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THE IMPORTANCE OF PULSED PHYSICAL EVENTS FOR SUSTAINABILITY OF LOUISIANA COASTAL FORESTED WETLANDS

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ABSTRACT

A number of freshwater diversions from the Mississippi River into Louisiana's coastal wetlands are currently in operation or in the planning stage. These diversions have multiple objectives including maintaining a desirable salinity gradient, restoring deteriorating wetlands, and enhancing fisheries. The extensive freshwater forested wetlands surrounding the western end of Lake Pontchartrain receive little or no sediment input and are currently deteriorating due to continuous flooding. Diverting nutrient-rich water through wetlands can lead to substantial nutrient removal and to enhanced accretion. The objective of this paper is to compare the impacts on freshwater wetland ecology, accretion, and water quality of several scenarios for diverting freshwater from the Mississippi River. Accretion will be increased so that the area will become progressively less flooded, enhancing productivity and seedling recruitment. With overland flow, about 73% of N and 48% of P will be retained in the wetland, while other alternatives are estimated to remove 0-33% of N and 0-40% of P. Productivity of the forested wetland will decrease by at least 20-50% over the next 50 years if nothing is done, but there would be a substantial increase in productivity if river water is diverted into the area. We recommend that a 45-55 m^3/s diversion be placed in the southern portion of the swamps of Lake Maurepas and that the diversion be operated annually from winter to early spring. There are indications that a diversion in late summer and fall would be beneficial, as that is when salt pulses typically occur.

KEYWORDS. Forested wetlands, hydrology, saltwater intrusion, nutrients, freshwater diversions, swamps, productivity, Louisiana.

INTRODUCTION

Historically, wetland forests in both the Lower Mississippi River Valley and the Deltaic Plain of Louisiana were intimately connected to the Mississippi River and its tributaries and distributaries. Annual pulses of freshwater, sediments, and nutrients collected from the 3 million square km Mississippi River drainage basin were dispersed during flood events creating a mosaic of soil types and plant communities. While coastal wetlands can maintain their surface elevation despite sea-level rise with sediment inputs and organic accumulation from high primary productivity (Baumann et al., 1984; DeLaune et al., 2004), the construction and maintenance of flood-protection levees has isolated south Louisiana from Mississippi River sediments, nutrients, and freshwater, which are critical to the long-term survival of coastal wetland forests (Kesel, 1989; Boesch et al., 1994; Day et al., 2000).

The Bonnet Carre Spillway was originally designed to carry flood waters from the Mississippi to Lake Pontchartrain when high water levels threatened the city of New Orleans (USCOE, 1987). The Spillway was constructed in 1931 after the devastating flood of 1927 and has been opened eight times since during high water events, most recently in 1997. It is located 25 km west of New

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Orleans, Louisiana, in an area that was one of the many crevasses that breached the Mississippi River levee in the 1800s and which introduced up to 4,000 m^3s^{-1} of water into Lake Pontchartrain (Davis, 1993). The present spillway is designed to divert up to 7000 m^3s^{-1} from the river during floods and was designed strictly for flood control. Some have suggested that the spillway should be used to regularly divert freshwater into Lake Pontchartrain in order to lower salinities in the Chandeleur and Mississippi Sounds (Chatry et al., 1983; Chatry and Chew, 1985), which are hydrologically linked to Lake Pontchartrain. Initially, the design for the diversion consisted of a new structure on the river for low river stage diversion and a straight channel through the spillway connecting the Mississippi River and Lake Pontchartrain with no overland flow within the spillway.

High concentrations of nutrients in Mississippi River water and concern over pollutants led to questions about the effects of the Bonnet Carre diversion on water quality and fisheries in Lake Pontchartrain (Louisiana Department of Environmental Quality, 1990). Mississippi River discharge has had significant water quality impact on shelf waters near the river mouth and at some other diversion sites. High nutrient concentrations in river water lead to intense phytoplankton blooms, which cause low dissolved oxygen in bottom waters when they sink and decompose. A 'dead zone' of low oxygen bottom water is now widespread each year and has been linked to fish kills and other deleterious effects (Turner and Rabalais, 1991). Concern about similar conditions in Lake Pontchartrain led to a reanalysis of the project. Also, the original project provided little wetland benefits as required by the State wetland plan.

The reanalysis was designed to examine the potential for flowing diverted Mississippi River water through wetlands to both improve water quality and to add sediments to subsiding wetlands. The extensive freshwater forested wetlands surrounding the western end of Lake Pontchartrain receive little or no sediment input and are deteriorating in part due to continuous flooding (Myers et al., 1995; Thomson et al., 2002). Research has shown that diverting nutrient-rich water through wetlands can lead to substantial nutrient removal and to enhanced accretion (Richardson and Nichols, 1985; Breaux and Day, 1994).

ALTERNATIVES

The focus of the analysis presented here considers the impact of diverting river water into the forested wetlands between the natural levee of the Mississippi and Lake Maurepas, an area of approximately 100 km^2. The area consists almost totally of forested wetland with some freshwater marsh. The forested wetland area is deteriorating as evidenced by the low density of trees, lack of recruitment, and poor growth form of the trees. The overall objective of this paper is to compare the impacts of four different alternatives for diverting freshwater into Lake Pontchartrain on aspects of wetland ecology, accretion, and water quality.

Four different scenarios with differing amounts of overland flow through wetlands were examined. Based on information gathered from the literature, the impacts of the alternatives were estimated.

Alternative 1

Water is diverted into forested wetlands upstream of the Bonnet Carre Spillway. This alternative assumes that complete overland flow is achieved before the water reaches Lakes Maurepas and Pontchartrain. For this alternative, we assumed that the water was dispersed over a 100 km^2 area.

Alternative 2

All diverted water flows through a channel, and river water is discharged into Lake Pontchartrain with no changes in nutrient or suspended sediment concentration.

Alternative 3

Overland flow is achieved to the maximum extent possible for existing forested wetlands (13 km^2) within the spillway.

Alternative 4

Diversion of 42.5 m^3s^{-1} (1500 cfs) through the LaBranche wetlands and the balance of the water through the spillway as in alternative 3.

The diversion schedule for each of the alternatives is as follows:

January	113.3 m^3s^{-1} (4000 cfs)
February	240.8 m^3s^{-1} (8500 cfs)
March	240.8 m^3s^{-1} (8500 cfs)
April	240.8 m^3s^{-1} (8500 cfs)

Water Quality

The general approach for the water quality analysis was to calculate total input of nitrogen (N) and phosphorus (P) based on the inflow of river water and the concentration of the nutrients in river water. Nutrient assimilation was then calculated based on the area of receiving wetland and published curves of nutrient uptake vs. loading rate.

METHODS

Nutrient loading for each month was calculated by multiplying the total discharge for the month by the mean nutrient concentration in Mississippi River water. Nitrate (NO_3) and phosphate (PO_4) were determined from data gathered by the U.S. Geological Survey while total Kjeldahl nitrogen (TKN) and ammonia (NH_4) concentrations were from results reported by the U.S. Army Corps of Engineers. It was assumed that flow was constant for the entire month. Total nutrient loading for the four month period was obtained by summing the loading for each month (Table 1).

Table 1. Water and nutrient input for the four diversion altrenatives.

Month	Flow (m^3/mo)	NO_3 (g/mo)	TKN+NH_4 (g/mo)	P (g/mo)	TSS (kg/mo)
January	2.9×10^8	2.9×10^8	3.2×10^8	7.3×10^7	5.9×10^7
February	6.2×10^8	6.2×10^8	6.9×10^8	1.6×10^8	1.2×10^8
March	6.2×10^8	6.2×10^8	6.9×10^8	1.6×10^8	1.2×10^8
April	6.2×10^8	6.2×10^8	6.9×10^8	1.6×10^8	1.2×10^8
TOTAL	**2.2×10^9**	**2.2×10^9**	**2.4×10^9**	**5.4×10^8**	**4.3×10^8**

The ability of wetlands to remove nutrients from inflowing water is primarily dependent on the nutrient concentration and volume of the input water and the area of wetlands. Nutrient uptake is also influenced by temperature and the hydrology of the specific wetland site. In the experimental diversion carried out as part of the reanalysis, for example, most flow was channelized and there was minimal wetland contact (Lane et al., 2001). Inflow into a wetland is normally expressed as a loading rate that integrates the concentration and volume of the inflow and the area of the receiving wetland. Loading rate is expressed as the amount of nutrient introduced per unit area of wetland per unit time; normally as g N or P m^{-2} y^{-1}. Loading rate incorporates residence time since it has units of time.

Nutrient removal is inversely related to loading rate. Richardson and Nichols (1985) reviewed a number of wetland wastewater treatment systems and found a clear relationship between loading rate and nutrient removal efficiency. Nutrient removal efficiency is the percentage of nutrients removed from the overlying water column and retained within the wetland ecosystem or released into the atmosphere. The relationship between nutrient removal efficiency and loading rate is not linear and there is very efficient removal at low loading rates but removal efficiency decreases rapidly with loading rate.

There are a number of studies from Louisiana where loading rates have been reported for coastal wetlands. Breaux and Day (1994) provided estimates of loading rate and removal efficiencies for forested wetlands near Thibodaux, Louisiana, where secondarily treated sewage was being discharged. Gosselink and Gosselink (1985) reported loading rates of wetlands in the Atchafalaya

River basin. The Atchafalaya basin encompasses 333,000 ha of forested wetlands in south central Louisiana that are seasonally inundated by the Atchafalaya River, a distributary of the Mississippi River. Nutrient uptake has also been demonstrated for the Caernarvon diversion (Lane et al., 2004), which is similar to the above cited studies. Wetlands of the Atchafalaya basin, the Caernarvon area, and those of the sewage treatment systems (Day et al., 2004) are ecologically similar to wetlands within and surrounding the Bonnet Carre spillway and bordering Lake Maurepas. Therefore, loading rates reported in these studies were used to estimate water quality improvement associated with the different alternatives (Lane et al., 2003).

The monthly total nutrient input (Table 1) was used to calculate loading rates for each of the alternatives. It is the instantaneous loading rate that the wetland "sees" at any particular time that determines the retention efficiency. Therefore, the monthly input rates were multiplied by 12 to obtain an equivalent annual input rate. This was then divided by the area of wetland for alternatives 1, 3, and 4 to obtain the instantaneous loading rate for each month. This calculation was not done for alternative 2 since there is no wetland overflow. Nutrient retention for each month was based on the loading rate. Retention was estimated separately for NO_3 and TKN plus NH_4. Nitrate is removed much more quickly than TKN or NH_4 because NO_3 can be removed by the process of denitrification. In anaerobic soils, denitrification rapidly converts NO_3 to N_2 gas which is permanently lost from the system. Studies in sewage treatment systems in Louisiana (Breaux and Day, 1994; Day et al., 2004) and at Caernarvon (Lane et al., 1999, 2004) show that the loss of NO_3 is several times faster than other forms of nitrogen. We estimated conservatively that NO_3 loss was three times faster than for TKN plus NH_4. The amount of nutrient retained in the wetland was subtracted from the total loading each month to estimate nutrient input to the lake for alternatives 1, 3, and 4. For alternative 2, nutrient input to the lake was equal to inflow from the river for each month. Total input to the lake was obtained by summing the individual monthly flows. A loading rate to the lake was determined by dividing the input in g/yr by the area of the lake in m^2.

Total suspended sediment (TSS) input from the diversion was calculated by multiplying the total water inflow over four months by the average concentration of TSS in river water (200 mg/l). For Alternative 1, the total quantity of TSS was divided by the number of m^2 in 100 km^2 to obtain the TSS loading rate in g $m^{-2}yr^{-1}$.

RESULTS

Water Quality

The uptake of N and P in wetlands and export to the lake for Alternatives 1-4 are given in Table 2. For Alternative 1 with complete overland flow, about 73% of N and 48% of P was retained in the wetland. Calculations showed that all NO_3 was assimilated. Most N exported to the lake is in the TKN or organic N form. This form does not stimulate phytoplankton growth directly. Some will be slowly transformed in the lake to inorganic N that does support phytoplankton growth, but export of organic N is less likely to lead to phytoplankton blooms. Export of P occurs in both the PO_4 and organic P forms. As with organic N, organic P does not directly stimulate phytoplankton growth. Overall, Alternative 2 had the highest N and P export to the lake while Alternative 1 had the least. Alternative 4, using the LaBranche wetlands, resulted in uptakes of 33% of N and 40% of P; a substantial improvement over Alternative 3.

Table 2. Input, uptake, and export of nitrogen and phosphorus for each alternative diversion scenario. All values are in grams except for percentages.

Alternative	N uptake	N export	% N uptake	P uptake	P export	% P uptake
1	3.3×10^9	1.3×10^9	72	1.06×10^8	1.14×10^8	48
2	0.0	4.6×10^9	0	0.0	2.2×10^8	0
3	0.6×10^9	4.0×10^9	13	0.6×10^8	1.6×10^8	27
4	1.5×10^9	3.1×10^9	33	0.9×10^8	1.3×10^8	41

Alternative 1 led to an increase in N loading to the lake of less than 1.0 g N/m^2/yr, while Alternatives 2 and 3 led to loading increases of about 2.5 g N/m^2/yr. Similarly, P loading to the lake was least for Alternative 1 and greatest for Alternative 2.

Forested Wetland Productivity

Total above ground net productivity of forested wetlands depends on several factors including flooding, nutrient levels, and salinity. Reported values for southeastern forested wetlands range from about 200 to 2000 g m^{-2}yr^{-1} (Mitsch and Gosselink, 1993; Conner and Day, 1976; Conner and Buford, 1997). The lowest values (742-925 g m^{-2}yr^{-1}) are from stagnant, permanently flooded wetlands with little external nutrient or water input and the highest values (1050-2017 g m^{-2}yr^{-1}) are from alluvial river swamps (Conner and Day, 1987, 1988, 1992; Conner et al., 1981, 1993; Conner and Brody, 1989; Rybczyk et al., 1996; Day et al., 1992; Megonigal et al., 1997).

The productivity of forested wetlands can be enhanced by increasing riverine input and nutrient inflow. Brown (1981) showed that productivity was related to P inflow for a wide range of forested wetland systems. Mitsch et al. (1979) reported that cypress growth was increased by higher annual river discharge in an Illinois system. In Louisiana, there have been several studies of the effects of increased nutrient input to forested wetlands. In a study of a forest which has received treated municipal sewage since 1950, Rybczyk et al. (1996) reported that productivity increased from 1140 to 2129 g m^{-2}yr^{-1} in 1994 and from 1280 to 1611 in 1995 g m^{-2}yr^{-1} when wastewater flow was switched to a new treatment site. Hesse et al. (1998) used tree ring analysis to measure annual growth of baldcypress from the 1920s until the 1990s. They found that tree ring diameter growth was about 34% higher and basal area increase was about 36% higher in the treatment area after wastewater flow began in 1950.

Productivity of the forested wetland south of Lake Maurepas will decrease over the next 50 years under current conditions (Shaffer et al., 2003), but there would be a substantial increase in productivity if river water is diverted into the area (Alternative 1). Tree density in the Maurepas swamp is less than the permanently flooded areas studied by Conner, Day, and others. Over the past five years, total aboveground productivity averaged 450-700 g m^{-2}yr^{-1} (Shaffer et al., 2003). If no action is taken, productivity will decrease at least 20-50% due to fewer trees and increased stress. On the other hand, if river water is diverted into the area seasonally, productivity will increase within 50 years to about 1000-1500 g m^{-2}yr^{-1}, or about twice the productivity at present.

Under Alternative 3, the forest is likely already productive due to the relatively high elevation of the area and periodic openings of the spillway for flood control. Regular diversions of water into this area would probably enhance productivity in the range of 25-50%; or similar to that reported by Hesse (1994). Accretion in the forest will eventually lead to a drier bottomland hardwood forest or even a moist upland type forest.

Accretion in Coastal Forested Wetlands in Louisiana

Conner and Day (1991) measured vertical accretion in swamps of the Verret and Barataraia basins in Louisiana. Accretion in cypress-tupelo forests was 6-8.8 mm/yr and 2.7 mm/yr for a higher bottomland hardwood ridge. The vertical accretion deficit for the cypress-tupelo forests were 2.5-4.9 mm/yr. In a forest near Thibodaux, Rybczyk et al. (1996, 2002) reported that accretion on a bottomland hardwood ridge was between 3.3 and 5 mm/yr compared to 5-7.3 mm/yr in a permanently flooded area. Given a relative sea level rise of 1.2 cm/yr, the accretion deficit for the permanently flooded area is 4.7-7 mm/yr. After addition of sewage effluent, the accretion rate increased to 11.0 mm/yr. These data suggest that if river water is diverted into the area south of Lake Maurepas, accretion will likely increase to levels greater than the rate of relative water level rise so that the area will become progressively less flooded.

Based on the amount of water diverted, the deposition of mineral sediments in the area will average 0.4 g of mineral sediment m^{-2}yr^{-1}. Based on relationships between vertical accretion and mineral sediment deposition given by Templet and Meyer-Aredt (1988), accretion for Alternative 1 in the Maurepas forested wetlands is projected to be about 22 mm/yr. Given a relative sea level rise of 1.2 cm/yr, the net gain in elevation will be 0.3-1.8 cm/yr or between 15 and 39 cm over the next 50 years. As this happens, productivity will increase and recruitment will become more successful.

Without any diversion, the area will become flooded to deeper depths. In 50 years, the water depth will probably increase by 12.5 cm to 24.5 cm assuming vertical accretion deficits of 2.5-4.9 mm/yr. This will lead to the higher stress and tree mortality and decreasing productivity discussed in the previous section.

CONCLUSION

Pulses of water through fresh water diversions from the Mississippi River into Louisiana's coastal wetlands result in nutrient uptake, enhanced accretion, lower salinities, and incorporation of riverine materials into local food webs. In unaltered river floodplain systems, seasonal flooding pumps energy into the system and enhances productivity (Odum et al., 1995). This periodic flooding enhances productivity by providing an adequate water supply for the vegetation, supplying nutrients, and offering a more oxygenated root zone than if the water were stagnant (Brinson et al., 1981). It has generally been reported that floodplains with an alternating wet and dry seasons are more productive than permanently flooded or less flooded zones (Conner et al., 1981; Conner and Day, 1982), although exceptions have been reported (Brown and Peterson, 1983; Mitsch and Rust, 1984). More recently, it has been shown that this pulsing can be both a stress and a subsidy, and Megonigal et al. (1997) found that while flooded swamps do have lower productivity, there was no difference in seasonally pulsed versus upland sites.

This analysis demonstrates that diversion of water through the deteriorating wetlands upriver of the spillway will lead to both enhanced productivity of the forested wetland as well as improvement in water quality. Without diverted river water, the wetland will continue to deteriorate and will likely largely disappear over the next 50 years. Diversion through the wetlands in the Bonnet Carre Spillway will lead to small improvements in water quality and small increases in wetland productivity. Use of the LaBranche wetlands would lead to greater improvements in water quality than use of the spillway alone, but less than for complete overland flow. The original project will have no wetland benefits and will substantially increase nutrient loading to the lake with subsequent water quality impacts. In summary, by using wetlands, the project will protect and enhance large areas of wetlands and improve lake water quality and would be consistent with the State's wetland program. One area that needs further exploration is the idea of using late summer and fall diversions at times when saltwater intrusions are common.

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