

LR = loading rate

Table 2. Flow distribution, nitrate concentration, loading, and removal of proposed Mississippi River diversion into the Maurepas Swamp.

Cell No.	Area (acres)	Area (m2)	Discharge (cfs)	Discharge (m3/d)	NO3 (g/m3)	Loading (g/m2/d)	Removal (%)	Remain (g/m3)
			Q1					
17	2,319	9.4E+06	550	1.3E+06	1.5	0.213	40	0.9
25	1,040	4.2E+06	200	4.8E+05	1.5	0.172	40	0.9
33	1,578	6.4E+06	150	3.6E+05	1.5	0.085	70	0.45
18	1,870	7.6E+06	500	1.2E+06	1.5	0.24	40	0.9
			Q2					
16	2,667	1.1E+07	300	7.3E+05	0.9	0.061	90	0.09
24	1,383	5.6E+06	150	3.6E+05	0.9	0.058	95	0.045
32	1,885	7.6E+06	225	5.4E+05	0.45	0.032	95	0.023
41	2,069	8.4E+06	500	1.2E+06	0.45	0.065	90	0.045
27	2,714	1.1E+07	225	5.4E+05	0.9	0.045	95	0.045
			Q3					
28	3,968	1.6E+07	100	2.4E+05	0.045	0.023	95	0.002

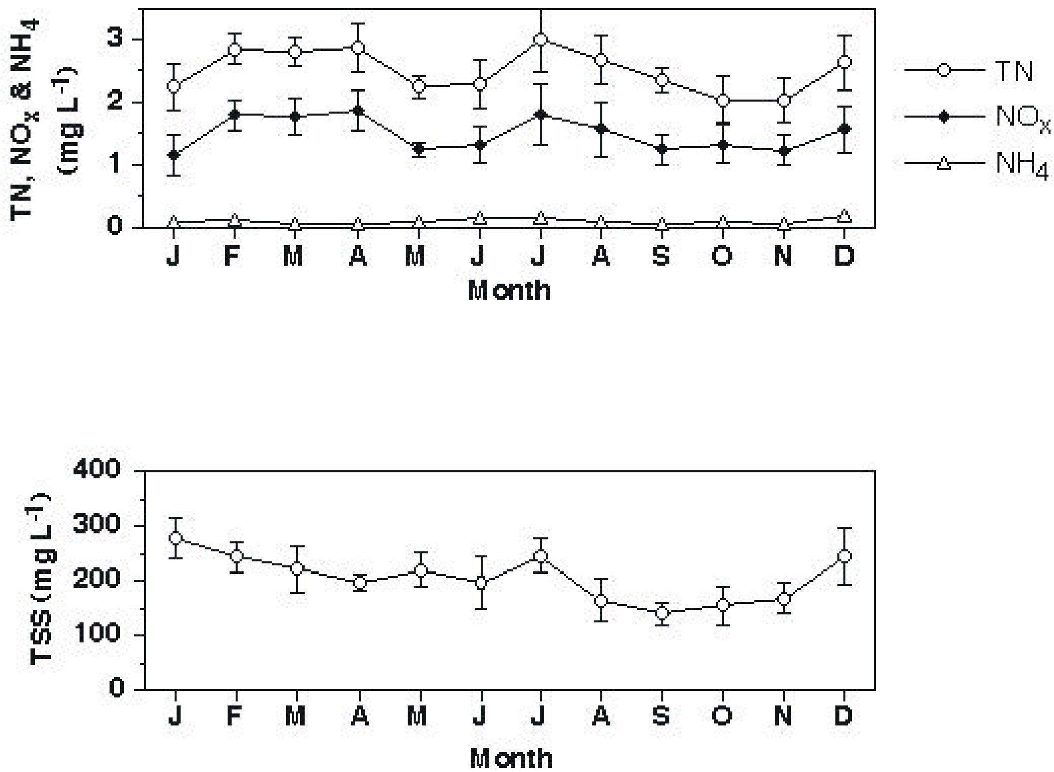

Figure 1. Average Mississippi River total nitrogen (TN), nitrite-nitrate ($NO_3^- + NO_2$), ammonium (NH_4^+), and total suspended sediment (TSS) concentrations. Water samples were taken monthly at Caernarvon Louisiana from January 1988 to December 1994. (See Lane et al. 1999). Error bars are 1 s.e.

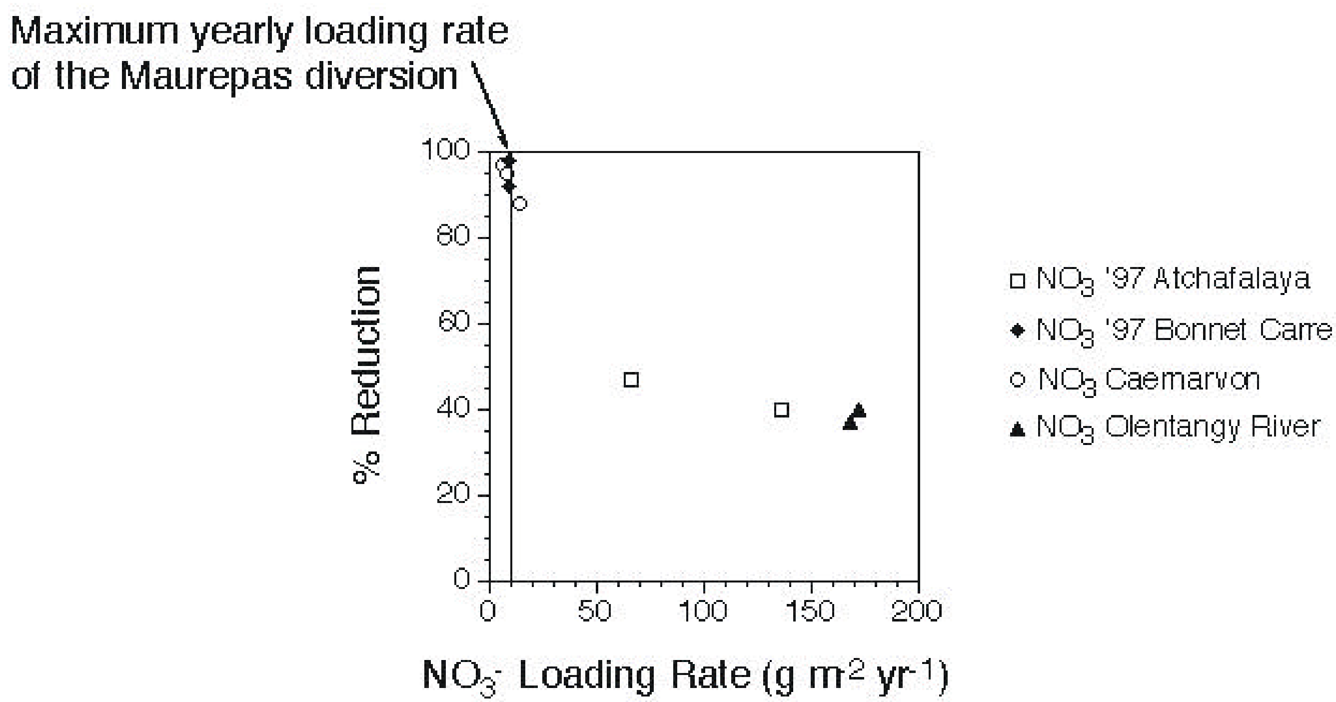

Figure 2. Yearly nitrate loading rate versus removal efficiency for various river diversions. Data sources: Atchafalaya, Lane et al. 2001b; Bonnet Carre, Lane et al. 2001a; Caernarvon, Lane et al. 1999; Olentangy River, Spieles and Mitsch 2000.

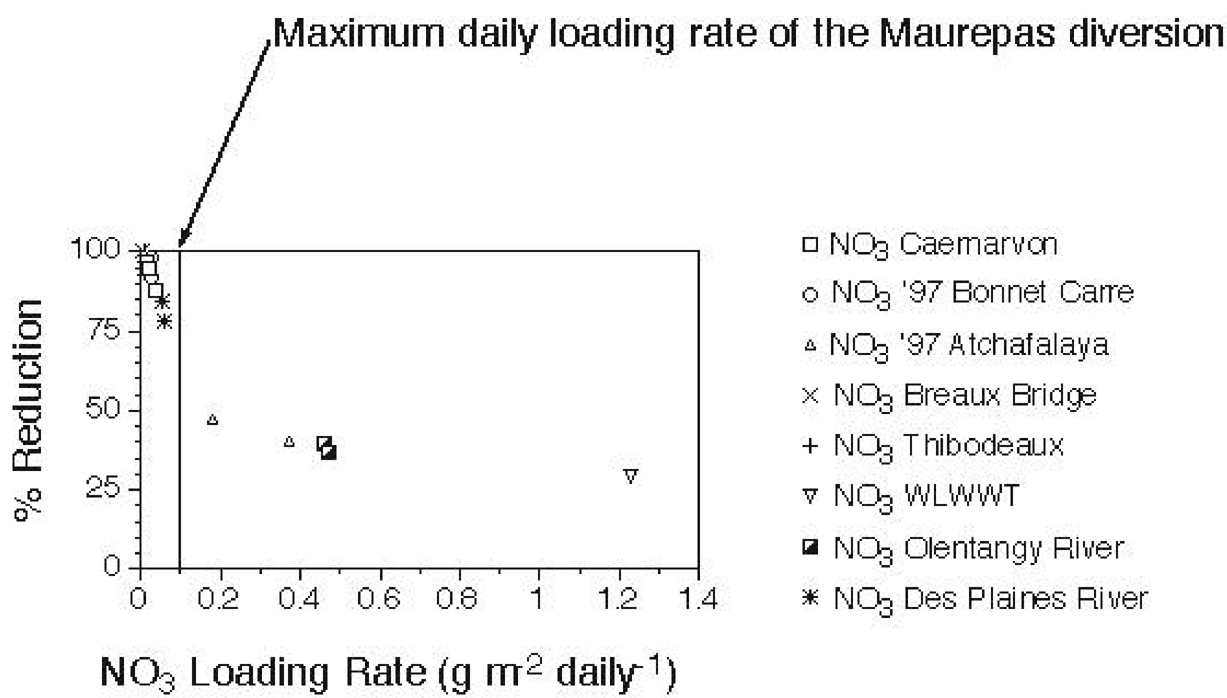

Figure 3. Daily nitrate loading rate versus removal efficiency for various river diversions and wetland wastewater treatment systems. Data sources: Caernarvon, Lane et al. 1999; Bonnet Carre, Lane et al. 2001a; Atchafalaya, Lane et al. 2001b; Breaux Bridge, Breaux and Day 1994 and Blahnik and Day 2000; Thibodaux, Breaux and Day 1994 and Zhang et al. 2000; WLWWT, Olentangy River, Spieles and Mitsch 2000, Des Plaines River, Hey et al, 1994.

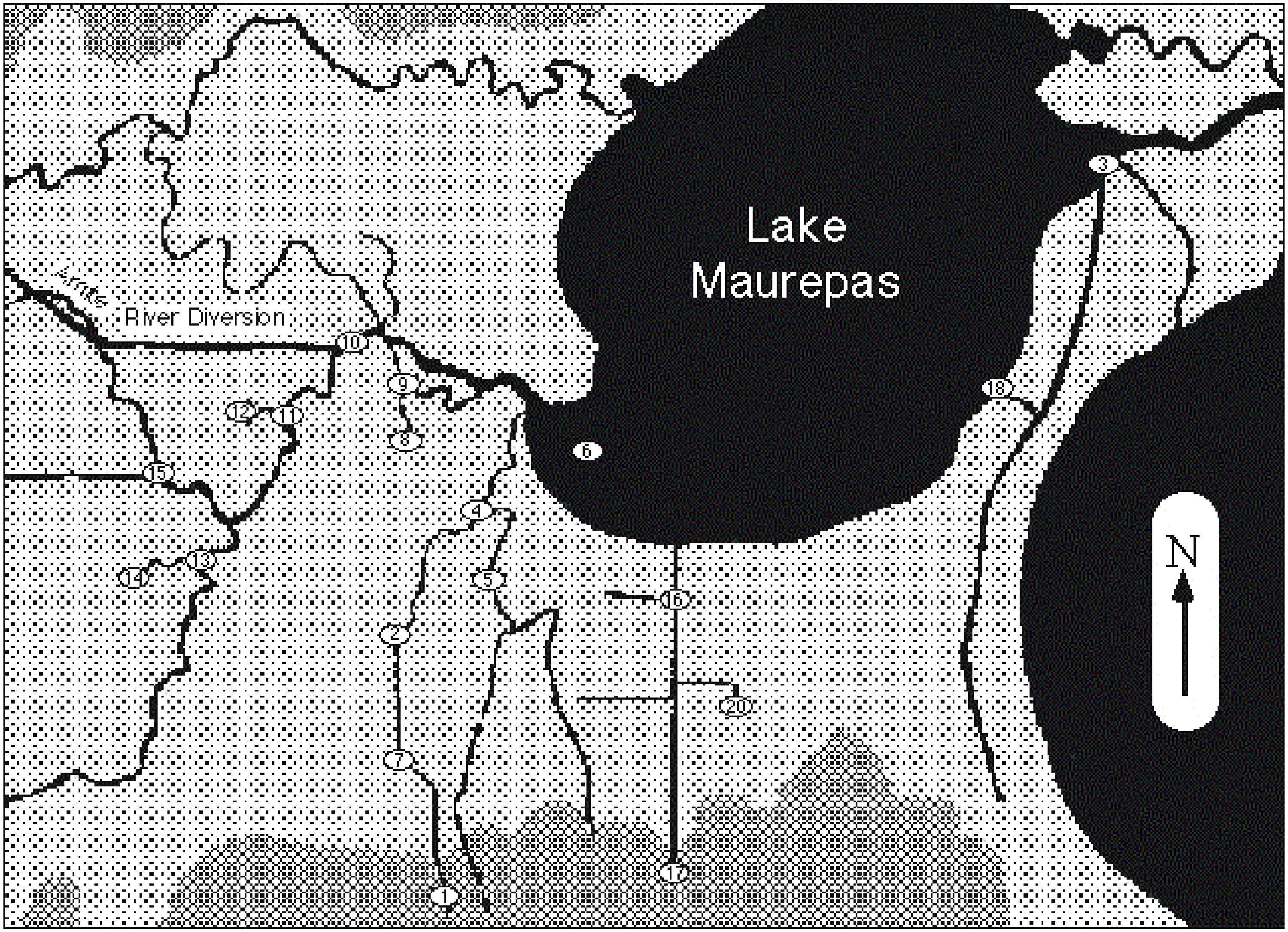

Figure 4. Location of water quality monitoring sites in the Maurepas swamp.

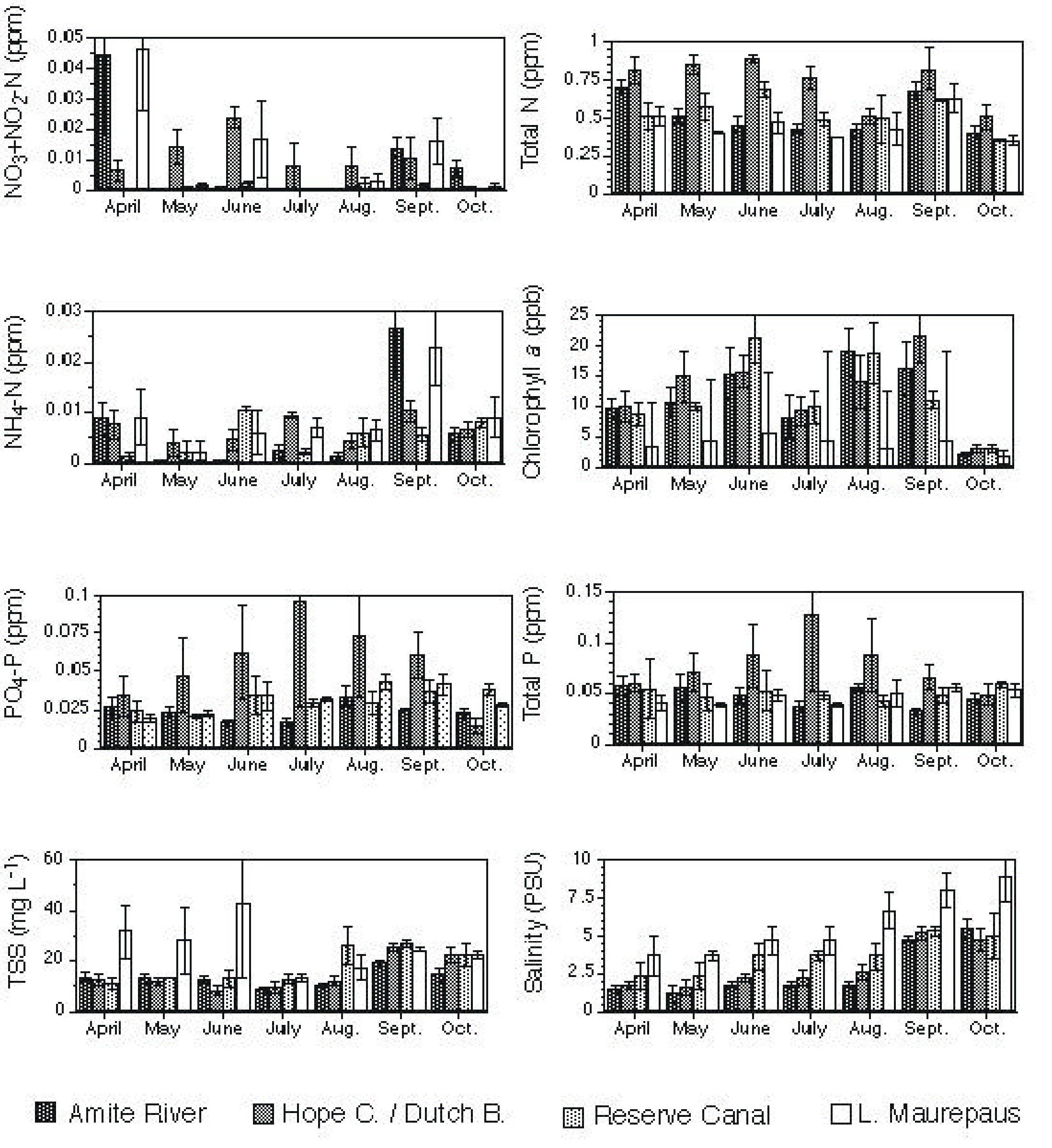

Figure 5. Average nutrient, total suspended sediment (TSS), and salinity concentrations in the Amite/Blind River, Hope/Dutch Bayou, Reserve Canal, and Lake Maurepas regions.

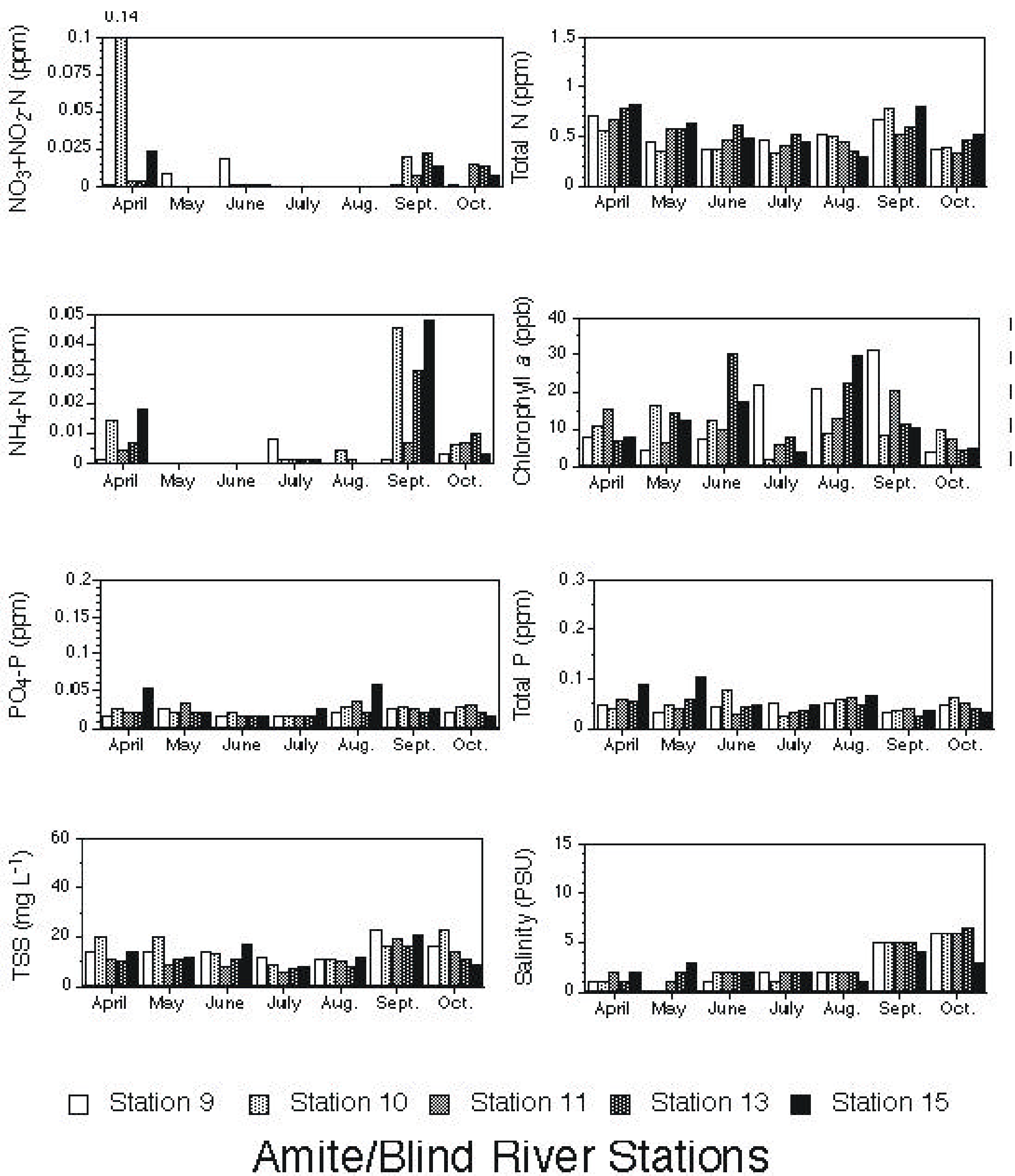

Figure 6. Nutrient, total suspended sediment (TSS), and salinity concentrations in the Amite/Blind River region.

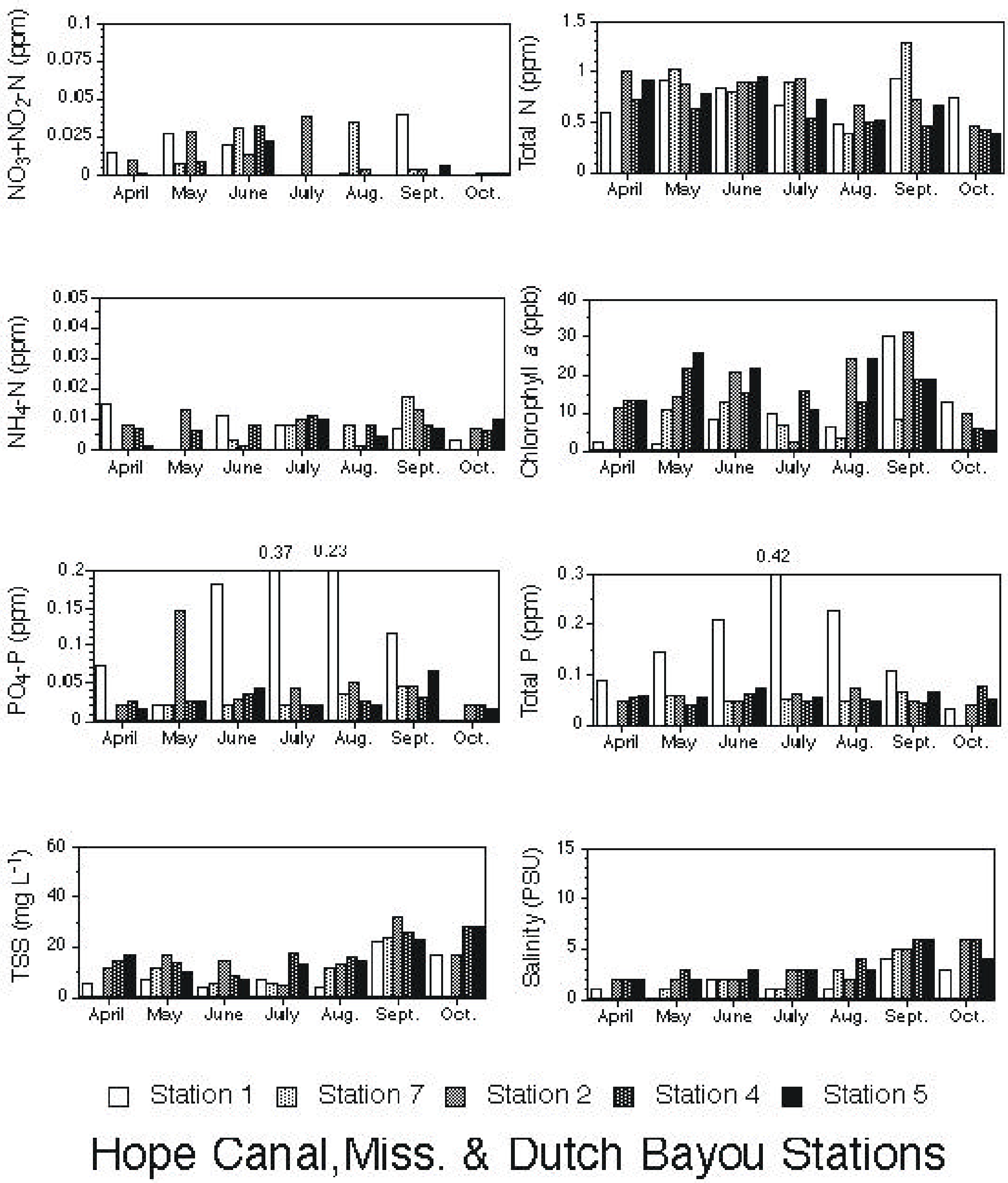

Figure 7. Nutrient, total suspended sediment (TSS), and salinity concentrations in the Hope/Dutch Bayou region.

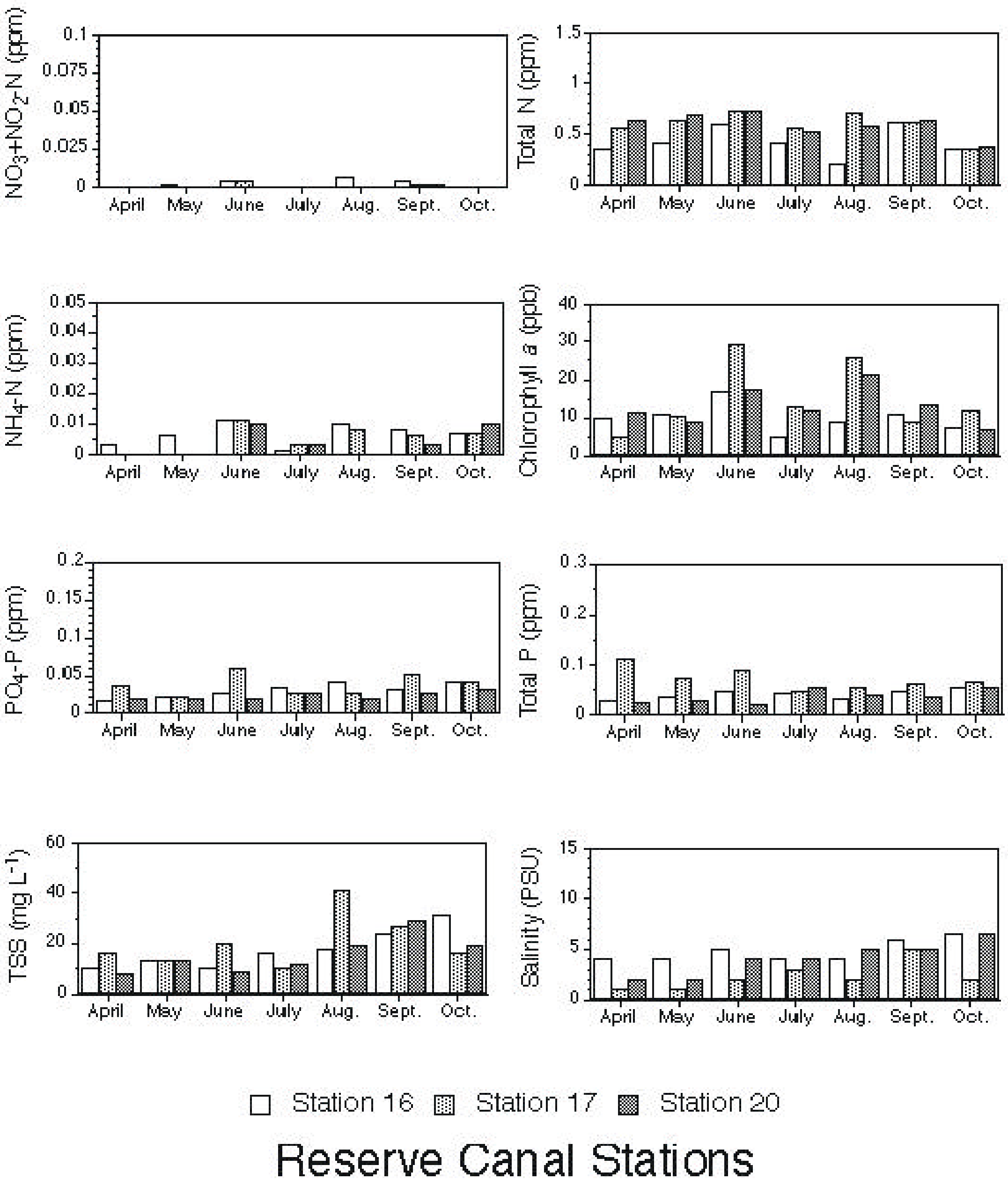

Figure 8. Nutrient, total suspended sediment (TSS), and salinity concentrations in the Reserve Canal region

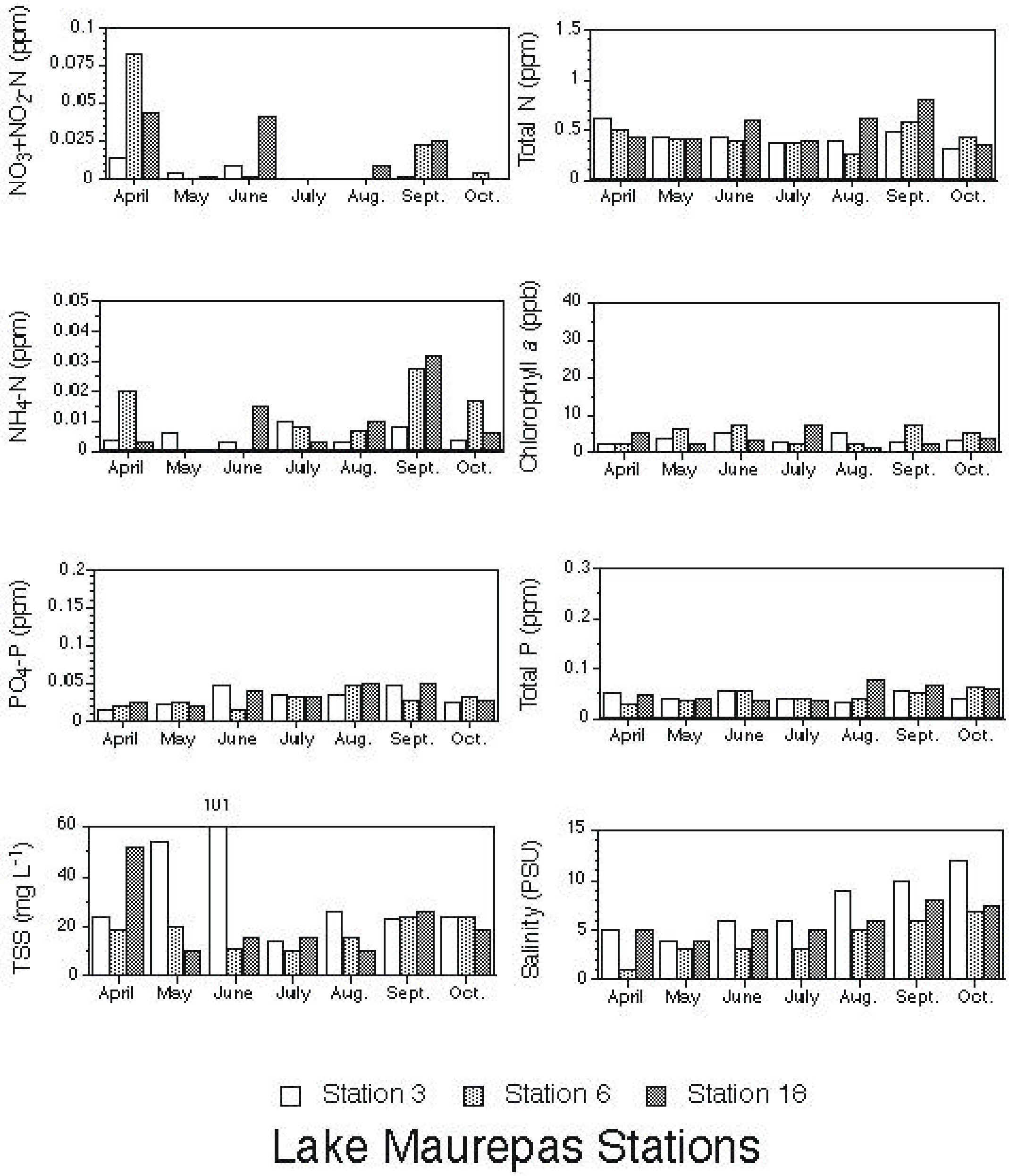

Figure 9. Nutrient, total suspended sediment (TSS), and salinity concentrations in the Lake Maurepas region.

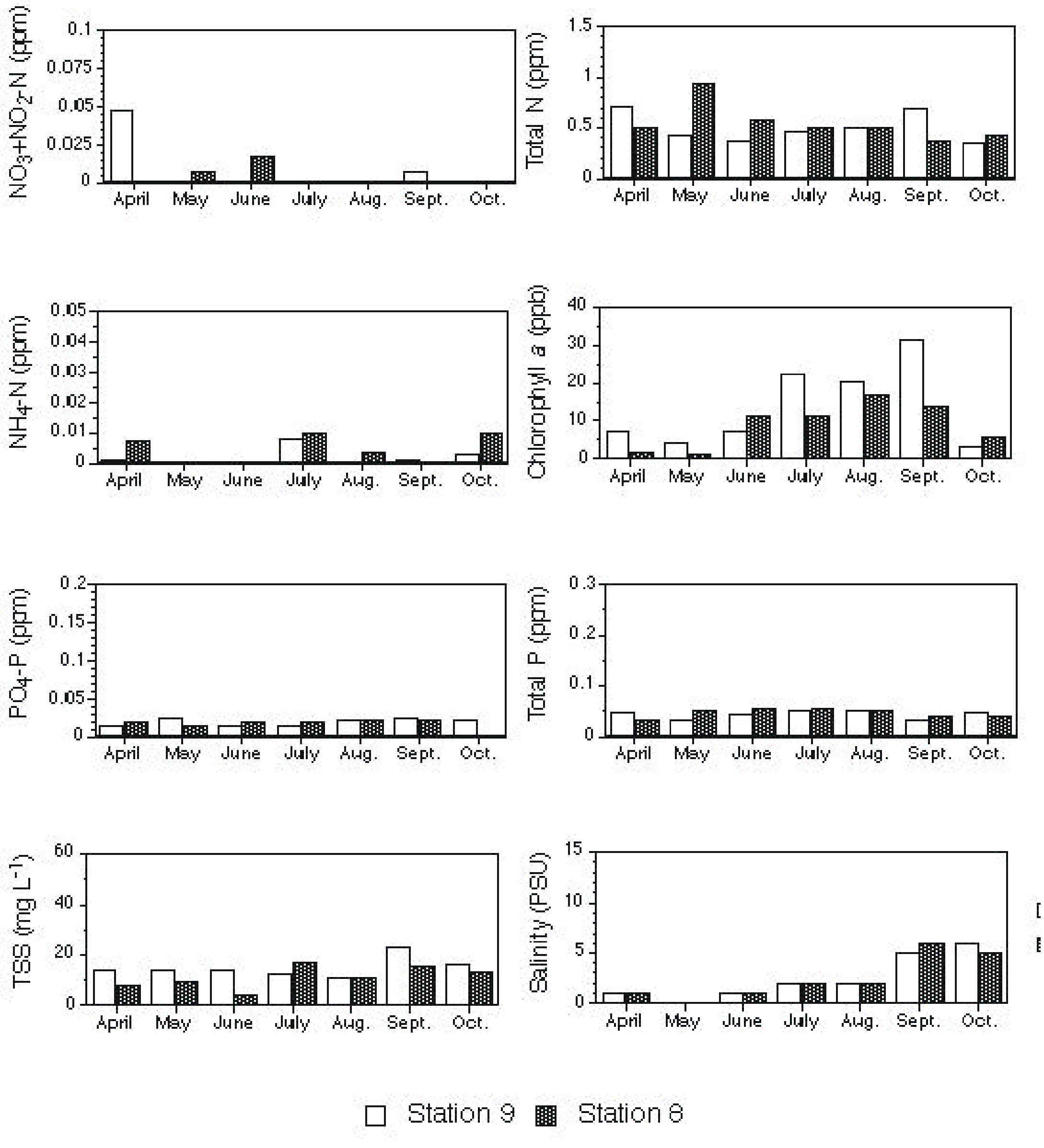

Figure 10. Comparison of main channel versus adjacent side channel constituent concentration.

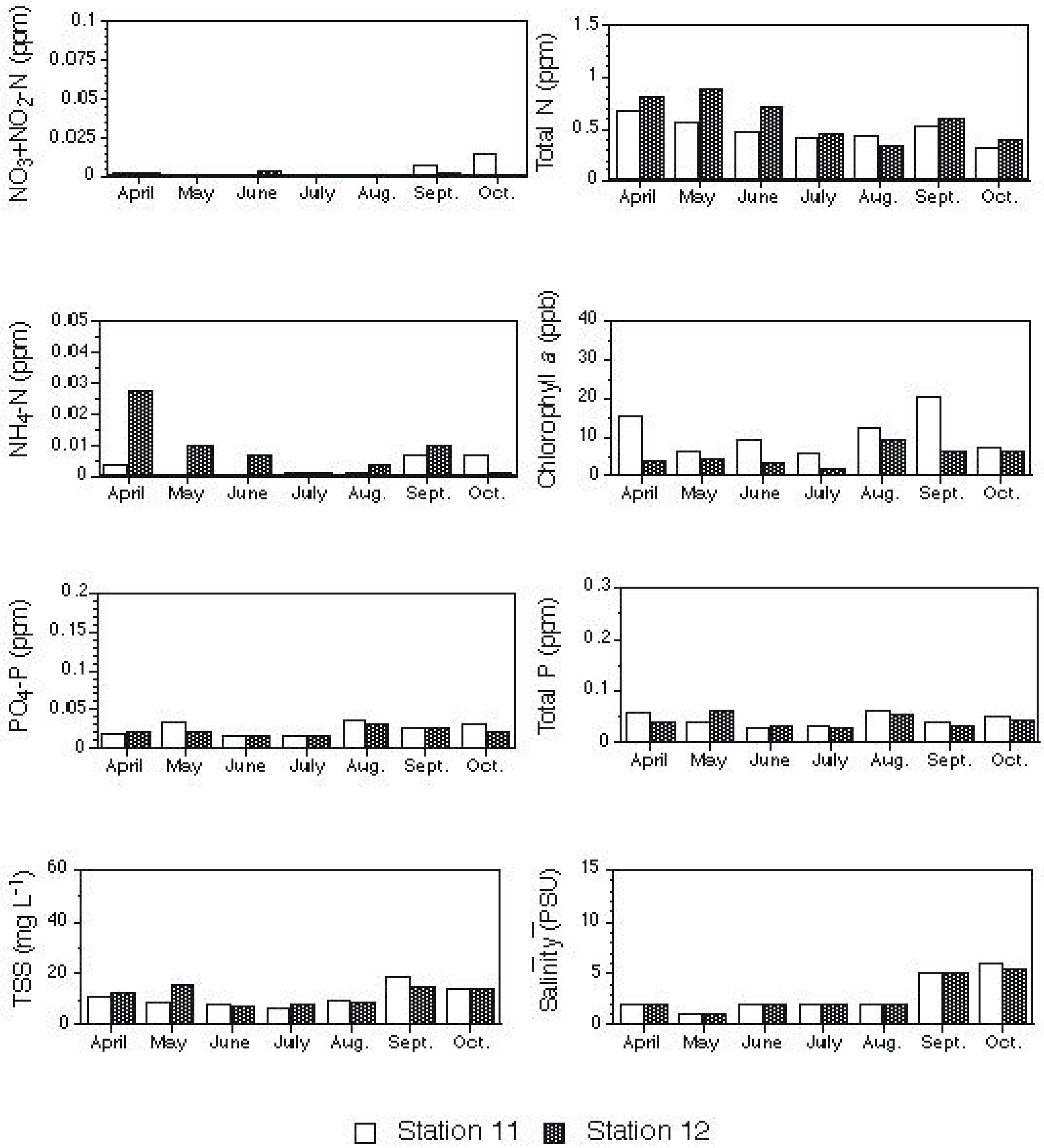

Figure 11. Comparison of main channel versus adjacent side channel constituent concentration.

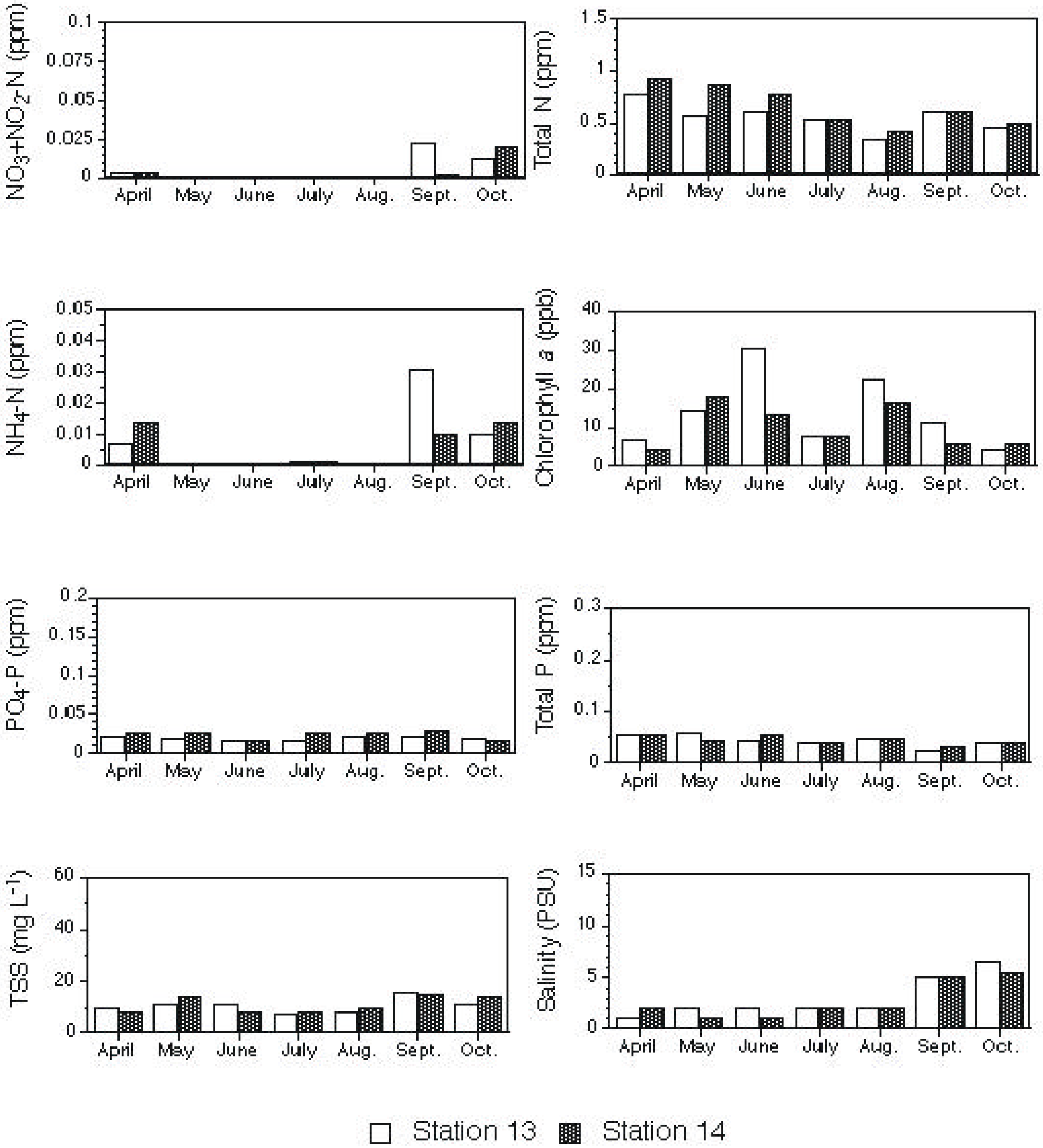

Figure 12. Comparison of main channel versus adjacent side channel constituent concentration.

APPENDIX 1: Raw Data

Table 1. Total suspended sediment concentrations (mg L^{-1}) at water quality monitoring stations in the Maurepas swamp.

STATION	April	May	June	July	Aug.	Sept.	Oct.
1a	5.2	3.7	3.6	7.8	4.8	22.2	18.3
1b	6.7	10.6	5.0	6.9	3.9	22.7	15.0
2a	13.1	17.0	20.2	5.9	12.0	31.1	17.5
2b	11.3	16.4	9.9	4.9	14.2	32.6	16.7
3a	24.0	41.9	100.4	15.6	34.0	24.4	26.2
3b	25.0	65.2	102.3	12.8	18.0	21.3	22.3
4a	14.8	21.1	7.6	15.8	16.3	25.6	32.8
4b	15.5	6.7	9.6	20.0	16.5	26.4	23.2
5a	16.2	9.6	6.7	10.9	14.0	24.1	24.2
5b	17.7	11.3	7.0	14.4	16.8	22.1	31.7
6a	19.6	16.3	12.0	9.1	15.2	22.9	22.2
6b	18.3	23.9	10.1	10.9	16.1	25.2	25.8
7a		14.6	5.6	5.7	12.4	23.9	
7b		9.2	5.8	7.2	12.1	24.1	
8a	8.6	9.8	2.8	16.8	10.0	16.1	12.7
8b	8.0	7.6	6.1	16.6	11.9	14.6	14.1
9a	15.0	21.7	8.3	11.3	10.8	21.5	13.7
9b	13.4	5.3	20.3	12.9	11.1	23.9	18.8
10a	20.4	20.3	8.4	9.0	10.5	13.9	28.7
10b	20.2	19.1	17.3	9.0	11.5	18.1	17.1
11a	10.2	10.1	7.9	6.2	8.8	17.4	17.6
11b	10.9	8.4	8.9	6.1	11.3	20.0	10.0
12a	14.8	11.3	5.8	7.2	8.0	14.1	13.3
12b	11.5	20.5	7.5	8.3	9.0	15.6	15.1
13a	10.6	11.2	12.1	6.3	10.0	15.7	14.0
13b	9.8	10.3	10.5	7.3	5.7	15.9	8.8
14a	5.0	14.4	8.4	8.1	11.0	14.6	15.9
14b	11.3	14.3	7.9	7.6	8.3	14.6	12.1
15a	13.7	11.0	16.3	5.1	13.5	20.3	9.6
15b	14.4	13.8	18.3	11.6	10.5	22.3	8.8
16a	11.2	15.0	8.8	18.8	18.5	23.9	40.0
16b	9.8	11.9	11.1	13.9	17.3	25.0	22.6
17a	22.7	16.9	18.0	9.9	42.0	19.3	16.5
17b	8.3	9.5	22.4	10.5	39.5	34.6	15.9
18a	54.4	8.5	18.0	14.3	5.0	23.3	18.2
18b	48.8	12.2	14.6	17.3	14.5	29.6	19.5
20a	8.9	13.3	8.8	12.8	19.5	28.6	17.2
20b	7.9	13.5	8.7	12.1	18.0	29.5	21.8

Table 2. Chlorophyll a concentrations (ppb) at water quality monitoring stations in the Maurepas swamp.

STATION	April	May	June	July	Aug.	Sept.	Oct.
1a	1.82	0.91	8.33	10.59	7.57	28.76	17.30
1b	2.12	1.59	8.33	9.08	4.54	31.79	7.80
2a	6.06	13.62	20.43	3.03	25.73	31.03	12.29
2b	16.65	15.14	21.19	1.51	22.70	31.03	7.74
3a	3.10	4.16	4.16	3.10	4.54	2.42	2.37
3b	2.04	3.41	6.06	2.72	5.30	3.10	4.73
4a	13.62	21.19	15.14	16.65	17.41	17.41	4.55
4b	12.87	21.95	15.14	15.14	8.33	19.68	6.83
5a	14.38	25.73	25.73	6.43	16.65	16.65	6.37
5b	12.11	25.73	18.16	15.14	31.79	21.19	4.10
6a	1.82	6.81	6.06	2.57	2.12	7.64	5.01
6b	3.03	6.05	9.08	1.59	2.19	7.11	5.46
7a		9.08	13.62	8.33	3.33	8.33	
7b		12.87	12.11	4.92	2.88	8.33	
8a	2.12	1.97	10.59	0.83	16.65	8.33	5.46
8b	1.74	0.61	12.11	21.19	16.65	19.68	6.37
9a	8.33	4.16	8.33	27.24	19.68	28.76	4.55
9b	6.81	4.54	6.06	16.65	21.95	34.06	2.28
10a	10.59	13.62	0.00	2.27	7.57	7.72	8.19
10b	10.59	18.92	12.11	0.76	9.84	8.33	10.92
11a	15.14	7.57	9.08	3.78	14.38	21.19	5.46
11b	15.14	4.54	10.22	7.57	10.60	19.68	9.10
12a	4.16	5.30	6.06	2.27	8.33	5.30	6.83
12b	3.78	3.03	1.36	1.51	10.97	7.11	6.37
13a	6.06	13.62	27.24	9.08	22.70	13.62	4.10
13b	7.57	15.14	33.30	6.43	21.95	9.08	4.42
14a	3.03	19.68	16.65	7.57	16.65	5.07	7.28
14b	6.06	15.89	9.84	8.33	15.89	6.28	4.55
15a	8.33	15.14	12.11	6.81	29.52	7.72	4.55
15b	6.43	9.08	22.71	1.36	30.27	12.87	5.01
16a	9.08	15.14	13.62	4.54	9.08	10.60	8.19
16b	10.59	6.81	19.68	4.39	8.70	11.35	5.92
17a	5.30	11.35	30.27	19.68	30.27	10.97	14.57
17b	4.16	9.08	28.76	6.06	21.19	6.43	8.65
18a	5.30	1.67	3.78	12.11	1.89	1.59	2.82
18b	4.54	3.18	3.03	3.03	0.61	2.35	5.01
20a	13.62	9.84	21.19	8.70	18.16	19.68	1.56
20b	9.08	7.95	13.62	15.14	24.22	6.66	11.84

Table 3. Salinity concentrations (PSU) at water quality monitoring stations in the Maurepas swamp.

STATION	April	May	June	July	Aug.	Sept.	Oct.
1a	1	0	2	0	1	3	3
1b	1	0	2	1	1	4	3
2a	1	2	2	3	2	5	6
2b	2	2	2	2	2	5	6
3a	5	4	6	6	8	10	12
3b	5	4	6	5	9	10	12
4a	2	3	2	3	3	6	6
4b	2	3	2	3	4	6	6
5a	2	2	3	3	3	5	5
5b	2	2	3	2	3	6	3
6a	1	3	3	3	5	6	7
6b	1	3	3	3	4	6	7
7a		1	2	1	3	5	
7b		1	2	1	3	5	
8a	1	0	1	2	2	5	5
8b	1	0	1	1	2	6	5
9a	1	0	1	1	2	5	6
9b	1	0	1	2	1	5	6
10a	1	0	1	1	2	5	6
10b	1	0	2	1	2	5	6
11a	1	1	2	2	1	5	6
11b	2	1	2	2	2	5	6
12a	2	1	2	2	1	5	6
12b	2	1	1	2	2	5	5
13a	1	2	2	1	2	5	6
13b	1	2	2	2	2	5	7
14a	2	1	1	2	2	5	6
14b	1	1	1	2	2	5	5
15a	2	3	2	2	1	4	3
15b	1	3	1	1	1	4	3
16a	3	4	5	4	2	6	6
16b	4	4	4	4	5	6	7
17a	1	1	2	3	2	5	2
17b	1	1	2	3	2	5	2
18a	5	4	5	5	6	8	8
18b	5	4	5	4	5	8	7
20a	2	2	3	4	5	5	6
20b	2	2	4	3	5	5	7

APPENDIX 2: Quality Assurance/Quality Control

Introduction

Center for Ecology and Environmental Technology /Analytical Services is a nonprofit analytical laboratory providing state of the art instrumental analytical chemistry. We presently specialize in primary nutrient analyses using a GC, NC 2500 elemental analyzer and an alpkem autoanalyzer. Services include testing for NO_3 and CO_2, NO_2, NH_4, PO_4, SlO_4, total Nitrogen and total Phosphorus in water; and total Nitrogen and total phosphorus in plant and soil. Our mission is to provide high quality chemical analysis using state of the art techniques. Providing the best possible data of known and acceptable quality is our foremost concern. As part of our commitment to quality, we have written this Quality Assurance manual which describes the procedures that are followed to monitor the quality of our work.

Employee Training

All new laboratory personnel must read and fully understand all policies discussed in this manual and in the standard operation procedure (SOP) manual. Each employee receives a copy of the SOP pertaining to the analyses he or she will perform. All training is conducted by a technician who has a minimum of six months experience working in the laboratory. This person will cover in detail the theory and rationale for existing procedures with each new employee. Each new employee is responsible for producing a calibration curve which has an R square value of at least 0.9998 for each analytical procedure he or she is to perform. This curve is to be signed by Dr. Twilley, and by the analyst and kept on file as documentation of that particular employees training. An evaluation of method performance is conducted every six months.

Quality Assurance Procedures

The quality control program consists of both internal and external checks on precision and accuracy of analytical results. The responsibility for maintaining the program rests with the Quality Assurance officer. Employees are trained in quality control biannually, including policies, SOP's and regulations.

Internal Quality Control

A hard bound log book is maintained for each instrument. This log book is used to document the analysis of samples. This log book is also used to record calibration and maintenance information. Equipment used in the laboratory is calibrated before each use. Maintenance for each instrument is monitored daily. Detailed information for types of calibrations and maintenance performed is given in SOP # 222. Additional log books are also kept to monitor our stock and working standard preparations. Procedures for recording stocks and standard preparation are described in detail in SOP # 221. These logs are reviewed periodically by the Quality Assurance Officer.

To assess contamination, method blanks are analyzed at the beginning, middle and end of the run. To assess analytical precision within every sample batch, a duplicate sample is analyzed for every sample. A **sample unit** is defined as a single container appropriately sealed and labeled. **Sample duplication** is defined as obtaining two data values per sample unit. Sample duplication is required for each sampling unit. Accuracy can be assessed through the use of standard reference materials (SRM). An SRM and SRM duplicate is analyzed every 20 samples. To monitor accuracy and matrix interference, a matrix spike sample (MS), and a matrix spike duplicate (MSD) is analyzed once per run. Refer to instrument SOP for specific internal quality control procedures.

Precision and Accuracy in Quality Control

As a general QC procedure replicate analyses are performed for determining precision and spiked samples are analyzed to determine accuracy. Within run precision is determined from duplicates based on relative percent differences between samples at an acceptance limit of RPD $\leq$ 5%. Accuracy is determined by the analysis of SRM and SRMD, MS and MSD at an acceptance limit of RPD $\leq$5%.

$$RPD = \frac{X1 - X2}{X1 + X2} * 100$$

X1 = result from sample
X2 = result from duplicate

% Recovery = (S - X) * 100/ T

S = value after the spike
X = value before the spike
T = Theoretical value of spike

External Quality Control

Our laboratory participates in the following performance evaluation for each analyses performed.

Absolute grade Proficiency Testing
WS-WP-DMRQA
NIST. NVLAP. EPA
Accredited program
Absolute standards, Inc.

ISO 9001 registered. DISANST - RAB

Intercomparison

Our laboratory is participating in an intercomparison for nutrient analysis in seawater.

NRCC (National Research Council Canada)
Ottawa, Canada
K1A OR6
(613) 993-2359

Data Packages, Data Review, and Audits

Raw data are assembled with QC summaries into data packages by the analyst. A face page summarizing the contents of the data package and any problems is signed by the analyst and a supervisor after the data have been reviewed. This package contains a copy of the instrument run log, QC summaries such as internal standard recovery, calibration, spike results, blanks and raw data, and a copy of the excel file. The packages are then kept in the instruments data log book or binder. There is also an electronic copy of all data, generated and stored in a 5.0 excel file in rm. 226, and rm. 249 in Billeaud Hall. A back up copy is stored on 1.4MB IBM diskettes, and on 128MB Optical disk. All data packages undergo an independent monthly audit by the Quality Control officer, and Lab Director. The Lab Director will initiate any corrective action required to comply with Quality Standards, generally involving the Quality Control Officer and analyst. The Quality Assurance System of QC procedures, preset QC limits, review of data packages, and approval of reports is designed to catch errors and problems prior to data being reported to clients. However, when corrective action affects previously reported data, the client is notified in writing describing the problem and resolution.

Data Documentation

A copy of the raw data should be kept in the Data binder specific for that instrument. Review raw data and mark any sample values that fall out of range or do not meet the RPD $\leq$5% rule. Same applies to all QC's. If a QC fails you must rerun all samples that preceded the bad QC and all samples that follow. The samples that fail, should appear at the beginning of the next run, marked rerun. Raw data files should be saved onto a 3.5" 1.4MB diskette, and deleted from the main frame, frequently. After data have been entered into an excel file, this should also be saved onto a 3.5" 1.4MB diskette. The final report should include the sample ID, analytes and an average replicate concentration. This 5.0 excel file is stored on the starmax in rm 226, under analytical services, and on a 128MB optical disk. This report should also include a QA\QC summary, this form is located in the file cabinet in room 249. Present this data package to your supervisor for review.

Report Format

The final report should be stored in a 5.0 excel file, and should include the sample ID, and averaged replicate concentrations. The name of the project, date, and list of analytes should appear in the top left corner. Column headers should include analytes and units of measurement. Column headers should repeat at the beginning of each new page. The page number, and file name should also appear on each page. All data should be reported with three significant digits. You may also refer to SOP# 223 for data documentation.

Corrective Action

Any sample duplicate value that does not fall within the accepted limit of RPD 5% is analyzed again. When an SRM or MS analytical value does not fall within the acceptable limit RPD $\leq$ 5%, all samples that were analyzed before the SRM or MS must be analyzed again. If reanalyzing the samples, SRM or MS does not resolve the problem, the analyst should notify his or her supervisor and together try to resolve the problem. After resolution, the analyst should continue with the corrective action steps to maintain control.

Chain of Custody

Samples are received in Lab 249 Billeaud Hall, where lab personnel are responsible for logging in the samples under the direction of the lab director. Chain of Custody (COC) procedures are followed because of their potential for litigation. All samples delivered to the lab should have COC records. This is necessary to preserve the security of samples as evidence. Samples are considered secure because access during working hours is monitored and the laboratory and building is locked during nonworking hours. The COC record is therefore used to document the change in possession from sampling, delivery, and receipt by the laboratory. Each sample should be clearly identifiable. The condition of the sample\container and the presence\absence of custody seals should be noted. Signatures of parties changing custody as well as date and time should be documented on the COC form.

Handling Submitted Samples

Upon the receipt of samples, lab personnel are to refer to the COC for the types of analyses to be performed. For sample storage and preservation lab personnel should follow the guidelines outlined in the SOP for that particular analyte. For samples requiring refrigeration, these samples are placed in a refrigerator designated for sample storage only, and the temperature of the refrigerator is kept at $4^{0}C$. This temperature is monitored daily, and recorded on a log sheet, which is kept on the door of the refrigerator. The same applies for samples that require freezer storage. Freezer temperatures are kept at $< 0\ ^{0}C$ and are also monitored daily on a temperature log sheet, located on the door of the freezer.

Waste Disposal

All hazardous waste is stored in 20 L nalgene containers in Lab 249, Billeaud Hall. We have a contract with Treatment One to annually remove and properly dispose of all of our waste.

Our EPA code is : LAD 981057441, contact person is Mr. Barton, department of Physical Maintenance (tel. 337-482-6441). Acidic and alkaline solutions that do not contain hazardous materials are neutralized before disposal.

Complaint Resolution

Anytime a serious complaint is received, it is logged for a permanent record, tracked to insure resolution, and brought to the attention of our senior manager. A serious complaint is one that questions the validity of our results or any complaint about service. In general, the nature of the complaint is documented on a form which is given to the Lab Director. Someone is then assigned to resolve the issues. The progress of the complaint resolution is discussed and tracked during weekly staff meetings. After resolution, the client is contacted for their final comments, and a permanent record is kept by the Lab Director.