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The Use of Hydrologically Altered Wetlands to Treat Wastewater in Coastal Louisiana.

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THE USE OF HYDROLOGICALLY ALTERED WETLANDS TO TREAT WASTEWATER IN COASTAL LOUISIANA

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To Roy, Nada, Alla, Caedmon, and Elsie

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ABSTRACT

Two major environmental problems currently affecting Louisiana are a high rate of coastal wetland loss and high levels of surface water pollution. The application of secondarily treated wastewater to wetlands is proposed as a means of dealing with these problems. The benefits of wetland wastewater treatment include improved surface water quality, increased accretion rates to balance subsidence, improved plant productivity, and decreased capital outlays for conventional engineering treatment systems. Wetland treatment systems can be designed and operated to restore deteriorating wetlands to previous levels of productivity. Hydrologically altered wetlands in the Louisiana coastal zone have been selected as appropriate for receiving municipal and some types of industrial effluent.

While the U.S. Environmental Protection Agency has determined that wetland wastewater treatment is effective in treating municipal effluent, it has discouraged the use of natural wetlands for this purpose. As a result, hydrologically altered wetlands in the Louisiana coastal zone are being neglected and ultimately lost, while scarce funds are being applied to the construction of artificial wetlands to treat municipal effluent. Effluent discharge to existing wetlands can be incorporated into a comprehensive management plan designed to increase sediment and nutrient input into subsiding wetlands in the Louisiana coastal zone.

Secondarily treated effluent discharged from industrial and municipal facilities in the Louisiana coastal zone were reviewed for their suitability for wetland wastewater treatment. Selection criteria for wetland treatment systems were developed for both dischargers and receiving wetlands. Analysis of field data for two existing wetland treatment projects shows favorable results. Designs for two potential case studies based on established selection criteria for wetland wastewater treatment systems are presented. An economic analysis of the four case studies indicates a high potential for financial savings when wetlands replace conventional engineering methods for tertiary treatment.

CHAPTER 1

INTRODUCTION: POLICY CONSIDERATIONS FOR THE USE OF WETLAND WASTEWATER TREATMENT IN COASTAL LOUISIANA

Preface

Wetland wastewater treatment has been widely used and is particularly feasible in coastal Louisiana. This dissertation will examine the potential for wetlands to treat municipal and small food processor effluents in coastal Louisiana. Chapter 1 is a literature review which presents scientific principles and political views, and applies those principles and views to Louisiana. Chapter 2 describes the locations and characteristics of specific dischargers in two hydrologic zones in the coastal region in relation to their potential for discharge to wetlands. Chapter 3 presents the methods, design, and results from a pilot site where food processor effluent is being applied to a bottomland hardwood site. Chapter 4 examines three actual or potential case studies in Louisiana where wetland wastewater treatment will or could be applied. The final chapter is an economic analysis of the costs and benefits of using wetland wastewater treatment in Louisiana.

1.1. Global and National Use of Wetland Treatment Systems

Wetlands have been used to treat wastewater for centuries, but only in the past two decades has their response to such use been scientifically analyzed (Richardson & Davis 1987). From an ecological perspective, interest in wetlands to purify effluent is based on a belief that the free energies of the natural system are both capable of and efficient at driving the cycle of production, use, degradation, and reuse (Odum 1978). The basic principle underlying wetland waste treatment is that the rate of application must balance the rate of decay or immobilization. The primary mechanisms by which this balance is achieved are physical settling and filtration, chemical precipitation and adsorption, and biological metabolic processes resulting in eventual burial, storage in vegetation, and denitrification (Patrick 1990; Kadlec & Alvord 1989; Conner et al. 1989).

Both natural and constructed wetlands are used to treat wastewater. Constructed wetlands -- those built to treat wastewater on non-wetland sites -- can be designed to treat all forms of effluent from raw effluent through tertiary treatment and are designed as either surface or subsurface systems. The latter are used extensively in Europe (Watson et al. 1989) while both systems are used in the United

States. Reed (1991) lists 56 surface flow systems and 98 subsurface systems in the U.S. There are considerably more systems, however, as the U.S. Environmental Protection Agency (1987) reports over 100 constructed wetland sites in Ohio, Pennsylvania, Maryland, and West Virginia that are not included in Reed's estimates. Natural wetlands, are legally limited to providing only tertiary treatment of secondary waste, and only after approval on a case by case basis. As of 1987, more than 400 natural wetland systems had been approved to receive wastewater discharge in the southeastern United States, with at least 100 more in the Great Lakes States (EPA 1987).

To a large extent, conventional treatment plants employ physical and biological principles that are identical to those operating in both natural and constructed systems. But whereas filtration, sedimentation, oxidation, reduction, and nutrient cycling occur in natural systems by the interaction of soils, vegetation, and microorganisms, these same processes occur in conventional plants only with substantially greater amounts of energy and chemical additives to compensate for the reduced space and time required to treat large volumes of effluent. Constructed wetlands generally fall in between the two extremes, depending on design and loading rates.

In any treatment system -- natural, constructed, or conventional -- a large number of variables can be manipulated to achieve pollutant reduction goals. While

conventional plants must produce constant heat and oxygen to accommodate the microbial mineralization of organic carbon, natural wetland treatment systems are designed to take advantage of existing site and climatic conditions such as soils, plants, pH under submerged conditions, temperatures, precipitation, and flooding regimes. The primary management controls in the natural system are loading rates and residence times, though design of the distribution system can increase the number of outfalls and take advantage of or create gradients or slopes.

1.2. Restoration Ecology

Restoration ecology has been defined as the reassembly or partial assembly of an ecological system (Jordan et al. 1987). Central to the hypothesis that controlled effluent application to Louisiana wetlands can benefit the receiving systems is the knowledge that a large portion of the state's coastal wetlands have undergone and continue to undergo severe deprivation of sediments and nutrients that has lead, quite literally, to the break up of the natural system. Impoundments, flood control projects, and oil and gas canals have all contributed to create a large number of hydrologically isolated wetlands (Day et al. 1990). Sediment deprivation combined with regional geologic subsidence, local subsidence where former wetlands have been drained, and rising sea levels have combined to produce

current wetland loss rates in the Louisiana coastal plain of approximately 65 km^2/yr (25 mi^2/yr) (Dunbar et al. 1992).

In attempting to replace what has been lost either by human alterations of the environment or by naturally occurring subsidence, the addition of sediments and nutrients to wetlands through effluent application constitutes a form of wetland restoration. The chief component of the restoration plan would be the selection of an adequate design and effective loading rates to ensure adequate hydrologic control and the health of the ecosystem. In reviewing appropriate sites in the Louisiana coastal region, attempts have been made to avoid pristine, ecologically sensitive, or highly urbanized areas. Impounded, hydrologically altered, sediment starved areas were the primary candidates for selection. But since most of the coastal region is in jeopardy, a much larger area of the coastal region should be considered as potentially appropriate to receive treated wastewater than has been considered to date. The success of wetlands as tertiary treatment systems has been amply established under conditions where populations are not large and natural wetland acreage is available (Nichols 1983; Richardson & Nichols 1985; Khalid et al. 1981; Best 1987). A wetland wastewater treatment management plan could be established as a general practice in the Louisiana coastal region where these conditions exist. The assimilative capacity of wetlands to serve as more than tertiary systems (i.e., to

treat effluent less than secondary) should be investigated through scientific experiment (See Chapter 3 on Zapp's potato chip factory and Chapter 4 on seafood processors). New wetlands should not be constructed if resources spent on artificial systems contribute to the neglect or abandonment of natural but ailing wetlands.

Wastewater application to wetlands does not usually lead to biological communities identical to those either preceding application or surrounding the receiving site, though such communities would probably be desirable. The ultimate aim of the discharge would be to make use of the assimilative capacity of the wetland to treat wastewater in order to maintain biological productivity and to offset subsidence. In a state with a relative sea level rise ten times greater than eustatic sea level rise and 4 times the average of any other state (Templet & Meyer-Arendt 1988 from Hicks 1978, Gornitz et al. 1982), the first problem should be to keep the land above water. Only after succeeding in that attempt will we have the option of determining exactly what type of vegetation is optimal. It is likely that the attempt itself will prove enlightening by answering critical questions on vegetation, nutrient, and sedimentation dynamics. Monitoring and research should be an integral part of any program that attempts to make use of or enhance the environment. Duplication of wetland functions is the important point. This is emphasized by Jordan et al. (1987)

in their discussion of restoration ecology as both environmental technology and ecological technique:

> What is needed...is not rote copying, but imitation -- the distinction being that copying implies reproducing systems item for item, while imitation implies creating systems that are not identical but that are *similar* in critical ways and that therefore *act* the same. It is imitation, then, and not copying, that is the critical test of understanding, because it is this that implies reproduction of the essentials, the critical parameters of the system grasped as abstractions.

Wetland treatment systems in Louisiana can be established in hydrologically altered areas as experimental systems designed to imitate the critical functions of previously healthy wetlands nourished routinely by sediments and nutrients. In so doing, knowledge of the essentials will be both expanded and refined. The essentials deal with the hypothesis that wetlands improve water quality and that added sediments and nutrients will benefit subsiding wetlands. Maintaining coastal wetlands will prevent the loss of not only water purification functions and values but also flood control benefits, wildlife habitat and diversity, direct economic use, education, and research.

1.3. The Louisiana Coastal Zone: Some Considerations for Wetland Treatment

In general, a sediment deficit occurs annually in coastal Louisiana as a result of an apparent water level rise in excess of accretion. Approximate annual accretion rates in coastal Louisiana wetlands range from 0.66 to 1.31

cm in salt marshes, 0.84 cm in brackish marshes, and 0.75 to 2.97 cm in fresh marshes (Cahoon & Turner 1989; Knaus & Van Gent 1989). DeLaune et al. (1989) concluded that

> It is obvious that many Louisiana Gulf Coast marshes are not accreting or aggrading rapidly enough to keep the marshes intertidal....From a coastwide view, it is evident that vertical marsh accretion rates on the order of 0.6 to 0.8 cm/yr are not sufficient to maintain the elevation of the marsh, which is submerging at rates as great as 1 to 3 cm/yr.

A similar accretion deficit is occurring in forested wetlands. Conner and Day (1988) measured accretion rates in cypress-tupelo forests in the Barataria and Verret basins of 0.6 and 0.88 cm/yr, respectively. Given the apparent water level rise in those areas (0.85 and 1.37 cm/yr), the resulting vertical accretion deficits are 0.25 cm/y in the Barataria forest and 0.49 cm/yr in the Verret forest. Sedimentation rates on a bottomland hardwood ridge in the Verret forest were much lower than the cypress forests, measuring only 0.27 cm/yr and resulting in a deficit of approximately 1.1 cm/yr. Using a calculated relative sea level rise of 1.45 cm/yr (estimated from Penland et al. 1986), recent estimates for the Thibodaux study site in the Terrebonne Basin show an average deficit in the three study areas of -0.72 cm/yr (Table 1-1).

Table 1-1: Accretion deficits in the Thibodaux Swamp Forest (cm/yr) (Source: I. Hesse, Center for Wetland Resources, personal communication).

	1990	1991
Cypress-Tupelo Flooded Site	0.25	-0.65
Cypress-Tupelo Control Site	-0.75	-0.95
Bottomland Hardwood Ridge	-1.05	-1.15

Accretion deficits can only be balanced by increased vertical accretion resulting from both mineral matter and in situ plant production. Vegetation stimulates the formation of mineral as well as organic soil by trapping inorganic sediments (DeLaune et al. 1989). Maintenance of vegetation is crucial to the survival of existing marshes, and biomass production by vegetation can be as important as mineral sediment input (Day & Templet 1989).

Additions of wastewater effluent can provide a valuable stimulus to biomass production and to subsequent soil formation. For the Houghton Lake, Michigan natural wetland treatment system that has operated annually from May through September since 1978 to treat secondary effluent, there was an increase in annual background accretion levels from 2-3 mm yr^{-1} to 10 mm yr^{-1} (Kadlec & Alvord 1989). While increased sedimentation in wetlands might be considered a drawback in some geographic areas due to the filling in process and resulting alteration of water levels, for Louisiana wetlands it is an asset in maintaining current land levels against the forces of subsidence.

The Mississippi Delta can be considered as a wetland waste treatment system on a grand scale. Gosselink & Gosselink (1985), for example, emphasized the importance of both burial as a permanent sink for excess nutrients and the buildup of sediment in wastewater treatment systems, in their attempt to answer the question of whether the Mississippi River Delta is "a useful analog for a municipal overland flow system". They calculated that surface nutrients were effectively removed from the root zone and permanently deposited in the deep marsh sediments after approximately 30 years. They concluded that wastewater treatment systems in the region must accrete in order to permanently immobilize nutrients not lost by gasification.

Gosselink & Gosselink (1985) also presented some interesting findings pertaining to the present natural levels of nutrients and sediments in Mississippi and Atchafalaya River water and in the receiving wetlands for that water in the Atchafalaya Basin. Waters of the Atchafalaya River in 1980 had substantially lower concentrations of total nitrogen and phosphorus after passing through forests and pastures, than waters applied to selected overland treatment systems in Michigan, Pennsylvania, and Minnesota. The vast quantities of water contributed by the river, however, produced nutrient loading rates far greater than the treatment systems to which it was compared. Total nitrogen and phosphorus loading rates were 1060 kg/ha/yr and 150 kg/ha/yr respectively for the

Atchafalaya River Basin -- 35 times higher for nitrogen and 12 times higher for phosphorus -- than the loading rates for the Houghton Lake, Michigan natural wetland treatment system processing secondarily treated effluent. In addition, loading rates for suspended sediments in the basin were 184,000 kg/ha/yr.

A number of generic questions arise from the Atchafalaya Basin example that pertain to the maintenance of virtually all Louisiana wetlands. Wetland wastewater treatment could be used as a component of a restoration plan to return nutrients and sediments to the wetland, but only after knowledge of the system and goals for its maintenance are established. The Atchafalaya Basin, for example, is frequently described as one of the few remaining natural wetland or wilderness areas in the country. It is unlikely, however, that the high loadings measured by Gosselink & Gosselink (1985) are typical of those that formed the system before confinement of the basin by water control structures. Nutrient loadings to the Mississippi River have, in fact, dramatically changed over the course of this century as a result of increased fertilizer use. Turner and Rabalais (1991) reported a doubling of the nitrate concentration in the lower Mississippi River over the past 35 years compared to the first half of this century, with an apparently similar rise in phosphorus and an inversely related decline in silicate.

In addition to the question of historic flows, then, other questions that need to be addressed include: is the present vegetation identical or similar to previous types, or have different species established themselves? Are natural rates of succession occurring, or have human alterations sped up or changed the natural course? Where human intervention has brought about changes, then what is the ultimate goal -- to revert to the previous system, maintain the present one, or manipulate the present one to achieve functional goals or aesthetic values deemed desirable by some segment or all of the present population? Clearly a comprehensive management plan is needed to save coastal Louisiana, and wetland wastewater treatment can be an integral part of such a plan. While the primary benefit of wetland treatment will be the improvement of water quality, it can contribute to the halting of wetland loss by increasing the number of sediment and nutrient distribution points to subsiding wetlands. Holding ponds, pretreatment techniques, rotating receiving areas, and multiple outlet distributions systems could be incorporated into wetland treatment systems in order to restore sediment and nutrients to the coastal plain.

1.4. Benefits of Wetland Wastewater Treatment

The primary benefits derived from wetland wastewater treatment in Louisiana are 1) improved surface water quality, 2) increased accretion rates to balance subsidence,

3) increased productivity of vegetation, and 4) the financial savings of capital not invested in conventional tertiary treatment systems.

A number of factors associated with wetlands in general, and with Louisiana coastal wetlands in particular, will lead to efficient reductions in biological oxygen demand, total suspended sediments, total organic carbon, and nitrogen and phosphorus levels contained in typical municipal or food processor effluent. These factors include 1) a high rate of burial due to subsidence and 2) higher than the national average denitrification rates due to warm temperatures and wetland plants which enhance denitrification. Relatively high temperatures compared to other geographic areas are also responsible for higher metabolic rates, and higher plant productivity in general. A third factor related to phosphorus removal is the adsorption and precipitation of inorganic phosphorus which is facilitated by reactions with iron and aluminum under the neutral conditions of saturated wetland soils (Nichols 1983; Patrick 1990). Phosphorus removal rates in the southeast are variable but potentially high. Nixon and Lee (1986), in a review of field studies of wetlands and water quality, found overall phosphorus removal rates in the southeast to range from 9% to 98% for a range of loading rates between 0.4 to 46 $gP/m^2/yr$. By using conservative hydraulic and nutrient loading rates and employing design

criteria to optimize contact time, effective removal rates for all water quality constituents could be achieved.

1.5. Potential Problems and Concerns

A great deal has been learned about wetland wastewater treatment over the past two decades. For every problem raised there can usually be found some case study that has used innovative ways to solve it, or a study with contradictory findings since site specific factors often determine removal efficiencies. There is a great deal of flexibility in the use of hydrologically altered systems, both from the contributions of scientists and engineers and from the nature of the systems themselves.

The question of adequate phosphorus removal efficiencies or the prevention of phosphorus saturation is a case in point. Where natural soils do not contain sufficient amounts of iron, aluminum, or calcium to effectively remove phosphorus (Nichols 1983), other techniques have been employed successfully in the field or lab such as the addition of an anaerobic zone in a section of the activated sludge system at the Walt Disney World treatment system (Knight et al. 1987). When phosphorus loadings are high or a wetland lacks the assimilative capacity to transform or remove it, Richardson and Davis (1987) suggest pretreatment using alum or iron, or aeration to decrease BOD and suspended solids. Khalid et al. (1982) found phosphorus removal from municipal wastewater to be

enhanced both by the addition of calcium carbonate and by the prereduction of the soil/plant system. Finally, Louisiana wetlands can assimilate much higher levels of phosphorus than elsewhere due to the high rate of burial resulting from a high rate of subsidence.

Two other commonly voiced concerns over the issue of wetlands used as wastewater treatment systems include the suggestion of incomplete pathogen removal and the implications of treatment to wildlife populations. Questions have been raised by some researchers (Shiaris 1985 and Grimes 1985), for example, about the effectiveness of wetland treatment in removing pathogens. At the same time, however, successful pathogen removal by natural die-off has been reported by EPA (1987), and measured in the field or lab by Meo et al. (1975), and Gersberg (1987) among others. Kadlec (1989) reported that fecal coliforms are generally reduced to acceptable water quality standards after passage through wetlands, as are viruses and bacterial indicators such as fecal streptococcus. He found no reported incidents of adverse effects to animals or humans resulting from wetland wastewater treatment.

Finally, concern for the potentially adverse effects of wastewater treatment to wildlife are sometimes expressed and the suggestion made that more artificial wetlands be built to serve as models of the natural system (e.g., Guntenspergen and Sterns 1985). But others acknowledge that there is no substitute for a natural system, and that

species diversity is usually lower in artificial systems (EPA 1987). Many believe that the use of natural wetlands as treatment systems has benefited, and can continue to benefit, wildlife populations (e.g., Best 1987). W.A. Wentz (1987), of the National Wildlife Federation, explains the benefit of and need for the carefully planned multiple use of wetlands:

> We must take people beyond the idea that because wetlands are valuable they cannot and should not be "managed." It is very important that people understand that manipulation of wetlands is not necessarily a bad thing. Many people will question the purposeful "use" of wetlands for such things as cleaning up wastewaters, but that, in itself, may not be bad because it will require those who advocate such uses to better understand what they are doing and its impacts in order to satisfy critics, and, in the end, we will have a better outcome and better public policy.

Indeed, manipulation of altered natural systems is essential in order to control the changes brought about by human interference.

The fact that 1991 waterfowl survey figures for ten species of diving and dabbling ducks show a decline for nine of those species from the 1955-1990 average, with the northern pintail showing a decrease of 62% (U.S. Fish and Wildlife Service 1991), emphasizes the need for full-scale habitat protection measures. The importance of Louisiana wetlands as waterfowl habitat, and the high wetland loss rates require efforts to increase and improve existing wetland acreage.

A careful design can combine the techniques of the engineer in terms of flow rates, holding ponds, stormwater diversions, and the pretreatment methodologies described above, with the impoundments, spoil banks, levees and sheer space available in the "natural" system.

1.6. Current Political and Regulatory Climate

1.6.1. EPA

The U.S. Environmental Protection Agency (EPA) has recognized the benefits and efficiency of wetland treatment systems. The Agency's Report on the Use of Wetlands for Municipal Wastewater Treatment and Disposal states:

> Wetlands appear to perform, to at least some degree, all of the biochemical transformations of wastewater constituents that take place in conventional wastewater treatment plants, in septic tanks and their drainfields, and in other forms of land treatment....Under appropriate conditions, both natural and constructed treatment systems have achieved high removal efficiencies for BOD, suspended solids, nutrients, heavy metals, trace organic compounds as well as natural die-off of pathogens from wastewater. (EPA 1987)

While the Agency acknowledges that constructed wetlands are often more costly "and rarely achieve the same level of biological complexity as natural wetlands systems", its stated policy is that "currently, use of constructed, rather than natural wetlands, is generally preferred by EPA when projects for wastewater treatment are proposed" (EPA 1987). The primary reason for preferring constructed over natural

wetland treatment systems is the presumed greater level of "control" in the former.

Two points in regard to the issue of control need to be addressed here. First, in Louisiana's case at least, it can be argued that the large number of isolated impounded or semi-impounded areas allow for as much control as might be available in a constructed wetland. Second, control in an artificially-created environment which lacks the diversity of a natural one, is not as instructive scientifically in terms of revealing the functions and processes of the wetland ecosystem. Again, Jordan et al. (1987) describe the situation appropriately with an emphasis on the value of control in natural systems, as opposed to artificial ones:

> A lot goes on in the healing of a salt marsh...that the practicing restorationist does not control and may not even be aware of. This, however, is of interest not only to the "theorist", but to the practising restorationist as well, since not knowing what is going on in a system limits his or her ability to deal with it under varying conditions....The essential idea is control -- the ability not only to restore quickly, but to restore at will, controlling speed, decelerating change as well as accelerating it, reversing it, altering its course, steering it, even preventing it entirely (which of course is actually a frequent objective of the ecological manager).

Louisiana's need to control or prevent wetland loss and deal with surface water pollution calls for an application of the proven abilities of natural wetlands as treatment systems. The use of hydrologically altered wetlands to treat

wastewater will enable the testing of hypotheses regarding ecosystem response and land loss, and will contribute to the overall knowledge of wetland ecosystems.

EPA's preference for constructed over natural wetlands as treatment systems has undoubtedly influenced national policy. In 1987 the Agency itself acknowledged that "the lack of EPA water quality criteria for wetlands and the resulting absence of State water quality standards for wetlands is one of the most serious impediments to a consistent national policy on use of wetlands for wastewater treatment or discharge" (EPA 1987). Florida is the only state to have instituted its own regulations for wetland treatment systems. Prior to the institution of those regulations in the mid-1980's, H.T. Odum (1978) used Florida as an example of a state who's regulatory authority lacked an appreciation of the environment's assimilative capacity: "An economy is vital when environment and economic developments are mutually reinforced and protected. Unfortunately, well-meaning efforts to draft laws to protect the environment have not always been made with an understanding of the ecological principles of symbiosis and recycling by which nature and humanity are best combined."

The regulations which Florida subsequently adopted allow for progressively stricter loading rates depending on the type of wetland to which effluent is discharged. The Florida plan allows for the following applications:

1. hydrologically altered wetlands are allowed to receive a maximum of 75 $g/m^2/yr$ of total nitrogen and 9 $g/m^2/yr$ of total phosphorus;
2. treatment wetlands are used to treat reclaimed water that has gone through secondary treatment with nitrification, and are allowed to receive 25 $gN/m^2/yr$ and 3 $gP/m^2/yr$;
3. receiving wetlands are used to receive reclaimed water that has gone through advanced (tertiary) treatment, and can accept only wastewater treated to 3 mg/liter total nitrogen and 1 mg/liter total phosphorus (Harvey 1988).

Florida's ranking of wetlands to treat wastewater is a response to environmental problems which include a high degree of water level reductions with relatively no subsidence. Discharge to treatment and receiving wetlands are generally prohibited in Class I and II waters and in non-cattail dominated herbaceous wetlands. Hydrologically altered wetlands in Florida are defined as those where upland vegetation has encroached and where substantial reduction in water levels have occurred. While Louisiana does have altered wetlands that fit this description due to drainage projects or deprivation of flows to some wetland areas, the problem of subsidence and rising water levels is a far more serious threat. Effluent with higher sediment and nutrient loads should be directed to submerging wetlands to increase accretion rates and productivity. While Florida needs to deal with the problem of wetland loss as a result of decreased water levels and the consequent transition to uplands, Louisiana needs to deal with the problem of wetland

loss as a result of increased water levels and the consequent transition to open water.

An additional factor favoring wetland wastewater treatment in Louisiana is its relatively low population and available land area. While Florida ranks first in the coterminous United States for total wetland acreage and Louisiana ranks second (Dahl 1990), Louisiana has a substantially greater amount of total land per capita, with 97 persons per square mile of land area compared to 240 for Florida (U.S. Bureau of the Census 1991). In addition, the general tendency for populations in Louisiana to be distributed along natural levee ridges backed by wetlands, facilitates use of those wetlands as treatment systems.

Since 1987, EPA has attempted to design standards that would be more appropriate for wetlands than the aquatic standards developed for surface water bodies. The Agency has recently published a manual describing numerical or narrative biological standards designed to prevent a decrease in wetland productivity or diversity (U.S. EPA 1990). While the Agency is still willing to permit the use of wetlands as tertiary treatment systems in some Louisiana cases, it will not allow such use as a form of wetland "enhancement". The term was used in the report on wetlands to treat municipal wastewater (EPA 1987) primarily as a possibility only in areas where insufficient water exists to maintain a wetland as occurs in the West, not in areas facing the possibility of conversion to open water as occurs

in Louisiana. There appears to be a reluctance to admit, or a basic disagreement with, the hypothesis that a natural but degraded wetland might adequately purify wastewater, while benefiting ecologically at the same time.

Consequently, EPA has discouraged wetland wastewater treatment in Louisiana as a form of "enhancement", and encouraged the state to approve wetland projects according to the "antidegradation" rule which requires that the state "provide for the protection of existing uses in wetlands..." (U.S. EPA 1990). In Louisiana's case, where sea level rise is predicted to drown a vast expanse of coastal marsh (Park et al. 1989; Day & Templet 1989), such an emphasis on "present uses" appears short-sighted and designed to accommodate only those who use or will use the wetland areas directly over the next 2 to 3 decades or less.

The Louisiana DEQ has granted permission to discharge secondarily treated wastewater to wetlands in Thibodaux and is considering the same permission in Breaux Bridge, but only as a "naturally dystrophic waters" exception on the premise that dissolved oxygen levels are naturally lower than the EPA standard of 4.0 mg/l in estuarine waters. State DEQ personnel have generally sought to establish expedient permitting of wetland treatment systems, though working within the inflexible national framework of EPA policy has been a deterrent. A memo from one staff member to the Secretary emphasized the need for prompt

consideration and processing of wetland treatment system permitting:

> If we are to make wetlands enhancement by wastewater application feasible in Louisiana, we must provide the regulatory structure to allow expedient permitting of such discharges. The establishment of appropriate wetland specific standards is the first step in providing the regulatory structure for permitting (Knox, no date).

Recently the state has developed a set of useful standards for the Thibodaux wastewater treatment site which include the following prohibitions designed to protect wetlands from any adverse effects due to wastewater application:

1. No more than 20% decrease in naturally occurring litter fall or stem growth.
2. No significant decrease in the dominance index or stem density of bald cypress.
3. No significant decrease in faunal species diversity and no more than a 20% decrease in biomass.

Monitoring of the site after effluent application begins in the Spring of 1992 will test the validity of these criteria and serve as a basis for their expansion or refinement.

EPA has already acknowledged the capability of wetlands to effectively treat wastewater. It remains for the agency to review the potential for treated effluent to benefit Louisiana's wetlands in light of the unique problems afflicting the state. If the basic premise that effluent can contribute valuable sediment and nutrients to the

wetlands is accepted, then wetland wastewater treatment could be incorporated as a major component of an overall comprehensive plan to protect and restore the state's wetlands. Seven years ago Gosselink and Gosselink (1985) suggested that wetland wastewater treatment be incorporated into plans to divert freshwater from the Mississippi River to the coastal plain. Templet and Meyer-Arendt (1988) have emphasized that the wetland sediment deficit is the primary reason for Louisiana's land loss. Their suggested policy is to use Mississippi River water, sediments, and nutrients to revive and nourish coastal wetlands. They state further that:

> The solution is to provide enough sediment for the wetlands to maintain a suitable base above water for plant growth....The greater the number of conduits delivering water, sediments, and nutrients into the wetlands, the greater is the level of restoration of a formerly viable ecosystem.... Strategy: Provide maximum distribution of the waters of the Mississippi River across the deltaic plain by using the maximum number of distribution points to move water, sediment, and nutrients into the coastal wetlands.

Water, sediment, and nutrients from small industries and municipalities throughout the coastal region could enhance the overall plan by increasing both the total volume and the maximum number of distribution points. Money saved from the construction of conventional or constructed wetland treatment systems, could be applied toward thorough preproject review of potential wetland treatment areas and a

sophisticated monitoring and modelling system designed to prevent any detrimental impacts to natural areas.

1.6.2. General Political Debate Over Wetland Identification

Wetland assessments have been carried out since the 1970's and have involved the specific areas of wildlife and habitat, ecosystem diversity, water quality, flood storage, flood conveyance, groundwater recharge and discharge, and educational and aesthetic value (Silberhorn 1974; Kusler 1986; Adamus et al. 1987). The practice of placing economic values on wetland functions has gone hand in hand with attempts to raise the technique of wetland identification to the status of a science (Gosselink et al. 1974; Mumphrey et al. 1978; Lynn et al. 1981; Thibodaux & Ostro 1981; Farber 1987; Titre et al. 1988; Costanza et al. 1989; Scodari 1990). That a field of wetland science exists is irrefutable given that wetlands comprise a type of system with natural phenomena in the form of properties, functions, and species distinct from terrestrial or aquatic systems. Less apparent is exactly where wetlands begin and end in their positions in between dry land and open water. The difficulty in delineating wetland boundaries is at the core of the controversy today, leading to different opinions on even the basic definition of a wetland. Two recently expressed views in the National Wetland Newsletter illustrate this point:

> "...regulatory limitations, such as seven days of saturation or inundation versus 15 days or even 21 days, merely serve as artificial limits on an ecological concept we call wetlands" (Huffman, Nov,1991).

> "Ecologically speaking, the term 'wetland' has no meaning;....For regulatory purposes, a wetland is whatever we decide it is" (Pierce, Nov 1991).

While some wetlands consistently exhibit hydrological, vegetative, and edaphic characteristics that make them indisputably wetlands, many types do not exhibit all three characteristics all year, every year. It is for the latter type that the "artificial limits" are devised. Differences between the 1987 Corps Manual, the 1989 Federal Manual, the EPA Proposal, the Reilly/Quayle Proposal (56F.R. 40446), and the Hayes Bill (H.R.1330) deal with temporal limits such as number of days of inundation or number of weeks before or after the growing season; or spatial limits such as the number of inches of saturation; and, for vegetation, frequency analyses or prevalence indices (National Wetlands Newsletter, Sept. 1991). The ultimate decision on spatial and temporal criteria for regulatory purposes will, indeed, be arbitrary and the possibilities are virtually infinite.

1.6.3. The Future Course of Wetland Regulation

Wetland regulation may take one of three directions: (1) remain as it is, with the development or protection of each wetland tract determined on a "parcel by parcel" basis; (2) establish a ranking system designed to protect the most valuable wetlands first (Hayes Bill H.R. 1330; Conservation Foundation 1990); or (3) conform to a broader, landscape approach whereby wetlands would be considered according to the role they play in the regional landscape (Gosselink et al. 1990). Wetlands and water quality can benefit from the use of wetlands as treatment systems, regardless of the future regulatory framework. Some forms of wetland management, however, will be more complementary to the widespread use of wetland treatment systems than others. Implications of the different regulatory approaches to wetland treatment systems are described below.

Continuing the Permit System

In terms of the success or failure of the wetland-treatment system concept, the permit review process would be likely to hinder an overall wetland wastewater treatment policy, simply because the lack of a cohesive plan or framework would make each permit decision grounds for opposition by disgruntled parties. Shabman (1985) describes the susceptibility of the process to political opposition:

> ...a permit decision, by its nature, is a redistribution of wealth. As a result, no matter how well done the technical valuation, there will be little acquiescence of the parties affected by a regulatory outcome, regardless of how the balance is struck. Thus, assessment is not a neutral technical exercise but is rather an activity closely tied to the process of redistributing the rights to use the environment, and will become part of the political acrimony accompanying that process.

Experience has shown that anyone denied the right to develop land for the public good is likely to protest. Recognition that the maintenance of water quality or the purification of wastewater is a beneficial function of wetlands, will inevitably lead to conflict and debate over those benefits. Under the permit process this conflict will continue to emerge each time a permit is denied. In addition, the inability to predict whether an adjacent wetland will exist in the future, may inhibit the use of certain wetlands as treatment systems.

Ranking Wetlands

If a ranking approach were adopted, treatment wetlands could fall under either a damaged but restorable class or an irreparably damaged class, both of which would require the usual monitoring to ensure conformance with environmental water quality or wetland regulations. Many wetlands which would be lost or declassified under the Hayes bill or Reilly/Quayle proposal, could be maintained if used as wastewater treatment systems (see Chapter 3 on Zapp's Potato

Chip Factory site). Closely monitored wetlands would prevent any inadvertent damage resulting from wetland treatment and protect the basic functions of the system indefinitely, or until the landowner decided to develop the land if that were the permitted option.

Landscape Level Approach

The identification and use of appropriate treatment wetlands would fit well within a landscape level approach by singling out altered but conterminous wetland tracts that might serve the water treatment needs of a community or small industry within or adjacent to the regional wetland. Gosselink et al. (1990) use the bottomland hardwood system to discuss the importance of a landscape level approach to wetland protection. They describe the implications of the system's overall dependence and influence on the surrounding region as follows:

> 1. Management of individual processes or species generally ignores the integrated nature of bottomland hardwood forest systems.
> 2. Bottomland hardwood forest systems operate as integrated functional units.
> 3. The regulatory focus on an individual site ignores the context of that site in the landscape.
> 4. Important ecological processes occur at landscape scales.
> 5. A site-specific focus cannot deal adequately with cumulative effects.

Where direct or cumulative effects of wetland alteration have produced isolated sections of wetlands within a larger system, effluent application might serve to

restore the individual areas themselves, while also contributing to the reunification of the integrated functional unit as a whole. The receiving wetland for Zapp's Potato Chip Factory covered in Chapter 3 is an example of a hydrologically isolated wetland where wastewater treatment is being managed to conform to the ecological needs of the specific site in the context of the bottomland hardwood forest of which it is a part. The use of such isolated wetland tracts might serve as patches to link healthier intact systems.

Wetland treatment systems would be a useful component in an overall landscape management approach such as that being proposed by the Department of Environmental Quality's Nonpoint Source Division and the Nature Conservancy (LA. DEQ 1991) for the Wetland Protection Program in the Tensas Basin in northeastern Louisiana. The proposal emphasizes "compatible human use" as a major factor in large-scale planning. The draft proposal lists the following activities as a major step in the development of the plan:

> ...establish a general ranking of each wetlands complex that considers beyond the ecological processes, the opportunities for enhancing the quality of wetland habitat, connecting patches via corridors, [and] involving landowners in enhancing the environmental and economic value of their land....

While the Tensas Basin is not in the coastal area, it is an area of expansive and disappearing bottomland hardwoods that might benefit from wetland treatment. The precise boundaries of the Tensas study site are not delineated in

the draft proposal but there are several small towns in or around the area that are in need of additional wastewater treatment.

1.6.4. Hydrologically Altered vs. Constructed Wetlands

A survey of municipal treatment systems in Louisiana carried out by the Governmental Services Institute (GSI) at Louisiana State University in 1989 reviewed the status and needs of the state's municipalities (GSI 1989b). The survey gives a general indication of the potential needs for improved wastewater treatment in the state's 735 cities and towns. In the northeastern section that includes the Tensas Basin, four of the municipalities that responded to the survey (Newelton, Oak Grove, Richmond, and Wisner) listed oxidation ponds as the sole source of treatment for capacities ranging from 0.02 to 0.5 million gallons per day (GSI 1989a; LA DEQ, no date). Effluent from those ponds is being discharged into ditches which flow into surface water bodies (LA. DEQ, no date). Two additional respondents (Kilbourne and Pioneer) stated a need for information regarding treatment systems. Reed (1991) lists the towns of Oak Grove and Wisner, in addition to four other municipalities in the northeastern region (Lake Providence, Oak Ridge, Pioneer, and St. Joseph) as having built constructed wetlands as part of their treatment systems. Towns such as these, included in an area being managed under a landscape level wetland protection plan, should be

reviewed for their potential to contribute both to the restoration potential of the plan and to the overall economic benefit of the community before the expense of constructed wetlands is undertaken.

Louisiana has the largest number of wetlands constructed according to EPA Region VI Design Procedures (which comprises the largest category of constructed wetland types). Of a total of 62 such types in the United States, Louisiana has a total of 27, or 44% with the remainder located primarily in southern states such as Mississippi, Arkansas, Alabama, Oklahoma, and Texas. The mean national flow for these constructed wetlands is 0.402 million gallons per day (MGD), with a range of 3.5 to 0.002. The average hydraulic surface area is 5.8 acres per MGD (Reed 1991). The prevalence of constructed wetlands in Louisiana, and in the southern states in general, is likely due to the favorable climate and vegetation, in addition to relatively low populations and available land area.

The mean capital cost of subsurface constructed wetlands (the type used almost exclusively in Louisiana) is $87,218/acre and the mean cost of free water surface constructed wetlands is $22,200/acre (Reed 1991). These costs are undoubtedly far higher than natural treatment systems designed to make use of existing slopes, soils, and vegetation with a minimal amount of materials transport and site alteration. The use of natural wetlands as treatment

systems conforms to the general principle of ecological engineering described by H.T. Odum (1978):

> The large energy value stored in land configurations becomes obvious when one has to pay millions of dollars in bulldozer and truck operations to make a basin or other land form....Recognizing the high values in existing landscapes and finding ways to fit man's further developments without waste of the previous landscape values is the challenge to modern culture....

Constructed wetlands can be an excellent means to treat wastewater at all or various stages of the treatment process. Their expense, however, in addition to the deteriorating condition of Louisiana's natural wetlands which could benefit from the replacement of sediments and nutrients, calls for a consideration of natural wetlands as treatment systems proportionate to, if not greater than, artificial wetlands.

1.7. Summary

Wetland wastewater treatment systems are widely used and have proven to be especially effective in warm temperate regions such as the southern United States. When combined with careful designs and monitoring programs, wetland treatment systems show great promise in meeting the needs of both Louisiana's deteriorating wetlands and of the state's water pollution problems. Specific benefits include improved surface water quality, increased accretion rates to balance subsidence, increased productivity as a result of

the additions of nitrogen and phosphorus, and decreased financial outlays on conventional tertiary treatment components.

While the U.S. EPA has acknowledged the effectiveness of wetland wastewater treatment, it has encouraged the use of constructed over natural wetlands. Consequently constructed wetlands are taking precedent over natural wetlands to treat wastewater in Louisiana, despite the fact that the state's coastal wetlands are suffering from high subsidence rates and a deprivation of sediments and nutrients. The sediments and nutrients contained in secondariy treated municipal effluent and in some types of industrial effluent can be beneficially applied to subsiding wetlands in the coastal zone. The warm temperatures, relatively low population, and abundance of hydrologically altered wetlands make the Louisiana coastal zone an especially appropriate region for wetland wastewater treatment.

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CHAPTER 2

SELECTION OF APPROPRIATE DISCHARGERS FOR WETLAND WASTEWATER TREATMENT

2.1. Introduction

This chapter is an analysis of the potential utility of wetland wastewater treatment for municipal and small food processor facilities currently discharging into surface water bodies in the Terrebonne and Barataria Basins. Selection was based on effluent quality, facility location, and the nature of the receiving wetland. A methodology for extending the discharger selection process state-wide is presented.

2.2. Methods

2.2.1. Selection of Effluent Dischargers

Selection Criteria and General Characteristics

Selection criteria for effluent dischargers included the following:

1. Present discharge into a surface water body.

2. Type of effluent: Effluents considered were required to consist almost exclusively of biodegradable wastes with low levels of heavy metals or other persistent contaminants. Effluents not meeting these criteria were not

considered for discharge. Other characteristics that disqualified an effluent from consideration included high pH, or high levels of nutrients, heavy metals, or chlorine. The Department of Environmental Quality's (DEQ) Inventory or files did not generally contain any information on effluent chemistry for dischargers listed, and were thus assumed to have the equivalent of secondarily treated effluent (since that level of treatment is required by the state). Typical secondary effluent has an average five-day biological oxygen demand (BOD) and suspended solids (SS) content of 30 mg/l each, over 30 consecutive days (U.S. EPA 1987). Average ranges for secondary municipal effluent are provided in Table 2-1. Where groups of dischargers were obtained from other sources, such as the seafood processors along Bayou Grand Caillou and Bayou Pierre Part, typical values for that industry were obtained from the literature.

At the beginning of the study, only dischargers with a maximum of 4 million gallons per day (MGD) or less were reviewed, since a data base was available for that amount from the Thibodaux Swamp pilot site where effluent application began in Spring of 1992. But since both the total volume and the availability of receiving wetland acreage will determine the loading rates to the wetland, limits on total capacity were not included among the final selection criterion.

Table 2-1: Composition of Municipal Sewage and Secondary Sewage Effluent (Richardson & Nichols 1985)

Constituent	Raw Sewage Range*	Typical Value*	%Removal by Secondary Treatment	Secondary Effluent Range*	Typical Value*
Suspended Solids	100-350	220	70-95	13-62	25
BOD	110-400	220	80-95	13-75	25
COD	250-1000	500	-	50-160	70
Nitrogen, total	20-85	40	45-70	15-40	20
Phosphorus, total	4-15	8	40	7-10	10
Coliform bacteria	10^5-10^9	10^7	90-98	-	-
Refractory organics**	0.2-7.4	1.4	-	-	0.2
Chlorides	30-100	50	-	40-100	45
Trace Metals	50%***	90%***			
Cadmium	-	0.02	33	<0.005-6.4	<0.005
Chromium	0.2	3.6	58-67	<0.05-6.8	0.025
Cobalt	-	0.05		<0.05-0.05	<0.05
Copper	0.1	0.4	28-50	<0.02-5.9	0.1
Iron	0.9	1.9	47	0.10-4.3	
Lead	0.1	0.2	47	<0.02-6.0	0.05
Manganese	0.14	0.3	13	-	0.2
Mercury	0.001	0.0045	26-83	<0.0001-0.125	0.001
Nickel	0.08	0.2	33	<0.02-5.4	0.02
Zinc	0.18	1	47-50	<0.02-20	0.15

*all concentrations in mg/l except coliform bacteria MPN/100 ml

**primary surfactants

***50th and 90th percentiles, higher than 50% and 90%, respectively, of samples taken.

Barataria and Terrebonne Basin Dischargers

Potential candidates for wetland wastewater treatment were first selected by basin segment from the DEQ's Municipal and Industrial Discharger Inventory (1990b). Terrebonne and Barataria basin segments are delineated in Figure 2-1. Appropriate dischargers were further reviewed based on information contained within the DEQ permit files which the agency organizes as: A) State Permits, B) NPDES Permits, C) Discharge Monitoring Reports, D) Noncompliance, E) Inspections, Complaints, Spills, F) Federal and State Applications, G) Biomonitoring Reports, and S) Fees. All selected files were reviewed for capacities, effluent nutrient levels, description of treatment processes, general effluent characteristics, and location of facility. Further attempts to determine what dischargers existed in the basin that were not always included in the DEQ Inventory, involved the use of directories and permit lists such as the Louisiana School Directory (1990-91), National Marine Fisheries Service (1989), Terrebonne Parish Seafood Suppliers (Kendall, 1987), and seafood processor permits issued by the Department of Health and Human Services (1990).

Facilities were classified as subdivisions; schools; sewage treatment plants or oxidation ponds; other public facilities such as housing authorities, Department of Transportation facilities, parish recreation districts, and police juries; trailer parks; businesses; hospital or health

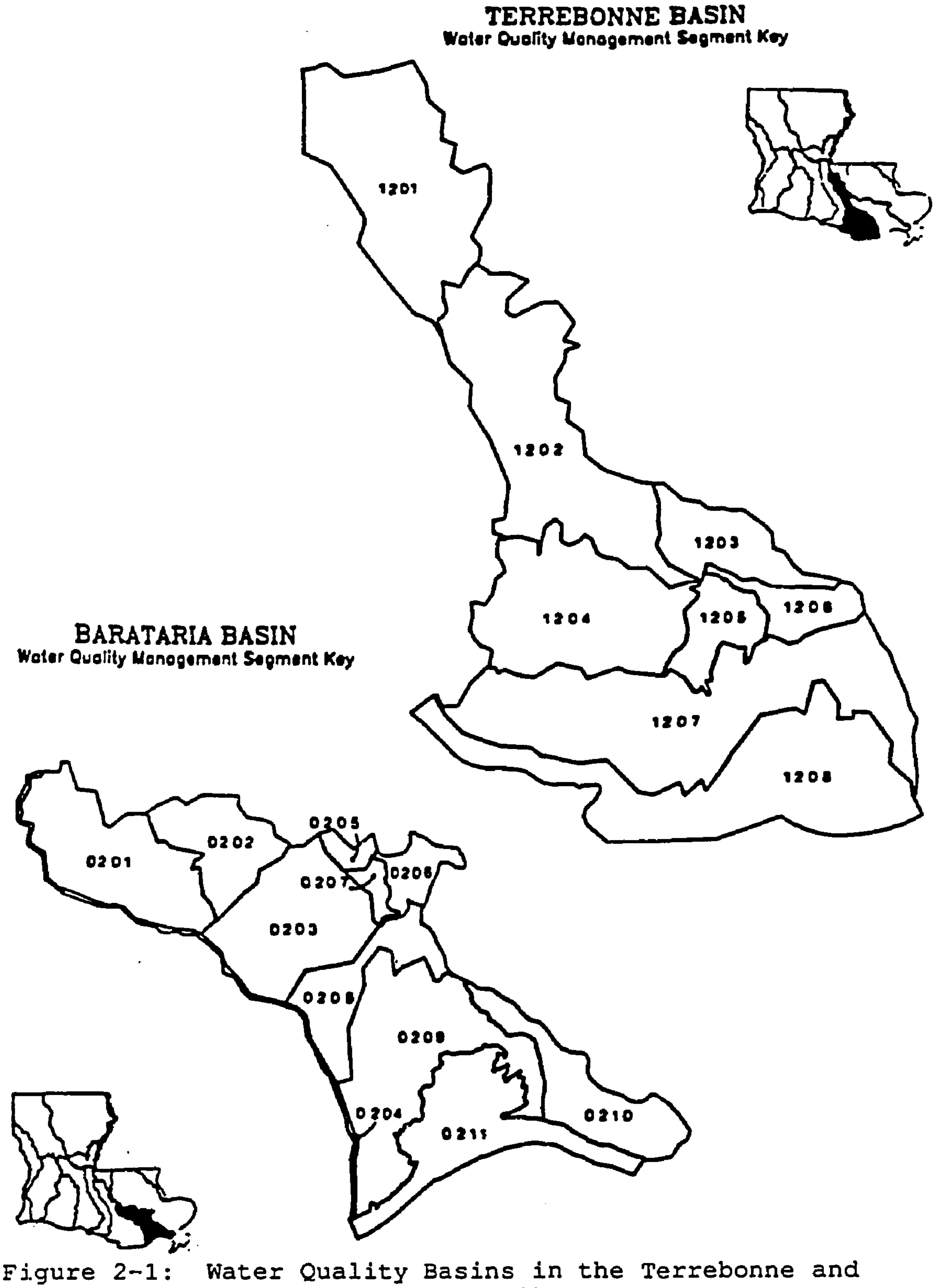


Figure 2-1: Water Quality Basins in the Terrebonne and Barataria Study Area (Source: DEQ).

care units; sugar mills or refineries; and "undetermined " when the function of the facility was not clear from its title and when no DEQ files describing the facility were located. In order to gain a general idea of the amount of wastewater discharged in the Louisiana coastal zone, all municipal dischargers were categorized regardless of capacity.

Effluent Discharger Map

In order to locate as many surface water dischargers as possible, available DEQ information was combined with the knowledge of local residents, civil engineers, and state personnel. Locations were then plotted on a 1:100,000 U.S. Geological Survey map covering the Terrebonne and Barataria Basins. Primary sources for the effluent discharger map include the DEQ Point Source maps for municipalities and industries discharging 50,000 gallons per day or more in the Terrebonne and Barataria basins; the limited number of maps contained within the DEQ files reviewed for this study; Robert Jones and Al Levron of Terrebonne Parish; Pat Breaux of the Lockport Branch of DEQ; Jerome Zeringue of the LSU Cooperative Extension Service, Terrebonne Parish; Bobby Simoneaux of the Thibodaux area; and the Bayou Grand Caillou Water Quality Study (Waldon 1991). Discharger locations on the map are either duplicates of any provided on published maps or in DEQ files, or the best estimates of those

individuals listed above. Discrepancies have occurred among sources where businesses have closed or become connected to treatment plants. Where sources conflicted, attempts were made to determine the exact location, actual existence of dischargers, or current means of treating wastewater. The DEQ Inventory may be inaccurate in its representation of the Houma area where recent attempts at expansion or consolidation of the treatment plant area have occurred. Locations are, therefore, approximations of discharger facilities currently emptying wastewater into surface water bodies.

It was originally expected that the DEQ Discharger Inventory would contain information on the precise location of all Louisiana dischargers. The requirement to include facility location on a topographical map with the permit application, however, was instituted only within the past few years, so few files provide exact locations of the discharger. Moreover, the supplemental directories described above indicated that many dischargers existed that do not have DEQ permits to operate.

2.2.2. Identification of Receiving Wetlands

Selection Criteria and General Characteristics

Wetlands selected to receive effluent from dischargers of secondarily treated wastewater should be reviewed according to the following criteria:

Exclusions:

1. Areas with noncompatible or priority uses such as urban or cultural areas, endangered or threatened species habitat, breeding grounds for fish, groundwater supply areas, established recreation or hunting sites, and archaeological or ecologically significant areas (Richardson & Nichols 1985). [Appropriate maps: Ecological Atlas for the Mississippi Deltaic Plain, (U.S. Bureau of Land Management & U.S. Fish and Wildlife Service). Recharge Potential of LA. Aquifers (U.S. Geological Survey)]

Requirements:

1. Present hydrologic isolation or confinement resulting from alteration of former hydrologic flows. [Appropriate maps: Small Scale Hydrologic Units, (LA. Department of Natural Resources); U.S. Geological Survey maps; Aerial photos.]

2. Proximity to dischargers. For initial review, a distance of five miles surrounding known dischargers has been set in order to encompass a fairly wide expanse of potential wetland treatment areas. Efficiencies of scale apply, however, and larger flows can be piped further than smaller flows. Kaczynski (1985) suggests up to 2 miles for 100 gallon per minute (gpm) or 0.14 million gallons per day (MGD) flows (3.2

kilometers for 378 liters/minute), up to 3 miles for 1,500 gpm or 2.2 MGD flows (4.8 km for 5678 liters/minute), and up to 12 miles for 20,000 gpm or 30 MGD flows (19.3 km for 75,7000 liters/minute).

Four existing or potential pilot sites are reviewed in this dissertation, all of which are located close to their receiving wetlands: the town of Breaux Bridge, LA is approximately 20 meters from the source to the wetland; Zapp's Potato Chip Factory is approximately 100 meters, and the city of Thibodaux is approximately 3000 meters. The fourth pilot study consists of numerous seafood processors in Dulac, LA, along Bayou Grand Caillou, with an average distance from the processor to the wetlands of between 300 and 500 meters. The seafood processors and the city of Thibodaux are or were discharging into surface water bodies. Zapp's and Breaux Bridge do not discharge into surface water bodies but rather into wetlands. Both were selected as pilot sites in order to study the effects of discharge on wetland productivity.

3. The size of a receiving wetland required to treat an effluent flow will depend on the volume of discharge. EPA (1987) has suggested 2.5 cm/wk over the receiving surface or 60 people/hectare as a conservative rate to treat secondary effluent. In their review of hydraulic loading rates to wetlands, Richardson & Davis (1987) pointed out that projects

which applied 2.5 cm/wk showed the same nutrient removal patterns as those which applied both more and less. The highest hydraulic loading rate was reported at approximately 22 cm/wk. Watson et al. (1989) reported typical hydraulic loading rates in constructed surface flow wetlands of 3.9 cm/day (27.3 cm/wk). In designing treatment systems in Louisiana, hydraulic application rates should be selected which attempt to mimic historic flows while providing adequate retention time. Adequate retention time will depend on site specific factors.

4. In addition to a relative degree of confinement, optimal wetland qualities include a low gradient to insure maximum residence time with eventual passage through the wetland. Flow of the wastewater down levees or spoil banks before entrance to treatment wetlands can maximize contact time and facilitate dispersion (Meo et al. 1975).

5. Backup treatment wetlands will provide the opportunity to alternate flows between different wetland sites and thereby prevent nutrient overload.

6. High subsidence areas should be reviewed first because of the potential for wastewater application to stimulate productivity and offset subsidence. [Appropriate maps: Soil Subsidence Potential (LA State Planning Office); Hydrology and Land Loss/Accretion Maps for Barataria Basin, East Terrebonne, and West

Terrebonne and Lower Atchafalaya Basin (Lee & Turner, Coastal Ecology Institute, LSU).]

All potential wetland treatment sites will require on site review of the area to determine feasibility.

General Wetland Characteristics Used in Determining Suitability for Wastewater Application

Hydrology

Wetlands are most often described and classified on the basis of vegetation, soils, and hydrology. For consideration as a treatment wetland, hydrology is, perhaps, the most important characteristic in controlling residence times and degree of contact with surrounding areas. Ideal sites in the Louisiana coastal zone include impounded areas that have been partially isolated. A marsh regularly flooded by tides might not provide sufficient detention time, though where impoundment leads to lower frequency of inundation, it might then become suitable as a treatment wetland. Excellent removal efficiencies of selected nutrients from screened shrimp processor waste were found in a periodically inundated *Juncus roemerianus* marsh in coastal Alabama (EPA 1986). Hydrologically similar areas are likely to occur in the impounded and subsiding wetlands located between the Houma Navigation Canal and Bayou Grand Caillou where the majority of seafood processors in segment 1205 are located. Ultimately loading rates should not exceed the

assimilation capacity of the wetland in terms of burial, uptake by vegetation, and denitrification.

The principle of replacing historic flows in isolated marshes applies to other coastal wetlands. Impounded segments of coastal forested wetlands, for example, exhibit rising water levels and remain permanently flooded. This will lead to eventual replacement of the forest community with aquatic surface vegetation (Conner & Brody 1989; Conner & Day 1982; Conner & Day 1988). Whether the general management objective is to maintain the existing forested wetland or to allow succession to proceed to a more herbaceous plant community, wetland wastewater treatment can be a valuable management tool. If the goal were to maintain existing cypress/tupelo swamps, periodic drawdowns could be practiced to ensure recruitment by redirecting flows to alternate wetland sites, while still attempting to offset subsidence with increased sediments and nutrients. But if the goal were to allow the community structure to change, added nutrients and sediment would stimulate productivity and help prevent submergence.

Depending on the ultimate course of wetland regulation, some areas now considered wetlands according to the current hydrologic criteria, might be considered non-wetlands according to proposed criteria. Such sites would make good wastewater treatment sites since, regardless of regulatory determinations, they would more often than not continue to

support wetland vegetation and current or relict wetland soils as long as hydrologic inputs are maintained.

Soils

A treatment system should be selected and designed based on attempts to maximize the nutrient retention or transformation capabilities of the soils without overloading the system with either too much organic or inorganic matter. Where wetlands have been altered, wastewater flows can be directed with the aim of reproducing previous loading rates. Developmental activities likely to decrease organic matter include drainage, levee construction, or upstream impoundments which deprive the system of water and, thereby, increase aeration and decomposition rates. Activities likely to increase organic matter by increasing flooding and subsequent anaerobic conditions include on site impoundments or upstream channelization (Scott et al. 1990).

The hydrologic gradient from impounded through rapid flow through systems, affects the nutrient and organic content of the soils. Impounded wetlands usually receive most water and nutrients from precipitation alone. If there is no other hydrologic exchange in or out of the wetland, a high organic carbon content will exist, and high organic loadings from wastewater additions may stress the system. At the other extreme is a rapid flowthrough system where inorganic sediments will predominate. In between the two

extremes are varying levels of organic and inorganic sediments (Brinson 1985).

In tidal areas, the more frequently flooded wetlands have higher mineral content and nutrient levels associated with sea water (Na, K, and Mg) which decrease inland as organic content and calcium increase (Gosselink 1984; Gosselink & Turner 1978). In bottomland hardwood systems, on the other hand, flooding frequency is more likely to result in higher mineral substrates in those zones closest to the river (Taylor et al. 1990). The entire bottomland hardwood system from river to upland contains higher amounts of clay and organic matter than upland systems (Patrick 1981). In tidal or forested wetlands, human alterations usually change the natural balance between organic and inorganic sediments.

The Zapp's Potato Chip Factory site in Gramercy, LA. provides an example of a predominantly organic waste stream that has been distributed in such a way as to increase organic matter and retard decomposition rates. Channelization directly through the site has diverted most flow through one zone. Analysis of field data collected over one year, has indicated that the zone outside of the waste stream's influence can assimilate greater sediment, nutrient, and hydrologic loads similar to those received before the site was impounded (Chapter 3).

Vegetation

All types of wetlands in the Louisiana coastal zone have proven effective to varying degrees in removing organic matter, nutrients, pathogens, or heavy metals. Studies include investigations of salt marsh plants such as *Spartina alterniflora* (DeLaune et al. 1981 and 1983 from Nixon & Lee 1986), *Spartina patens* (Payonk 1972; Turner et al. 1976), and *Juncus roemerianus* (EPA 1986); brackish marsh plants such as *Scirpus spp.* (Payonk 1972; Turner et al. 1976; Gersberg et al. 1987; DeBusk et al. 1990; Batchelor et al. 1990); intermediate marsh plants such as *Phragmites spp.* (Meo et al. 1975; Gersberg et al. 1987; Batchelor et al. 1990; Davies et al. 1990; Finlayson et al. 1990) and *Sagittaria falcata* (Payonk 1972; Turner et al. 1976; DeBusk et al. 1990); and fresh marsh plants such as *Typha spp.* (Finlayson et al. 1990). Table 2-2 provides examples of wetland types used as treatment systems and their nutrient removal efficiencies (Mitsch & Gosselink 1986 and Nixon & Lee 1986). These studies indicate that appropriately designed wetland waste treatment systems can function in a variety of wetland types.

Wetlands in the Terrebonne and Barataria Basins

At the request of personnel from the Department of Environmental Quality (DEQ), dischargers were reviewed and analyzed in the context of DEQ's water quality basins. Of the thirteen basins, Terrebonne and Barataria were selected

Table 2-2: Examples of Wetlands Receiving Wastewater and Mass Balance Studies

Type	Location	Loading, people/ha	Substrate*	Nutrient**	Percent Removal
Northern Peatlands					
Ombrotrophic bog	Wisconsin	30	O	NH4-N	97
				NO2-NO3-N	100
				TP	78
Sedge-shrub fen	Michigan	7	O	NH4-N	71
				NO2-NO3-N	99
				TDP	
Forest-shrub fen	Michigan	27	O	TDN	80
				TDP	88
Nontidal Freshwater Marshes					
Cattail marsh	Wisconsin	17	O	NO3-N	51***
				TP	32
Lacustrine Glyceria marsh	Ontario	-	-	TN	38
				TP	24
Deepwater marsh	Florida	99	O	TP	97
Lacustrine deep-water marsh	Wisconin	-	O	DP	14
				PP	82
Lacustrine Phragmites marsh	Hungary	-	-	TN	95***
Saw Grass freshwater marsh	Florida	-	O	TP	95
Waterhyacinth marsh	Florida	-	-	TP	16
Tidal Freshwater Marshes					
Deepwater Phragmites marsh	Louisiana	-	O	TN	51
				TP	53
Complex marsh	New Jersey	198	I	TN	40
				TP	0
Tidal Salt Marshes					
Brackish marsh	Chesapeake Bay	-	O/I	TN	0
				TP	1.5g/m2/yr
Salt marsh	Georgia	Sludge	O/I	TN	50
Salt marsh	Massachusetts	Sludge	O/I	TN	85
Salt marsh	Louisiana	-	-	TN	71

Table 2-2: Examples of Wetlands Receiving Wastewater and Mass Balance Studies (continued)

Type	Location	Loading, people/ha	Substrate*	Nutrient**	Percent Removal
Southern Swamps					
Mixed cypress-ash swamp	Florida	7	O	TN	90
				TP	98
Cypress domes	Florida	-	O	TN	98
				TP	97
Riverine swamp	South Carolina	-	O	NO3-N	0
				TP	50
Cypress swamp	Louisiana	-	-	TN	49
				TP	46
Cypress-tupelo swamp	Louisiana	-	-	TN	25
				TP	40
Cypress Dome	Florida	-	-	TN	74
				TP	92
Cypress swamp	Georgia	-	-	TN	39
				TP	75
Cypress, tupelo, hardwoods	North Carolina	-	-	TP (yr 1)	30
				TP (yr 2)	57
Tupelo swamp	North Carolina	-	-	TN	37
				TP	57
Gum swamp	Georgia	-	-	TP	9

Source: After Mitsch & Gosselink, 1986, and Nixon & Lee, 1986

*O: organic substrate
I: inorganic substrate

**NH4-N = ammonium nitrogen
NO2-N = nitrite nitrogen
NO3-N = nitrate nitrogen
TDN = total dissolved nitrogen
TN = total nitrogen
DP = dissolved phosphorus
PP = particulate phosphorus
TDP = total dissolved phosphorus
TP = total phosphorus

*** Indicates removal based on concentration

for intensive study because of high subsidence (LA State Planning Office 1976) and land loss rates (Craig et al. 1979; Gagliano et al. 1981; Morgan & Morgan 1983), in addition to their high proportion of coastal wetlands and low proportion of urban population (Table 2-3).

Table 2-3: Study Area Characteristics (Source: LA DEQ 1990a).

	Terrebonne Basin	Barataria Basin
Total Land Area (square miles)	4074	2580
% Water	27	31
% Wetland	46	55
% Urban	2	3
% Agriculture	14	10
% Forest (non-wetland)	11	0
% Other	<1	1

Both basins have a substantial amount of surface water pollution and a high proportion of unsewered areas (LA. DEQ 1990a) that could benefit from wetland wastewater treatment. Suspected causes of the pollution in 86% (36 of 42) of the waterbody segments of the Terrebonne Basin, include pathogens, nutrients, or organic enrichment -- water quality components that have a negative effect when applied to surface waters, but a positive or non-detrimental effect when applied to wetlands. Pathogens, nutrients, or organic enrichment are also listed as suspected causes of pollution in the Barataria Basin for 90% (18 of 20) of the waterbody segments. The reason for the water quality problems is the

inadequate sewage treatment in 50% of the Terrebonne segments and in 45% of the Barataria Basin segments (LA DEQ 1990a).

The most northern segment in the Terrebonne Basin (1201) was excluded from the analysis due to relatively high urban use compared to the available wetland area, and the comparatively low subsidence potential in the region.

In sum, criteria for treatment wetlands consist of compatible use, hydrologic isolation, hydraulic loading rates and detention times based on the size of the treatment wetland and total effluent volume, a sufficient gradient, available back-up wetland treatment areas, and the occurrence of subsidence. Economically feasible and hydraulically efficient distances from the discharge facility to the wetland depends on total effluent volume. Distances recommended here range from up to 2 miles for approximately 0.15 MGD, 3 miles for 2.2 MGD, and 12 miles for 30 MGD. Lower flows, such as the average of 0.013 MGD estimated for a typical school, would require facility location much closer to the treatment wetland.

The four case studies reviewed in Chapters 3 and 4 for wetland wastewater treatment -- Zapp's Potato Chip Factory, the towns of Thibodaux and Breaux Bridge, and the seafood processors along Bayou Grand Caillou -- conform to the above criteria. All are surrounded by spoil banks and, in some cases, by natural levees as well which confine hydrologic flows. In addition, all of the discharge facilities fall

within distances from their respective receiving wetlands of less than those recommended above. Selection of additional receiving wetlands can be determined, first, by review of aerial or satellite photos, and ultimately by field inspection of the site. An example of initial site selection is provided in the following section.

2.3. Results

2.3.1. Effluent Discharger Map

The bulk of the dischargers reviewed for this study occur along natural levees and surface water bodies. Discharger facilities are widely dispersed along natural levees and relatively close to wetlands, making wetlands a feasible means for treating wastewater. Shrimp and other seafood processors in addition to schools predominate near saline marshes while subdivisions and treatment plants are common near fresh marsh or alluvium areas. Figure 2-2 shows the general distribution of dischargers and the type of wetland or geologic stratum in the study area. Appendix 1 lists the source, map number, name, type, and segment number for each facility mapped as they appear on the 1:100,000 U.S.G.S. effluent discharger map.

It should be emphasized that while an intensive effort was made to investigate the seafood processor category in particular when it became apparent that the DEQ sources were inadequate, the basis for the discharger map was the DEQ

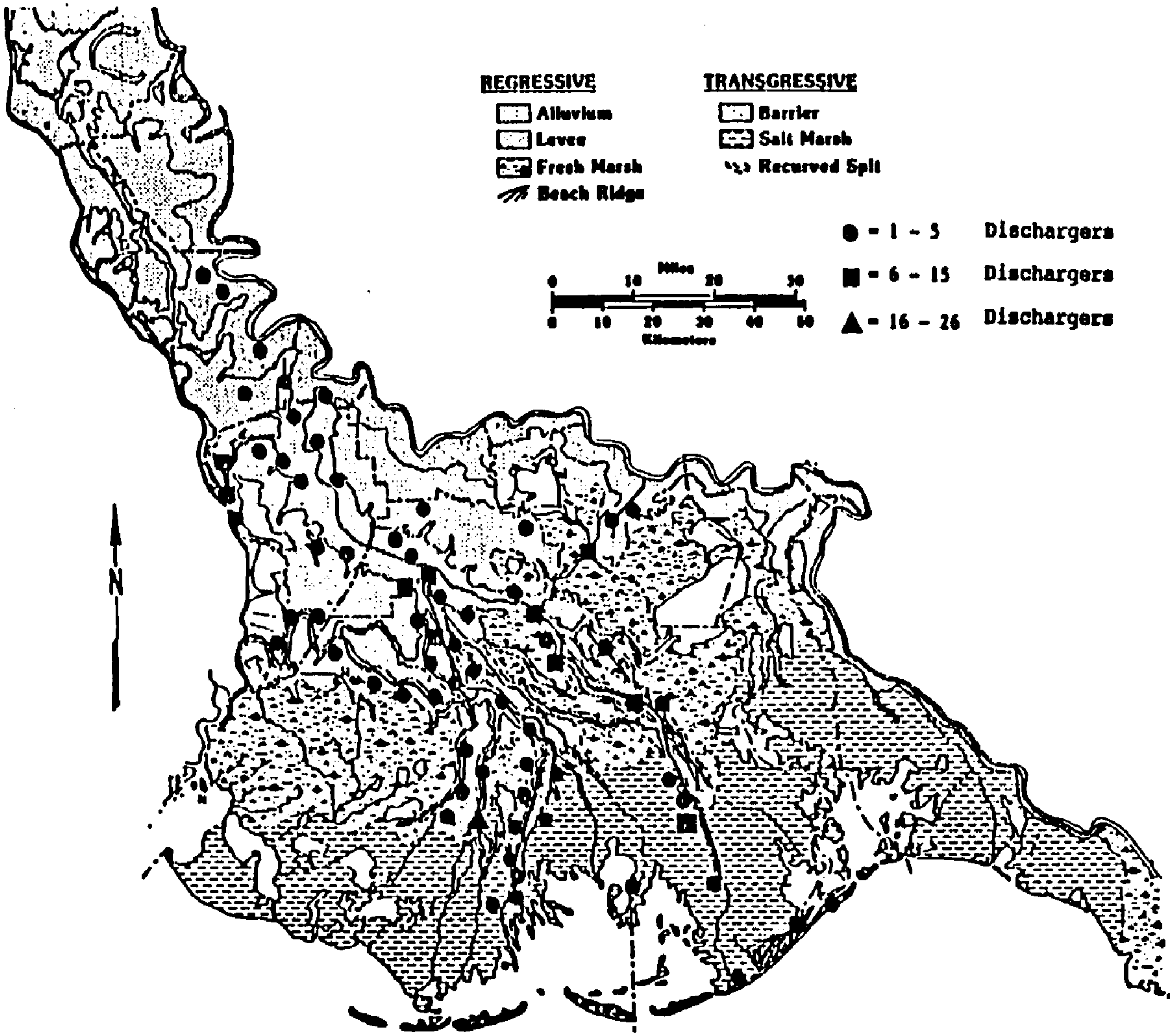


Figure 2-2: Distribution of Dischargers in the Terrebonne and Barataria Basins.

Inventory and files. As stated earlier, locations are rarely provided in these sources, and consequently many dischargers have not been mapped because their precise location was unavailable. The Dulac Sanitary Facility, for example, is listed in the Inventory as having a capacity of 0.0249 MGD with limits of 30 BOD and 30 TSS discharging into Bayou Grand Caillou, but no map or mention of latitude or longitude is provided, and consequently it is not mapped on the effluent discharger map.

The degree of sewage treatment by a number of small towns in the study area could not be determined from the Inventory. For example, towns such as Mulberry and Theriot along Bayou du Large, Boudreaux along Bayou Grand Caillou, and Bourg, Klondyke, Montegut, Point Barre, and Lapeyrouse along Bayou Terrebonne are not listed in the Inventory. Future research should determine the degree of treatment by such towns and the potential for wetland waste treatment.

2.3.2. Classification of Dischargers

Municipal Dischargers

Terrebonne Basin, Segments 1202-1208

Total effluent from municipal dischargers in the seven segments analyzed for the Terrebonne Basin is approximately 33.5 MGD. That amount is divided between 23 subdivisions, 40 schools, 22 sewage treatment plants or oxidation ponds (STP/OX), 21 other public facilities, 9 trailer parks, 6

businesses, 2 hospital or health units, and one facility whose function could not be determined. Further breakdowns between segments are listed in Table 2-4.

Approximately 92% of the total wastewater is discharged by sewage treatment plants or oxidation ponds. The discharge range of those plants or ponds is from 0.0003 to 16.0 MGD (the Houma treatment plant). Appendix 2 lists all the dischargers selected for this study in Terrebonne segments 1202 through 1208, along with their capacities, surface water discharge bodies, DEQ permit numbers, and the limits imposed by DEQ. While it is unlikely that sufficient wetland area would be available to treat Houma's 16.0 MGD, it is worth noting that the wetland area south of Houma was considered by local engineers to receive the plant's secondarily treated effluent. Opposition from the primary landowner thwarted further efforts (Al Levron, pers. comm.)

Subdivisions in the Terrebonne Basin contribute a substantial amount of effluent with approximately 1.7 million gallons being discharged daily from 23 separate facilities located primarily in two segments. Compared to subdivisions, schools discharge roughly one third the amount of water divided among twice the number of facilities. The low flows from and the high proportion of schools make them promising potential candidates for wetland wastewater treatment. Figure 2-3(a) describes the division of flow between types of dischargers for the Terrebonne basin. Figure 2-3(b) describes the same division with the

Table 2-4: Total Terrebonne Basin Municipal Dischargers from DEQ Inventory

Capacities (mgd)	1202	1203	1204	1205	1206	1207	1208	Totals
Subdivisions*	0.8865	0.731	0	0.049	0.012	0.04	0	1.7185
Schools**	0.036	0.225	0.006	0.128	0.07	0.078	0	0.543
STP/Ox Ponds***	3.67	17.792#	5.5	3.6589	0.021	0.024	0	30.6659
Other Public****	0.24	0.0396#	#	0.0009	0.0012	#	0	0.2815
Trailer Parks	0.087	0.089	0	0	0	0	0	0.176
Business	0	0.03	#	0.0015#	0	0	0	0.0315
Hospital/Health	0.042	0	0	0	0	0	0	0.042
Sugar Mill/Refinery	0	0	0	0	0	0	0	0
Undetermined*****	0	0	0	0	0	0	0	0
TOTALS	4.9615	18.9066	5.506	3.8383	0.1042	0.142	0	33.4584

Number	1202	1203	1204	1205	1206	1207	1208	Totals
Subdivisions*	11	9	0	1	1	1	0	23
Schools**	8	11	1	10	4	6	0	40
STP/Ox ponds***	8	5	2	5	1	1	0	22
Other Public****	1	8	2	4	4	2	0	21
Trailer Parks	4	5	0	0	0	0	0	9
Business	0	4	1	1	0	0	0	6
Hospital/Health	2	0	0	0	0	0	0	2
Sugar Mill/Refinery	0	0		0	0	0	0	0
Underterminedx*****	0	0		1	0	0	0	1
TOTALS	34	42	6	22	10	10	0	124

#capacity is underestimated, since one or more capacities were not reported in Inventory.

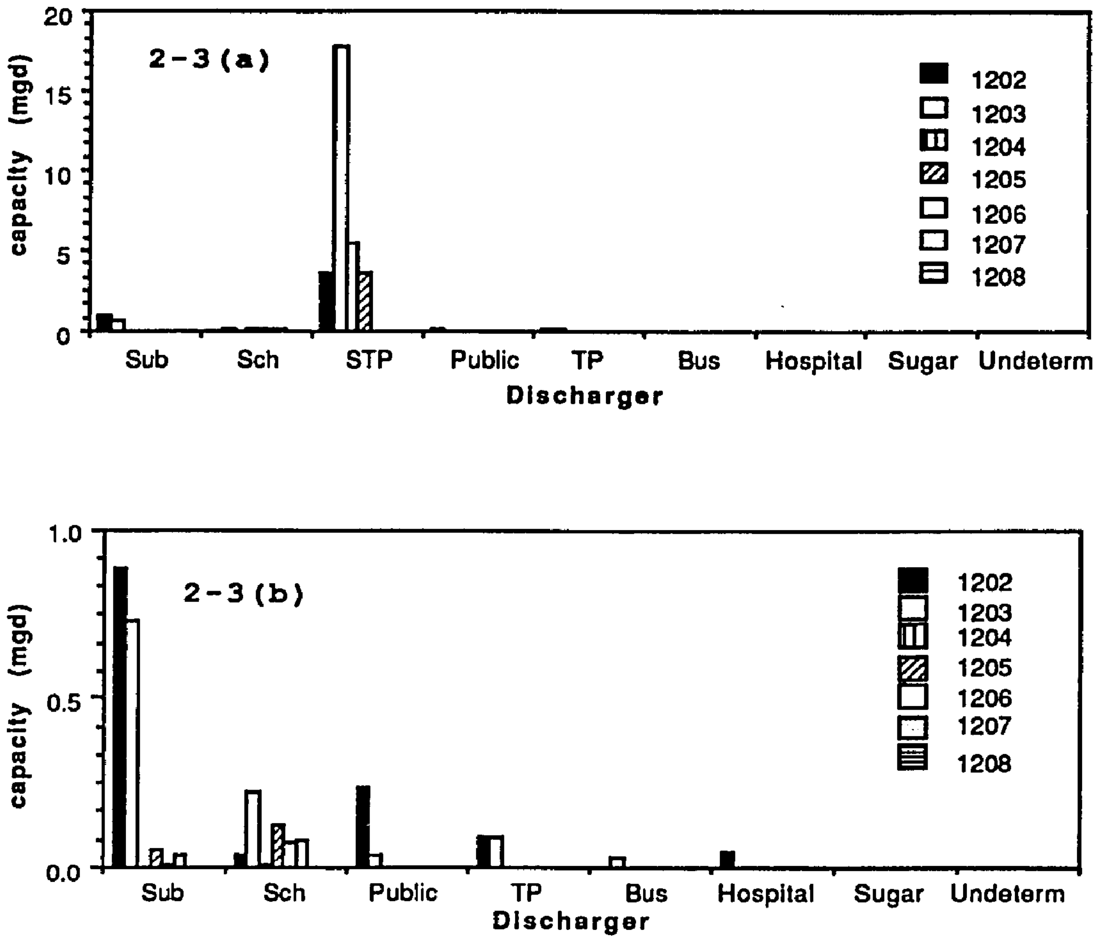
*Subdivisions include apartments, except where listing is a "parish housing project" in which case it has been placed under the public category.

** School capacities were based on student enrollment according to the LA School Directory.

***Sewage Treatment Plants or Oxidation Ponds

****Other public includes federal, state, parish, and town facilities, excluding schools. Facilities listed as oxidation ponds or sewage plants, were placed in the STP/OX category.

*****Undetermined: function not apparent from title, and no DEQ file found.



Sub = subdivisions
Sch = schools
STP = sewage treatment plants
Public = public
TP = trailer parks
Bus = businesses
Hospital = hospitals
Sugar = sugar mills/refineries
Undeterm = undetermined

Figure 2-3: (a) Total Terrebonne Municipal Dischargers; (b) Terrebonne Municipal Dischargers Excluding Sewage Treatment Plants (Source: DEQ Inventory).

overwhelming contribution from sewage treatment plants and oxidation ponds removed in order to reveal the other sources of wastewater discharge in segments 1202 through 1208.

Barataria Basin, Segments 0201-0211

Total effluent from municipal dischargers in the eleven Barataria Basin segments is approximately 21.6 MGD. The distribution of flow among categories is listed in Table 2-5 and names and characteristics of individual facilities are listed in Appendix 3. Again, the bulk of flow (93.5%) is from sewage treatment plants and oxidation ponds (Figure 2-4(a)) with a range of 0.017 to 10.0 MGD. Removal of that category reveals the distribution among the other eight discharger types (Figure 2-4(b)).

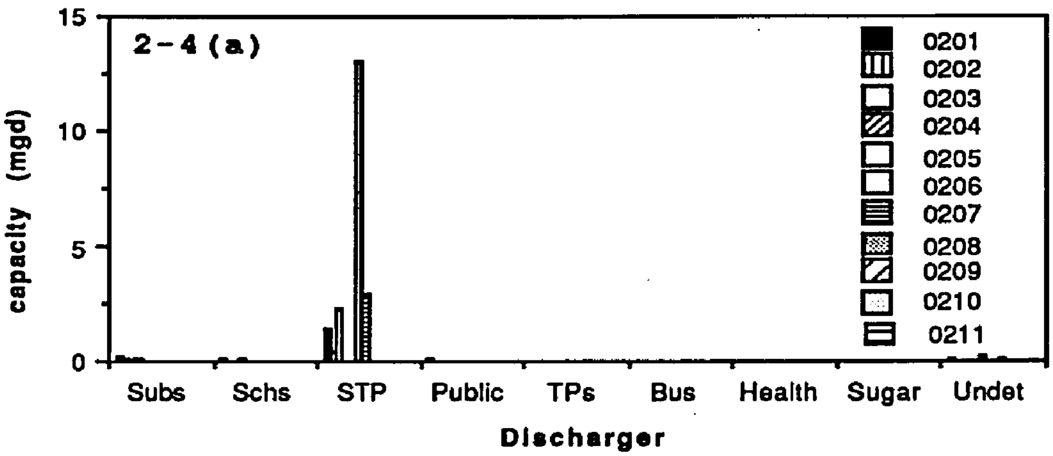
The Barataria basin has roughly the same number of subdivisions as the seven Terrebonne segments (23 in Barataria, 19 in Terrebonne), but it has less than half the number of schools (Barataria 17, Terrebonne 40). It also has approximately half the number of sewage treatment plants compared to the Terrebonne segments. Excluding the water discharged from sewage treatment plants or oxidation ponds in both basins, the remaining 1.4 MGD in the Barataria basin and the 2.7 MGD in the Terrebonne segments is divided between the other eight categories.

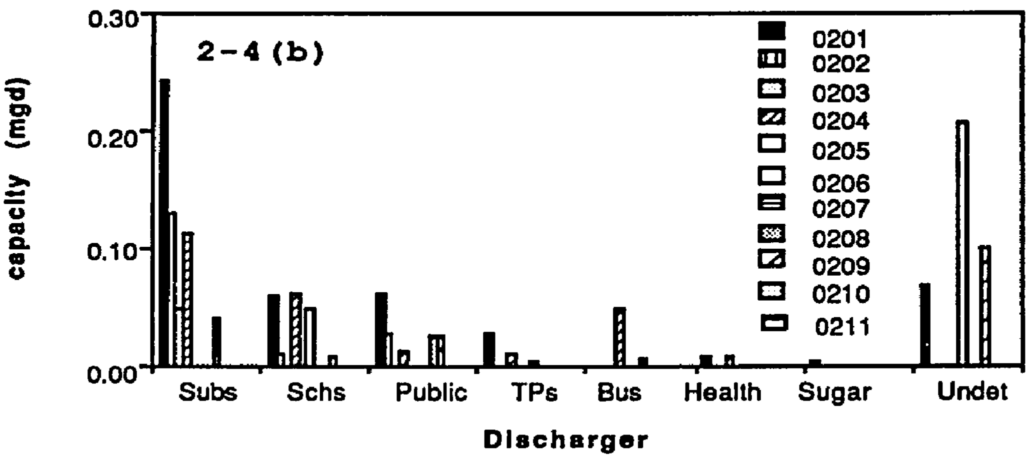
Some municipal dischargers may be more suitable for wetland treatment than others. Categories recommended for

Table 2-5: Total Barataria Basin Municipal Dischargers from DEQ Inventory

Capacities (mgd)	0201	0202	0203	0204	0205	0206	0207	0208	0209	0210	0211	Totals
Subdivisions*	0.2405#	0.13#	0.05	0.112	0	0	0	0.042	0	0	0	0.5745
Schools**	0.06	0.012	0	0.061	0	0.05	0	0	0.01	0	0	0.193
STP/ Ox Ponds***	1.517	0.4	2.275	0	#	13	3	0	0	0	0	20.192
Other Public****	0.062	0.03	#	0.0129	#	#	0	0.025#	0.025	0	0.002	0.1569
Trailer Parks	0.03	0	0	0.012	0	#	0.005	#	0	0	0	0.047
Business	0	0	0	0.0499	0	#	0.007	0	0	0.00024	0	0.05714
Hospital/Health	0.01	0	0	0.009	0	0	0	0	0	0	0	0.019
Sugar Mill/Refinery	0.005	0	0	0	0	0	0	0	0	0	0	0.005
Undetermined*****	0.07	0	0	0	0	0.205	0	0	0.1	0	0	0.375
TOTALS	**1.9945**	**0.572**	**2.325**	**0.2568**	**0**	**13.255**	**3.012**	**0.067**	**0.135**	**0.00024**	**0.002**	**21.619**
Number												
Subdivisions*	6	4	1	6	0	0	0	1	0	0	1	19
Schools**	8	1	0	5	0	1	1	0	1	0	0	17
STP/ Ox Ponds***	2	1	4	0	1	2	2	0	0	0	0	12
Other Public****	5	2	2	4	1	2	0	2	1	0	1	20
Trailer Parks	1	0	0	1	0	1	0	2	0	0	0	5
Business	0	0	0	4	0	1	1	0	0	1	1	8
Hospital/Health	1	0	0	1	0	0	0	0	0	0	0	2
Sugar Mill/Refinery	1	0	0	0	0	0	0	0	0	0	0	1
Undetermined*****	1	0	0	0	0	1	0	0	1	0	1	4
TOTALS	25	8	7	21	2	8	4	5	3	1	4	88

#capacity is underestimated, since one or more capacites were not reported in Inventory.
*Subdivisions include apartments, except where listing is a "parish housing project", in which case it has been put under the public category.
**School capacities were based on student enrollment according to the LA. School Directory.
*** Sewage Treatment Plants or Oxidation Ponds
**** Other Public includes federal, state, parish, and town facilities, excluding schools. Facilites listed as oxidation ponds or sewage treatment plants, were placed in the OX/STP category.
*****Undetermined: function not apparent from title, and no DEQ file found.





Subs = subdivisions
Schs = schools
STP = sewage treatment plants
Public = public
TPs = trailer parks
Bus = businesses
Health = Hospitals
Sugar = sugar mills/refineries
Undet = Undetermined

Figure 2-4: (a) Total Barataria Municipal Dischargers; (b) Barataria Municipal Dischargers Excluding Sewage Treatment Plants (Source: DEQ Inventory).

initial review include, first, sewage treatment plants and oxidation ponds because of their obvious and overwhelming contribution to daily flows, and the probability that the effluent is equivalent to at least secondary treatment. Subdivisions, schools, and trailer parks listed in the Inventory have their own treatment systems which are also required to discharge the equivalent of secondary effluent. While sugar mills or refineries may be an appropriate category for discharge to wetlands, facilities in that category are more likely to require an industrial permit rather than a municipal permit. Approximately 24 such facilities exist in southern Louisiana (LA Cooperative Extension Service, no date), but only one was listed in the Inventory under municipal permits. The nature of the effluent from businesses, hospitals/health care facilities, and undetermined facilities is less certain, and these categories should not be considered for wetland treatment unless a more careful documentation of the effluent is carried out.

Industrial Dischargers

Most industrial dischargers listed in the Inventory were excluded from consideration upon initial review due to the potentially toxic nature of the effluent. Examples of such industries include oil and natural gas companies, engine companies, ship yards, and canal yards. In some

cases, further investigation of what appeared to be a potentially suitable facility, disqualified it from consideration. This was the case for the Inventory listing of "Valentine Sugars", which is now a phenol formaldehyde resin manufacturing plant. In addition, capacities were generally provided for all municipal dischargers, but were rarely available for industrial dischargers. For example, capacities for only 5 of the 74 industries listed for the Terrebonne Basin segments were listed.

Many facilities are not listed in the DEQ Inventory. In the case of seafood processors, directories and local contacts identified considerably more facilities than are in the Inventory. For example, there are 12 industrial listings, including one crawfish processor, in segment 1202. Seafood directories for the area along Bayou Pierre Part and Belle River, however, list thirteen seafood processors which have been verified by personal contacts (Appendix 1, map dots 155 through 167). A total of 12 industries are in the Inventory for segment 1205 including only 3 processors on Bayou Grand Caillou and the Houma Navigation Canal. Directories and local contacts revealed between 10 and 25 major processing plants or docks (Appendix 3, map dots: 15, 35, 37, 38, 70-74, 118, 119, 122, 129-137) though some of these may have recently closed or consolidated. Recent concern over high pollution levels in Bayou Grand Caillou has prompted efforts by DEQ to regulate the processors, but the fact that so many facilities could exist unregulated in

the two areas mentioned above raises questions about the potentially high number of dischargers that are unaccounted for in the coastal region.

A number of industrial dischargers show promise for wetland wastewater treatment. Tables 2-6 and 2-7 list industries identified for further investigation in the Terrebonne and Barataria basins, respectively, based on DEQ Inventory and file data. An additional column is added based on DEQ maps for the Terrebonne basin showing point source facilities discharging 50,000 gallons per day or more. Inventory listings or files were not found for these facilities. The primary types of facilities considered appropriate for further review include seafood processors and sugar mills and refineries. Review of the comparable map for the Barataria basin showed no industries with effluent appropriate for discharge to wetlands.

2.3.3. Receiving Wetlands

Selection of wetlands appropriate for receiving treated effluent prior to site specific field investigation can be made using aerial photos or satellite imagery. Examples provided here are based on the Landsat Thematic Mapper sensor (Terra-Mar Resource Information Services, 1989) (figure 2-5). Red areas represent primarily bottomland hardwood or other healthy wetland vegetation; light brown areas represent cypress-tupelo swamps, dormant vegetation, or bare soil; and light blue areas represent urban centers

Table 2-6: Terrebonne Basin Industries Selected for further Investigation (DEQ data)

SEGMENT	TOTAL FROM INVENTORY	# SELECTED	NAME	CAPACITY (mgd)	ADDITIONAL SELECTIONS FROM DEQ MAP (NOT IN INVENTORY)
1202	9	4	Blanchard's Crawfish	0.00054	
			Glenwood Sugar	6	
			Lafourche Sugar	13 (?)	
			Supreme Sugar	4.03 (?)	
			Total	23.031	
1203	8	0			
1204	11	2	J-R Enterprises	NG	Seacoast Products
			Zapata Haynie Corp, Morgan City Plant	NG	
1205	12	4	Hi-Seas of Dulac, Inc	NG	Grand Caillou Packing Co.
			J & J Seafood, Inc.	NG	Ivy Authement Ice Co.
			Price Seafood Inc.	NG	Ivy Authement Ice Co.
			Zapata Haynie Corp. (Dulac Plant)	NG	Authement Packing Co.
					Voisin Canning Co.
					Gulf Coast Packing
1206	2	0			
1207	6	0			Indian Ridge Canning
1208	2	0			

NOTE: an additional 28 processors in the LSU Cooperative Extension Directory for Terrebonne Parish are not in the DEQ sources. It is expected that between 10-20 seafood processors are located on Bayou Grand Caillou.
Segment 1202 has an additional 12 seafood processors that are not listed in the DEQ sources.

Table 2-7: Barataria Basin Industries Selected for further Investigation (DEQ Data)

SEGMENT	TOTAL FROM INVENTORY	# SELECTED	NAME	CAPACITY (mgd)	ADDITIONAL SELECTIONS FROM DEQ MAP (NOT IN INVENTORY)
0201	3	2	Cajun Cypress Inc	N.G.	
			Caldwell Sugars Corp.	.55 (from file)	
0202	2	0			
0203	6*	2	D&A Seafood	N.G.	
			South Coast Sugars	N.G.	
0204	3	2	Gulf Shrimp Processors	N.G.	
			New Orleans Shrimp Co.	N.G.	
0205	2	0			Avondale North STP
					Avondale South STP
					Bridge City STP
					Live Oak Manor STP
0206	18	1	Southern Shellfish, Co	N.G.	Flora Haze STP
					Meadow Brook STP
					Terrytown #1 (STP?)
					Terrytown #2 (STP?)
					Harvey STP
					Charles Whitley's Trailer Park
0207	3	0			Floral Acres STP
					Marrero STP
0208	1	1	Johnson Seafood Co.	N.G.	
0209	2	0			
0210	1	1	Amvina Seafood Inc.	N.G.	
0211	5	0			
TOTAL	46	9			

*Current number is 5 since Collier's Fisheries has been connected to the city sewer.

Scale ≈ 1" = 9 miles

Figure 2-5: Hydrologically altered wetlands potentially appropriate for receiving wastewater effluent. Letters A, B, C, and D indicate suitable discharge areas (see text for explanation). (Source: Terra-Mar Resource Information Service, 1989. Reprinted with permission).

or cultivated fields. The following areas are presented as examples of those wetlands which might be selected for further review, based on the presence of bare soil (brown) or subsiding swamp areas interspersed among patches of healthy vegetation (red). An additional feature for selection included the presence of linear features indicating man-made structures such as canals, roads, and railroad lines which are likely to alter hydrologic flows. Letters on the figure have been placed to the right of the described wetland:

A. Thibodaux Receiving Swamp located approximately 2 miles south of the city of Thibodaux. Linear features indicate the drainage canal to the north and west, and the railroad line to the south.
B. Clearly defined linear features bordering the area along 5 sides, and enclosing patches of bare soil within an otherwise healthy bottomland hardwood complex. Missouri-Pacific Railroad line comprises the northern linear feature. This wetland area is south of the towns of St. James, Lagan, Hymel, and Welcome.
C. Two open area patches contained between linear features extending southward toward Thibodaux. This area is in the vicinity of the town of Chackbay.
D. Dark patches between what appear to be two natural levees that enclose a wetland area dissected by at least two linear features. The town of Choctaw is within this area.

These examples illustrate the types of receiving wetlands that should be considered for wastewater treatment and the tools with which those wetlands can be selected. Further identification and selection of particular sites should be made after potential dischargers are selected.

2.4. Summary

Information on municipal and industrial dischargers contained within the DEQ Inventory and files and on the DEQ point source discharger maps, provides a basis for characterizing the type and amount of effluent being discharged in the Louisiana coastal zone. While data is lacking or inadequate for many dischargers, it is generally sufficient to classify dischargers and the nature of their effluent. Analysis of this information indicates that effluent from sewage treatment plants, oxidation ponds, subdivisions, schools, trailer parks, seafood processors, and sugar mills is appropriate for consideration for wetland wastewater treatment. Effluent dischargers were found to be widely dispersed along natural levees and near semi-isolated wetlands. Locations of known dischargers are provided as a conservative estimate of the number of potential facilities currently discharging to surface waterbodies that could redirect their flows through subsiding wetlands given proper design, management, and monitoring of wetland treatment systems. Additional small town municipal dischargers are likely to meet the criteria for selection of effluent dischargers to wetlands, after further research determines the degree of treatment achieved by these towns.

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CHAPTER 3

ASSIMILATION OF POTATO PROCESSING WASTEWATER IN A FORESTED WETLAND

3.1. Introduction

Two major environmental problems currently affecting Louisiana are a high rate of coastal wetland loss and high levels of surface water pollution. The application of secondarily treated wastewater to wetlands could address both of these problems. The benefits of wetland wastewater treatment include improved surface water quality in receiving streams, increased accretion rates to balance subsidence, improved plant productivity, and decreased capital outlays for conventional engineering treatment systems. Wetland treatment systems can be designed and operated to restore deteriorating wetlands to previous levels of productivity. In this paper I describe a study carried out to determine the impact of discharge from a food processing plant on a freshwater forested wetland in coastal Louisiana.

In 1985, Zapp's Potato Chip Factory began discharging effluent to a bottomland hardwood swamp located in Gramercy, Louisiana. The discharge site had been partially impounded during the previous 30-40 years by the construction of a highway, a road, a canal, and an underground pipeline. Consequently, the receiving wetland had been isolated, to some extent, from the larger forested wetland system

surrounding Lake Maurepas. The isolated area retained some forms of its original woody vegetation while also providing conditions conducive to the establishment of more herbaceous types of vegetation.

Factory discharge to the wetland is confined primarily to approximately 2.5 hectares directly behind the plant. The hydraulic loading rate is approximately 1.25 cm/wk for the four day work week. The plant's treatment system has evolved over the past seven years from one providing little or no treatment to a current level of approximately 15 mg/l BOD and 20 mg/l TSS. Before treatment facility improvements were made, levels as high as 9,600 mg/l BOD and 8,900 TSS were reported (violations reported for 1987 in LA. DEQ, 1989). Current permit limitations for the plant are daily averages of 30 mg/l BOD and 30 mg/l TSS, with maximum daily limits of 45 mg/l BOD and 50 mg/l TSS. The present study was conducted to determine the effects of the potato processing wastewater on the receiving wetland at current discharge levels, and to test the hypothesis that the effluent may be beneficial to the forested wetland.

3.2. Description of Study Area

Zapp's Potato Chip Factory is located on U.S. Highway 61 approximately 3.2 km north of the Mississippi River and 4 km south of Blind River (figure 3-1). East of the factory, the highway divides the wetlands from the developed areas along the Mississippi River. The receiving swamp directly

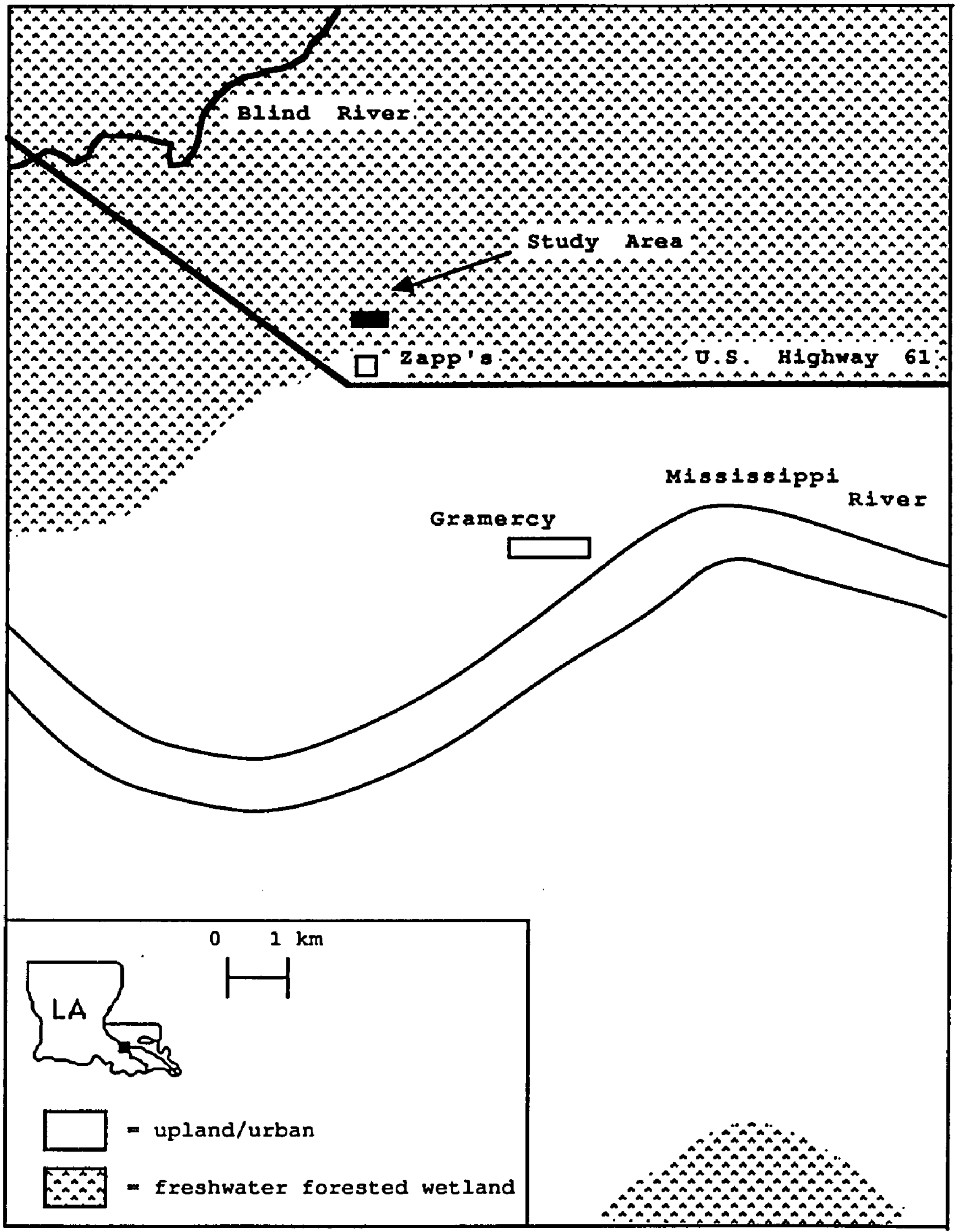

Figure 3-1: Zapp's Potato Chip Factory in relation to the Blind and Mississippi Rivers.

behind the factory is part of a larger forested wetland of several thousand hectares. The major hydrologic source is overland flow from natural levees except where interrupted by man-made structures which, in some cases, leads to only precipitation input.

The study sites consist of four 20 by 25 meter plots located approximately 100 meters behind the plant (figure 3-2). Nine water sampling stations were selected to trace the fate of the effluent from the plant and through the ditch and wetlands. Baseline measurements were collected from May 1991 through May 1992 from the plots and the 9 water monitoring stations. Table 3-1 describes the locations of the nine sampling stations, excluding two that were considered redundant and, therefore, eliminated in the early months of the study period.

Table 3-1: Sampling Stations at the Zapp's Study Site.

1. Pipe discharging runoff from parking lot
2. Effluent pipe discharging plant's wastewater
3. Discharge ditch
4. Discharge ditch
6. End of discharge ditch, vegetated by *Hydrocotyle sp.*
11. Ponded area in F1
8. Herbaceous wetland, 10 meters outside of F2 plot.
9. Forested wetland on ridge area in R1
10. Forested wetland on ridge area in R1

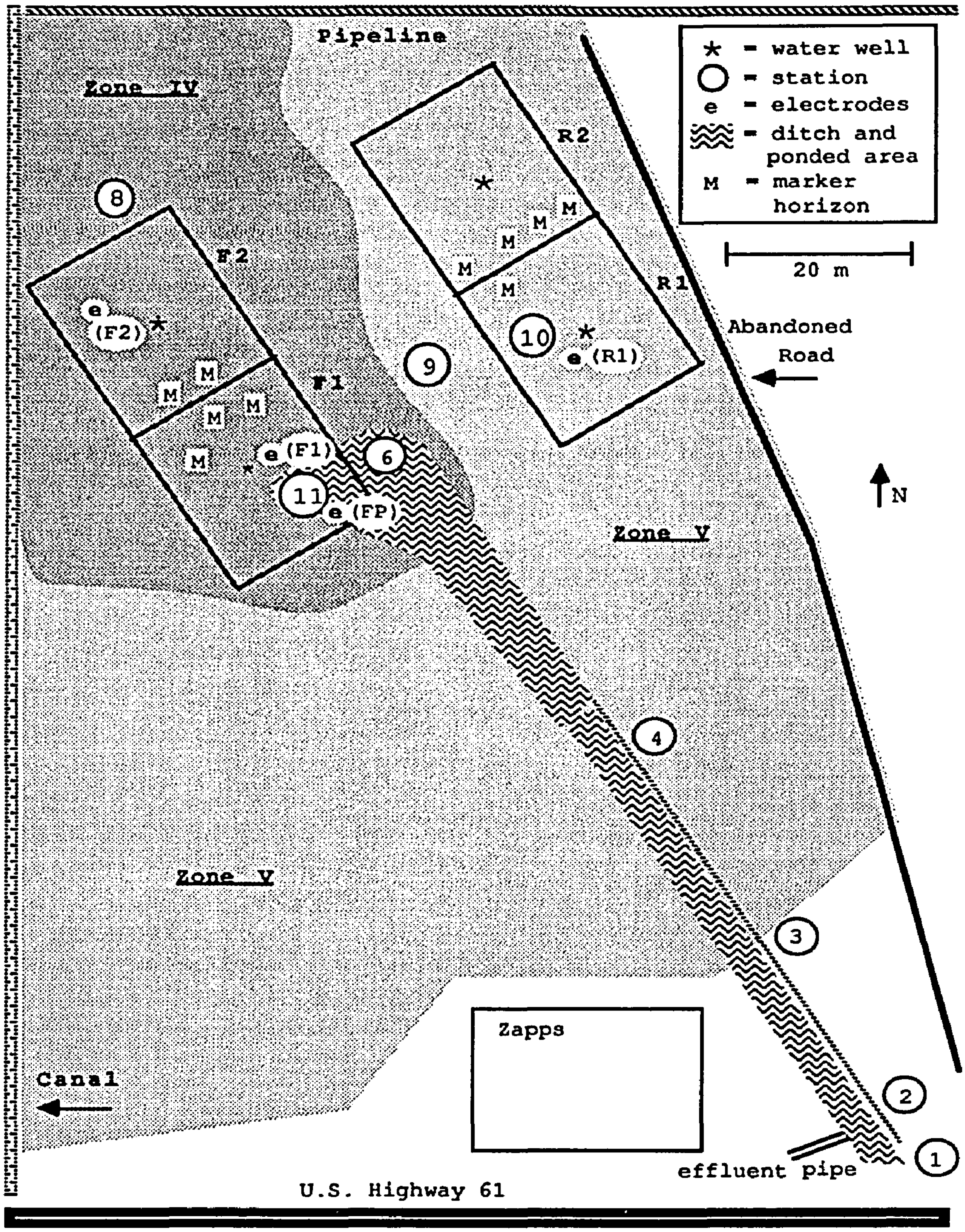

Figure 3-2: Zapp's Potato Chip Factory Study Site, Gramercy, LA. Zone IV is seasonally flooded and Zone V is temporarily flooded according to Mitsch and Gosselink (1986).

Hydrologic input for the Zapp's receiving wetland is confined to precipitation and runoff from the plant parking lot (station 1). After periods of heavy rain, flow is directed through a ponded area (station 11), and through a portion of the wetland as sheet flow (station 8). Stations 9 and 10 are forested wetland stations which do not receive effluent directly. While vegetative composition at station 8 is not identical to stations 9 and 10, the two latter stations are considered similar enough to serve as controls for station 8 which does receive effluent during high water periods.

The flooded plots (F1 and F2) contain remnants of vegetation indicative of less flooded conditions (Taylor et al. 1990). There are a number of large dead standing and fallen trees which were probably killed by flooding when the area was semi-impounded. The fallen trees have created large open spaces which encouraged the establishment of herbaceous wetland plants and young woody vegetation. Except under high water conditions, the drier plots (R1 and R2) do not receive effluent due to their slightly higher elevation of approximately 20-40 cm on a ridge which borders the effluent ditch. Vegetation on these ridge plots is generally healthy and appears to have been established under less frequently flooded conditions than those that originally formed the flooded site.

In a typical bottomland hardwood system, the two flooded and ridge areas would be classified as Zones IV

(seasonally flooded) and V (temporarily flooded) out of a total of six distinct zones from the river to the uplands (Clark & Benforado 1981; Mitsch & Gosselink 1986). Primary species in the flooded zone include American elm (*Ulmus americana*) and sugarberry (*Celtis laevigata*) (table 3-2). The flooded zone also contains nuttall oak (*Quercus nuttallii*) and green ash (*Fraxinus pennsylvanica*). Fourteen of the fifteen trees (93%) in the flooded zone are described as dominant species for Zone IV (Conner et al. 1990). Based on the wetland status of the tree species, 12 of the 15 trees (80%) are either obligate or facultative wetland species.

While the ridge has three American elms (*Ulmus americana*) which are classified as facultative wetland species, the general tendency is toward trees adapted to a drier hydrologic regime. The dominant species is water oak (*Quercus nigra*) which is typical of Zone V (Conner et al. 1990), with other species consisting of sugarberry (*Celtis laevigata*) and southern magnolia (*Magnolia grandiflora*). Based on the wetland vegetative status, 8 of the 19 trees (42%) in the ridge plots are facultative wetland species.

Table 3-2: Tree species composition in the Zapp's receiving wetland (from Conner et al. 1990; Reed 1988).

FLOODED ZONE

Species	Typical Zone	Wetland Status*	Number in Plot
1. Nuttall Oak (*Quercus nuttallii*)	4	OBL	1
2. Green Ash (*Fraxinus pennsylvanica*)	3,4	FacW	1
3. Sugarberry (*Celtis laevigata*)	4,5,6	FacW	5
4. Sweetgum (*Liquidambar styraciflua*)	4,5,6	Fac+	2
5. American elm (*Ulmus americana*)	3,4	FacW	5
6. Persimmon (*Diospyros virginiana*)	3,4,5,6	Fac	1
		TOTAL	15 = 150 trees/ha

RIDGE ZONE

Species	Typical Zone	Wetland Status*	Number in Plot
1. Sugarberry (*Celtis laevigata*)	4,5,6	FacW	3
2. Water oak (*Quercus nigra*)	4,5,6	Fac	10
3. Boxelder (*Acer negundo*)	4,5	FacW	2
4. American elm (*Ulmus americana*)	3,4	FacW	3
5. Southern magnolia (*Magnolia grandiflora*)	5,6	Fac+	1
		TOTAL	19 = 190 trees/ha

*Based on the following indicator categories for Region 2 (Southeast) from Reed (1988):

OBL = obligate wetland species (almost always occur in wetlands)
FacW = facultative wetland species (usually occurs in wetlands)
Fac = facultative (equally likely to occur in wetlands or nonwetlands)
FacU = facultative upland (usually occur in nonwetlands)
UPL = obligate upland (usually occur in nonwetlands in the region specified)
+ = More frequently found in wetlands than Fac, but less frequently than FacW

Whether the zones occur as broad, strictly delineated segments of the entire forest, or as microzones interspersed within the broader zones, the entire bottomland hardwood system would have formed over the centuries as part of a connected and unified whole based on the exchange of water, nutrients, and sediment between zones (Mitsch & Gosselink 1986). Research at the Zapp's site was directed toward determining whether the impacts on the semi-impounded flooded area could be alleviated by using the effluent in a manner designed to mimic the historic and naturally occurring exchange between the two zones.

3.3. Materials and Methods

Transect Elevations. The site was surveyed by transects in March 1991 to determine its general topography and the direction of water flow. Plots were established based on these transects.

Water Levels. Four ground water wells were installed in the center of each of the four plots to monitor ground water levels. Each well was lined with a 5 cm PVC pipe perforated with holes extending along the entire 1.5 meter length of the pipe. Before insertion into the ground, the pipes were lined with fiberglass screen to block the entry of large particles. Each pipe was capped to prevent false readings from precipitation. Water levels were measured every two weeks from mid-April through June 1991 and monthly thereafter through April 1992.

Biomass Production and Decomposition. Net primary production of trees was measured as the sum of litterfall and stem growth. Herbaceous biomass was measured by clip plots. Litterfall was collected monthly from July 1991 through May 1992 in 0.25 m^2 litter traps at an elevation of one meter above the ground, randomly placed in each of the four plots (total = 8 traps). After collection, litter was separated into leaves and woody material, dried, and weighed.

All trees 10 cm or greater in diameter were tagged, and measured at the beginning and end of the growing season. Differences in diameter at breast height (DBH) between pre- and post- growing season were used to determine annual change in diameter. Species specific regression equations relating the change in DBH to weight were used to determine annual production for aboveground dry biomass (Clark et al. 1985; Scott et al. 1985; Schlaegal 1984; Schlaegal & Wilson 1983).

Herbaceous biomass was collected at the peak of the growing season in September 1991 in both the flooded and ridge areas in ten randomly selected 0.25 m^2 plots in each zone (total = 20 plots). All vegetation in the plots was cut to ground level and returned to the laboratory where it was sorted by species, dried, and weighed.

Five decomposition bags were placed in each of the four plots to measure above and below ground decomposition. Each bag consisted of four 12.5-cm by 5-cm segments of 1-mm nylon

mesh, each containing 5 grams of tree litter (total weight per bag = 20 g). Litter is defined here as leaves only, and excludes woody material and fauna. Three segments were buried vertically down to a total soil depth of 37.5 cm., whereas the fourth segment was left on the soil surface. Duplicate bags were pulled from each zone at 0 (to serve as a blank), 1, 4, 12, and 28 weeks after burial to determine decomposition rates at varying depth and time intervals. Samples were put on ice in the field, frozen in the laboratory until analysis, and rinsed, dried, weighed, ground, and stored. Decomposition coefficients (k) were determined for each of the four depths (surface, 12.5 cm, 25 cm, 37.5 cm) at both the flooded and the drier zones. K-values were computed by linear regressions of the percent original dry mass remaining versus time, using a natural log transformation of the exponential decay model $\ln(X/X_o) = -kt$ where X_o = initial weight, X = final weight, t = time (Conner & Day 1991). Significance between sites was determined by Fisher's PLSD test ($p = 0.05$).

Soil Redox. Permanent platinum electrodes were installed in the field to measure the electrical potential of the soil. Redox potential has been found to correlate well with oxygen availability, and with the percent cover of obligate wetland species has been shown to increase below an oxygen content of 12% and a redox potential of +300mV (Josselyn et al. 1990). Welded electrodes were constructed according to methods described by Faulkner et al. (1989).

Triplicate electrodes were inserted at various depths in four different areas to determine redox levels and oxygen availability according to vegetation type, water levels and duration, and soil depth (table 3-3). The four electrode plots were selected along a hydrologic gradient: ponded primarily with effluent from the plant (FP), intermittently affected by effluent and supporting both woody and herbaceous vegetation (F1), herbaceous and unaffected by effluent (F2), and forested and unaffected by effluent (R1) (figure 3-2). The three F plots occur in the Zone IV segment of the forest while the R plot is in the Zone V segment. Three 30 cm electrodes were placed in all four plots in July 1991 because of the importance of this depth to plant growth and survival (Faulkner et al. 1989). Electrodes were not placed at other depths until August of 1991.

Redox was measured monthly until April 1992 with a portable millivolt meter and a saturated calomel reference electrode. The meter was allowed to stabilize for three minutes before recording values. In order to base the readings on the standard hydrogen reference electrode, meter values were adjusted by adding 244 mV (Faulkner et al. 1989).

Table 3-3: Description of platinum electrode sites.

Location	Depths (cm)
FP: Ponded Area in Flooded section, sparse to no vegetation	5, 15, 30, 60
F1: Water Well, intermittently flooded, woody and herbaceous vegetation	15, 30, 60
F2: Intermittently flooded, dominated by *Polygonum sp.*	5, 15, 30
R1: Ridge site, infrequently flooded, dominated by *Quercus nigra*	30, 60, 90

In order to test the equality of means at the 4 electrode sites, a one factor ANOVA was performed for all 30 cm values. Accuracy of the permanent electrodes at 30 cm was measured after 10 months. Fresh mercury-junction electrodes were inserted at 30 cm and allowed to stabilize for 24 hours. Readings were then compared to those of the 10-month old set and analyzed for variance.

Accretion Rates. Ten feldspar clay marker horizons (five each in Zone IV and Zone V) were laid down in March of 1991 in square meter plots along the center of the flooded and ridge areas to measure accretion rates (Cahoon & Turner 1989). Feldspar plots were cored 13 months later using the cryogenic technique of Knaus and Van Gent (1989). Four readings were taken from each core, providing a total of 20 readings for each of the two zones.

Water and Nutrient Samples. Measurements for conductivity, total dissolved solids (TDS), and pH were measured in the field with a Corning M90 portable meter. Water samples for nutrient analysis were collected in acid

washed 500 ml polyethylene bottles. Vials were then filled immediately with water filtered through 2.5-cm GF/F glass microfibre filters, stored on ice, and frozen in the laboratory. The remaining water in the 500-ml bottle was also stored on ice and returned to the lab for analysis of suspended sediment.

Suspended sediment concentrations were determined gravimetrically (Banse et al. 1963). Nitrate-nitrite was analyzed with a Technicron Autoanalyzer II. Total oxidized N (NOx) was measured after cadmium column reduction (EPA 1979, method #353.2). Ammonium was analyzed by the colorimetric, automated phenate method (EPA 1979, #350.1). Ortho-phosphate was analyzed by the colorimetric, ascorbic acid single reagent method (EPA 1979, #365.2).

Conductivity, TDS, and pH measurements were taken at the runoff pipe (Station 1), the plant effluent pipe (Station 2), at two points in the effluent ditch (Stations 3 and 4), at the end of the ditch (Station 6), in the center of the ponded area (Station 11), in the herbaceous wetland 10 meters outside of the flooded plot (Station 8), and at two forested wetland stations in the ridge plot (Stations 9 and 10). Suspended sediments and nutrient samples were taken at Stations 2, 6, 11, 8, 9, and 10. Samples were taken between May 1991 and March 1992. Due to the erratic nature of the effluent flow and of precipitation, water was not usually present at all stations on the same sampling date. The resulting data set contains more values for the

ditch and pond (3, 4, 6, 11) than for the wetland stations (8, 9, 10). The maximum number of measurements per station was nine at Station 6, while the minimum number was three at Station 10.

3.4. Results and Discussion

Transect Elevations and Water Levels. Ridge plots are approximately 20 to 40 cm higher than the flooded plots. Water levels were at or near the surface for approximately half the measurements over the course of the year in the flooded area (F1 and F2) (figure 3-3). Levels on the ridge were below the surface except in May and June 1991 and in February and March 1992. Levels were generally lower in all plots during the summer (June through September) probably due to higher evapotranspiration.

Biomass Production and Decomposition. Biomass and productivity values were greater for the ridge site (Zone V) compared to the flooded site (Zone IV) for litterfall, mean annual tree growth, and herbaceous biomass (table 3-4 and figures 3-4, 3-5, and 3-6). At the same time, the flooded site contained a high density of young trees (table 3-5), indicating revegetation in the flooded area receiving effluent.

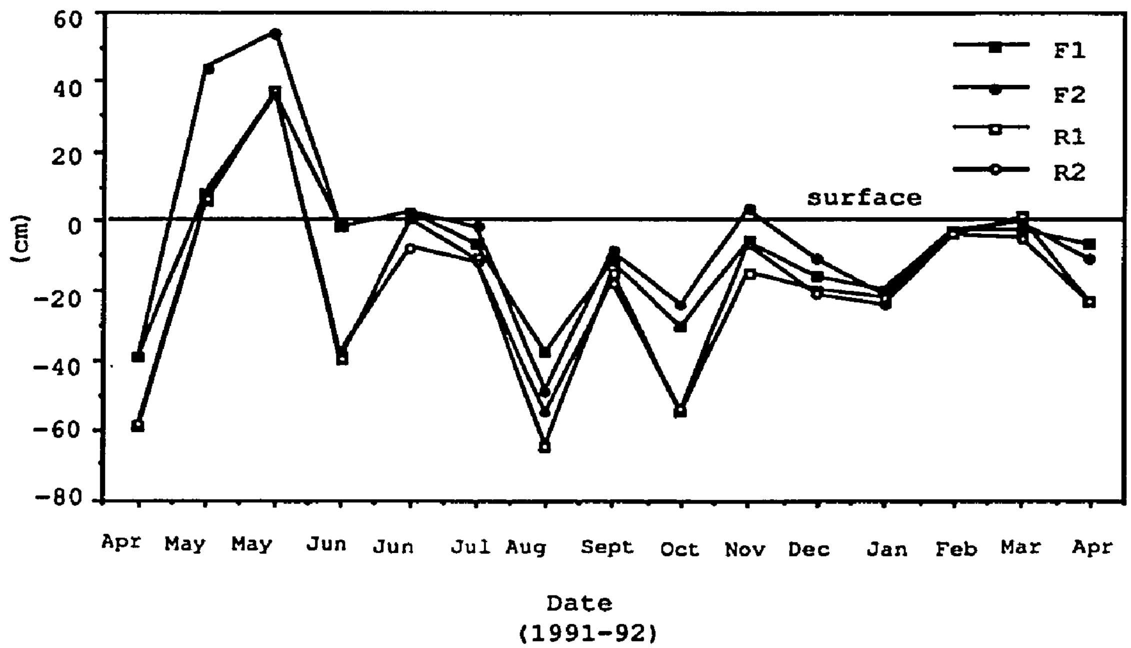

Figure 3-3: Water levels measured at each water well. The relative elevations of the soil surface at each site are F1=0, F2=0.04, R1=0.47, R2=0.42 (meters). Water levels are relative to the surface at that site.

Table 3-4: Tree Productivity ($g/m^2/yr$) and herbaceous biomass (g/m^2) of the Flooded and Ridge Sites .

	Litterfall	Annual Mean Tree Stem Growth	Above-ground NPP[1]	Herbaceous Biomass
Ridge (Zone V)	584[2]	676	1272	107
Flooded (Zone IV)	219[2]	227	482	81

[1]NPP = litterfall + stem growth

[2]estimated values for annual litterfall based on 11 months of data (July 1991-May 1992)

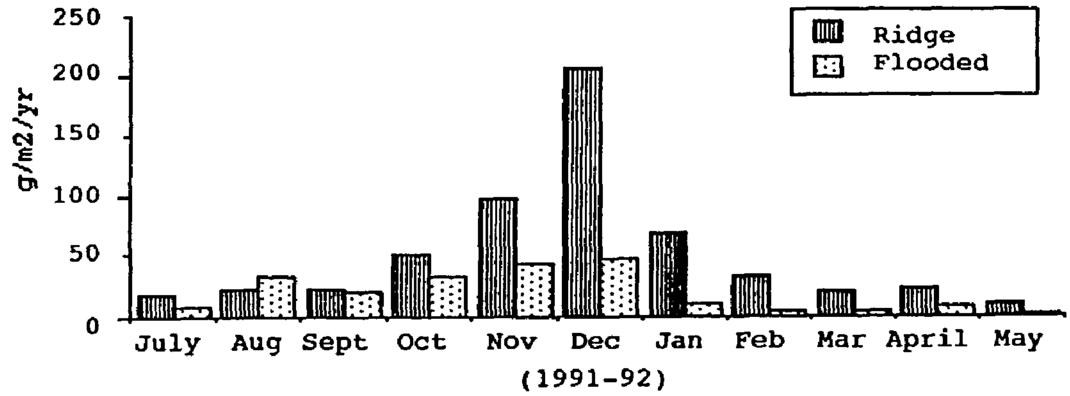

Figure 3-4: Litterfall.

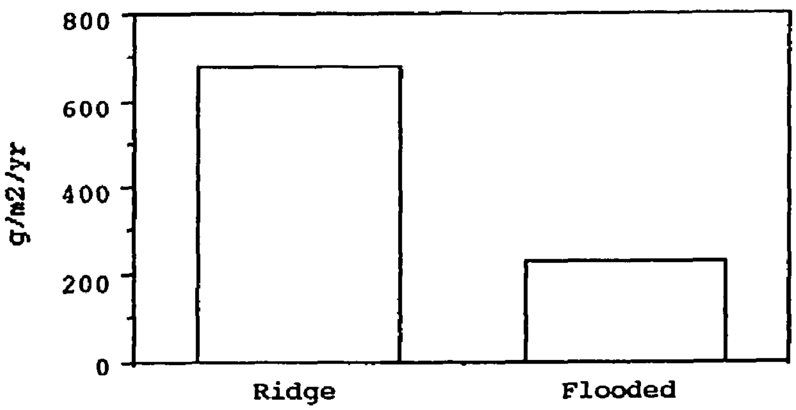

Figure 3-5: Mean Annual Aboveground Stem Growth (1991).

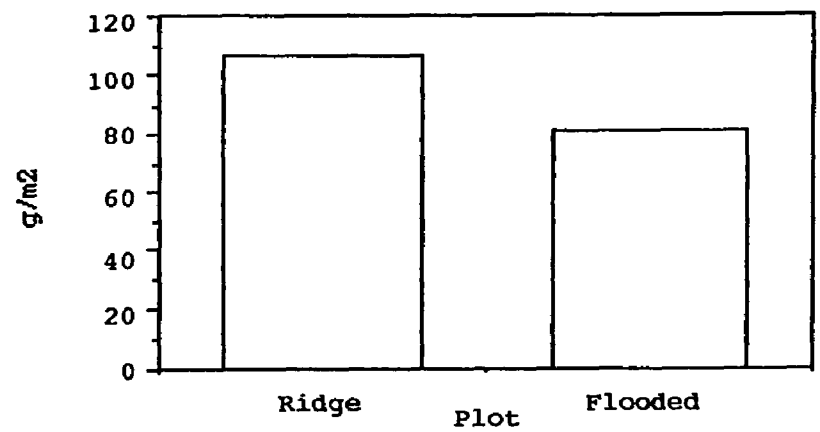

Figure 3-6: Average Herbaceous Biomass (collected in 1991).

Table 3-5: Density and type of young trees (< 10 cm diameter) in flooded plots (each plot = 20 x 25 meters).

Species	Typical Zone	Wetland Status*	Number in F1	Number in F2
1. Black Willow (*Salix nigra*)	2,3	OBL	16	29
2. Red Mulberry (*Morus rubra*)	4,5	Fac	1	0
3. Sycamore (*Platanus occidentalis*)	4,5,6	FacW-	1	0
4. Red Maple (*Acer rubrum*)	3,4,5,6	OBL, Fac	17	35
5. Green ash (*Fraxinus pennsylvanica*)	3,4	FacW	37	33
6. Winged elm (*Ulmus alata*)	4,5,6	FacU+	9	3
7. Boxelder (*Acer negundo*)	4,5	FacW	4	5
TOTAL			85	105
Total trees/ha			1700/ha	2300/ha

*Based on the following indicator categories for Region 2 (Southeast) from Reed (1988):

OBL = obligate wetland species
FacW = facultative wetland species
Fac = facultative
FacU = facultative upland
UPL = obligate upland

Litterfall was not significantly different between the two areas during the months of July, August, September, or October, but differences were highly significant during December, January, and February ($p = 0.0001$) and significant during the remaining four months ($p < .03$).

Litterfall for the ridge (584 $g/m^2/yr$) is slightly higher than the average of 570 $g/m^2/yr$ reported for other riverine fresh water forested wetlands in the U.S., Puerto Rico, and Czechoslovakia (Lugo et al. 1988), whereas the flooded site (219 $g/m^2/yr$) falls below the lowest amount reported (320 $g/m^2/yr$). Litterfall values are also high for the ridge and low for the flooded area when compared to litterfall amounts reported for southeastern U.S. forested wetlands (Conner & Day 1982), and for riparian wetlands (Mitsch & Gosselink 1986).

The average estimate of woody biomass production or stem growth of 676 $g/m^2/yr$ for the ridge is close to or higher than the average for other forested wetlands: 694 $g/m^2/yr$ (Lugo et al. 1988) and 558 $g/m^2/yr$ (Conner and Day 1982). Stem growth in the flooded area (227 $g/m^2/yr$) is very low when compared to other freshwater forested wetlands. Net primary production value for the ridge (1260 $g/m^2/yr$) is similar to the average of 1265 $g/m^2/yr$ reported by Lugo et al. (1988), whereas the flooded area (446 $g/m^2/yr$) is below their lowest reported estimate of 668 $g/m^2/yr$.

Litter decomposition rates were higher at the ridge site and generally decreased with depth in the dry area (table 3-6). In the dry area, k-values were greatest at 12.5 cm, followed by the surface, 25 cm, and 37.5 cm. The surface k-value of 1.54 is relatively high compared to other ridge decomposition values measured in the Terrebonne basin, LA (k = 0.88, J. Rybsczk, Center for Wetland Resources, LSU, Baton Rouge, LA, personal communication), and for freshwater wetlands, excluding northern peatlands, in general (k = 0.90, Brinson et al. 1981). The ridge value is also high compared to two flooded sites in Louisiana (k = 0.83 and 0.77, Conner & Day 1991) and to southeastern deepwater swamps (k = 0.23-1.39 for most of the sites reviewed, Mitsch & Gosselink 1986). The ridge surface k-value is, however, less than a Louisiana crayfish pond where water depths were controlled by pumping (k = 2.081, Conner & Day 1991). Because the 28-week period at which the final bags were collected occurred during February, decay rates in the ridge and flooded areas are likely to increase as the new growing season begins.

Decomposition in the flooded plots was very slow. K-values ranged from 0.069 to 0.530, and litter at the surface was actually heavier at the end of 28 weeks. While slow decay rates are to be expected in anaerobic environments, those determined for the Zapp's flooded area are lower than those found in flooded areas at Thibodaux (0.68 and 0.78) or in Barataria Basin (0.832 and 0.769) (Conner & Day 1991).

Table 3-6: Decomposition Coefficients and Mass loss at 4 Different Depths in the Flooded and Ridge Areas.

Flooded

Depth	R^2	k	p-value	% remaining at 28 weeks
surface	0.008	-0.142	0.8083	107%
12.5 cm	0.008	0.069	0.8046	95%
25 cm	0.275	0.530	0.1196	82%
37.5 cm	0.264	0.284	0.1285	84%

Ridge

Depth	R^2	k	p-value	% remaining at 28 weeks
surface	0.887	1.547	0.0001	44%
12.5 cm	0.847	2.162	0.0002	30%
25 cm	0.461	0.706	0.0308	69%
37.5 cm	0.407	0.518	0.0473	82%

No significant differences in decay rates were found between sites during the first 12 weeks ($p = 0.627$). Differences were significant, however, between the flooded and ridge areas for all depths between 12 and 28 weeks ($p = 0.0148$).

In order to determine the capacity of each site to decompose the local litterfall at the surface, the formula $A_t = A_o e^{-kt}$ was used where:

A_t = final biomass after one year,
A_o = initial biomass
k = decay coefficient (from table 6)
t = 1 year.

Results indicate that approximately 87% of the total litterfall deposited on the surface would remain after one year in the flooded area, whereas 21% would remain on the ridge surface. Thus, while the flooded area receives less than half the amount of litter deposited on the ridge, most of that litter is not decomposed, particularly in the upper 12.5 cm of the soil.

Soil Redox. Overall mean redox levels for all depths generally increased from wettest to driest areas (FP < F1 < F2 < R1). The ponded area (figure 3-7a) remained reduced at all depths from August through March. Water levels below the surface should generally be reflected by levels measured in F1, which is located approximately 5 meters from the pond (FP). Pond water levels were generally at the surface which consisted primarily of mud, except in August when the surface was dry. Consistently lower readings for the 5-cm depth compared to those for 15 and 30 cm may reflect the

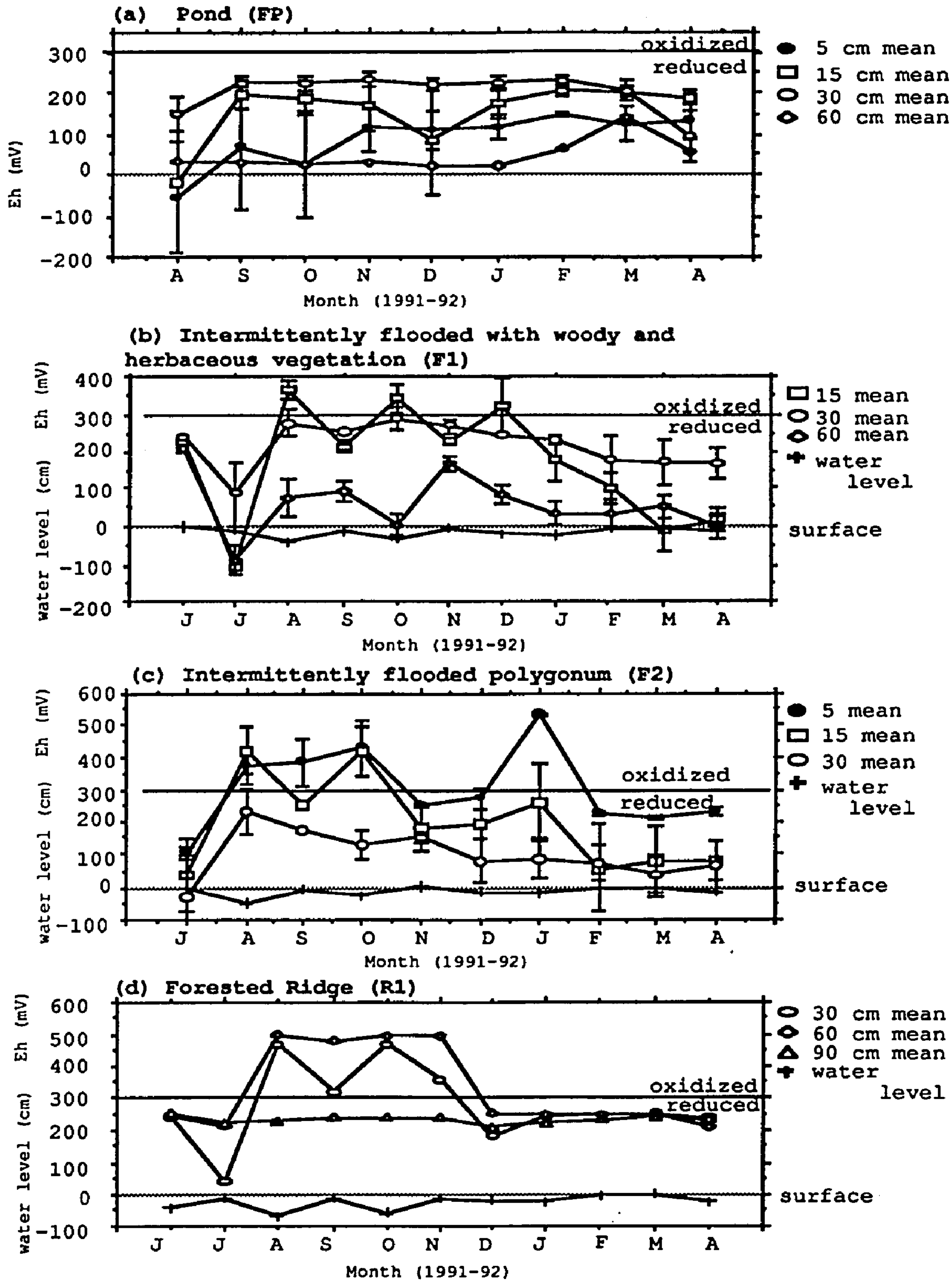

Figure 3-7: Mean redox levels (error bars = one standard error).

high microbial demand for oxygen due to the accumulation of organic matter from effluent input. Redox levels at 30 cm were slightly lower in the pond (FP) compared to the nearby intermittently flooded plot (F1) (figure 3-7b). Both areas show highly reduced levels at 60-cm depths. Unlike the ponded plot (FP), the intermittently flooded area (F1) does show some oxidation at the shallower 15-cm depth, which is probably a result of the higher amount of vegetation in this plot compared to the pond plot.

The F2 intermittently flooded *Polygonum sp.* plot was generally highly oxidized at 5 cm except during those months when water levels reached the surface (figure 3-7c). Polygonum has been shown to oxidize the rhizosphere which is likely conducive to denitrification (Boustany 1991). Redox levels at 30 cm were lower compared to FP and F1, which may be the result of decomposition of *Polygonum* root material.

Redox levels at the forested ridge site were higher at all depths compared to the other three plots (figure 3-7d). Levels were oxidized for both 30 and 60 cm throughout most of the growing season. Levels at 90 cm were only moderately reduced throughout the entire period of measurement. A one factor ANOVA of the 30 cm readings showed significant differences between all four plots ($p = 0.0001$). Fisher's PLSD test revealed that the significance was due to large differences between the R1 and F2 plots while plots F1 and FP were not statistically different from each other at $a = 0.05$. At 30 cm, the ranking of means from highest to lowest

was: R, F1, FP, F2. Standard error bars for the four plots reveal both the large variations in F2 and R1, and the relatively small variation in both F1 and FP (figure 3-8).

Differences between means for both fresh and older electrodes were minor for the forested ridge plot (R1) (10 mV), intermediate for the ponded (FP) and intermittently flooded (F1) plots (30 and 19 mV, respectively), and largest for the *Polygonum sp.* plot (F2) (59 mV). Variation between the fresh and 10-month old sets followed similar patterns, with the F2 plot showing the greatest variability (table 3-7). Differences between the 24-hour set and the 10-month old permanently planted set were not statistically significant, indicating that the older electrodes were still accurate after ten months in the field. .

Accretion Rates. Analysis of accretion over 13 months showed highly significant differences ($p = 0.0001$) between average accumulation rates in the flooded area (11.5 mm) and the ridge area (2.9 mm, figure 3-9). This is probably due to the lower elevation of the flooded area and the application of effluent to that area which increase flooding and provide a greater opportunity for sediment inuput.

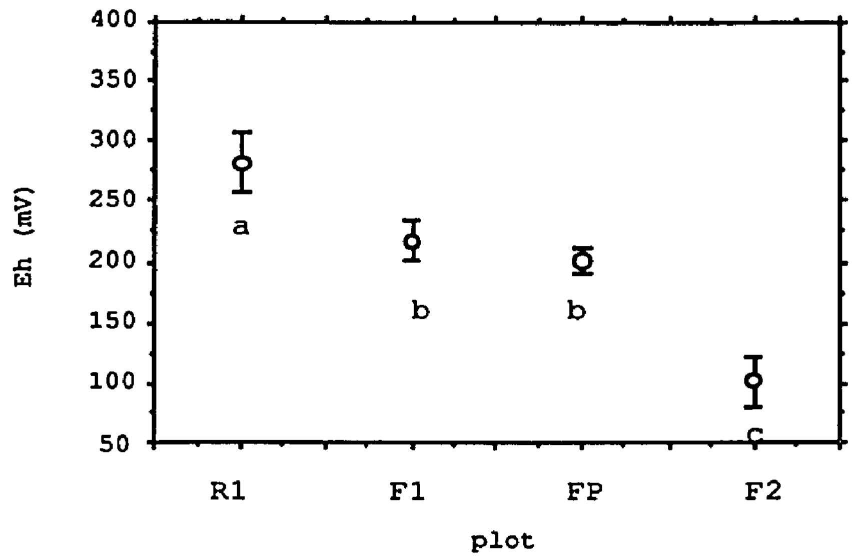

Figure 3-8: 30 cm redox means for July 1991 through April 1992 (error bars = one standard error; different letters indicate statistically significant difference).

Table 3-7: Readings for 24-hour electrodes compared to 10-month old electrodes at 30 cm (mV)

	24-HOUR ELECTRODES	10-MONTH ELECTRODES	
Plot	Field Reading Averages	Field Reading Averages	p-value
R1	230 (± 2)	240 (± 16)	0.2208
FP	157 (± 71)	187 (± 56)	0.5502
F1	147 (± 52)	166 (± 85)	0.7193
F2	124 (± 137)	65 (± 158)	0.5352

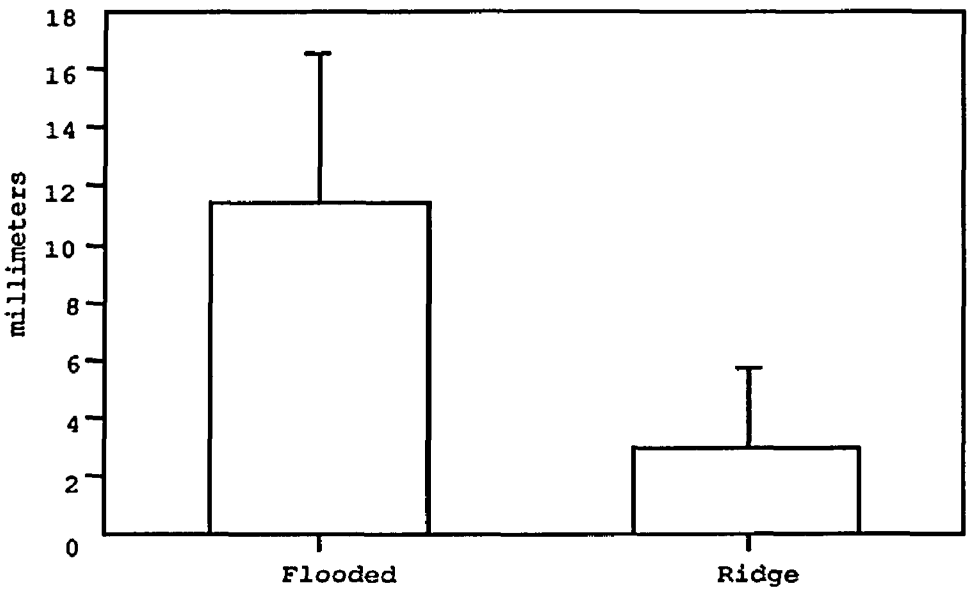

Figure 3-9: Mean Accretion Rates after 13 months.

Water and Nutrient Samples. There was a general trend for most water quality parameters (NH_4, PO_4, TDS, conductivity, and suspended sediments) to increase from the effluent pipe (Station 2) to the ditch and pond (Stations 6 and 11) and to decrease toward the more distant wetland areas (Stations 8, 9, 10; figures 3-10). The order of stations in Figure 3-10 indicates the pattern of water flow. The plant effluent had a pH of between 6.5 and 7.0, a TDS level of below 500 mg/l, and a conductivity level of less than 1000 µS. TDS and conductivity tended to increase slightly along and at the end of the effluent ditch (Stations 3, 4, and 6), and to increase substantially in the ponded area (Station 11). TDS and conductivity were lower and less variable in the wetland stations. Values for pH were generally between 6-8 at all stations.

Suspended sediments were approximately 350 mg/l higher at the end of the ditch (Station 6) and in the ponded area (Station 11), compared to the effluent pipe and the three wetland stations (8, 9, 10). The high suspended sediment concentration at the end of the ditch is probably responsible for the filling in of that station and the subsequent growth of *Hydrocotyle sp.* The ponded area currently contains little or no vegetation.

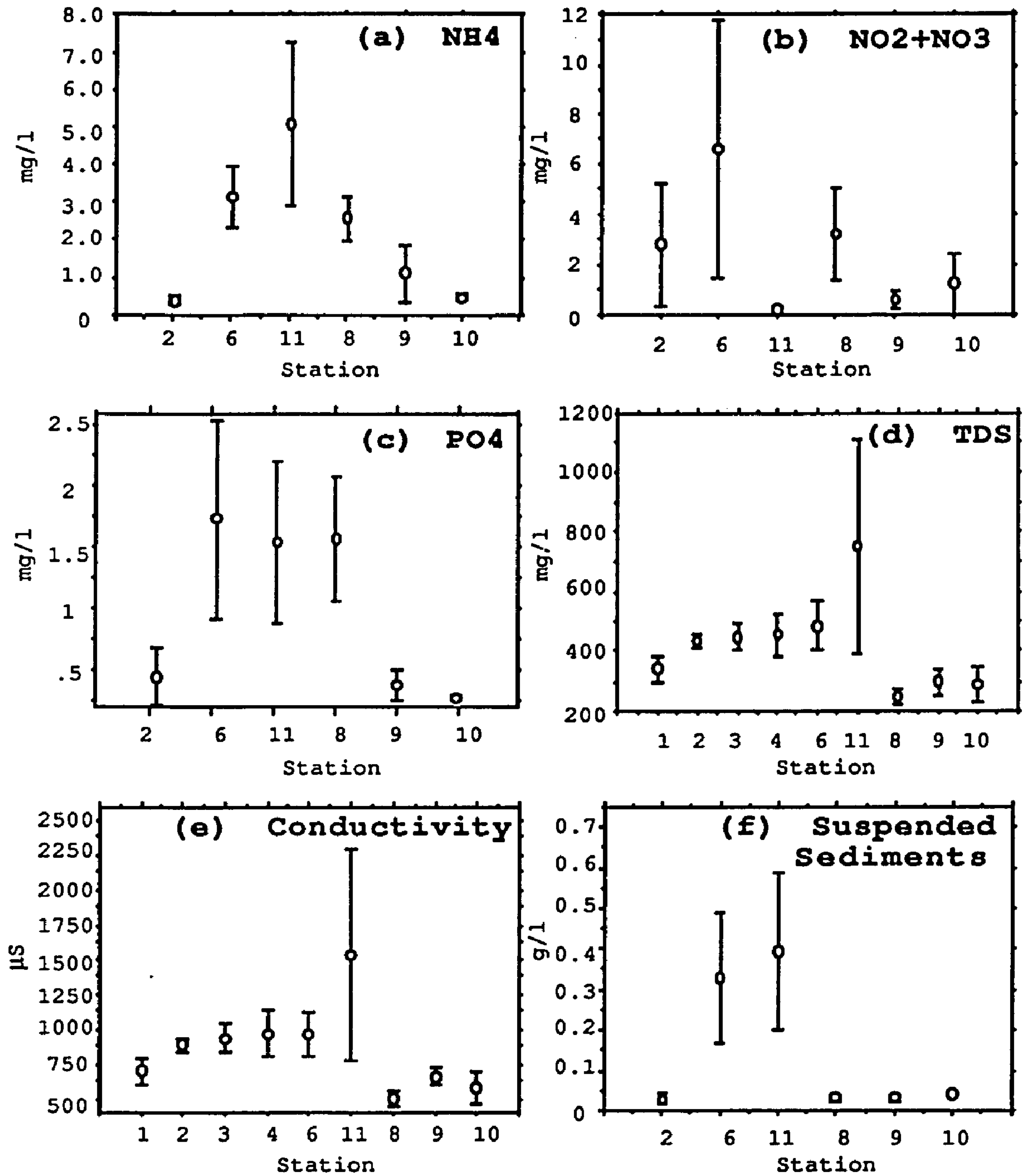

Figure 3-10: Nutrients and water quality parameters. Station 1 = parking lot pipe; 2 = effluent pipe; 3,4 = ditch; 6,11 = pond; 8,9,10 = wetlands. Individual means are for all dates on which there was standing water at the station. Error bars = one standard error.

Plant effluent contained an average of 3 mg/l NO_2+NO_3 and less than 1 mg/l NH_4 (figures 3-10a and 3-10b). At the end of the ditch, nitrogen levels increased to about 7 mg/l NO_2+NO_3 and 3 mg/l NH_4 indicating nitrification. The lack of available oxygen in the ponded area appears to lead to the reduction of a portion of the NO_2+NO_3 to NH_4 which reached an average but highly variable level of approximately 5 mg/l. Means for both NH_4 and NO_2+NO_3 levels at the wetland stations remained under 3 mg/l.

Ortho-phosphate levels averaged 0.5 mg/l at the effluent pipe and were generally below 1 mg/l at the wetland stations, except for the flooded area wetland station (8) (figure 3-10c). The high variation and relatively high PO_4 mean for Station 8 compared to the other wetland stations results from a single high reading in February of 12.2 mg/l. Excluding this value which may have resulted from a contaminated sample, the PO_4 mean at Station 8 was 1.56 mg/l, with a maximum of 3.3 and a minimum of 0.27 mg/l. The higher values of PO_4 and NH_4 in the ditch and pond suggest high levels of remineralization of applied organic matter. High biological activity could be responsible for the high concentration of suspended sediments at these stations (6 and 11). Overall, the effluent discharged from the plant appears to be within the typical range for biologically treated wastewater, and below typical limits after passing through the wetland (table 3-8).

Table 3-8: Typical Water Quality Parameters compared to Zapp's plant effluent and wetland treatment (mg/l).

Parameter	Typical secondary effluent	Typical Limits	Zapp's effluent (Sta 2)	Zapp's Pond (Sta 11)	Zapp's Zone IV wetland (Sta 8)	Zapp's Zone V wetland (Sta 9,10)
TKN			34[b]			
N03		10[d]	3[a]	0[a]	3.25[a]	1.0-2.0[a]
NH3	24[d]	3-5[d]	20[b]			
NH4			0.5[a]	5.0[a]	2.5[a]	0.5-1.0[a]
TN	15-40[c]; 26[d]					
PO4	7[d]		0.5[a]	1.5[a]	1.5[a]	0.25-0.4[a]
TP	7-10[c]; 8[d]	0.05-0.1[f]				
TDS		500[e]	350[a]		225[a]	275[a]

a Mean of field measurements
b reported by Zapp's plant personnel
c Richardson & Nichols 1985
d Viessman & Hammer 1985
e Montgomery 1985
f U.S. EPA 1976

A univariate ANOVA with repeated measurements was used to test for differences between the stations. In order to increase the number of measurements within groups, stations were combined in terms of their distance away from the effluent pipe. The three combinations included: stations 1 and 2 as effluent stations; 3, 4, 6, and 11 as ditch and pond stations; and stations 8, 9, and 10 as wetland stations. Differences in suspended sediments were statistically significant at a = 0.05; NH_4 was significantly different at a = 0.01; and no significant differences were found between groups for NO_2+NO_3 or PO_4. As stated above, the lack of strong statistical support is probably due to the limited data set, in addition to the wide variation among measurements at individual stations.

Results indicate that the Zone IV vegetation in the wetland receiving the potato processing wastewater has begun to recover from the effects of impoundment that began in the 1950's. The impoundment appears to have led to increased flooding that killed many of the Zone IV species. Input water from the processing plant since 1985 increased sedimentation and encouraged the growth of new woody vegetation. Results also show that the wastewater is assimilated by the wetland within 100 meters of the discharge.

3.5. General Considerations

Three primary issues emerge from the results of research at the Zapp's receiving wetland: 1) the ability of wetlands to purify wastewater, 2) the potential for added wastewater effluent to enhance recovery of altered wetlands, and 3) wetland delineation. Each of these will be discussed below.

3.5.1. Wastewater Purification.

The general reduction of NH4, PO_4, TDS, conductivity, and suspended sediments with distance from the ditch and ponded area suggests that the added nutrients are being assimilated by the system and water quality is being improved. The primary sinks for these nutrients are denitrification, incorporation as herbaceous or woody tissue, and permanent burial. This will be addressed in more detail in the following section. Results of the field measurements indicate that an even greater degree of water purification than that currently taking place could be realized with an alteration of the existing discharge system. In analyzing the soil redox measurements for potential effluent application, results indicate that the plots in the flooded area (FP, F1, and F2) are probably not different enough in terms of redox status to spray the effluent on a large scale throughout the flooded area. While the higher measurements at 5 and 15 cm in the F2 *Polygonum sp.* plot might indicate the capacity of that plot to assimilate some of the effluent currently being applied

to the ponded area, future application should probably be divided between the currently ponded area (FP) and the forested ridge (R1). The extensive redox range for R1 at 30 cm, with a mean very close to 300 mV, suggests a high potential for denitrification where redox levels alternate between the oxidized and reduced zones.

While the ponded area is generally reduced at all depths, it will probably fill in and become vegetated with plants in a manner similar to the adjacent, formerly ponded area which previously received most of the effluent. This previous pond, which was devoid of both woody and herbaceous vegetation before 1985 when Zapp's began to discharge its effluent to the swamp, is now covered with the obligate wetland species *Hydrocotyle sp.* The increased productivity, therefore, appears to be a result of effluent application. Directing some of the current effluent away from the ponded area to the forested ridge would allow time for the pond to dry out and establish vegetation more rapidly. The highly oxidized redox levels on the ridge and the rapid decomposition rates indicate that the ridge would be capable of assimilating a portion of the effluent.

3.5.2. Assimilation and Recovery.

Zone IV vegetation in the Zapp's receiving wetland deteriorated as a result of partial impoundment in the 1950's. It appears that these impoundments artificially raised water levels to a point that killed the existing

vegetation. Bottomland hardwood vegetation cannot tolerate prolonged waterlogging (Harms et al. 1980; Conner & Day 1982; Hook 1984; Mitsch & Gosselink 1986) In 1985, Zapp's began to discharge wastewater to the flooded and dying section of the forested wetland. The effects of this discharge were to fill in the open water area (as indicated by the high accretion rates) leading to the establishment, first, of herbaceous wetland vegetation which was then followed by young woody vegetation (table 3-5). The sequence of events from death, to open water, to herbaceous vegetation, and finally to woody vegetation, suggests that the system has responded favorably to the sediment-laden effluent and has begun to revert to a forested wetland similar in composition to its predecessor. While the reconstruction of events affecting the receiving wetland are not based on historical data, it appears to offer a plausible explanation for the present vegetative composition of the wetland.

Based on the reported TKN value for Zapp's effluent of 34 mg/l and the average effluent content of 3 mg/l NO_2+NO_3, the 49,000 liter flow per day for a four day work week, and the approximately 2.5 ha of receiving wetland, total annual areal loadings for TKN are less than 15 $g/m^2/yr$. This value is at the low end of those reported in the literature for total nitrogen loadings, which generally range from 13 to 428 $g/m^2/yr$ (Richardson & Davis 1987; Nixon & Lee 1986; U.S. EPA 1985 from Richardson & Nichols 1985).

Using the same flow and area with the typical value for TP of 8 mg/l for biologically treated effluent (Viessman & Hammer 1985), areal loadings are calculated as approximately 3 $g/m^2/yr$. Again, this value is at the low end of those reported for total phosphorus loadings which generally average approximately 12 $g/m^2/yr$ in the southeast (Nixon & Lee 1986) and 14 $g/m^2/yr$ in the U.S., Ireland, and Canada (U.S. EPA 1985 from Richardson & Nichols 1985). The areal loadings at Zapp's of 15 g $N/m^2/yr$ and 3 g $P/m^2/yr$ are lower than those currently being applied to the Thibodaux receiving wetland (20g $N/m^2/yr$ and 4g $P/m^2/yr$). Based on calculations derived for the Thibodaux receiving wetland for denitrification, storage in woody tissue, and burial (table 3-9), the Zapp's receiving wetland can assimilate the added nitrogen and phosphorus from the wastewater.

Accretion rates measured in the flooded area at Zapp's (12 mm/yr) indicate that nutrients will be permanently removed while water levels are maintained, assuming a relative sea level rise in the Mississippi Deltaic Plain of between 1.0 and 1.2 cm/yr (Gornitz et al. 1982; Hoffman et al. 1983; DeLaune et al. 1989). In addition, the storage in woody tissue and the high potential for nitrification in the herbaceous *Polygonum* plot and on the ridge, indicate the rates of nutrient removal will be comparable to those at the Thibodaux receiving wetland.

Table 3-9: Estimates of nitrogen and phosphorus retention via denitrification, storage in woody tissue, and burial in sediments for the Thibodaux, LA receiving wetland (modified from Conner & Day 1989).

Denitrification

System	Value (g/m2/yr)	Reference
LA Swamp	12.6-110	Lindau et al. 1988
NC Swamp	12.9	Brinson et al. 1984

Range of values = 12-110 g N m2/yr

Storage in Woody Tissue

Parameter	Value	Reference
stem production		Conner & Day 1976
in LA swamp	738 $g/m^2/yr$	Conner et al. 1981
N in woody tissue	1.5%	Straub 1984
P in woody tissue	.08%	Brinson et al. 1984

Uptake = 11 g $N/m^2/yr$
0.6-2.2 g $P/m^2/yr$

Burial

Parameter	Value	Reference
N in LA swamp soil	0.75%	Lindau et al. 1988
P in FL swamp soil	0.083%	Nessel & Bayley 1984

Burial = 75 g $N/m^2/yr$
8.3 g $P/m^2/yr$

Thibodaux application rate: 19.9 g $N/m^2/yr$
4.3 g $P/m^2/yr$

3.5.3. Wetland Delineation

A plan to use the forested wetland at Zapp's for wastewater treatment should include consideration of the issue of wetland delineation. Precipitation records for the Reserve and Gramercy, LA stations, show that 1991 precipitation was approximately 76 cm greater than the preceding eleven year average, and was the highest value in 12 years. For those months when the ridge water levels were at or above the surface, precipitation was always higher than the average for the preceding eleven or twelve years.

The atypical water levels are relevant to the current controversy over wetland delineation and, therefore, to the issue of whether the Zapp's site is a suitable candidate for wetland wastewater treatment. The two forested wetland zones represented at the Zapp's site are among the most important in terms of primary productivity, litterfall and decomposition, organic export, and consumer activity (figure 3-11). Normally, Zone IV vegetation, remnants of which are represented in the flooded site at Zapp's, would be flooded for 12.5-25% or approximately 30-60 days of the growing season. Zone V would be flooded for 2-12.5% or approximately 5 to 30 days of the growing season (Clark & Benforado 1981; growing season estimates based on 246 days, derived from Faulkner et al. 1991). Recent federal proposals to set the hydrologic criteria for wetland delineation at 21 days, would probably protect Zapp's Zone IV from development or human alteration, but leave Zone V

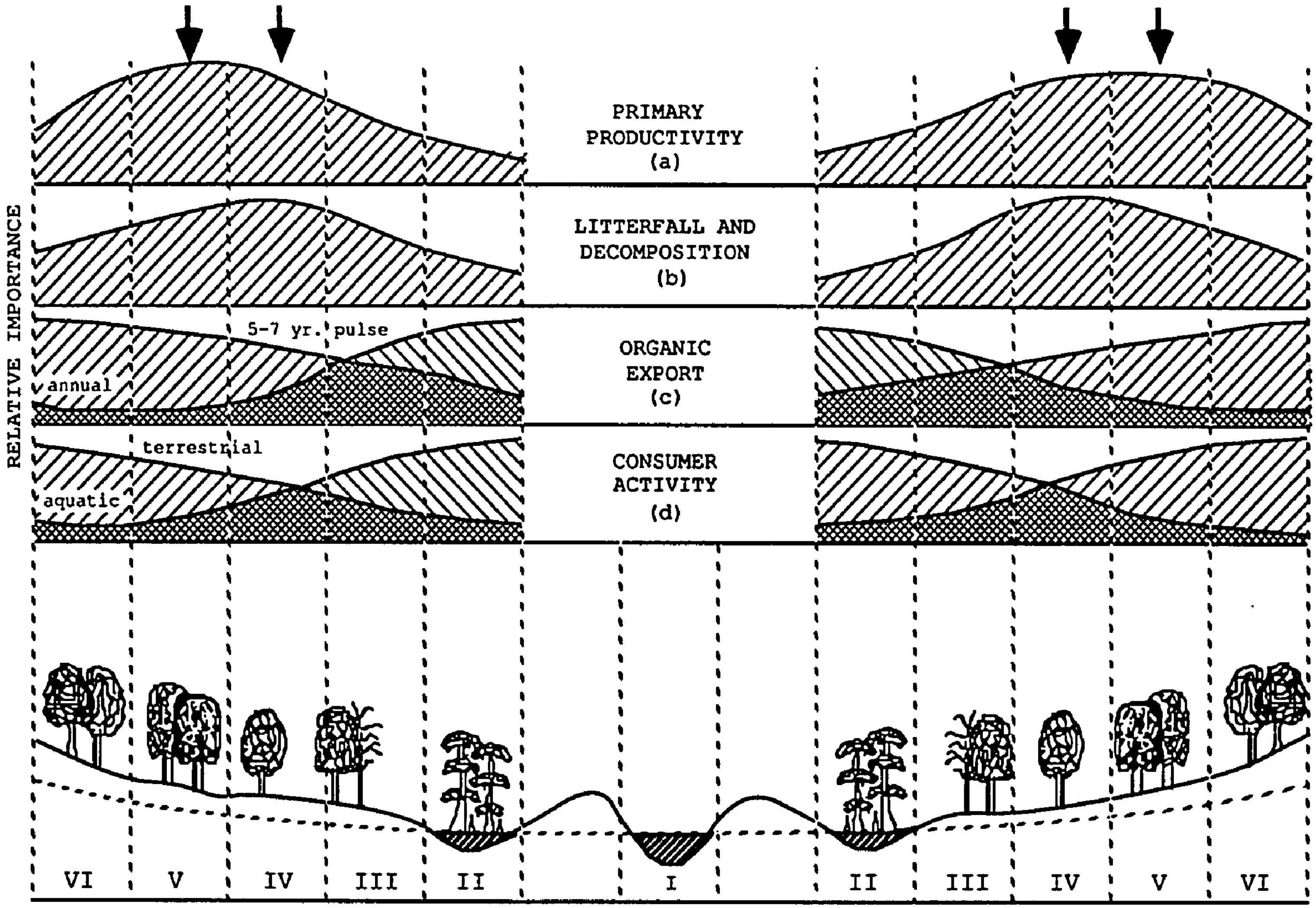

Figure 3-11: Ecosystem functions of bottomland hardwood wetlands. Arrows indicate zones represented at Zapp's study site, Gramercy, LA (from Mitsch and Gosselink 1986, p. 379; Copyright © by Van Nostrand Reinhold, reprinted with permission).

classified as a "non-wetland." The additional proposal that wetland delineation be based on water levels that are taken during a "normal" year, would further increase the chances that Zone V would be unprotected.

Results of this study indicate that the Zapp's site is a good candidate for effluent application due to the alterations which have both separated it from its parent bottomland hardwood system and left it vulnerable to development. As a transitional wetland -- and one with dubious regulatory status -- it can buffer the more pristine forest closer to the Blind River. As a hydrologically altered wetland, it can benefit from added nutrients without jeopardizing the adjacent and unaltered forest.

3.6. Summary and Conclusion

The wetland receiving the effluent from the Zapp's Potato Chip factory is part of the larger forested wetland between the Blind and Mississippi Rivers but it has been partially isolated by impoundment. The impoundment led to the deterioration of one segment of the forest (Zone IV), while not adversely affecting the other segment (Zone V). Both current and proposed delineation regulations would probably attempt to maintain the flooded and degraded wetland, while abandoning the more productive ridge site as a "non-wetland", in spite of its function as an integral component of the bottomland hardwood system. Maintaining the flooded wetland under current regulation prohibits the

discharge of effluent to that wetland. Results of this analysis indicate that, while the current methods of applying the wastewater could be improved by a spray dispersal system, the effluent from Zapp's discharged over the past seven years has benefited Zone IV by filling in the area and encouraging the replacement of the former but dying woody vegetation with aquatic wetland species and young woody vegetation. Results also indicate that the productive ridge area (Zone V) could be used to assimilate the current effluent load.

Fragmented or transitional forested wetland sites such as Zapp's which may be classified as non-wetlands in the future and left open for development, would make excellent candidates for wetland wastewater treatment. There is scientific value both in attempts to steer the progression of Zone IV to an herbaceous wetland that can imitate the water quality functions of the previously healthy forest, and in monitoring the responses of Zone V to added water, nutrients, and sediments. There is educational value in scientific study sites not only for the application and demonstration of sophisticated scientific techniques, but also from the environmental perspective of recycling natural materials (in this case water), which is easily grasped by young students. There is habitat value in the semi-open tracts of forest such as Zapp's Zone IV, interspersed among zones of more densely vegetated areas. Over a brief observation period of only five daytime visits to the Zapp's

site, 28 different bird species were recorded. The deteriorating condition of the trees in Zone IV provide broken tops, cavities, and open but protected spaces favored by some species. Finally, there is economic value in the savings in tertiary treatment costs to industries and municipalities.

A study of the capacity of the same forested wetland which surrounds Zapp's to assimilate the total organic carbon (TOC) loading from a neighboring sugar refinery, determined that complete mineralization of the TOC discharge occurred in the wetland before reaching the Blind River approximately 3.5 km away (Gambrell et al. 1987). (Discharge from the refinery ranged from 9.5×10^6 to 30.0×10^6 L [2.5 to 8.0 MGD] compared to Zapp's discharge of approximately 5×10^4 L [0.013 MGD]). The sugar refinery study is one of many indicating the ability of wetlands to improve water quality (Richardson & Nichols 1985).

With only 20% of the hardwood forests in the Lower Mississippi Valley remaining (Harris & Gosselink 1991), efforts should be directed toward protecting what is left. Since Zone V bottomland hardwood systems are not currently protected at the federal level, it is up to the state to devise means of maintaining these zones. The use of isolated wetlands such as Zapp's as treatment wetlands could serve to both unify and nourish fragmented segments of the remaining bottomland hardwood forests.

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CHAPTER 4

WETLAND WASTEWATER TREATMENT CASE STUDIES

4.1. Introduction

In this chapter three wetland wastewater case studies are presented to illustrate how the principles developed in the preceding chapters can be applied. The city of Thibodaux, LA. began discharging its effluent to a cypress-tupelo and bottomland hardwood swamp in the spring of 1992. The town of Breaux Bridge, LA. and the seafood processors along Bayou Grand Caillou near Dulac are both currently confronted with regulatory orders to improve their treatment efficiencies or to cease discharging into wetlands or surface water bodies.

4.2. Thibodaux, Louisiana

In 1985 the City of Thibodaux was charged with violation of its NPDES permit to discharge in the Lafourche drainage canal. As a result, over $2.8 million was spent to upgrade the 4 MGD secondary treatment system which now achieves less than 20 mg/l BOD and 20 mg/l TSS, and a minimum of 5 mg/l dissolved oxygen. These numbers are better than the values typically achieved by secondary municipal treatment (see Chapter 2, Richardson & Nichols

1985). The city also meets the non-toxic waste criteria established for this study in that it has effluent low in heavy metals. The improved output, however, was not sufficient to meet the 1989 classification of Thibodaux's receiving stream as a "water quality limited" water body. Limits for water quality limited receiving streams are 10 mg/l BOD, 15 mg/l TSS, and 5 mg/l ammonia nitrogen. Sand filtration was initially determined to be the most efficient tertiary treatment method for achieving 10/15/5 limits at a cost of approximately $1.6 million (Bergeron 1990).

As an alternative to sand filtration, the Department of Environmental Quality (DEQ) and the U.S. Environmental Protection Agency (EPA) have allowed the city to participate in a pilot project designed to measure the potentially beneficial effects of the effluent on a local cypress-tupelo and bottomland hardwood swamp formerly flooded by the Lafourche Bayou. Discharge of the City's secondary effluent to the swamp began in February of 1992. A two-year baseline study of the swamp was designed and implemented prior to initiation of effluent discharge (Conner et al. 1989). Over the next two years, monitoring data will be collected to accomplish three primary objectives: 1) to determine the fate of toxins and pathogens including coliforms and priority pollutants, 2) to determine the impact of the effluent on floral and faunal communities, and 3) to determine the impact of the effluent on nitrogen, phosphorus, and carbon cycles (Conner et al. 1989).

4.2.1. Study Site

The Thibodaux study area consists of a swamp/bottomland forested area in Terrebonne Parish about 10 km southwest of Thibodaux, Louisiana (figure 4-1). The total basin consists of over 3,500 acres with approximately 570 acres to be used for wastewater treatment. A ridge approximately 500 meters wide connects the northeast to the southeast section between the two shallow water areas. The shallow water area to the east of the ridge is currently being used as a control, and would serve as a backup wetland if necessary. A spoil bank runs generally from east to west at the northern boundary of the project area, and an oil and gas access road runs down the western boundary. The shallow water areas are flooded for most of the year while the ridge area is only flooded during periods of extremely high water. Water flows southward between the ridge and the access road and exits at a point where these two features nearly meet. Thus, the site is semi-impounded and can be monitored at the single point of discharge (Conner et al. 1989).

The city's current treatment system consists of primary and final clarifiers and a high rate trickling filter. After passage through these components, the effluent is treated with ultraviolet radiation. The wetlands distribution system consists of 2000 feet of pipe laid along the spoil bank bordering the swamp. Four-inch diameter discharge points are located 50 feet apart, totaling 40 discharge points. Final treatment before entry into the

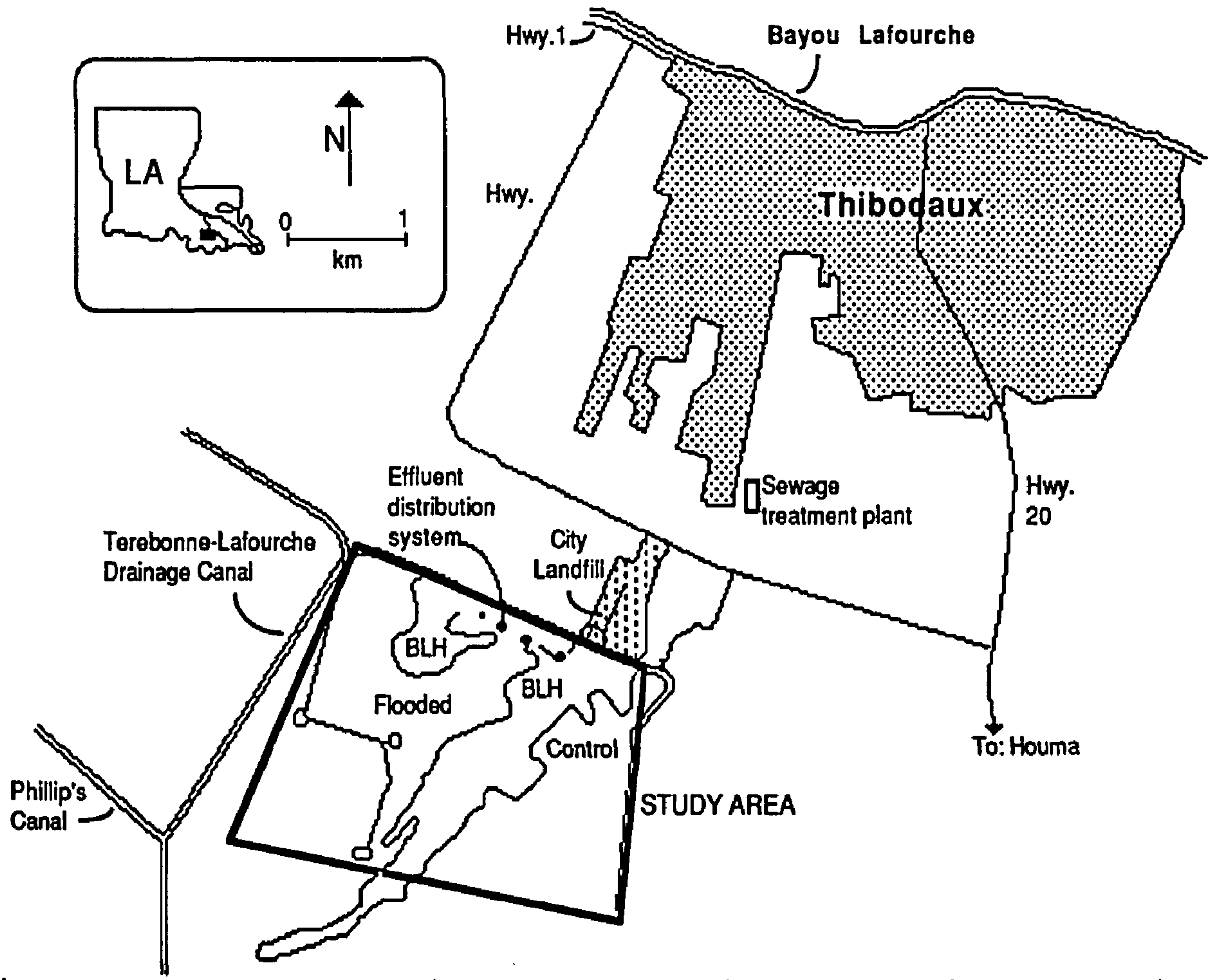

Figure 4-1: Map of the Thibodaux area showing the location of the city landfill and proposed wastewater application area (outlined in dark). The bottomland hardwood (BLH) ridges are populated with oaks, sweetgum, ash, elm, and maples. The flooded and control areas are populated with mainly ash, willow, maple, and cypress trees (from Conner et al. 1989).

swamp consists of flow over a rock bed (Conner et al. 1989). Loading rates to the wetland over the study area are: 1.1 inches per week (150 cm per yr) of treated effluent, 19.9 $g/m^2/yr$ of nitrogen, and 4.3 $g/m^2/yr$ of phosphorus. The nutrient application rate over the total basin is 3.2 $g/m^2/yr$ of nitrogen and 0.7 $g/m^2/yr$ of phosphorus (Day et al. 1992).

4.2.2. Baseline Study

Two years of baseline data were collected at the Thibodaux study site since October 1988. A total of fourteen stations were set up in a cypress-tupelo area, a bottomland hardwood ridge, and the control site similar in vegetative composition to the cypress area. The stations are designed to determine the effects of the wastewater at various uniform distances (25, 50, and 100 meters) from the discharge point. Parameters measured for trees and shrubs include species composition, diversity, relative abundance, density, basal area, and biomass. Water quality parameters include dissolved oxygen levels, temperature, pH, suspended solids, nitrate-nitrite, ammonia, ortho-phosphate, TKN, total phosphorus, chloride, and conductivity. In addition, sedimentation plots were laid down, and benthic and nekton populations sampled (Conner et al. 1989).

Analysis of the first two years of data indicate that the Thibodaux forested wetland is similar to other cypress-tupelo and bottomland hardwood sites in the region in terms

of litterfall (the average for 1989 and 1990 was 532 $g/m^2/yr$), a pH near neutrality, and dissolved oxygen levels generally below 5.0 mg/l. There are seasonal patterns for chloride, conductivity, and nitrate with increases in the colder and wetter months, while decreases occur for orthophosphate and suspended solids during the warmer months (Conner et al. 1989; Day et al. 1991). This system has relatively low nutrient levels compared to non-isolated forested wetlands in south Louisiana, and Conner et al. (1989) concluded that the system should benefit from the effluent discharge.

Complete assimilation of nitrogen and phosphorus from the effluent is expected based on estimates of denitrification, storage in woody tissue, and burial (Conner et al. 1989)(figure 4-2). Average sedimentation rates for 1990 and 1991 over the three areas are 0.35 cm/yr on the ridge, 0.6 cm/yr on the flooded control site, and 1.25 cm/yr on the flooded cypress-tupelo site (Hesse, personal communication, Center for Wetland Resources, LSU, Baton Rouge, LA). These rates confirm the expectation that Louisiana wetlands can provide a permanent sink for added nutrients.

4.2.3. Monitoring

Monitoring of the Thibodaux swamp will allow the determination of impacts resulting from the effluent

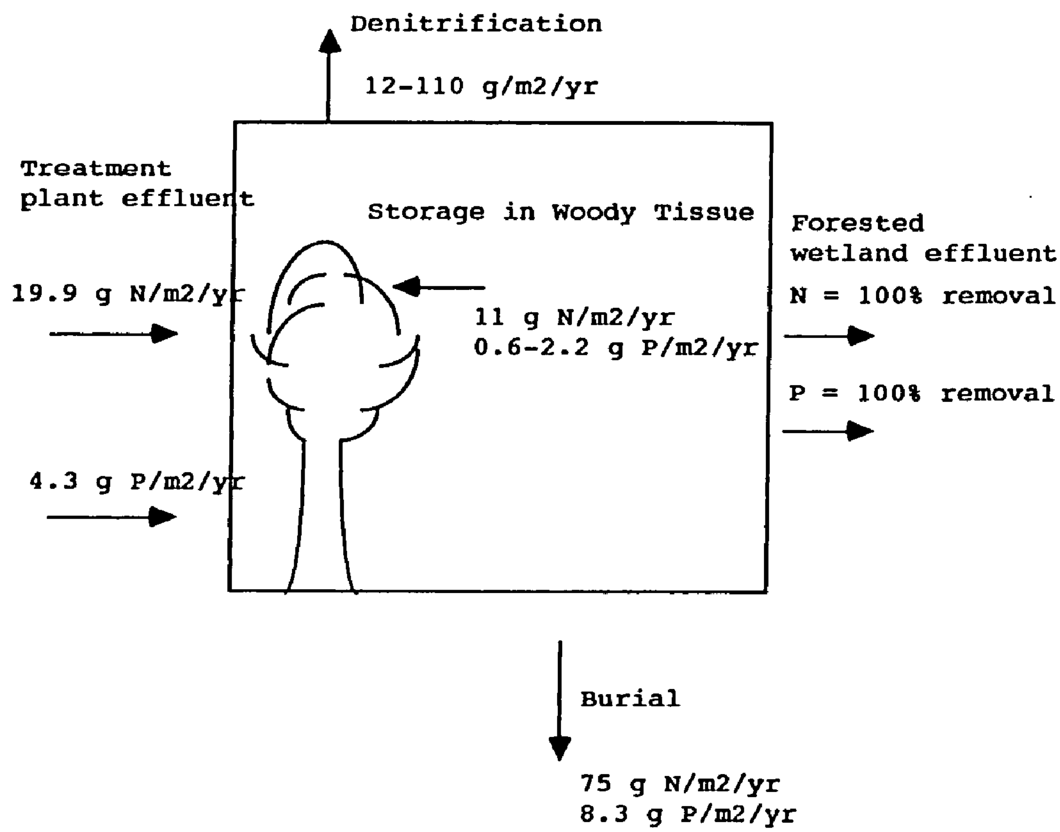

Figure 4-2: Estimates of nitrogen and phosphorus assimilation (from Conner et al. 1989).

discharge. As mentioned in Chapter 1, the Louisiana DEQ established the following interim standards specifically for the Thibodaux swamp:

1) No more than 20% decrease in naturally occurring litter fall or stem growth,
2) No significant decrease in the dominance index or stem density of bald cypress,
3) No significant decrease in faunal species diversity and no more than a 20% decrease in biomass (LA DEQ, 1991).

These standards are applied to the forested wetland under the exception granted to the swamp as a "naturally dystrophic waters segment". They are not yet part of a comprehensive set of wetland standards. It is likely, however, that these standards will be expanded and refined as DEQ continues to develop standards designed for the exclusive application to wetlands, as opposed to those designed for aquatic water bodies only.

In summary, the Thibodaux project meets the discharger criteria for wetland wastewater treatment of 1) discharge into a surface water body and 2) non-toxic effluent. The receiving wetland meets the criteria in terms of 1) hydrologic isolation, 2) proximity to the discharger, 3) sufficient size to allow conservative loading rates that are close to those recommended by EPA (2.5 cm/wk), 4) a backup system, 5) a high subsidence region, 6) a slight gradient that facilitates a southerly flow toward the single outlet, and 7) the presence of spoilbanks down which the effluent now flows. Finally, no cultural or social uses were made of the wetland before discharge began.

4.3. Breaux Bridge, Louisiana

Since the 1950's the town of Breaux Bridge has been discharging its wastewater into an adjacent cypress-tupelo and bottomland hardwood swamp approximately 20 meters from the treatment area. A trickling filter was constructed in the 1950's and was replaced by a total of three oxidation ponds built in the 1970's and 1980's. The town is not currently discharging into a surface water body, but the situation provides a unique opportunity to analyze the effects of municipal wastewater application to wetlands over approximately 40 years. Consequently, the discharger criterion that effluent be discharged to a surface water body was waived in the selection of Breaux Bridge, but the second criterion of non-toxic municipal effluent is met. The major benefit of this potential pilot study site is the opportunity to gain information on the long-term nature of sewage effluent application.

EPA has recently required the town to upgrade its treatment plant from its current discharge of approximately 30 mg/l BOD and 30-35 mg/l TSS to 10 BOD and 15 TSS. The lower 10/15 limits are those designed to maintain a dissolved oxygen content of 5 mg/l in flowing streams, and do not consider the health or assimilative capacities of wetland ecosystems.

4.3.1. Study Site

Breaux Bridge is located on the natural levee of Bayou Teche in St. Martin Parish. A forested wetland tract of approximately 1,295 hectares is located west of the natural levee. Hydrologic inputs to the wetland include precipitation and drainage from the levee which flow southward to the Ruth and Evangeline canals, and then to Bayou Teche or the Vermillion River. Backwater flooding from the Vermillion River is a primary determinant of high water levels in the wetland (C. Courville & D. Richard, Domingue, Szabo, & Associates, Lafayette, LA., personal communication).

The current treatment system consists of 3 oxidation ponds (figure 4-3). Effluent from the town has been flowing into the swamp since at least the 1950's and is currently serving a population of approximately 7,000 people with a total daily flow of approximately 600,000 gallons.

4.3.2. Site Characterization

The site was investigated on November 4, 1991 by representatives of the LSU Coastal Ecology Institute, DEQ, and the town of Breaux Bridge. A site characterization was submitted to DEQ by LSU representatives followed by preliminary baseline and permit suggestions by DEQ personnel.

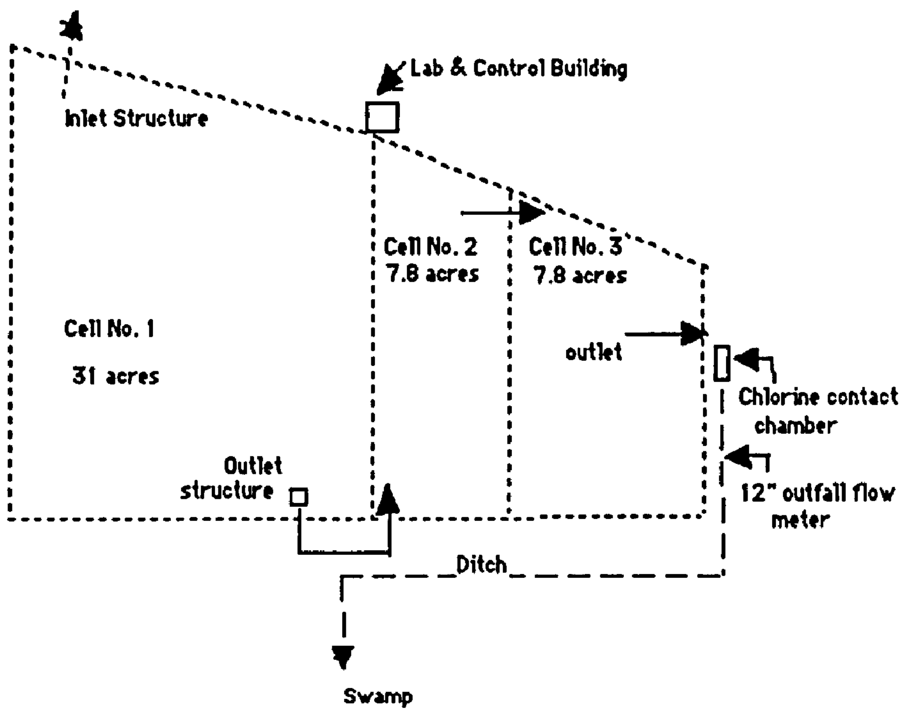

Figure 4-3: Existing Breaux Bridge Water Treatment Facility.

Four areas were characterized in terms of hydrology, soils, and vegetation (figure 4-4):

Zone 1: The initial 300 meters of swamp in the direct vicinity of the oxidation pond outlet and following the southerly path of water flow toward the Ruth Canal.

Water levels were at or near the surface with numerous shallow channels of approximately 5-10 cm. deep. Drainage appeared to be rapid, as evidenced by a lack of standing water after several days of heavy rains. Soils consisted of a fluid mud approximately 20-30 cm. deep, with depths decreasing away from the discharge point. Soils northwest of this impacted area were firmer, suggesting that the fluid mud is a result of the discharge. According to consulting engineers for Breaux Bridge, the area where fluid mud occurs was historically a low area and the fluid mud may be in a slight depression.

Vegetation consists of large cypress trees, a few fallen maples, and almost no undergrowth in the area of fluid mud. Beyond that are cypress, tupelo, swamp maple, and a greater amount of understory vegetation.

Zone 2: A forested wetland zone near a petroleum access road approximately 1000 meters northwest of the oxidation ponds.

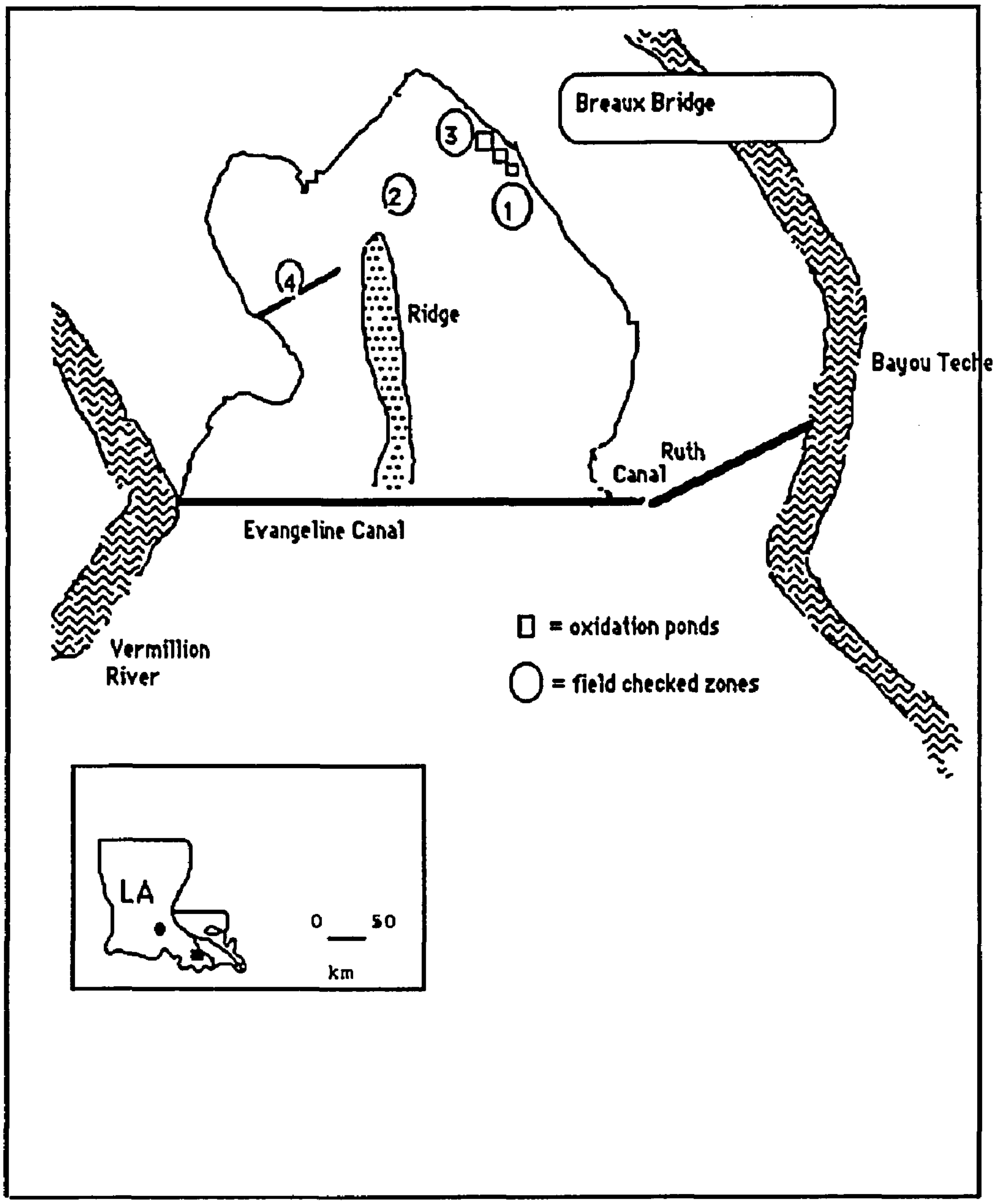

Figure 4-4: Breaux Bridge Forested Wetland

Water levels were at or near the surface, drainage appeared to be rapid, and several small depressions of 5-20 cm deep were observed. Soils were firm with no fluid mud. Vegetation consisted of cypress, tupelo, swamp maple, bottomland hardwood species, and dense understory vegetation.

Zone 3: The swamp between the petroleum access road and the northwest corner of the oxidation ponds.

As for zones 2 and portions of zone 1, water levels were at or near the surface with numerous shallow depressions of 5-20 cm deep, drainage appears to be rapid, and no fluid mud existed. Vegetation was similar to that observed in zone 2 (cypress, tupelo, swamp maple, and abundant understory plants) with the exception of a higher proportion of bottomland hardwood species.

Zone 4: Approximately 1,600 meters along an abandoned raised road originating at the western edge of the swamp and terminating near a higher ridge area in the central portion of the swamp.

The road divided this area into two subzones, one north and one south. Standing water was present in both subzones indicating poor drainage. Water levels in the north subzone were approximately 5-10 cm higher than the southern subzone. Soils along both sides of the road were firm with no evidence of fluid mud. While the area supported typical

bottomland hardwood species, there were distinct differences in vegetation in zone 4 compared to the other three zones. Fewer and smaller cypress trees were present throughout, and dense stands of swamp maple existed in both the north and south subzones, as well as on the ridge running through the central portion of the swamp. Numerous willows were observed on the western side of the southern subzone. Some trees showed signs of waterlogging stress such as crown deaths, sparse limbs, adventitious roots, and stunted growth.

Results of the field investigation indicate that the forested swamp receiving the Breaux Bridge effluent can be characterized by two broad areas. The first area includes the zones near the oxidation ponds (zones 1, 2, and 3) which are composed primarily of cypress, tupelo, and bottomland hardwood species. A layer of fluid mud within the immediate area of the discharge point indicates an impact from the effluent which may be inhibiting understory growth. Discussion with the town engineers suggests that this was a low area and may have filled in. The remaining area drains well, has typical swamp soils which appear to be composed of clay and organic matter, and shows no direct effect from the discharge. The second area (zone 4) has been affected by partial impoundment due to the road, the ridge, and possibly to the spoil banks created along the Evangeline Canal. The poor drainage resulting from these structures has apparently affected the vegetation and encouraged the growth of willows

and swamp maples at the expense of cypress, tupelo, and bottomland hardwood species.

4.3.3. Baseline Study, Permitting, and Monitoring

The Breaux Bridge forested wetland offers a unique opportunity to determine the effects of wetland wastewater treatment from a small community over a period of nearly 40 years. Since our preliminary investigation has shown no widespread adverse effects as a result of the discharge, we have recommended that a study of the wetland be continued. The following are suggestions for a baseline and monitoring study:

1. Vegetation: Composition and productivity analyses including tree ring analysis, stem growth, and litter fall in zones 1, 2, and 3 and in the western area of the site.
2. Chemistry: Quarterly nutrient samples in zone 1 and in the southern portion of the swamp near the Ruth canal. A single ICAP analysis of the discharge and of the outfall at Ruth canal.
3. Soils: A precise determination of the extent of the fluid mud area to compare to the non-affected areas. Soil cores to determine the sediment history.
4. Fauna: Analysis of benthos and nekton.
5. A priority pollutant scan, transect elevations, and characterization of the discharge.

6. Determination of direction and rate of flow through dye studies.

DEQ has provided additional suggestions for the baseline study in addition to specifying permit requirements (table 4-1).

The Breaux Bridge effluent represents a typical flow from a small municipality receiving effluent with approximately 220 mg/l BOD_5 and 220 mg/l TSS and treating it to approximately 30 mg/l BOD_5 and 35 mg/l TSS. The low population of about 7,000 people generates a total flow of about 600,000 gallons per day. The low flow and extensive system of oxidation ponds allows a residence time of between 70-80 days. An intensive study of the history of the receiving forested wetland is expected to reveal the type of impact, if any, the discharge has had on the hydrology, soils, and vegetation in the wetland. The only known impact to date is the presence of a localized fan of fluid mud in the immediate vicinity of the discharge outlet. Staggering outlets or dispersing flow will probably alleviate this problem. Until it is discovered whether or not the discharge has impacted the wetland, construction of a new treatment plant is not recommended.

The town of Breaux Bridge is not currently discharging to a surface water body but it does meet the criterion for non-toxic waste. The receiving wetland does not have any known priority uses that would exclude it from selection. The forested wetland is hydrologically isolated, close to

Table 4-1: Additional Suggestions by DEQ for Baseline Study and Permitting (Source: DEQ 1991)

Baseline Study

Flora:

1. Vegetation composition -- species classification, percentage of whole for each species, and canopy (percentage cover).

2. Tissue analysis of the dominant vegetation (woody and vegetative portions) for bioaccumulation of the following: Mg, Pb, Cd, Cr III and IV, Zn, Fe, Ni, Ag, Se, TKN, TP.

Fauna: Species classification and abundance.

Surface Water: Sampling of the surface waters near the oxidation pond outfall area and at the entrance to Ruth Canal for the following:

Stage (water level) as well as Mg, Pb, Cd, Cr III and IV, Cu, Zn, Fe, Ni, Ag, Se, TKN, TP, pH, BOD_5, TSS, NH_3-N, NO_3, NO_2.

Sediments: Sampling of the sediments in vicinity of present discharge point and two or three other sites for: Mg, Pb, Cd, Cr III and IV, Cu, Zn, Fe, Ni, Ag, Se, TKN, TP, pH, NH_3-N, NO_3, NO_2.

Permit Requirements

Effluent: BOD_5, TSS, fecal coliform, pH, Limits for chlorine if used as a disinfectant.

Measurements performed for flora, fauna, surface water, and sediments under baseline study would be required once per permit period (usually every 5 years).

Additional sampling will be required if flow increases to greater than 1 MGD or if industrial wastewater is accepted.

the treatment system, and large enough both to receive conservative hydraulic and nutrient loads and to provide a backup treatment wetland. Spoil banks exist to confine the wetland and to serve as dispersal mechanisms. Hydraulic flow is southward toward the Evangeline Canal by a slight gradient.

The field investigation of the wetland revealed the possibility of a direct impact only within the immediate area of the effluent outlet, with no visible impact over the remaining four kilometers of the site. Impacts on drainage and vegetation appear to be more pronounced and more widespread in areas of the swamp affected by the construction of an oil and gas access road than in the area surrounding the point of discharge. It is suggested here that the Breaux Bridge swamp may have benefited from the effluent load over the past 30 years. Moreover, spending the $1.5 million estimated to upgrade the existing treatment system may be an unnecessary expense and even detrimental to the wetland if the added sediments and nutrients have increased vegetative productivity and stimulated accretion.

4.4. Seafood Processors in Dulac, Louisiana

4.4.1. Introduction

Shrimp processors in Dulac, LA are currently confronted with severe water quality problems resulting from disposal of untreated wastes into Bayou Grand Caillou. A persistent

problem in the bayou is low dissolved oxygen which has been attributed to the discharge of seafood processor wastewater (Waldon 1991). The effluent is primarily organic, non-toxic waste. Thus the processors meet both of the discharger criteria for wetland wastewater treatment. The value of the seafood processing industry in Louisiana, the fact that the majority of the state's seafood processors are as yet unregulated, and the potential for a wasteload allocation to dictate severe limitations on the industry, have created a sense of immediacy among both shrimp processors and environmental regulators. In this section I suggest the use of a wetland pilot project to treat screened shrimp processor effluent by routing the discharge through an oxidation pond, over spoil banks, and eventually through wetlands. The design of the project is based on previously successful wetland treatment projects carried out in the Gulf coast region.

Several factors make wetland wastewater treatment a particularly attractive option for the seafood processing industry. These include a long growing season, abundant rainfall, and the presence of aquatic plant communities particularly suited for nutrient removal. A review of maps and aerial photos of the area indicates that six of the seven criteria for selection of receiving wetlands can be met: 1) a high subsidence rate exists in the Dulac area where extensive land loss has occurred since the 1930's, 2) there is a predominance of impounded wetland areas between

the Houma Navigation Canal and Bayou Grand Caillou creating confined wetland areas, 3) most processors appear to be within 500 meters of potential receiving wetlands, 4) the potential size of the treatment area bounded by Bayou Provost on the north and the intersection of the Houma Navigation Canal and Bayou Grand Caillou on the south, is approximately 1153 hectares -- an amount adequate to apply conservative hydraulic loads, 5) enough wetland area to provide backup treatment wetlands, and 6) spoil banks exist close to the processing plants which could be used for wastewater flow. The criterion for priority uses remains to be investigated. None of these uses is known at the present time.

Use of the abundant but rapidly subsiding and impounded wetlands or spoil banks in the area to treat effluent offers four principal benefits:

1. improving water quality in Bayou Grand Caillou through reduction of high BOD, SS, and nutrient quantities
2. increasing wetland productivity through application of suspended sediments and nutrients which should serve both to fertilize vegetation and offset subsidence by increasing biomass and trapping suspended sediments
3. providing a substantial savings to the seafood processors by avoiding expensive conventional treatment systems at each plant, in addition to the potential expense of piping the pre-treated effluent 15 miles north to the Houma treatment plant or building an entirely new plant
4. offering scientific value by providing information on the ecological effects of wetland wastewater treatment for purifying municipal and food processor waste, as well as serving as a small-scale model for the extensive river diversion projects designed to increase sediment and nutrient input into rapidly subsiding Louisiana wetlands.

The project outlined here proposes to set up a wetland pilot study site receiving discharge from one of the seafood processor plants located along Bayou Grand Caillou. If the pilot project is successful, then the method could be extended to treat the wastes of the other processors along the Bayou.

4.4.2. Water Quality and the Seafood Processing Industry

Historical Background and Current Options

Attempts to deal with the problems of the Dulac area seafood processing plants date back to the early 1970's when the same institution and professional interests that are involved with the wastewater issue today tried to solve the problem of untreated wastes. In 1972 the state of Louisiana Stream Control Commission demanded and received from some processors "implementation schedules for waste treatment" (DEQ files). By 1979 engineering plans for a "Parish-Wide Sanitary Sewage" system were drawn up and included the area below Dulac to Kings Bayou (DEQ files). During the mid-1970's, scientific studies of wetland wastewater treatment were carried out that showed favorable results in improving water quality and increasing productivity. Yet by the early 1990's, the seafood processors are still virtually unregulated and the problem of how to deal with their waste remains.

The options available to the processors are the same now as they were 20 years ago: 1) continue to dispose of untreated wastewater into Bayou Grand Caillou, 2) discharge to an expanded treatment plant in Houma, or a new one closer to the processing plants, 3) treat wastes at the individual plants before discharge into the bayou, or 4) discharge to wetlands. Options 2 and 3 are considered by many to be prohibitively expensive.

The proposal presented here for wetland treatment is based on the belief that the impounded area adjacent to the Dulac processors is ideally suited to wastewater treatment (figure 4-5). The climate in Louisiana favors high denitrification rates and a long growing season that coincides with the shrimp processing season. In a review of wetlands used for wastewater organic carbon removal, Khalid et al. (1981), concluded that "mineralization of organic carbon is accelerated by warm temperatures, abundant oxygen supply, presence of living plants, and longer residence time....The results of...experiments suggest that artificial wetland systems were very efficient in purifying sewage effluent and that a residence time of seven or more days would result in an essentially 100% removal of BOD and COD."

While the authors refer to artificial wetlands, the climate and indigenous wetland plants in the Louisiana coastal zone are favorable for wetland treatment. Residence time and loading rates would be the primary factors to be manipulated in a wetland treatment system. A

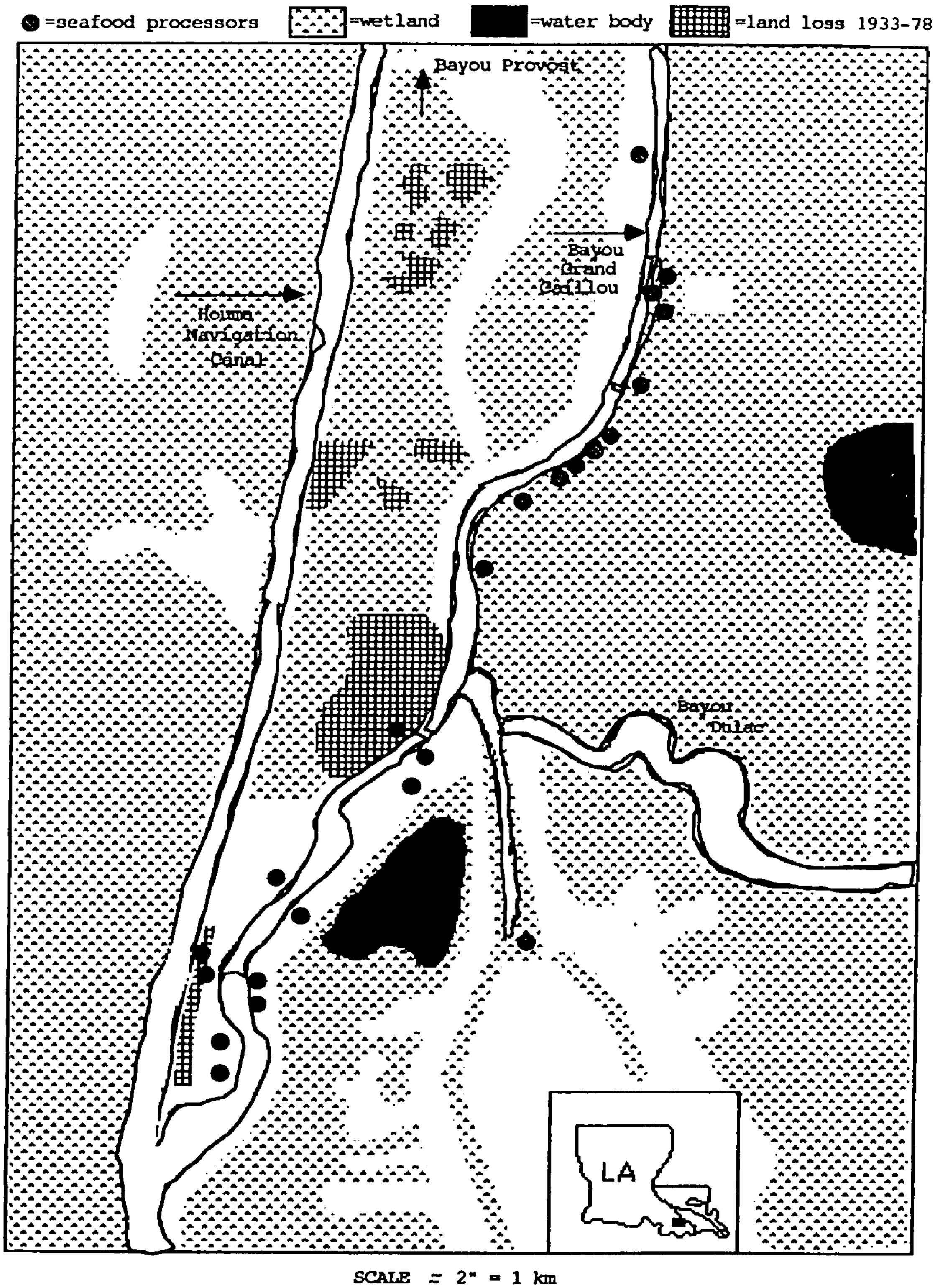

Figure 4-5: Seafood processor plants located along Bayou Grand Caillou.

recent engineering report on the use of natural wetlands for wastewater treatment concluded that "Further study is needed for widespread use of this approach, but it does show promise as a low-cost treatment method for seafood processors located at sites that could take advantage of nearby wetlands" (Zachritz & Malone 1991).

4.4.3. Wetland Treatment

Two wetland treatment studies showing favorable results in treating seafood processing wastewater have already been performed in the area, in addition to a third in Alabama (EPA 1986). In the Louisiana studies, which were carried out in the early 1970's, menhaden processing waste from the Zapata Haynie plant in Dulac, LA. was applied directly to nearby marshes. The first project consisted of an overland flow system (total area = 0.06 hectares) which achieved an 83% reduction in total organic carbon concentrations from the source (800 mg/l TOC), over a 40 meter vegetated spoil bank to the marsh edge (136 mg/l TOC). Total nitrogen and phosphorus content showed decreases of about 91% and 75%, respectively (Table 4-2) *Phragmites communis* receiving wastewater showed a 55% increase in live standing crop, a 47% increase in nitrogen content, and a 13% increase in phosphorus content. Moreover, total coliform numbers were reduced by 66% after flowing downslope, and further reduced with distance through the marsh. *Salmonella sp.* was present in the untreated menhaden waste, but not detected in samples

Table 4-2: Five month average organic carbon and nutrient concentrations in the Overland Flow during Operations (Meo et al. 1975; Turner et al. 1976; and corrected numbers from Khalid et al. 1981).

		Distance downslope (m)				
	Source	7.5	15	36.4	40	% reduction
TOC	800	559	518	437	136	83
DOC	480	360	380	272	120	75
Total P						76
Total N						91

taken from the marsh (Meo et al., 1975). Since the time the overland flow study was carried out, further evidence has emerged revealing that aquatic plants such as *Phragmites communis* and *Scirpus lacustris* are particularly effective in eliminating fecal indicators and pathogenic bacteria such as *Salmonella*, due to root excretions poisonous to certain viruses and bacteria (Gersberg et al., 1987).

In a second project, menhaden wastewater was applied directly to three macrophyte communities. The live standing crop was significantly higher in treated plots compared to controls: approximately 25% higher in *Sagittaria falcata*, 10% in *Scirpus validus*, and 36% in *Spartina patens* (Payonk, 1972 and Turner et al., 1976). More recently, both *Phragmites* and *Scirpus* have been shown to be particularly effective in removing nitrogen. A recent study of a constructed wetland in Santee, CA. showed *Scirpus validus* (root zone to a 60 cm depth) and *Phragmites australis* (root zone to a 76 cm depth) removed 94% and 78% nitrogen, respectively, compared to an unvegetated removal rate of only 11% (Watson, 1989). The extensive vegetated areas near the seafood processing plants should achieve similar results, thus avoiding the conventional nitrogen removal mechanisms such as fluidized beds, rotating biological contractors, or slow sand filters.

In a pilot study in southwest Alabama, shrimp processor waste was applied to a saltwater marsh after it was determined that flows to the 1 MGD Bayou La Batre treatment

plant were exceeding 3 MGD during the peak processing months of May through September (EPA 1986). The processor wastewater was distributed over the *Juncus roemerianus* saltmarsh at hydraulic loading rates of 3.6, 1.8, and 1.3 cm/wk during the months of August through December of 1984. Parameters were monitored during predischarge (2 months), discharge (5 months), and post discharge (6 months).

The Alabama study found no impacts from any of the wastewater loadings to the adjacent canal water quality or benthic and nekton communities. Nor were any negative impacts found on plant productivity, species composition, species diversity, or to epifauna on the marsh study plots. Total abundance of marsh infauna was slightly less in the control plots than in the treated plots. Seepage to groundwater was minimal or non-existent, though nitrogen was slightly higher in the top 5 cm. of the sediments (EPA 1986).

Model results based on field data indicated that assimilation of total nitrogen applied at 3.6 cm/wk would occur at a fairly low rate of 37 percent (25 percent of TON and 50 percent of NH4). In order to increase the efficiency of nitrogen removal, a hydraulic loading rate of 2.0 cm/wk was recommended, resulting in a loading rate of 0.73 g/m2/day (4.72 lbs N/acre/dy) of total nitrogen (EPA 1986). This rate is relatively high (see table 4-3), though it is assumed that application would take place only during the

Table 4-3: Examples of Areal Nitrogen Loadings

Source, Location/Type	**g/m2/yr**	**g/m2/dy**
Nixon & Lee (1986). Range for Region 3 studies of n additions to salt marshes	17-112	0.05-0.31*
EPA (1986). Alabama Study @ 2.0 cm/wk		0.73 (for 9 months)
@ 3.6 cm/wk	183	
EPA (1985)		
1. Cattail Marsh, MA	53.6	0.15*
2. Cattail Marsh, MA	428**	1.17*
3. Deepwater Marsh, Ontario	78.6	0.22*
4. Glyceria, Ontario	404	1.11*
Richardson & Davis (1987)		
1. Pottsburg Creek, FL	16.6	0.04*
2. Basing Swamp, FL	13.8	0.04*
3. Reedy Creek, FL	72.6	0.20*

*estimated by dividing by 365 days
** system was apparently overloaded, since for the 69 years of application, only 1 percent of total N was removed. The other 3 systems presented in the EPA (1985) source show removal rates of at least 31 percent for periods of either 55 or 69 years.

shrimp processing season (April-December) which generally corresponds to the growing season.

4.4.4. Study Design

This section will present the options for Louisiana seafood processors in the Dulac area in terms of pretreatment possibilities and the extent of coastal marshes available for wetland treatment. Typical raw seafood processor effluent is high in BOD, TSS, and nutrients (table 4-4) but can be reduced substantially with various treatment mechanisms. Reported estimates of land requirements to achieve various levels of treatment for different types of waste range from 8 to 134 hectares (20 to 330 acres) for flows of one million gallons per day (Table 4-5). I estimate that between 12 to 40 hectares of marsh would be required per processor along Bayou Grand Caillou for *untreated* waste at peak loads during the April through December processing season.

The design of the pilot project, however, would incorporate two forms of treatment in addition to screening, to reduce the strength of the wastewater flowing through the receiving marsh and thereby reduce the land requirements. The first treatment component would be a lagoon system. According to McGilberry (1980) lagoons are relatively maintenance free, able to handle moderate shock loads, and can be very effective for treating food processor wastes and "for treating seafood processing wastes in particular." For

Table 4-4: Typical values for untreated seafood effluent (mg/l)

SOURCE	BOD	TOC	TSS	TON	TKN	NH3	NH4	NO3-NO2	TP	PO4
Zachritz & Malone [1991], from mechanical peelers	1000-1800		400-800	229						
Polyengineering [1979] in EPA [1986]	617		163							
Gulf Coast Lab in EPA [1986]	1612 (mean)		509							
EPA [1986], applied to marsh	864 (mean)	752 (mean)			202 (mean)		89 (mean)	0.04 (mean)	19 (mean)	12 (mean)
	167-2324 (range)	18-10005 (range)			13-554 (range)		10-206 (range)	.02-0.4 (range)	2.76-100 (range)	0.84-27 (range)
Samanie Pkg. #2, after screening with 18 mesh	374		194			122				
Delahoussaye, DEQ [pers comm] screened wastewater	500-1000									
Meo [1975] raw menhadden wastewater		800			600 (described as Total N)					

Table 4-5: Estimates of land requirements for wetland treatment

SOURCE	OBJECTIVE	HYDRAULIC LOADING	LAND REQUIRED (acres/MGD except where otherwise indicated)
EPA (1986)	1. To treat processor waste while maintaining acceptable ecological parameters in a natural wetland such as little or no change in floral and faunal composition, improved water quality in adjacent water bodies, and favorable nutrient removal rates.	2 cm/wk 2 cm/wk	330 46 acres (at 27,000 gpd)
EPA (1985) from EPA (1979)	2. To treat primary or secondary effluent in constructed wetlands a. marsh (detention time = 10 days; typical depth = 0.75 ft)	(given as ac/mgd)	38
	b. marsh (detention time = 6 days; typical depth =0.75 ft) pond (detention time = 8 dys; typical depth = 2.0 ft)	(given as ac/mgd)	23 13 TOTAL = 36
Small (1979) from Khalid (1981)	3. To treat raw domestic waste (200 mg/l BOD) to 15 mg/l. Marsh/pond system		20
Watson (1989)	4. To treat raw municipal sewage with surface or subsurface flow constructed wetlands	33 cm/wk (subsurface) 13 cm/wk (surface)	20 50
Meo (1975)	5. To maintain acceptable ecological parameters and improve water quality in natural wetland)	5 cm/wk	0.15 acres (total vol. NG)

"a low technical requirement approach" to treating seafood processor waste, Zachritz and Malone (1991) recommend the use of an aerated lagoon rather than an anaerobic one, followed by facultative lagoons with a detention time sufficient to degrade solids and remove soluble BOD. By way of contrast, high technical approaches not employing land or wetland treatment, would require more complicated techniques with increasing sophistication (and expense) depending on the ultimate levels of treatment required by the state (table 4-6).

Anaerobic ponds have been found to be especially effective in bringing about the rapid stabilization of strong organic wastes with the following design parameters: detention time: 10-50 days; depth: 8-15 ft; BOD loading: 200-500 lb/ac/dy; BOD conversion to CO_2, CH_4, and bacterial cell tissue: 50-80% (McGilberry 1980). The estimated remaining effluent suspended solids of 80-160 mg/l could be used to build up the subsiding marshes between Bayou Grand Caillou and the Houma Navigation Canal which show land loss rates of 3.8 km^2/yr between 1983-1990 (Dunbar et al. 1992). Ponds in the area that have formed through erosion and subsidence might provide efficient sites for the oxidation pond. The design of the pond (aerobic vs. anaerobic) and its exact location would be determined with the assistance of an engineer.

Table 4-6: Comparison of Treatment Efficiencies for Various Treatment Methods and Possible Methods Required of Mechanical Shrimp Peeling Processors (from Zachritz & Malone, 1988).

Treatment	Parameter Removed	% Removal Efficiency	Possible Methods Required of Mechanical Shrimp Peeling Procesors to Achieve Limits* 30/30	20/20	10/10/5	5/5/2
Primary	TSS BOD	50-65 24-45	sedimentation	mechanical screens/ sedimentation	mechanical screens/ sedimentation	mechanical screens/ sedimentation
Roughing	TSS BOD	40-60 40-60	aerated lagoon /trickling filter	aerated lagoon /trickling filter	aerated lagoon /trickling filter	aerated lagoon /trickling filter
Secondary	TSS BOD	85-95 75-95	facultative lagoon/ extended air activated sludge	facultative lagoon/ extended air activated sludge	facultative lagoon/ extended air activated sludge	facultative lagoon/ extended air activated sludge
Polishing	TSS BOD P N	80-99 65-98 70-80 85-98	Rock-reed filter	Rock-reed filter/sand filter	Rock-reed filter/slow sand filters/ Rapid sand filters & nitrification	Rock-reed, slow sand filters and nitrification/ Rapid sand filters & nitrification

*(mg/l for all 3 parameters: BOD_5, TSS, NH_3)

The second treatment component would consist of pumping the effluent from the oxidation pond to the spoil banks along the Houma Navigation Canal, and allowing it to flow down the spoil bank and into the wetland. This would promote high ammonium oxidation by providing significant levels of oxygen and adequate retention times. More than one receiving wetland, or multiple cells designed in the same wetland, could be used in order to allow for alternating periods of flooding and draining and the resulting stimulation of nitrification and denitrification during the growing season (Patrick 1982). If possible, wetlands that are irregularly flooded, similar to the Alabama saltmarsh used for the EPA (1986) study, will be used in order to maintain natural flow levels and retention times while maximizing the nitrification/denitrification capabilities of the marsh. The National Wetland Inventory Map for Dulac shows both regularly and irregularly flooded estuarine marshes in the study area.

4.5. Summary

The three case studies presented in this chapter indicate that a variety of effluent types can be successfully treated using wetlands. All three dischargers produce non-toxic effluents, and all occur near areas of extensive but impounded wetlands surrounded at least partially by spoilbanks. Both the city of Thibodaux and the seafood processors along Bayou Grand Caillou are located in

rapidly subsiding areas, and no priority uses exist that would be hindered by effluent application. It is likely that both the three dischargers and their respective receiving wetlands are typical of many that exist in coastal Louisiana.

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CHAPTER 5

ECONOMIC ANALYSIS OF FOUR WETLAND WASTEWATER TREATMENT CASE STUDIES

5.1. Introduction

The economic value of wetland tertiary treatment has been debated among ecologists and economists since the early 1970's. Typical approaches have summed values for a variety of functions, in addition to tertiary treatment, in order to derive a total per acre wetland value (Farber & Costanza 1987; Thibodeau & Ostro 1981; Gosselink et al. 1974). This chapter applies two economic valuation methods to four separate wetland wastewater treatment pilot sites in Louisiana. The first method analyzes the costs of wetland tertiary treatment using the simple avoided cost, or replacement, method for water purification. The method is applied to two sites already using wetland treatment in Thibodaux, LA and at Zapp's Potato Chip Factory in Gramercy, LA. In addition, the method is applied to two potential sites where wetland wastewater treatment is an option in Breaux Bridge, LA and in Dulac, LA. An argument is made that in light of environmental regulatory requirements that have become more stringent over the past 20 years, criticisms raised over the validity of the avoided cost

method both in the 1970's (Shabman & Batie 1978) and as recently as 1991 (Anderson & Rockel 1991) are no longer appropriate.

The second valuation method involves an energy analysis applied to the receiving wetland for the Zapp's Potato Chip factory in Gramercy, LA. Results of both methods indicate that the standard economic approach of marginal analysis, which values each project in isolation, should be avoided in evaluating hydrologically altered wetlands for wetland wastewater treatment. Instead, efforts should be devoted toward valuing wetlands on a systems basis and toward considering their value in unifying or connecting segregated patches.

The four wetland wastewater treatment pilot sites measured or reviewed for this dissertation (Zapp's Potato Chip Factory in Chapter 3; and Thibodaux, Breaux Bridge, and Dulac seafood processors in Chapter 4) were initiated in response to the economic needs of these municipalities and industries. Over the past twenty years increasingly strict environmental regulations designed to halt unacceptably high levels of polluted surface water bodies have resulted in high financial costs for the dischargers. Recent EPA estimates project a fifty percent increase in annual sewage treatment costs for the average urban household during the 1990's, and a doubling of annual fees for the small municipalities with fewer residents to pay fees (U.S. Water News 1991). These national figures undoubtedly reflect the

current and future circumstances of Louisiana dischargers, since water quality regulations are expected to become more stringent in the state (Zachritz & Malone 1991) and construction grant funds are no longer available to assist municipalities.

5.2. Methods

Discount rates and time periods for wetland treatment case studies follow those used in the primary sources. It should be emphasized, however, that discounting natural resources based on the assumption that goods and services are worth more to the present generation now than in the future, may not be an appropriate consideration where environmental resources are concerned. Various options have been put forth in order to protect natural resources for future use, including:

1) presenting two impact categories when natural resources are pitted against developmental projects:
   (a) a category favoring present generation impacts where these impacts are discounted and totaled.
   (b) a category favoring future generations where impacts are totaled but not discounted (McAllister 1986).
2) using an infinite time period for natural systems (Costanza et al. 1989; Turner et al. 1988) based on the assumption that natural resources will not degrade in the normal time span (15-50 years) assumed for man-made projects.
3) using no or a low discount rate (0-3.3%) for natural systems and the current rate for man-made systems (9-12%) (Farber, unpublished, 1992a).

A combination of these suggestions was employed in the Zapp's Energy Analysis case study, in order to illustrate

the substantial difference in wetland enhancement values when different discount rates are used. Values are determined at 3%, 4%, and 9% for unlimited time periods.

5.2.1. Avoided Cost

The avoided cost method attempts to determine the value of the environmental service performed by substituting the cost of an alternative technological mechanism. For the city of Thibodaux, the two most technologically and financially feasible choices satisfying both the regulatory requirements and the city's needs were determined to be sand filtration and wetland treatment (Bergeron 1990). Capital and operation and maintenance costs for both options were adjusted by lowering the discount rate in the city engineer's report from 10.6% to 9%, the latter being the rate applied by the U.S. Army Corps of Engineers. The life of both projects were estimated for 30 years. Costs for both treatment options were then compared. The comparison for the town of Breaux Bridge, LA was based on the Thibodaux estimates. The cost comparison of dissolved air flotation and wetland treatment for seafood processors in Dulac, LA was based on EPA cost calculations for 25 years at 8%. Finally, cost comparisons for the Zapp's potato chip factory in Gramercy, LA were determined for a treatment facility lifetime of 15 years at 9%.

5.2.2. Energy Analysis

Energy Analysis (EA) applied to ecological systems translates units of Gross Primary Production (GPP) into dollar values through an energy conversion factor. The three-step methodology consists of 1) conversion of net primary productivity (NPP) values collected in the field to GPP values, 2) conversion of GPP values to fossil fuel equivalents (FFE's) and, 3) conversion of FFE's to economic value (based on methods described by Turner et al. 1988). Considerable controversy surrounds the use of this method which has been used to emphasize the higher amounts of embodied energy in natural systems compared to manmade systems such as agricultural or urban areas (Turner et al. 1988; Farber & Costanza 1985; Costanza et al. 1989). The method is used here (1) to compare the economic values derived from embodied energy from two different ecological zones at the same site, and (2) to estimate the enhancement value of increased productivity resulting from effluent application to a receiving wetland.

Annual NPP was estimated for the two bottomland hardwood zones comprising the Zapp's receiving wetland. The first is a formerly healthy hardwood zone which currently consists of dying old trees, herbaceous vegetation, and numerous young trees. The trees appear to have suffered as a result of excess flooding following impoundment over the last several decades. The second zone occurs on a slightly

higher ridge and consists of more vigorous trees which appear to have been unaffected by the impoundment.

In selecting a conversion ratio for converting NPP to GPP based on the range provided by Turner et al. (1988), the successional stage of both zones was considered. The flooded zone has changed from a forested to an herbaceous wetland and is now supporting young trees (< 10 cm diameter). The ridge has larger and well established, though still young, trees. Both zones are at a stage where each is allocating a relatively large portion of its GPP to NPP, and consequently the low ratio was used. Results may, therefore, underestimate the value of the ridge.

5.3. Results

5.3.1. The Avoided Cost Method Applied to Treatment Options for Thibodaux, LA.

Total capitalized costs, including capital, operating, and maintenance costs, were approximately \$1.6-\$1.7 million for the sand filtration system and \$1.1-\$1.2 million for wetland treatment in 1990 dollars (table 5-1) (Bergeron 1990; Farber, unpublished, 1992). Costs presented in Table 5-1 are for equal disinfection costs and the resulting range of capitalized cost savings for use of the wetland treatment system is \$447,560-\$503,720. Three additional options for disinfection were presented: 1) adding a dechlorination system to the existing chlorination system, 2) using an

Table 5-1: Tertiary Treatment Cost Estimates for Thibodaux, LA. (Source: Bergeron 1990; Farber, unpublished, 1992b)

	Capital Cost Item	Cost	Capitalized Item Cost Range*	Operation and Maintenance Cost	Capitalized Operation & Maintenance Cost*	Total Capitalized Costs
Sand Filter	1. Land (2 acres)	$3,000	$1,143,000- $1,170,000	$46,900/yr	$440,860- $483,070	$1,583,860- $1,653,070 (≈$1.6-$1.7 M)
	2. Transfer Pump	$185,000				
	3. Filter & Equipment	$760,000				
	4. Engineering	$195,000				
	TOTAL	$1,143,000				
Wetland	1. Pump station and force main	$690,000	$1,000,000- $1,000,000	$14,500/yr	$136,300- $149,350	$1,136,300- $1,149,350 (≈$1.1-$1.2 M)
	2. Property lease and survey	$185,000				
	3. Monitoring	$125,000				
	TOTAL	$1,000,000				

* Capitalized costs are discounted at 9% for 30 years.

ultraviolet system (UV), 3) using one of the above for the sand filtration system but no disinfection for the wetland system.

Studies have shown that the natural die-off rate of pathogens and bacteria is high in wetlands due to time outside the host species, exposure to sunlight and oxygen, soil-water interactions, and predatory protozoa that feed on bacteria (Kadlec 1989; Hemond and Benoit 1988; Gersberg et al. 1987; Krishnan and Smith 1985; Meo et al. 1975). After the submission of the Thibodaux engineering report, the LA Department of Environmental Quality (DEQ) decided to require the UV system as a component of the disinfection cost which may be dispensable if further study reveals acceptable levels of pathogen and bacterial die-off. It appears that cholorination/decholorination disinfection was considered for the sand filters but not for the wetland because part of the chlorination system was already in place. The resulting cost savings for wetland treatment considering these different disinfection requirements, range from $447,560 to $1,306,215. The cost savings divided by the 570 acres of treatment area ranges from $785 to $2,292 per acre (table 5-2). Recognizing that UV was required by the state DEQ for wetland treatment, it seems reasonable to exclude the third option which includes no disinfection cost for wetland treatment, leaving a per acre cost savings range of between $785 to $1501. This means that, on average, an

Table 5-2: Cost Savings for Wetland vs Sand Filtration System for Thibodaux, LA.* (1990 dollars) (from Bergeron 1990; and Farber, unpublished, 1992b).

	CAPITALIZED COSTS Low	High	Total Cost Savings per Acre, Including Disinfection Costs
1. Equal Disinfection	$447,560	$503,720	$785-$884
2. Chlorination/ Decholorination for Sand Filter, UV for Wetlands	$799,491	$855,651	$1,403-$1501
3. Chlorination/ Dechlorination for Sand Filter, no disinfection for Wetlands	$1,250,055	$1,306,215	$2,193-$2,292

*based on the following costs: Chlorine/Dechorination:
Capital Cost...........$91,000
O & M.................$711,495
Total...........$802,495

Ultraviolet Disinfection:
Capital Cost..........$259,500
O & M.................$191,064
Total...........$450,564

acre of wetlands saves $785 to $1501 in capitalized costs, which can be considered the water treatment value of one acre of wetland.

In relation to other municipalities and industries in the Louisiana coastal zone, the wetland treatment costs for Thibodaux are likely to be higher due to the distance from the city's treatment plant to the forested wetlands. Compared to the other three case studies reviewed in this dissertation, Thibodaux's distance to the wetland is 6 to 150 times greater than the other three sites. The oxidation ponds for the town of Breaux Bridge, for example, are approximately 20 meters from the receiving wetlands, compared to Thibodaux's 3,000 meters. Since the pump station and force main represent approximately 70% of the capital costs for Thibodaux's wetland treatment system, costs should be substantially lower for closer receiving wetlands. In addition, Thibodaux is at the high end for size of population (17,000) and treatment plant design flow (4 MGD) compared to many small rural Louisiana coastal towns.

The wetland treatment cost savings range for the three options listed in Table 2, translates into a savings of $.30/1000 gal to $.90/1000 gal. This range is less than the $0.47 to $1.99 cost savings range (adjusted from 1977 dollars to 1989 dollars) calculated for seafood processors in the Dulac, LA area 15 years ago (Meo et al. 1977). If land costs of 18.5% of the total wetland treatment cost for

the Thibodaux wetland are subtracted from the seafood processor cost savings estimate (which did not apply costs for lease or purchase of wetland treatment acreage), the resulting cost range would be $0.38 to $1.62 for seafood processor cost savings. The $1.06/1000 gal savings for wetland treatment over tertiary treatment determined for the city of Waldo, Florida (costs adjusted from 1976 dollars to 1989 dollars; Fritz et al. 1984) is also higher than the $0.30 to $0.90 cost savings range calculated for the Thibodaux wetland. Overall, costs will vary by site depending primarily on distance to the wetland, the costs of purchase of wetland treatment areas, and flow volume. It is likely, however, that wetland treatment costs will consistently be lower than conventional, advanced treatment systems when distances are below 5 miles (see Chapter 2) and sufficient wetland area is available.

5.3.2. The Avoided Cost Method Applied to Breaux Bridge, Louisiana.

The town of Breaux Bridge, LA has been discharging its secondarily treated effluent to a forested wetland for over 40 years. The current system of oxidation ponds serves a population of approximately 7,000 people at a flow rate of 600,000 gpd. Effluent discharged from the ponds consists of approximately 30 mg/l BOD and 30-35 mg/l TSS which flows into the wetland about 20 meters away. The total receiving basin consists of approximately 3000 acres of forested wetland. The town has been ordered to upgrade its current

treatment system in order to achieve levels of 10 mg/l BOD and 15 mg/l TSS. The estimated cost of the upgrade would be $1.5 million (D. Richard, Domingue, Szabo & Associates, Lafayette, LA, personal communication).

Since discharge has been ongoing for 40 years, no land costs are assumed here. In addition, the current system of oxidation ponds, pumps, and pipes is already in place and would not require new construction. If the U.S. EPA and state DEQ retract the order and allow Breaux Bridge to continue to discharge to the forested wetland, the only remaining cost is that of monitoring. The monitoring cost for Thibodaux was estimated to be $125,000 and was counted as a capitalized cost. The cost savings for wetland treatment would, therefore, be the difference between the $1.5 million for a conventional treatment system minus the cost of wetland monitoring, which is a savings of $1.375 million. This translates to a savings of approximately $460/acre for wetland treatment.

5.3.3. The Avoided Cost Method Applied to Seafood Processors in Dulac, Louisiana.

The seafood processing industry in Dulac, LA has been confronted with wastewater disposal problems since the 1970's. The state's annual dockside fisheries harvest ranges from $250 to $350 million, with Dulac ranking among the nation's top ten ports in both the amount of pounds landed and in the value of the landings (Keithly 1991). Processors are currently disposing of their untreated waste

into Bayou Grand Caillou. The nearest treatment plant is 15 miles away which was considered by many local residents to be too far to pump the wastes. This section compares the costs of two other options available to the processors: the processing of wastes by conventional methods at each individual plant versus the application of screened effluent to wetlands.

Costs for conventional methods were based on an extensive EPA study (1979) evaluating the dissolved air flotation method which is a physical process that can meet secondary standards. This method does not guarantee any tertiary treatment designed to remove nutrients (Zachritz & Malone 1991).

Costs were adjusted from 1977 dollars to reflect 1990 dollars, resulting in a total annualized cost range for the conventional air flotation system of between $211,000 to $266,000 (table 5-3). Sludge disposal costs range from 20-46% of the total costs.

Wetland treatment would not include sludge disposal costs, but would consist primarily of costs for screening, piping, and pumping. Estimates for those treatment components were based on costs provided by EPA (1979 and 1981) and adjusted to reflect 1990 dollars. The EPA estimates and their adjusted values are presented in Table 5-4. The total wetland annualized capital cost range is $78,771-$90,064. Costs for piping and pumping should err on

Table 5-3: Costs of Dissolved Air Flotation for Gulf Shrimp Processing Wastewater, 1990 dollars (Source: Farber, unpublished 1992b)*.

	500 gpm (8-peeler)			250 gpm (4-peeler)	
		Sludge Disposal			Sludge
	Treatment	Low	High	Treatment	Disposal
1. Annualized Capital	$57,528	$31,824	$34,476	$43,860	$22,032
Variable:					
Energy	2,142	765	3,519	1,071	1,836
Chemicals	14,664	2,632	188	7,332	188
Maintenance	15,990	2,666	10,250	12,915	10,250
Labor	94,710	0	32,390	79,540	32,390
2. Annual Variable	127,506	6063	46,347	100,858	44,664
3. Total Annualized	$185,034	$37,887	$80,823	$144,718	$66,696
4. Total Annualized	Treatment	+ Disposal	Cost:		
		$223,000-	$266,000	$211,000	

*Costs are based on 25 year lifetime at 8% discount rate.
Adjustments from 1977 dollars to 1990 dollars were based on the following estimated 1990 price index relative to 1977:

Construction	118.1/57.8 = 2.04
Energy	66.7/43.6 = 1.53
Chemicals	116.3/62.0 = 1.88
Labor and Maintenance	121.3/59.3 = 2.05

Since price indices were not available later than 1988, the above indices were constructed under the assumption that inflation between 1977 and 1990 would be the same as that between 1975 and 1988. The ratios in Table 3 are P_{1988}/P_{1975} (Sources: Statistical Abstract of the U.S., 1990, Construction p. 710, Energy p. 476, Chemicals p. 477, and Labor and Maintenance p. 480; Farber, unpublished, 1992b)

Table 5-4: Costs of Wetland Treatment for Gulf Shrimp Processing Wastewater (Sources: U.S. EPA 1979; Farber, unpublished, 1992b).

	1977 Dollars		1979 Dollars	1990 Dollars	Annualized Capital Cost Range in 1990 Dollars[2]
	250 gpm	500 gpm	750 gpm[1]		
1. Screening:					
Annualized capital costs	$6,880[3]/yr	$9,024[3]/yr		$14,035-$18,409[5]/yr	
Annualized O&M costs	$12,425[3]/yr	$15,800[3]/yr		$25,471-$32,390[6]/yr	
TOTAL SCREENING	$19,305[3]	$24,824[3]			$39,506-$50,799[5]
2. Capital piping			$98,842[4]	$148,263[7]	
3. Capital pumping			$180,587[4]	$270,880[7]	
TOTAL PIPING AND PUMPING				$419,144	$39,265
TOTAL WETLAND ANNUALIZED COST RANGE					$78,771-$90,064

[1] The mid range value for a 3 peeler processing plant generating between 600-900 gpm for an 8 hour day (total daily flow = 360,000 gpd; Zachritz & Malone 1991, p. 39).
[2] Based on a 25 year lifetime at 8%.
[3] Based on estimated capital costs of screening systems at 32% of capital costs for screens plus air flotation system and estimated operation and maintenace costs of 25% those of full screening plus air flotation system (U.S. EPA 1981)
[4] Estimated from EPA 1981 and based on a 12-inch pipe (pp. B-3, B-4, 4-18) and based on 0.5 miles.
[5] Based on construction cost index = 2.04.
[6] Based on labor & maintenance cost index = 2.05.
[7] Based on Handy Whitman cost indices.

the high side, since the flow estimate used in this study is up to three times the reported value for some operations (U.S. EPA 1986; LA DEQ files 1990/91; Jeff Scott, personal communication., Scottco's, Dulac, LA). However, neither wetland treatment nor dissolved air flotation treatment includes the cost, if any, of disposal of screened shell matter. It is not certain at this point whether this matter will be sent to a compost, a landfill, or a factory for producing fertilizer. If shells can be used as fertilizer, then there may be no disposal costs involved.

The total annualized cost savings for wetland treatment based on the above values is calculated as follows:

	Low Savings	High Savings
Dissolved Air Flotation Treatment	$211,414	$265,857
Wetland Treatment	- 90,064	-78,771
	$121,350/yr	$187,086/yr

The approximate cost savings for wetland treatment compared to the conventional treatment method is approximately $121,000/yr to $187,000/yr.

5.3.4. The Avoided Cost Method Applied to Zapp's Potato Chip Factory in Gramercy, Louisiana

The Zapp's plant currently treats its own waste to secondary levels and discharges the effluent to a bottomland hardwood receiving wetland. The treatment system consists of settling and oil separation tanks, biological aerators, and a series of clarifiers before discharge to the wetland

(figure 1). The current treatment system achieves approximately 15 mg/l BOD and 20 mg/l TSS which is better than the 30 mg/l BOD and 30 mg/l TSS required by the plant's current discharge permit. Annual operation and maintenance costs are $19,000/yr and capital costs were $100,000 for the secondary treatment components consisting of the two aerators and second and final clarifiers.

There are two additional treatment options available to the owner: pipe the effluent to the newly constructed municipal treatment plant in Gramercy LA, or continue to discharge to the wetlands. Treatment by the municipal publicly operated treatment works (POTW) would consist of piping the effluent from the primary clarifier to the municipal plant. Costs for piping and hook up would be approximately $70,000 which would be recouped by the POTW in the annual service charge of $2100 (Chuck Fromhertz, engineer for town of Gramercy, New Orleans, LA, personal communication).

It should be emphasized that the avoided cost method in the Zapp's case study compares the cost of the three treatment options only to the factory owner. Construction of the Gramercy treatment plant represents a case opposite from the city of Thibodaux but potentially similar to the town of Breaux Bridge, in that Gramercy's wastewater was being treated in an oxidation pond and then pumped to a canal adjacent to wetlands before the new construction

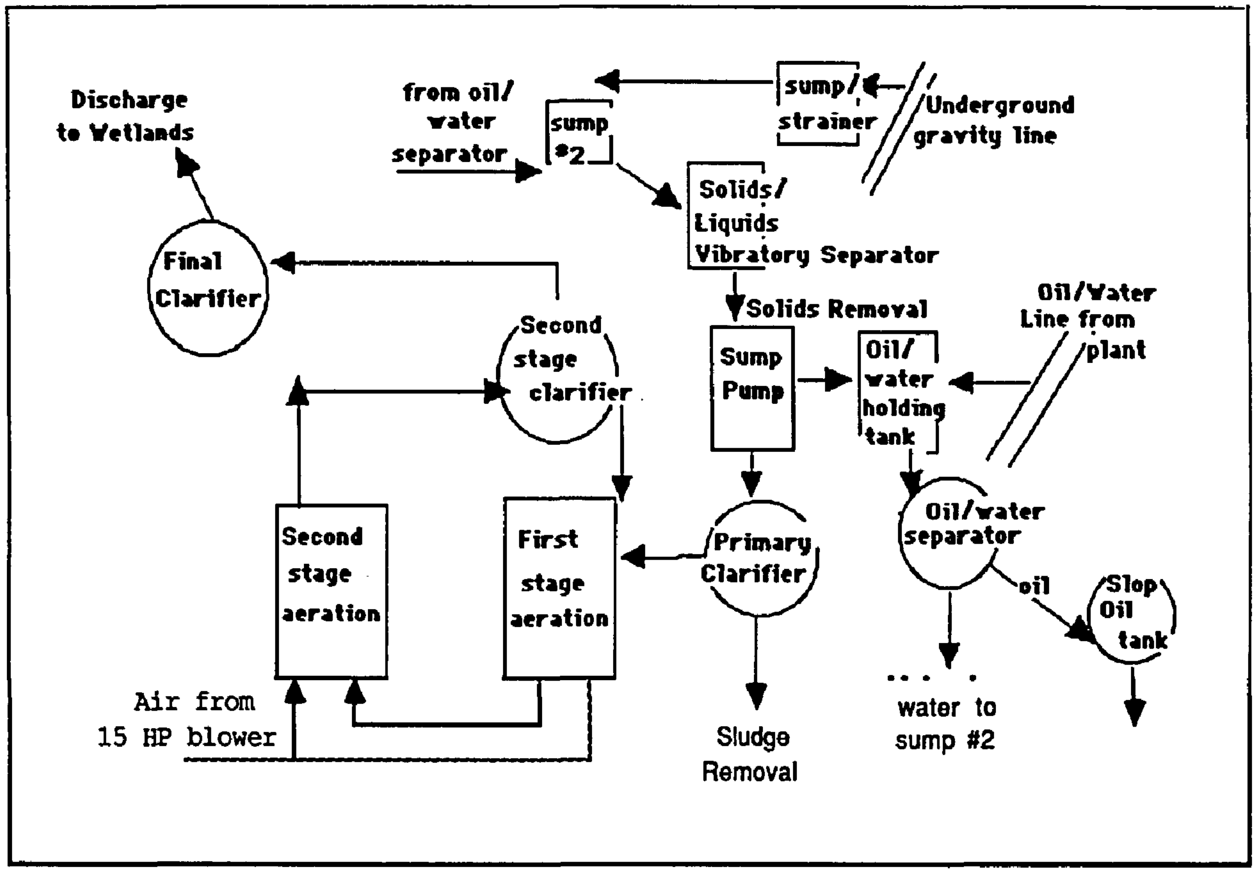

Figure 5-1: Zapp's Potato Chip Factory Treatment System.

began. The new treatment system consists of the addition of baffles and aerators to the 17-acre ponds, followed by pumping 3.5 miles to the Mississippi River. The new treatment consists primarily of naturally aspirated oxidation ponds (Fromhertz, personal communication). It is possible that a cost savings analysis of wetland treatment versus surface water disposal would have revealed a per acre savings for wetland treatment on the scale of Thibodaux or Breaux Bridge. Since the wetland treatment was not considered in upgrading Gramercy's treatment system, the cost analysis performed here deals only with the potential options available to the Zapp's factory.

Continued discharge to the wetlands would be financially feasible for the owner only if the costs of the aerators and clarifiers were eliminated. Based on the analysis of field data collected in 1991-92 (Chapter 3), we estimate that discharge directly from the primary clarifier to the wetlands would be ecologically feasible only if a dispersal system were installed which would spray the effluent to ten areas of the receiving swamp.

Capital and annualized costs of the three options are presented in Table 5-5. The secondary treatment system which the factory currently operates is far more expensive than the cost of either piping the primary effluent to the city sewage system or dispersing the primary effluent to the receiving wetland. Municipal treatment is the least expensive method representing an annual savings of $2606/yr

Table 5-5: Costs of three options available to Zapp's Potato Chip Factory for treating wastewater (Source: Ron Zappe, personal communication, 10/31/89 and 5/29/92; Chuck Fromhertz, personal communication, 6/1/92).

			Total Annualized Cost*
1. Secondary treated effluent to Wetlands			
Capital Cost		$100,000	
	[annualized = $12,406/yr]		
O & M Costs:			
	Electricity	9,800/yr	
	Labor	6188/yr	
	Maintenance	3000/yr	
Total O & M		19,000/yr	$31,406/yr
2. Primary treated effluent to Wetlands			
Capital Costs:			
	Sprinklers	270	
	Pipe	1170	
	Labor	1670	
Total Capital		3110	
	[annualized = $386/yr]		
O & M Costs:			
	Electricity	660/yr	
	Maintenance	3000/yr	
	Labor	660/yr	
Total O & M		4320/yr	$4706/yr
3. Primary treated effluent to city sewage system			$2100/yr

*based on 15 year lifetime at 9%

compared to wetland dispersal of primary effluent, and a savings of $29,306/yr compared to the wetland disposal of secondary effluent. It should be noted that the cost for municipal treatment of the wastewater reflects only the cost to the factory owner, and does not consider social costs or economic costs of building the Gramercy plant (total cost = $1.1 million, Chuck Fromhertz, personal communication) or of discharging the effluent into the Mississippi River.

Wetland dispersal of primary effluent would require a special permission from the state regulatory agency. Whether the owner of the factory would decide to forego the $2606 annual savings realized by sending the effluent to the POTW would depend both on his perception of the social and ecological value derived from the wetland enhancement resulting from effluent application to the wetland, and on the anticipated increase in sewage charges. The potential increase in value to the wetland from the discharge is covered in the following section based on the increase in embodied energy resulting from the added sediment and nutrients in the potato processing wastewater.

5.3.5. Energy Analysis Applied to the Zapp's Potato Chip Factory Receiving Wetland

(a) Comparison of Ecological Zones in the Receiving Wetland.

Initial results of the EA indicate that the values for the ridge area are over two and a half times greater than those for the flooded area based on the energy production by each respective zone. The derived economic values, however,

assume an independence among wetland zones. In addition, EA determines worth solely on the basis of energy productivity. Thus, while the values shown in Table 5-6 indicate a greater worth for the ridge based on energy production, the ridge may not be worth more based on habitat quality.

In discussing the detrimental impact to wildlife habitat of forest fragmentation, Harris & Gosselink (1990) list the following components as an integral part of an undisturbed bottomland hardwood forest: trees with broken tops, cavity trees, fallen tree boles, and preferred fruit, nut, and berry producing species. These are precisely the elements that exist in the flooded portion of Zapp's wetland. Over 28 species of birds using both the flooded and ridge zones were observed during only a few brief periods of daylight observation, indicating a high rate of use by wildlife. Presumably, the high avian use reflects a similar use by mammals, reptiles, arthropods, and down the line to bacteria. The dying trees in the flooded area may be as useful to wildlife for food and nesting sites as the healthy trees on the ridge. If both areas could be viewed as a unit instead of separate entities, their value as both habitat and as an area for wastewater purification would be increased. Moreover, if either zone is removed, the remaining one may prove useless for either function. Overall, the values of wildlife, erosion control, nutrient cycling, flood control or aesthetics might make the value of any particular wetland acre completely dependent on another.

Table 5-6: Energy Production and derived economic values for Zapp's Receiving Wetland (field data from 1991-92).

	Annual NPP ($g/m^2/yr$)	1989$/acre* at 3%	1989$/acre* at 4%	1989$/acre* at 9%
Ridge zone	1272	$4100	$3075	$1370
Flooded zone	482	$1530	$1150	$ 520

*Based on the following conversions from Turner et al. 1988:

NPP => GPP: $g/m^2/yr$ * .01 = NPP (mT/ha/yr) * 1.42 = GPP

GPP => FFE: GPP * 4 * 10^6 [calories of plant production /mT] * 0.05 [calories of fossil fuel quality/calorie plant production]

FFE => Annual economic value in $1982: divided by 15,000/1982 dollars [calories of fossil fuel quality]

Final values were converted from 1982 dollars to 1989 dollars using 1989 GNP deflator of 126.3 and a 1982 deflator of 100.0.

In short, the two subunits may complement each other. The value of one, taken alone, may be very low if not accompanied by the complementary subunit.

(b) Enhancement Value of Effluent Applied to Total Costs.

Despite the above caveat, the value of the flooded zone was reviewed separately in order to determine an enhancement value resulting from the application of potato processing effluent to the wetland. The death of the mature trees in the flooded zone appears to have resulted from impoundment of that zone beginning in the 1950's. Personnel from the plant reported that the flooded zone was an open area when the factory began to discharge its effluent to the forested wetland in 1985. The area has since filled in with herbaceous vegetation and young trees, and currently has a net primary productivity of 4.82 mT/ha/yr.

Assuming an open water NPP value of 0.50 mT/ha/yr (Turner et al. 1988), the productivity of Zapp's flooded zone has increased by approximately nine hundred percent to 4.82 mT/ha/yr since discharge began seven years ago. This increase was used as the basis for the energy and economic enhancement values and was applied to the three treatment options presented in the previous section. It should be emphasized that if growth of the established vegetation in Zapp's flooded area continues, the net primary productivity values will increase and eventually reach productivity rates

similar to the ridge. Thus the enhancement value used for this study is likely to underestimate the value for future years.

Costs for the three treatment options were converted to energy values according to conversions presented in Turner et al. (1986). In the two cases where enhancement is expected to occur -- i.e., where either secondary effluent is applied to the wetlands as has been done for the past seven years or where primary effluent might be dispersed by a sprinkler system -- enhancement values were subtracted from derived total energy costs. Results are presented in Table 5-7.

Accounting for the increased productivity in the flooded portion of Zapp's receiving wetland, and attributing that increase to the wastewater discharge over seven years (based on field research described in Chapter 3), alters the costs for the three treatment options. Secondary treatment at the factory with wetland application is still overwhelmingly expensive for the owner -- approximately ten times more than the other two options when all options are discounted at 9%. Savings for municipal treatment compared to primary treatment at the factory with wetland application, however, decreases from a savings of $2600/yr using the avoided cost method alone, to a net social savings of $1450/yr when enhancement values are incorporated.

Table 5-7: Energy and Economic Cost Comparison for Zapp's Potato Processing Wastewater Treatment Options, including Enhancement Values discounted at 9%.

Treatment Option	Annualized Cost[1] (a)	Annualized Cost Converted to FFE's [2, 3] (cal) (b)	Enhancement Value (= increase in NPP) converted to FFE's (cal)[4] (c)	Net Energy Use (column b + c) (cal) (d)	Economic Value of Enhancement[5] (e)	Net Economic Value (column a + e)
1. Secondary treatment at factory with wetland application	$31,406	373,880,950	-1,226,880	372,654,070	-$1150/ha	$30,250/yr
2. Primary treatment at factory with wetland application	$4706	56,023,810	-1,226,880	54,796,930	-$1150/ha	$3,550/yr
3. Municipal treatment, no wetland application	$2100	25,000,000	0	25,000,000	0	$2100/yr

[1] From Table 6. Costs are annualized for 15 years at 9%.

[2] FFE = fossil fuel equivalent

[3] Based on annual cost * 15,000 cal fossil fuel quality/1982 dollar (Turner et al. 1988) and converted from 1989 dollars to 1982 dollars based on calories/$1989 = calories/$1982 + price index value of 1.26 [GNP deflator index for 1989 = 126, for 1982 = 100; 126 + 100 = 1.26].

[4] Based on 4.32 mT/ha/yr increase in NPP * 1.42 (the ratio used to convert NPP to GPP; the low ratio was selected from Turer et al. 1988 because of the early successional stage of the site). Formula to convert GPP to FFEs = 4.32 * 1.42 * 4 * 10^6 *.05 (Turner et al 1988).

[5] Col (c) + 15,000. Adjusted from 1982 dollars (Turner et al. 1988) to 1989 dollars using GNP 1989 deflator = 126 and GNP 1982 deflator = 100.0. Discounted at 9%.

As stated earlier, two factors in the analysis make the enhancement value for the flooded area conservatively low: (1) the lowest NPP to GPP ratio was used in calculating the energy increase, and (2) NPP was based on 1991-92 field data which should increase annually. In addition, the cost of municipal treatment only covers the annual fee to the factory owner and does not include the allocated cost of the treatment plant. Adjustments in any of these factors could decrease the $1450 difference between the two options, and may make primary treatment at the factory with wetland application the least socially expensive alternative.

When lower discount rates are used for enhancement values, the difference between primary factory treatment followed by wetland treatment and municipal treatment is altered further: at 4% the enhancement value narrows the gap between the two options to a difference of only $6 per year. At a 3% discount rate for enhancement, wetland treatment shows an annual savings of $864 per year (table 5-8).

Table 5-8: Cost Savings for Primary Treatment at Zapp's Factory with Wetland Application based on three different discount rates.

Discount Rate	Economic Value of Enhancement (ha/yr) (a)	Net Economic Value for Primary and Wetland Treatment at Factory[1] (b)	Savings for Primary and Wetland Treatment at Factory Compared to Municipal Treatment[2] (c)
3%	$3470	$1236	$864/yr
4%	$2600	$2106	-$6/yr
9%	$1150	$3556	-$1450/yr

[1]Based on annualized cost of $4706 (from Table 5-7) minus enhancement value (column a).
[2]Column (b) minus $2100, the cost for municipal treatment.

5.4. Discussion

5.4.1. Use of the Avoided Cost Method for Valuing Wetlands

A number of theoretical and practical criticisms have been made of previous attempts to use the replacement cost method in valuing wetland functions, such as water purification, water supply, and flood control. Virtually all of these attempts have been labeled invalid for one reason or another (Shabman & Batie 1978; Shabman & Batie 1988), and one economic study claims that no credible estimates exist for the water quality improvement function of wetlands (Anderson & Rockel 1991). These economists' criticisms of valuation approaches performed by ecologists will be discussed below.

Gosselink et al. (1974) sought to estimate the economic value of tidal marshes by evaluating, among other things, the waste treatment capacity of wetlands using the alternative or replacement cost method. The conclusion was that while mid-Atlantic estuarine marshes provided only low economic value ($.04/lb of BOD removed/day) and were inefficient treatment systems for secondary municipal effluent, their value as tertiary systems was both high ($2/lb of BOD removed/day) and efficient due to their assimilative capacity. Replacement costs were based on conventional treatment plant estimates for secondary and tertiary treatment.

The analysis was criticized by economists for a reported failure to adhere to the basic theoretical components of valid replacement cost methods: 1) there should be evidence that society would demand the service, and 2) the replacement method considered should be the least-cost alternative (Shabman & Batie 1978; Scodari 1990; Anderson & Rockel 1991). Each of the two requirements for the replacement cost method are reviewed below.

There should be substantial evidence that society would demand the service. Proof of inadequate consideration of this issue is described by the economists as follows:

> A...serious flaw in [the ecologists'] use of the alternative cost technique was their implicit assumption that the demand for advanced waste treatment in fact exists....However, what values would society receive from tertiary treatment?....To go beyond [secondary treatment] may increase oyster production and may open some fishing grounds, but would these increases be worth the equivalent of the cost of tertiary treatment? The burden of proof lies with those who would argue that the alternative cost method is an accurate reflection of willingness to pay for tertiary treatment (Shabman & Batie 1978).

Almost 15 years later the tenet that evidence of willingness to pay is required for effective use of the replacement cost method still exists (Scodari 1990; Anderson & Rockel 1991).

Tertiary treatment to remove nutrients using traditional methods is prohibitively expensive in many instances. What is important from a current perspective is that communities no longer have the luxury of demanding or doing without, but are rather ordered by the Environmental

Protection Agency or state environmental agency to treat their wastes to levels deemed acceptable for disposal into surface water bodies. Increases in oyster production and fishing grounds have been deemed a priority, whether they are truly worth the equivalent of the cost of tertiary treatment or not. The fact that EPA requires tertiary treatment in some water bodies implies, assuming efficient social decision making, that willingness to pay is at least as great as treatment costs.

The replacement method should be the least-cost alternative. Economists argue that the full range of engineering and cost alternatives should be reviewed, and that comparisons based on general EPA cost estimates of tertiary treatment such as those used by Thibodeau & Ostro (1981), or on costs derived in a different state such as those used by Gosselink et al. (1974), are insufficient evidence of the least cost alternative (Scodari 1990; Shabman & Batie 1978). Presumably the municipalities or industries confronted with a mandate to improve their discharge will seek the lowest cost alternative meeting the prescribed regulations. The city of Thibodaux reviewed seven options to improve its effluent, including: the improvement of its existing secondary treatment system, sand filtration, microscreen technology, land application, constructed wetlands, reuse of treated wastewater, and discharge to forested wetlands. The two most feasible

alternatives were determined to be sand filtration and wetland discharge.

In addition to the above theoretical issues, two more general criticisms of the studies employing the replacement cost method for water quality improvement were levied by the same economists (Park & Batie 1979; Shabman & Batie 1988). These included:

> 1. the costs of transporting sewage sludge from its source to a marsh are not included, and may be prohibitive except for nearby marsh.
> 2. the cost savings must be offset by value losses that might occur if other wetland services are reduced.

The Thibodaux, seafood processor, and Zapp's studies include the cost of transporting effluent from the treatment plant to the receiving wetland. It was not necessary to separately estimate transport costs for Breaux Bridge since the existing system includes transport and pumping costs to the receiving wetland.

The determination of value losses in accordance with criticism 2 was complicated for the Thibodaux treatment wetland. Two potential value losses specified by the terms of the lease were initially considered but later dismissed as invalid. The first value loss considered was that of recreation, which occurred before the lease was signed only as trespassing on private property. The illegal use of private property was not considered a valid value loss.

The second potential loss considered was the loss of oil and gas reserves, as a result of the directional drilling stipulation of the lease. The increase in costs for directional drilling would have ranged from 30% to 300% more than non-directional drilling. A more precise cost estimate would be impossible without detailed information on the site (J.F. Cooper, III, personal. comm., Beta Operating Inc.) The Thibodaux site was drilled in the early 1980's and found to contain no oil or mineral reserves. Conceivably, oil could be found by drilling deeper, or simply by drilling more wells close to the dry well. This is too speculative, however, to be the basis of a value-lost estimate.

The Zapp's treatment wetland is privately owned. A few empty bottles and cans, and an occasional spent shot shell, attest to the fact that the land is sometimes used for recreation. Presumably plant personnel use the area with the owner's permission, or trespassers use it without the owner's permission. If the owner allows the use, then the recreational value is obviously not lost and is compatible with wastewater treatment. If the owner does not permit use for recreation, then illegal use of the land should not be considered a valid value loss. Potential value losses for the Breaux Bridge and seafood processor sites have not yet been determined since scientific field studies are still in the planning stages, and only limited information exists on

land use and ownership in the two areas. No exact location for a seafood processor pilot study has been selected.

5.4.2. Natural vs. Constructed Wetlands for Wastewater Treatment

As discussed in Chapter 1, a reluctance to use existing, hydrologically altered wetlands as treatment systems in the subsiding coastal zone of Louisiana relinquishes an opportunity to restore those wetlands. That wetlands are accepted as efficient water purification systems is evidenced by the construction and use of artificial wetlands to treat wastewater. Why does a state with such a large amount of altered wetlands rank among the highest in the number of constructed wetlands being built (Reed 1991)?

Four reasons come to mind: 1) no available wetland acreage exists within a reasonable distance from a treatment plant; 2) there is a public awareness of wetland values in general, but not of the water purification function specifically; 3) there is a belief that constructed wetlands are inexpensive to build and operate; 4) the public and regulators may be concerned about the water quality, and the use of wetlands for natural treatment.

The belief that constructed wetlands are inexpensive may result from regulatory policy:

> In some respects, the regulatory and resource agencies helped create this illusion because their permit conditions were not specific enough, or they actually developed the plan and assumed responsibility for ensuring its success. This pattern is not likely to continue because of substantial increases in the agencies' workload. In fact, we foresee wetland creation becoming less attractive as mitigation conditions become standardized and developmental costs become prohibitive (Perry & Garskof 1989).

Cost estimates for existing constructed wetlands in the Baltimore, Maryland area range from $12,000 to $67,000/acre excluding consulting, design, monitoring, and maintenance costs (Perry & Garskof 1989). Mean capital costs for constructed subsurface flow wetlands located primarily in the southern United States are approximately $87,000/acre (Reed 1991). Since relevant data concerning capitalization of costs is not provided in the two preceding estimates, a direct comparison with the Thibodaux cost results is not possible. A general idea of the potentially high cost can be determined, however, by applying estimates based on 30 planned or existing subsurface-flow constructed wetlands. The mean hydraulic surface area for the 30 constructed wetlands was 5.8 acres/MGD (Reed 1991). At $87,000/acre, Thibodaux's 4 MGD flow would require 23 acres of constructed wetlands at a cost of approximately $2.0 million. This cost is considerably higher than the capital costs for either sand filtration or natural wetland treatment systems (table 1). If a higher economic use could be found for the Thibodaux receiving wetland, then an argument might be made

favoring a constructed over the existing wetland treatment. If not, it makes both economic and ecological sense to make use of the available wetland.

One additional caveat should be mentioned regarding the use of constructed wetlands to treat wastewater. Simply because created wetlands are put together by man, does not mean that they necessarily entail any greater degree of certainty in their operation compared to restored wetlands. The engineering view sees the replacement of wetlands that have formed over thousands of years as a simple and predictable feat, and one that should be considered as a cost alternative:

> As an alternative to identifying the least cost combination of substitutes, the physical construction of another similar wetlands area can be presumed to replace whatever services were flowing from the area being valued without having actual knowledge of linkages. Similar structural features of the replacement area could insure substitution of the ecological and hydrological function; it could then be presumed that the service vector of the substitute wetlands will be identical to the service vector of the area being valued (Anderson & Rockel 1991).

Those charged with or interested in substituting the services of an existing wetland with a created one, however, have not always been successful. Simple attempts to reestablish species formerly existing in any area -- without efforts to maximize specific functions such as water purification -- sometimes fail due to edaphic, biotic, chemical, or physical incompatibilities (Kline & Howell

1987) The ability to adequately replace lost functional values is by no means assured in a constructed wetland.

5.4.3. Benefits Beyond Cost Savings

The avoided cost methodology used in this chapter covers only the specific costs for water purification. The Energy Analysis applied to Zapp's determined overall energy costs and the enhancement value derived from wastewater application to wetlands. Further consideration of the economic value of sites where wetland treatment alleviates surface water pollution, should heavily weigh the additional benefit of improved water quality in those water bodies.

In the three bottomland hardwood cases reviewed in this dissertation (Thibodaux, Breaux Bridge, and Zapp's), preservation values would include the conservation of timber, wildlife, and future recreational opportunities, in addition to benefits derived from flood control and storage.

Measurements from Zapp's discussed in Chapter 3, revealed a benefit in sediment replenishment as a result of the discharge of the potato wastewater. The annual accretion rate of 1.15 cm would probably be sufficient to offset subsidence in high subsidence zones, if similar discharges were applied in these zones. The accretion resulting from both the increased vegetative growth due to the applied nutrients, in addition to the mineral and organic component of the potato wastewater, may also increase the ability of the wetland to treat wastewater.

Other benefits in preserving wetlands that are frequently mentioned but not priced, include preservation of biodiversity and educational, scientific, and aesthetic benefits. In addition, where food processing or municipal facilities discharge into surface water bodies (such as the seafood processors in Dulac), substantial benefit to those water bodies should occur after wetland treatment is established. Finally, lower treatment costs using wetlands will increase demand for treatment. Facilities or households using inadequate treatment systems such as septic systems, or even those using no treatment at all, may be induced to include the use of hydrologically altered wetlands for tertiary treatment.

Presumably, estimates for some of these values could be derived. Appropriate functions applicable to the bottomland hardwood sites discussed above, and estimated values for those functions based on a number of studies, are listed in Table 5-9. The per acre values are shown here only for illustrative purposes, since specific monetary values would need to be derived on a site specific basis if a strict cost-benefit analysis was performed. In addition to these, timber values could also be calculated. Flood storage and sediment replenishment values are more difficult to derive, but have been attempted. The wastewater treatment values derived for Thibodaux could also be used, but as stated earlier, those values are specific for the Thibodaux site, and may be on the low side due to the distance from the

Table 5-9: Estimated Values Applicable to Bottomland hardwood systems (1984$) (from Anderson & Rockel 1991).

Function	Per acre capitalized value at 5%
Flood conveyance	$3,820
Waterfowl habitat	$3,340
Mammal & reptile habitat	$240
Recreation	$120-$1520
Historic & archeological use	$6,480
Education & research use	$120
TOTAL	$14,120-$15,520

(Total in 1989 $ = $16,558-$18,200)

treatment plant to the receiving wetland. If the land were publicly owned and recreational use prohibited during treatment, recreational values would have to be subtracted from the total value. It should be noted, also, that the high historic and archeological use value could be as low as zero in some wetland areas.

On the other hand, some values could be considerably higher. There is a high potential for the Thibodaux site to either encourage or discourage other wetland treatment projects in the state based on the scientific research that has taken place there over the last four years. Farber (unpublished, 1992b) describes the resulting high value of Thibodaux's treatment wetland as follows:

> If it shows that such treatment is feasible, and therefore induces other similar projects, the scientific benefit equals the cost savings and enhanced wetlands benefits of all future impacted potential projects. On the other hand, if the project is a failure, the scientific benefit equals the savings that other projects make by not making the same mistake. Either way, failure or success, the project has large scientific benefits....If 50 coastal communities used this type of alternative treatment as a result of the proven success of this project and saved $800,000 each by doing so, their joint cost savings would be $40 million. The scientific benefits of the project would then be $40 million plus the value of enhanced wetlands in other project areas.

It would be possible, then, to derive per acre wetland values, and possibly enormous ones, for any site. The complexity involved in valuing diverse functions, and the debate over standards and methods applied, however, might

require more financial resources than those contained in the site at issue. Deriving values for all of the functions mentioned above for the 6 acre receiving wetland at Zapp's, for example, would be a time-consuming and costly effort. The high degree of uncertainty involved in pricing the non-market functions would inevitably lead to some degree of subjectivism in the estimates. Unless a strict cost-benefit analysis is required for a particular wetland site under the threat of development, attempts to price difficult unquantifiable benefits should be avoided.

5.5. Conclusion

The selection of treatment wetlands should be based on two factors: 1) a financial savings to the community or industry based on the water treatment function of wetlands, 2) the environmental protection of the receiving wetland, in addition to a potential for enhancement of the wetland and the associated receiving surface water body. Where large wetlands consisting of hundreds or thousands of acres are used for treatment, such as at Thibodaux and Breaux Bridge, benefits to landscape level processes are important.

Smaller treatment tracts, such as the Zapp's and seafood processor sites, should be selected with the aim of buffering existing wetland systems in order to preserve those systems from fragmentation. The bottomland hardwood system currently located between the Mississippi and Blind Rivers is likely to eventually lose dischargers such as

Zapp's and the Colonial Sugar factory to the new Gramercy treatment plant. Zapp's effluent has been shown to be beneficial to its receiving wetland (Chapter 3). The wetland receiving effluent from the Colonial Sugar factory has not been analyzed for either beneficial or adverse effects, but the receiving swamp was shown to completely mineralize the excess total organic carbon load before the effluent reached the Blind River (Gambrell et al. 1987). Industrial land owners would have a far greater incentive to preserve these contiguous wetland tracts, if those tracts could safely be used to treat secondary effluent.

Given the high rate of loss in bottomland hardwood systems resulting from past economic incentives to convert them, efforts need to be directed toward conserving remaining systems along with the surrounding acreage (Harris & Gosselink 1990). From an ecological perspective, a site such as Zapp's with its falling and broken trees, has a high potential for both providing quality wildlife habitat and linking existing habitat zones. A regional approach to preserving sites such as this, would not only realize the benefits mentioned above in the immediate receiving wetland, but also increase many of those benefits on the adjacent wetlands. Where cost savings for wetland over advanced treatment are realized, wetlands should be selected with the objective of maximizing the overall regional landscape processes of water quality and habitat maintenance. Where large, complete wetland tracts or smaller adjoining tracts

can be used as treatment systems, opportunities for increasing the recognized values of wetlands will be realized.

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CHAPTER 6

MANAGEMENT RECOMMENDATIONS AND CONCLUSIONS

6.1. Management Recommendations:

1. Recognize the overall potential benefits of wetland wastewater treatment [Chapter 1]:

   a) improved surface water quality
   b) increased accretion rates to balance subsidence
   c) increased plant productivity
   d) decreased financial outlays for conventional engineering tertiary treatment systems

2. Recognize the unique regional features that make the Louisiana coastal zone particularly appropriate for wetland wastewater treatment [Chapter 1]:

   a) subsidence leads to permanent burial of pollutants
   b) warm temperatures lead to high denitrification rates and to high metabolic rates and increased plant productivity
   c) neutral pH of saturated soil leads to reactions of inorganic phosphorus with iron and aluminum, leading to adsorption and precipitation
   d) levees and spoil banks provide an element of control of impounded wetlands
   e) low populations and available wetland area provide ideal conditions for tertiary wetland treatment

3. Before investing in conventional tertiary treatment facilities or secondary treatment upgrades, review facility for possible wetland treatment based on conformance to selection criteria for dischargers and receiving wetlands (see Chapter 2).

4. Identify appropriate dischargers based on [Chapter 2]:

--current discharge into surface water bodies or wetlands
--biodegradable nature of nonpersistant effluent (e.g., food processing industries, sewage treatment plants, oxidation ponds, schools, subdivisions, and trailer parks)
--proximity to wetlands: feasible distance depends on volume of flow. Distances of Louisiana pilot site facilities [Chapters 3 and 4] from their respective receiving wetlands range from 20-3,000 meters. Distances of several miles may be feasible for very large flows. [Appendix 1 lists discharger locations found on 1:100,000 U.S.G.S. Map; Appendices 2 and 3 list potentially appropriate municipal dischargers in the Terrebonne and Barataria Basins.]

5. Identify suitable wetlands for receiving effluent based on [Chapter 2]:

--exclusion of wetlands with noncompatible or priority uses
--hydrologic alteration and confinement of the wetland resulting from canals, roads, flood control structures, etc.
--high subsidence zones
--potential for backup wetland treatment systems
--size, type, and dispersal capabilities of the receiving wetland. A conservative loading rate recommended by EPA is 2.5 cm/wk, though rates as high as 27.3 cm/wk have been successfully reported for constructed wetlands. Loadings should depend on the historical flows to the wetland before hydrologic alteration, and the potential for the distribution system to ensure periods of drawdown and adequate residence times. All types of wetlands have proven effective in removing organic matter, nutrients, pathogens, or heavy metals.

6. Seek financial savings for appropriate municipal or industrial facilities in terms of both the savings of wetland wastewater treatment over conventional engineering methods, and the potential for wetland enhancement of hydrologically altered and degraded wetlands [Chapter 5].

6.2. Conclusions:

Chapter 1: Wetlands have been proven to be effective wastewater treatment systems. Louisiana wetlands can benefit from the added sediments and nutrients contained in secondarily treated effluent.

Chapter 2: Appropriate dischargers include sewage treatment plants, oxidation ponds, subdivisions, schools, trailer parks, seafood processors, and sugar mills. Effluent dischargers are widely dispersed along natural levees and near semi-isolated wetlands.

Chapter 3: Effluent discharge to the Zapp's receiving wetland has increased productivity and helped to regenerate vegetation killed by impoundment. Water quality of the effluent was improved after passage through the wetland.

Chapter 4: Pilot study sites in Thibodaux, Breaux Bridge, and Dulac, LA conform to the selection criteria for dischargers and receiving wetlands, and show promise as effective wetland wastewater treatment systems.

Chapter 5: Wetland wastewater treatment realizes a social cost savings over conventional tertiary treatment systems.

Cost savings to industries depend on the existence and location of municipal treatment plants, and on the extent of treatment performed by the receiving wetland.

APPENDIX 1

EFFLUENT DISCHARGER LOCATIONS IN THE LOUISIANA COASTAL ZONE

Names, locations, and types of municipal and industrial dischargers selected for their potential as suitable candidates for wetland wastewater treatment. Dot number refers to location on U.S.Geological Survey map (scale = 1:100,000). Segment number refers to Louisiana DEQ water quality basin segment number.

	A	B	C	D	E	F
1	APPENDIX 1: EFFLUENT DISCHARGER MAP					
2	SOURCE	Dot #	Name	Type	Segment	Description
3	DEQ files	1	Lucky Hit Subdivision	Sub	0204	Aucoin's
4	DEQ files	2	Elmfield	Sub	0204	Aucoin's
5	DEQ files	3	Bon Service Shopping Center	Bus	0204? or 1202	Aucoin's
6	DEQ files	4	Kingston Subdivision	Sub	204? or 1202	Aucoin's
7	DEQ files	5	Labadie Estates	Sub	0204	Aucoin's
8	DEQ files	6	Lucky Hit Shopping Center	Bus	0204	Aucoin's
9	DEQ files	7	Magnolia Subdivision	Sub	0204	Aucoin's
10	DEQ files	8	Aucoin's Trailer Park	TP	0204	Aucoin's
11	DEQ files/Map	9	City of Donaldsonville	Mun	0201	DEQ Map label: M-1
12	DEQ files	10	St. James Sugar Mill	Sugar	0204	
13	DEQ files	11	Caldwell Sugar Co	Sugar	0201	
14	DEQ files	12	South Coast Sugars	Sugar	0203	
15						
16	Bob Jones 1	13	Acadiana Elementary	Sch		hooked up to Houma? possible city sewage?
17	Bob Jones 2	14	Andrew Price Voc. Sch.	Sch		Schriever
18	Bob Jones 3	15	Hi-Seas #2	SFP	1205	formerly Authement Packing Co.
19	Bob Jones 4	16	Bayou Black Elem. Sch	Sch	1204	not in DEQ inventory
20	BJ 5	17	Boudreaux Canal Sch	Sch	1205/07	I've got 2 with this name
21	BJ 6	18	Bourg Elementary	Sch		(Houma?)
22	BJ 7	19	Broadmore Elem.	Sch		(Houma?) possible city sewage?
23	BJ 8	20	Caldwell Middle	Sch	1203	I've got 2 with this name
24	BJ 9	21	Coteau Bayou Blue Elem	Sch	1203	
25	BJ 10	22	Cypress Village Sanitary Sewer S	Trt. plant	1202	
26	BJ 11	23	Dularge Elem	Sch	1205	possible sewage treatment plant
27	BJ 12	24	Dularge Middle Sch	Sch	1205	
28	BJ 13	25	East Houma Elem	Sch		Houma possible city sewage?
29	BJ 14	26	East Street Sch	Sch		Houma possible city sewage?
30	BJ 15	27	Ellendale Subdivision	Sub	1203	
31	BJ 16	28	Ellendale Memorial High School	Sch		Houma possible city sewage?
32	BJ 17	29	Elysian Fields School	Sch		possible city sewage?
33	BJ 18	30	Evergreen Junior High Sch	Sch	1203	
34	BJ 19	31	Genesis Alternative High Sch.	Sch		Houma possible city sewage?
35	BJ 20	32	Gibson School	Sch	1202/04?	
36	BJ21	33	Grand Caillou Elementary	Sch	1205	
37	BJ22	34	Grand Caillou Middle	Sch	1205	
38	BJ23	35	Grand Caillou Packing	SFP	1205	Closed (source = DEQ files)
39	BJ24	36	Greenwood Middle Sch	Sch	1204	
40	BJ25	37	Gulf Coast Packing	SFP	1205	
41	BJ26	38	High Seas of Dulac	SFP	1205	
42	BJ27	39	Honduras Elementary	Sch		Houma possible city sewage?
43						
44	BJ29	40	Huey Ice		1205	
45	BJ30	41	H.L. Bourgeois High School	Sch	1203	
46	BJ31	42	Indian Ridge Canning		1207?	
47	BJ32	43	Ivy Authement Ice		1205	"permitted to monitor temp & pH monthly" (EPA) Source = DEQ 11/9/91
48	BJ33	44	Lacache Middle Sch	Sch	1205	
49	Bj34	45	Legion Park school	Sch		Houma possible city sewage?
50	BJ35	46	Lisa Park School	Sch		Houma possible city sewage?
51	BJ36	47	Little Caillou Elementary	Sch	1205	
52	BJ37	48	Montegut Elem	Sch	1207 (?)	
53	BJ38	49	Montegut Middle	Sch	1206	

	A	B	C	D	E	F
1	APPENDIX 1: EFFLUENT DISCHARGER MAP					
2	SOURCE	Dot #	Name	Type	Segment	Description
54	BJ40	50	Mulberry Elem	Sch		Houma possible city sewage?
55	BJ41	51	Oaklawn Jr. High	Sch		Houma possible city sewage?
56	BJ42	52	Oakshire Elementary	Sch		possible city sewage?
57	BJ43	53	Offshore Food Service		1203	
58	BJ44	54	Point au Chein Elem	Sch	1206	
59	BJ45	55	Price Seafood	SFP	1205/07	
60	BJ46	56	School for Exceptional Children	Sch		Houma
61	BJ47	57	Schriver Elementary	Sch	1203	
62	BJ48	58	South Terrebonne High School	Sch	1206(?)	
63	BJ49	59	Southdown Elementary	Sch		Houma possible city sewage?
64	BJ50	60	Terrebonne High School	Sch		Houma possible city sewage?
65	BJ51	61	Terrebonne School Maintenance		1203	
66	BJ52	62	Terrebonne Vocational Rehab. Center			Houma possible city sewage?
67	BJ53	63	Terrebonne Vocational Tech. H.S.	Sch		Houma possible city sewage?
68	BJ54		Terre.Parish Southdown Sewer Lag	STP		closed
69	BJ55	65	Upper Little Caillou Elementary	Sch	1205	
70	BJ56	66	Village East School	Sch		Houma
71	BJ57	67	Voisin Canning		1205	Closed. Sold freezing operation to D'Luke. Now an unloading dock o
72	BJ58	68	West Park Elementary	Sch		Houma possible city sewage?
73	BJ59	69	Zapata Haynie	SFP	1205	
74						
75	Zeranque	70	Sea Tang	SFP	1205	Bayou Grand Caillou
76	Zeranque	71	Bluewater	SFP	1205	B. Grand Caillou (not on DEQ map; maybe no peeling machines)
77	Zeranque	72	D'Luke	SFP	1205	B. Grand Caillou (checks with Levron's "Luke")
78	Zeranque	73	Samanie Packing Co, Ince #1	SFP	1205	Closed
79	Zeranque	74	Scotco's	SFP	1205	B. Grand Caillou
80	Zeranque	75	Pi Foret	SFP	1207	Bayou Petit Caillou
81	Zeranque	76	Houston Foret	SFP	1207	Bayou Petit Caillou
82	Zeranque	77	Houston #2	SFP	1207	Bayou Petit Caillou
83	Zeranque	78	Lapreyrouse	SFP	1207	Bayou Petit Caillou
84	Zeranque	79	Rocky's Sea food	SFP	1207	Bayou Petit Caillou (not in Health & Human S. or NMSF)
85	Zeranque	80	Terry & Brenda's	SFP	1207	Bayou Petit Caillou
86	Zeranque	81	Wilson's Oyster	SFP	1205	Bayou du Large (not in H&HS or NMSF)
87	Zeranque	82	Allan Marie	SFP	1207	Pointe-au-Chien (not in H&HS or NMFS)
88	Zeranque	83	Lake Chien (Duet's Seafood)	SFP	1207	
89						
90	DEQ Files	84	Glenwood Sugar	Sugar	1202	
91	DEQ Files	85	Supreme Sugar	Sugar	1202	
92	DEQ Files	86	Lafourche sugar	Sugar	1202	
93						
94	DEQ Map	87	St. Louis Subdivision	Sub	1202	M-1
95	DEQ Map	88	City of Plaquemine	Trt plant	1202	M-3
96	DEQ Map	89	Town of White Castle	Trt plant	1202	M
97	DEQ Map	90	Town of Napoleonville	Trt plant	1202	M-12
98	DEQ Map	91	St. Mary Sewer District #14	Trt plant	1202	M-8
99	DEQ Map	92	St. Mary Sewer District#4	Trt plant	1202	M-9
100	DEQ Map	93	Magnolia Park Subdivision	Sub	1202	M-14
101	DEQ Map	94	Country Club Subdivision	Sub	1203(?)	M-13
102	DEQ Map	95	Plantation Trace Subdivision	Sub	1202	M-17
103	DEQ Map	96	City of Thibodaux	Trt plant	1202	M-18
104	DEQ Map	97	Twin Oaks Subdivision	Sub	1203	M-20

	A	B	C	D	E	F
1	APPENDIX 1: EFFLUENT DISCHARGER MAP					
2	SOURCE	Dot #	Name	Type	Segment	Description
105	DEQ Map	98	Thoroghbred Park Subdivision	Sub	1203	M-19
106	DEQ Map	99	Oak Grove Park Subdivision	Sub	1203	M-16
107	DEQ Map	100	Town of Lockport	Trt plant	1203	M-15
108						
109	New Levron map	101	Willowdale Subdivision	Sub	1203	
110	New Levron map	102	Mobile Home Estates	TP?	1203	
111	New Levron map	103	Linda Ann	Sub?	1203	
112	New Levron map	104	Eureka	Sub?	1203	
113	New Levron map	105	Tara	Sub?	1203	
114	New Levron map	106	Country Boy	Sub?	1203	
115	New Levron map	107	Fairlane	Sub?	1203	
116	New Levron map	108	Cresent	Sub?	1203	
117	New Levron map	109	St. Agnes	Sub?	1205	
118						
119	Pat Breaux, DEQ (A)	110	Abby Plantation Sewage Corp	Sub	0204	
120	Pat Breaux, DEQ (B)		Acadia Woods Subdivision	Sub	1203/0203	
121	Pat Breaux, DEQ(C)	112	Acadia Seafood Processor	SFP	0208/1206(?)	Hwy 308 at 12th Street
122	Pat Breaux, DEQ(D)	113	Brandywine Subdivision	Sub	1203	
123	Pat Breaux, DEQ(E)		C&G	SFP		Hwy 56 on Bayou side, below Chauvin?)
124	Pat Breaux, DEQ(F)	115	Charle Hardison's	TP, camps	0209	
125	Pat Breaux, DEQ(G)	116	Cigar's Marina	camps	0209	
126	Pat Breaux, DEQ(H)	117	Claude Seafood	SFP	1202	Pierre Part; south Bay Rd. toward Lake Verret
127	Pat Breaux, DEQ(I)		Collier's Fisheries			Discontinued (connected to Trt. Plant) Bayou Des Allemands
128	Pat Breaux, DEQ(J)		Community Sewage Service			Not mapped (Dugas subdivision;
129	Pat Breaux, DEQ(K)	120	Community Sewage Service	Sub	1202	St. Maurice
130	Pat Breaux, DEQ(L)	121	Community Sewage Service	Sub	1202	Terr-Laf. Drainage Canal
131	Pat Breaux, DEQ(M)	122	Country Boy	TP		not mapped (Kevin St)
132	Pat Breaux, DEQ(N)	123	Aucoin Sewer Utility Service, Wi	Sub	1202	
133	Pat Breaux, DEQ(O)	124	Aucoin SUS, Greenleaf	Sub	1202	
134	Pat Breaux, DEQ(P)	125	Aucoin SUS, Bayou Pierre	Sub	1202	
135	Pat Breaux, DEQ (Q)	126	Aucoin SUS, Bayou Tranquill	Sub	1202	in Belle River (by Lake Verret)
136	Pat Breaux, DEQ(R)	127	Berwick Levron Trailer Park	TP	1203	Atta St., (about 13 trailers)
137	Pat Breaux, DEQ(S)	128	Bayou Vista	TP	0107(at; bastin)	about 7 trailer parks (Morgan City)
138	Pat Breaux, DEQ(T)		Duet's Crawfish	SFP		boiling facility; Hwy 308 & East 125th St, Galliano
139						
140	Pat Breaux, DEQ	111*	Orgeron's Crab Co.(?)	SFP	0208/1206(?)	(into subdivision ditch, to Bayou La Fourche or Intra C.W.W)
141	Pat Breaux, DEQ	114	Golden Meadow Farms	SFP	0209	alligator farm
142						
143	USL for DEQ	118	Southern Gulf Seafood	SFP	1205	
144	USL for DEQ	119	Samanie Packing #2	SFP	1205	
145	USL for DEQ	122	Gulf Breeze	SFP	1205	
146	USL for DEQ	129	Luke's Seafood	SFP	1205	Closed (was near D'Luke's)
147	USL for DEQ	130	Tex-a-Coon Seafood	SFP	1205	Closed
148	USL for DEQ	131	Tideland Seafood Col	SFP	1205	
149	USL for DEQ	132	Sea King Packing Co	SFP	1205	
150	USL for DEQ	133	Stop & Go Seafood	SFP	1205	
151	USL for DEQ	134	Dulac Seafood	SFP	1205	
152	USL for DEQ	135	J&K Seafood	SFP	1205	
153	USL for DEQ	136	Samanie Dock	SFP	1205	
154	USL for DEQ	137	Royal Gulf	SFP	1205	
155						

	A	B	C	D	E	F
1	APPENDIX 1: EFFLUENT DISCHARGER MAP					
2	SOURCE	Dot #	Name	Type	Segment	Description
156	Pat Breaux (approx)	138	R&R Factory of Crab	SFP	0202/03(?)	Des Allemands (Health & HS lists 5 Processors for Des Allemands)
157	Pat Breaux (approx)	139	Mrs. Mathern's Seafood	SFP	0202/03(?)	Des Allemands
158	Pat Breaux (approx)	140	Harbor Seafood, Inc.	SFP	0202/03(?)	Des Allemands
159	Pat Breaux (approx)	141		Sub	0202/03(?)	
160	Pat Breaux (approx)	142		Sch	0201	Raceland. School Directory lists 3 for Raceland
161	Pat Breaux (approx)	143		Sch	0201	Raceland
162	Pat Breaux (approx)	144		Sch	0201	Raceland
163	Pat Breaux (approx)	145	R & M Seafood	SFP	0201(?)	Raceland. Health & HS lists 6 for Raceland
164	Pat Breaux (approx)	146		SFP	0201(?)	Raceland
165	Pat Breaux (approx)	147		SFP	0209	Leeville. Health & HS lists 2 for Leeville
166	Pat Breaux (approx)	148		Sch	1203/0203(?)	Matthews. School Directory lists 2 for Matthews
167	Pat Breaux (approx)	149	Lockport Lower Elementary	Sch	1203(?)	Lockport. School Directory lists 3 for Lockport150
168	Pat Breaux (approx)	150	Lockport Upper Elementary	Sch	1203(?)	Lockport
169	Pat Breaux (approx)	151	Lockport Junior High	Sch	1203(?)	Lockport
170	Pat Breaux (approx)	152	Larose Lower Elementary School	Sch	0208/1206(?)	Larose. School Directory lists 3 for Larose
171	Pat Breaux (approx)	153	Larose Middle School	Sch	0208/1206(?)	Larose
172	Pat Breaux (approx)	154	South Lafourche High School	Sch	0208	Galliano. School Directory lists 2 for Galliano
173	Bobby Simoneaux	155	Rivere's Seafood Processors	SFP	1202	Bell River
174	Bobby Simoneaux	156	Wilbert J. Herbert Seafood	SFP	1202	Belle River
175	Bobby Simoneaux	157	Breaux & Daigle	SFP	1202	Pierre Part
176	Bobby Simoneaux	158	Claude's	SFP	1202	Pierre Part
177	Bobby Simoneaux	159	Alleman	SFP	1202	Pierre Part
178	Bobby Simoneaux	160	Blanchard's	SFP	1202	Pierre Part
179	Bobby Simoneaux	161	D & I	SFP	1202	Pierre Part
180	Bobby Simoneaux	162	Roy Leblanc	SFP	1202	Pierre Part
181	Bobby Simoneaux	163	Errol's Cajun Foods	SFP	1202	Pierre Part
182	Bobby Simoneaux	164	Landry's Oyster House	SFP	1202	Pierre Part
183	Bobby Simoneaux	165	Royaloff Cavian Co.	SFP	1202	Pierre Part
184	Bobby Simoneaux	166	Mike Blanchard	SFP	1202	Pierre Part
185	Bobby Simoneaux	167	Ernie's Seafood	SFP	1202	Pierre Part
186	Bobby Simoneaux	168	Hahnville High School	Sch	1202	Boutte
187	Bobby Simoneaux	169	Westfield Sugar Mill	Sugar	1202	
188	Bobby Simoneaux	170	Lula Sugar Mill	Sugar	1202	
189	Bobby Simoneaux	171	McCall Sugar Mill	Sugar	1202	
190	Bobby Simoneaux	172	Cora Texas Sugar Mill	Sugar	1202	
191	Pat Breaux	184	Chackbay (?) Elementary School	Sch	0201	have their own treatment plant
192	Pat Breaux	185	St. Charles Elementary	Sch	1203	have their own treatment plant
193	Pat Breaux	186	Central Lafourche Vocational Tra	Sch	0208	Mathews
194	Pat Breaux	187	Larose-Cutoff Jr. High School	Sch	1206	Larose
195	Pat Breaux	188	Cuttoff Elementary	Sch	1206	Cutoff
196	Pat Breaux	189	Special Ed. District #1	Sch	1206	Cutoff
197	Pat Breaux	190	South Lafourche Voc. Training Ce	Sch	0208	Cutoff
198	Pat Breaux	191	Golden Meadow SR. High	Sch	1207	Golden Meadow
199	Pat Breaux	192	Golden Meadow Lower Elementary	Sch	1207	Golden Meadow
200	Pat Breaux	193	Golden Meadow Middle	Sch	1207	Golden Meadow
201	Pat Breaux	194	Bayou Boeuf Elementary	Sch	0201	Kraemer
202	Pat Breaux	195	Grand Isle High School	Sch	0211	Grand Isle
203	Pat Breaux	196	Allemands Elementary	Sch	0202	Des Allemands
204	Pat Breaux	197	Martin, J.B. Middle School	Sch	0203	Paradis
205	Pat Breaux	198	Vial, R.J. Elementary	Sch	0203	Paradis
206	Pat Breaux	199	Mimosa Park Elementary	Sch	0203	Luling

	A	B	C	D	E	F
1	APPENDIX 1: EFFLUENT DISCHARGER MAP					
2	SOURCE	Dot #	Name	Type	Segment	Description
207	Pat Breaux	200	Shamrock Seafood, Inc.	SFP	1203	Raceland
208	Pat Breaux	201	Deep South Company Inc.	SFP	0201	Raceland
209	Pat Breaux	202	Southeast LA. Crap Co.	SFP	1203	Raceland
210	Pat Breaux	203	Golden Ranch Seafood	SFP	0203	Gheens
211	Pat Breaux	204	James Seafood .	SFP	1203	Lockport
212	Pat Breaux	205	C & S Seafood	SFP	1203	Lockport
213	Pat Breaux	206	Galliano Elementary School	Sch	1207	Galliano
214	Pat Breaux	207	Roy Meek Seafood Inc.	SFP	1207	La Rose
215	Pat Breaux	208	Red & Sons Seafood	SFP	1207	Cutoff
216	Pat Breaux	209		SFP		
217	Pat Breaux	210	Louisiana Seafood	SFP	1206	La Rose
218	Pat Breaux	211	Gulf Farms South Inc.	SFP	1207	Gallliano
219	Pat Breaux	212	Gulf Shrimp Processors, Inc.	SFP	0208	Golden Meadow
220	P. Breaux & R. Guidry	213	LA. Langline Inc.	SFP	1207	Golden Meadow
221	P. Breaux & R. Guidry	214	Marshland Seafood	SFP	1203	Mathews
222	P. Breaux & R. Guidry	215	Cajun Ladies	SFP	1207	Chauvin
223	P. Breaux & R. Guidry	216	Grand Bay Seafood	SFP	1203	
224	P. Breaux & R. Guidry	217	Breaux Crab Co., Inc.	SFP	1203	
225	P. Breaux & R. Guidry	218	T & D Bayou Seafood	SFP	0202	Des Allemands
226	P. Breaux & R. Guidry	219	Gulf Crab	SFP	0203	Des Allemands
227	P. Breaux & R. Guidry	220	J & L Seafood, Inc.	SFP	0209	north of Leeville Bridge, Hwy. 1
228	P. Breaux & R. Guidry	221	D & A Seafood	SFP	0202	Des Allemands, Hwy 90 west
229	P. Breaux & R. Guidry	222	Hubert Lafont Shrimp Co., Inc.	SFP	1207	Golden Meadow
230	P. Breaux & R. Guidry	223	Peggy's Seafood	SFP	0203	Mathews
231	P. Breaux & R. Guidry	224	Wayne Estay Shrimp Co.	SFP	0211	Grand Isle
232	P. Breaux & R. Guidry	225	Estay Ice Co.	SFP	0211	Grand Isle
233	P. Breaux & R. Guidry	226	Bobby Collins Seafood	SFP	0211	Grand Isle
234	P. Breaux & R. Guidry	227	Cheramie's Wharf	SFP	0211	Grand Isle
235						
236						
237		111*	Acadia Woods Subdivisions	Sub		Candy/Pat Breaux. Check this. Conflicts with Ogeron's Crab.
238						

APPENDIX 2

TERREBONNE BASIN MUNICIPAL DISCHARGERS

Municipal dischargers selected for consideration for wetland wastewater treatment in segments 1202 through 1208 in the Terrebonne Basin.

	A	B	C	D	E	F
1	APPENDIX 2: TERREBONNE BASIN MUNICIPAL DISCHARGERS					
2	Facility	Permit #	Capacity	Limits	Discharge to:	Parish
3	MUNICIPALITY 1202		(MGD)			
4	1. Aucoin's Sewer Utility Services	WP0610	0.015	Secondary	Bayou L'ourse to Bayou Boeuf	Assumption
5	Greenleaf Park Subdivision					
6	2. Aucoin's Sewer Utility Services	WG020052	0.02	30/30	Bayou L'ourse to Bayou Boeuf	Assumption
7	Wildwood Subdivision					
8	3. Aucoin's Sewer Utility Services	WG020051	0.0135	30/30	Bayou L'ourse to Bayou Boeuf	Assumption
9	Greenleaf Park Subdivision					
10	4. Brule Apts	N.G.	0.011	Secondary	Unnamed ditch to William Canal to Grassy Lake to Lake Palourde	Assumption
11	5. Community Sewage Services, Inc.	WP1888	0.06	10--15	Terrebonne-Lafourche Drainage Canal to Bayou Black	Lafourche
12	Magnolia Park Subdivision					
13	6. Community Sewage Services, Inc	LA0080411	0.036	20/20	Bayou Terrebonne	Lafourche
14	St. Maurice Subdivision	WP0971				
15	7. Cypress Village Sanity Sewer Sy	LA0080345	0.019	Secondary	Hanson Canal to Bayou Black	Terrebonne
16	Berry Dupree (Houma)	WP2209				
17	8. Ellendale Subdivision	N.G.	0.264	10--15	Bayou Black to Intracoastal Waterway	Terrebonne
18	9. STD Corp., Marydale Housing Pro	N.G.	0.045	20/20	Phillips Canal to Terrebonne-Lafourche Drainage Canal to Bayou Black	Lafourche
19	10. Thoroughbred Park Service Corp	WP2076	0.18	10--15	Unnamed ditch to Terrebonne-Lafourche Drainage Canal to Bayou Black	Lafourche
20	Plantation Trace Subdivision					
21	11. Bayou Goula School	N.G.	0.0004	secondary	Roadside ditch to Bayou Tigre to Lake Natchez to Lake Verret	Iberville
22	12. Dorseyville School	N.G.	0.0004	secondary	Grand Bayou	Iberville
23	13. Pierre Part Middle & Primary S	N.G.	0.007	secondary	Pierre Part Bayou to Lake Verret	Assumption
24	14. Plaquemine High School	N.G.	0.0004	secondary	Unnamed stream to Lake Long to Lake Natchez to Lower Grand River	Iberville
25	15. Samstown School	N.G.	0.0004	secondary	Grand Bayou	Iberville
26	16. Stephensville Elementary Schoo	N.G.	0.005	secondary	Unnamed ditch to Bayou Milhomme to Lake Palourde	St. Martin
27	17. Terrebonne Parish School Board	LA0040312	0.006	secondary	Unnamed drainage canal to Bayou Black	Terrebonne
28	Gibson Elementary School					
29	18. TPSB, Gibson Elementary School	WG020042	0.005	30/30	Unnamed ditch to Big Bayou Black	Terrebonne
30	(*double counting with #??????)					
31	19. TPSB, Greenwood School	WG020040	0.011	30/30	Unnamed ditch to Hanson Canal to Bayou Black	Terrebonne
32	20. Iberville Parish Policy Jury	LA0051586	0.24	10--15	Lake Long to Lake Natchez to Belle River	Iberville
33	St. Louis Subdivision (Plaquemine)					
34	21. Napoleonville, Town of	LA0043966	0.2	10--15	Godchaux Canal to Lake Verret	Assumption
35	22. St. Martin Parish Severage Dis	WP0846	0.05	secondary	Belle River	St. Martin
36	Belle River STP					
37	23. St. Mary Parish Sewage Distric	LA0065188	0.09	secondary	Bayou Ramos and BAyou Boeuf to Atchafalaya River	St Mary
38	Siracusa Subdivision STP (e. c	WP0602				
39	24. St. Mary Parish Sewage Distri	LA0033006	0.65	Individ. Analysis	Lake Palourde	St. Mary
40		WP0395				
41	25. Terrebonne Parish Consolidated	LA0049263	0.4	secondary	Hanson Canal	Terrebonne
42	Southdown Lagoon	WP0862				
43	26. T.P. Police Jury, Ellerdale La	WP0425	0.25	secondary	Quick Bayou	Terrebonne
44	27. Thibodaux, City of	LA0032948	1.4	Individ.Analysis	Phillips Canal to Terrebonne-Lafourche Drainage Canal to Bayou Black	Lafourche
45	28. White Castle, Town of--Oxidati	LA0020052	0.63	Individ. Analysis	Unnamed stream to Bayou Corne(?) to Lake Verret	Iberville
46		WP1815				
47	29. A&L Trailer Park	N.G.	0.04	20/20	Bayou L'ourse to Bayou Boeuf	Assumption
48	30. Cajun Campsite	WP0324	0.012	secondary	Belle River	Assumption
49	31. L.H. & S. Mobile Home Park	N.G.	0.0004	secondary	Unnamed canal to Bayou Lafitte to Lake Long to Lake Natchez to Belle Ri	Iberville
50	32. Ridgeway Mobile Home Park	N.G.	0.035	20/20	Unnamed canal to Lake Verret	Assumption
51	33. Assumption General Hospital	N.G.	0.012	secondary	Unnamed canal to Lake Verret	Assumption
52	34. Assumption Health Care Center	LA0058980	0.03	20/20	Unnamed canal to Lake Verret	Assumption
53						

	A	B	C	D	E	F
1	APPENDIX 2: TERREBONNE BASIN MUNICIPAL DISCHARGERS					
2	Facility	Permit #	Capacity	Limits	Discharge to:	Parish
54	MUNICIPALITY 1203					
55			(mgd)			
56	1. Acadia Woods	N.G.	0.03	20/20	Drainage ditch to Devil's Swamp to Bayou Terrebonne	Lafourche
57	2. Country Club	N.G.	0.25	10--15	Unnamed ditch to Forty Arpent Canal to Company Canal to Lake Fields to	Lafourche
58	3. Cresent Subdivision	N.G.	0.13	10--15	Little Bayou Black to Bayou Black to Intracoastal Waterway	Terrebonne
59	4. Fairlane Sewage Corp.	LA0040541	0.016	secondary	Bayou Canes to Bayou Terrebonne Swamp Area	Terrebonne
60	5. Oak Grove	N.G.	0.06	10--15	Hollywood Canal to Bayou Blue	Lafourche
61	6. Suburban Estates	N.G.	0.03	20/20	St. Louis Canal to Intracoastal Waterway	Terrebonne
62	7. Superior Sewage/Elmwood	WP0831	N.G.	N.G.	Bayou Folse	Lafourche
63	8. Tara Subdivision	N.C.	0.03	20/20	St. Louis Canal to Intracoastal Waterway	Terrebonne
64	9. Thoroughbred	WP2077	0.065	10--15	Bayou Cut Off to Company Canal to Intracoastal Canal	Lafourche
65	10. Twin Oaks	LA0049344	0.12	10--15	Bayou Cut Off to Lake Fields to Company Canal to Intracoastal Canal	Lafourche
66	11. Al's Trailer Park	N.G.	0.025	20/20	Bayou Cane to Bayou Terrebonne	Terrebonne
67	12. Capri Trailer Park	N.C.	0.025	20/20	St. Louis Canal to Intracoastal Waterway	Terrebonne
68	13. Country Boy	N.G.	0.03	20/20	C.C. ditch to St. Louis Canal to Intracoastal Waterway	Terrebonne
69	14. LeBeouf's Trailer Park	N.G.	0.019	secondary	Bayou Cane to Bayou Terrebonne	Terrebonne
70	15. Seawell Enterprises--Crestview	WP0970	N.C.	N.G.	Bayou Terrebonne	Terrebonne
71	16. Twin Oaks Trailer Park (LaRose	WP0909	0.009	secondary	Highway ditch to Intracoastal Canal	Lafourche
72	17. Matherne	N.G.	0.006	secondary	Bayou Cane	Terrebonne
73	18. Lady of the Sea	N.G.	0.028	20/20	Unnamed canal to Bayou Blue	Lafourche
74	19. Palace Inn Motel	N.C.	0.0004	secondary	St. Louis Canal to Intracoastal Waterway	Terrebonne
75	20. White House Restaurant	WG010007	0.001	30/30	Gulf Intracoastal Waterway	Terrebonne
76	21. White House Restaurant	WG010007	0.0008	45/45	Unnamed ditch to Houma Lake to unnamed ditch to Intracoastal Waterway	Terrebonne
77	22. St. Anne's Professional Park	LA0069183-				
78		WP0667	N.C.	N.G.	Bayou Folse	Lafourche
79	23. Golden Meadow Upper El.	N.C.	0.033	20/20	Unnamed canal to Catfish Lake to Grand Bayou Blue	Lafourche
80	24. Golden Meadow Lower El	N.G.	0.022	secondary	Unnamed canal to Catfish Lake to Grand Bayou Blue	Lafourche
81	25. Golden Meadow Jr. High	N.G.	0.03	20/20	Unnamed canal to Catfish Lake to Grand Bayou Blue	Lafourche
82	26. St. Mary Nativity School	N.G.	0.012	secondary	Drainage canal to Bayou Folse to Lake fields to Company canal to Intrac	Lafourche
83	27. Coteau/Bayou Blue El. (Houma)	LA0050784	0.016	secondary	Bayou Little Coteau to St. Louis Canal to Intracoastal	Terrebonne
84	28. Coteau/Bayou Blue School	WG020045	0.014	30/30	Unnamed ditch to Bayou Devil Swamp to St. Louis Canal to Intracoastal W	Terrebonne
85	29. Caldwell Middle (Schriver)	LA0050776	0.016	secondary	Bayou Cane to Bayou Terrebonne	Terrebonne
86	30. Caldwell Middle	WG020046	0.014	30/30	Unnamed ditch to Ouiski Bayou to Little Bayou Black to Bayou Black	Terrebonne
87	31. Schriver Elementary	WG020034	0.021	30/30	Unnamed drainage canal to Ouiski Bayou to Little Bayou Black to Bayou B	Terrebonne
88	32. Grand Caillou Middle	WG020039	0.025	30/30	Unnamed ditch to Bayou Grand Caillou	Terrebonne
89	33. Evergreen Jr. High (Houma)	LA0040304	N.G.	N.G.	Ouiski Bayou and Bayou Cane	Terrebonne
90	34. Evergreen Jr. High	WG020043	0.022	30/30	Unnamed ditch to Ouiski Bayou to Little Bayou black to Bayou Black	Terrebonne
91	35. Bourgeois, H.G. High School	LA0040282	0.059	10--15	St. Louis Canal to Intracoastal Waterway	Terrebonne
92	36. School Maintenance Facility	WG010046	0.005	45/45	Unnamed ditch to Bayou LaCarpe to Bayou Grand Caillou	Terrebonne
93	37. LA DOTD, Houma Nav. Canal Brid	WG010028	0.0003	45/45	Houma Navigation Canal	Terrebonne
94	38 LA DOTD, Bayou Blue Pontoon Bri	WG010030	0.0003	45/45	Intracoastal Waterway	Lafourche
95	39. LA DOTD, Bayou Terrebonne Brid	WP0621	N.C.	N.G.	Bayou Terrebonne	Terrebonne
96	40. Laf. Parish Housing Authority:					
97	(Raceland/St. Patrick)	LA0047716	N.G.	N.G.	Bayou Folse	Lafourche
98	41. Laf. Parish Housing Authority:					
99	(Raceland/St. Patrick)	LA0047732	N.G.	N.G.	Bayou Folse	Lafourche
100	42. Laf. Parish Housing Authority:					
101	(St. Patrick B Housing Project	N.C.	0.007	secondary	Bayou Cut Off to Lake Fields to Company Canal to Intracoastal Canal	Lafourche
102	43. Laf. Parish Housing Authority:					
103	(St. Patrick C Housing Project	N.G.	0.02	secondary	Bayou Cut Off to lake Fields to Company canal to Intracoastal Canal	Lafourche
104	44. Laf. Parish Housing Authority					

	A	B	C	D	E	F
1	APPENDIX 2: TERREBONNE BASIN MUNICIPAL DISCHARGERS					
2	Facility	Permit #	Capacity	Limits	Discharge to:	Parish
105	(West 21st St. Housing Project	LA0047694	0.012	secondary	Drainage ditch to Intracoastal Canal	Lafourche
106	45. Terrebonne Parish Consol. Govt	LA0040207-				
107	(Main lagoon WWTP)	WP0431	16	10--15	St. Louis Canal	Terrebonne
108	46. Terrebonne Parish Consol. Govt	LA0040215-				
109	(Oakshire Lagoon)	WP0431	1.1	Indiv. analysis	St. Louis Canal to Intracoastal Waterway	Terrebonne
110	47. Terrebonne Parish Consol. Govt	LA0060674-				
111	(???aihi Lagoon)	WP0503	.9(?)	30/50	Big Black Bayou	Terrebonne
112	48. Terrebonne Parish Consol. Govt	LA0050636-				
113	(Village East Lagoon)	WP0503	N.G.	N.G.	Terrebonne River Basin	Terrebonne
114	49. Severage District #12 (Houma)	N.G.	0.242	N.G.	St. Louis Canal	Terrebonne
115	50. Lockport, Town of --STP	LA033286	0.45	10--15	Arpent Canal to Bayou Leau to Intracoastal Canal	Lafourche
116						
117						
118	MUNICIPALITY 1204					
119	1. Southern States Management					
120	Tarpon Heights Shopping	LA0064513-				
121	Plaza (Galliano)	WP0204	N.G.	N.G.	Bayou Lafourche	Lafourche
122	2. Greenwood School	LA0040339	0.006	secondary	Hanson Canal to Bayou Black	Terrebonne
123	3. LA DOTD, Romy Dr. Bridge					
124	(south of Lockport)	WP0745	N.G.	N.G.	Bayou Lafourche	Lafourche
125	4. Morgan City Sewage Force					
126	Line Discharge (Federal)	LA0040576	3	Ind. Analysis	Bayou Boeuf	St. Mary
127	5. Sewerage District #24					
128	(Houma)	N.G.	2.5	Ind. Analysis	Bayou Black to Waterproof Canal	Terrebonne
129	6. Terrebonne Parish Recre-					
130	ation District #10 (Theriot)	LA0049361	N.G.	N.G.	Marmande Canal to Monors Canal	Terrebonne
131		WG10013	0.0005	30/30	Houma Navigation Canal	Terrebonne
132						
133	MUNICIPALITY 1205					
134	1. Bayou Dularge Elementary	WG020048	0.009	30/30	Unnamed ditch to Bayou Dularge	Terrebonne
135	2. Boudreaux Canal (Chauvin)	LA0040363	0.006	N.G.	Bayou Little Caillou	Terrebonne
136	3. Boudreaux Canal	WG0047	0.005	30/30	Unnamed ditch to Boudreaux Canal to Bayou Petit Caillou	Terrebonne
137	4. Dularge Elementary	N.G.	0.006	secondary	Bayou Dularge	Terrebonne
138	5. Dularge Middle	WG020044	0.014	30/30	Unnamed ditch to Bayou Dularge	Terrebonne
139	6. Dularge Middle (Houma)	LA0072885	0.017	secondary	Bayou Dularge	Terrebonne
140	7. Grand Caillou Elem.	LA0040321	0.012	secondary	Bayou Grand Caillou	Terrebonne
141	8. Grand Caillou elem	WG020034	0.025	30/30	Unnamed ditch to Bayou Grand Caillou	Terrebonne
142	9. Schriever School (Schriever)	LA0040401	0.016	secondary	Drainage Canal to Bayou Terrebonne	Terrebonne
143	10. Upper Caillou Elem.	WG020033	0.0175	30/30	Unnamed canal to Boudreaux Canal to New Canal to Lake Boudreaux	Terrebonne
144	11. LA DOTD, Bayou Dulac Bridge	WG010029	0.0003	45/45	Bayou Dulac to Lake Boudreaux	Terrebonne
145	12. LA DOTD, Bayou LaCarpe Bridge	WG010026	0.0003	45/45	Bayou LaCarpe to Houma Navigation Canal	Terrebonne
146	13. LA DOTD, Falgout Canal Bridge	WG010027	0.0003	45/45	Falgout Canal to Lake DeCade	Terrebonne
147	14. Terrebonne Parish Consol.	LA0062111-				
148	Govt., Ashland Landfill	WP0186	N.G.	N.G.	St. Louis Canal	Terrebonne
149	15. Terrebonne Parish Consol.					
150	Govt., Bobtown STP	N.G.	0.012	30/30	Bayou Grand Caillou	Terrebonne
151	16. Terrebonne Parish Consol.					
152	Govt., Dularge Lagoon--	LA0040223-				
153	Fairfield Subdiv. (Houma)	WP0505	0.28	secondary	Houma Navigation Canal via a swamp	Terrebonne
154	17. Terrebonne Parish Consol.					
155	Govt., Houma, South Plant	LA00400274	3.3	secondary	Houma Navigation Canal	Terrebonne

	A	B	C	D	E	F
1	APPENDIX 2: TERREBONNE BASIN MUNICIPAL DISCHARGERS					
2	Facility	Permit #	Capacity	Limits	Discharge to:	Parish
156	18. Terrebonne Parish Consol.					
157	Govt., S. Terrebonne Est. Lagoo	LA0038954	0.042	10--15	Company Canal to Bayou Terrebonne	Terrebonn
158	19. Crozier Heights	N.G.	0.024	secondary	Bayou Grand Caillou	Terrebonn
159	20. Dulac Sanitary Sewer					
160	Improvements	WP2244	0.0249	30/30	Bayou Grand Caillou	Terrebonn
161	21. B.J. Titan Services (Houma)	WP0239	N.G.	N.G.	Bayou Grand Caillou	Terrebonn
162	22. N.L. Baroid--Dulac Facility	WG010014	0.001	30/30	Bayou Grand Caillou	Terrebonn
163	23. Unocal Pipeline Co. Office	LA0040444-				
164		WG10013	0.0005	30/30	Houma Navigation Canal	Terrebonn
165						
166	MUNICIPALITY 1206					
167	1. Montegut Elementary	WG020037	0.006	30/30	Unnamed ditch to Bayou Terrebonne	Terrebonn
168	2. Montegut Middle	WG020036	0.0175	30/30	Unnamed drainage canal to a marsh to Point Aux Chenes Bayou	Terrebonn
169	3. Pointe-au-Chein Elem.	WG020035	0.012	30/30	Unnamed ditch to Niqverie Canal to Bayou St. Jean Charles	
170					to Bayou Terrebonne	Terrebonn
171	4. Terrebonne High School	LA0040398	0.035	20/20	Drainage Canal to Intercoastal Waterway	Terrebonn
172	(Bourg)					
173	5. LA DOTD, Boudreaux Bridge	WG010022	0.0003	45/45	Boudreaux Canal to Lake Boudreaux	Terrebonn
174	6. LA DOTD, Boudreaux Bridge	WG010023	0.0003	45/45	Company Canal to Bayou Terrebonne	Terrebonn
175	7. LA DOTD, Montegut Bridge	WG010025	0.0003	45/45	Bayou Terrebonne	Terrebonn
176	8. LA DOTD, Sarah Bridge	WG010024	0.0003	45/45	Bayou Little Caillou	Terrebonn
177	9. Terr. Parish Consolidated	LA0076732-				
178	Govt., Bourg Heights Lagoon	WP1791	0.021	secondary	Bayou Terrebonne to Lake Barre to Bayou Lafourche	Terrebonn
179						
180	MUNICIPALITY 1207					
181	1. Lacache School	WG020038	0.012	30/30	Unnamed drainage canal to New Canal to Lake Boudreaux	Terrebonn
182	2. Lacache School (Lacache)	LA0040371	0.012	secondary	Lake Boudreaux, New Canal	Terrebonn
183	3. Little Caillou (Chauvin)	LA0040291--	0.00217	30/30	Marsh to Lake Boudreaux to Bayou Little Caillou	Terrebonn
184		WG010045				
185	4. Lower Montegut (Montegut)	LA0040428	0.014	secondary	Drainage canal to Bayou Barre to Lake Barre	Terrebonn
186	5. Montegut Middle (Montegut)	LA0040428	0.014	secondary	Lake Barre Drainage to Bayou Barre	Terrebonn
187	6. Pointe-au-Chein (P-au-C)	LA0040380	0.024	secondary	Bayou Jean LaCroix to Lake Felicity to Lake Barre	Terrebonn
188	7. Golden Meadow, Town Landfill	LA0061778--	N.C.	N.C.	Unnamed marsh	Lafourche
189		WP0315				
190	8. Lafourche Parish Housing					
191	Authority, Palmetto Street	LA0047686	N.G.	N.G.	Catfish Lake	Lafourche
192	9. Terrebonne Parish Consol.					
193	Govt., Orange St. STP	LA0075302	0.024	secondary	Lake Boudreaux	Terrebonn
194	10. Central Heights	N.G.	0.04	20/20	Bayou Chauvin & Lake Boudreaux Canal	Terrebonn
195						
196	MUNICIPALITY 1208					
197	0					

APPENDIX 3

BARATARIA BASIN MUNICIPAL DISCHARGERS

Municipal dischargers selected for consideration for wetland wastewater treatment in segments 0201 through 0211 in the Barataria Basin.

	A	B	C	D	E	F
1	**APPENDIX 3: BARATARIA BASIN MUNICIPAL DISCHARGES**					
2	**Facility**	**Permit #**	**Capacity**	**Limits**	**Discharge to:**	**Parish**
3			**(MGD)**			
4	**MUNICIPALITY 0201**					
5	Abby Plantation Estates	na	0.12	10\15	80 Arpent Canal to L. Bouef	Lafourche
6	Ascension Parish Jail	na	0.013	Secondary	B. Verret to B.Grand to Lac Des Allemands	Ascension
7	Aucoin's Sewer U. Service-St. Jude Subdiv.	WP1786	0.045	20/20	B. Verret to B. Grand to Lac Des Allemands	Ascension
8	Aysenne Construction Inc. -Greenbriar Estates	WP0983	na	na	Baker canal to Des Allemands	Assumption
9	Country Estates Trailer Park	na	0.03	20/20	Rathborne Swamp to Lake Des Allemands	Assumption
10	Donaldsonville, City of - Oxidation Pond	LA0043931	1.5	hdiv. Analys	Outfall Canal to B. Napolean	Ascension
11	Elmfield Subdivision	na	0.04	20/20	Rathborne Swamp to Lake Des Allemands	Assumption
12	Fifth Ward Elementary	na	0.015	Secondary	Bayou Chevreuil	St. James
13	Lafourche P. Housing Author. Allidor St. STP Rac	LA0047724	0.017	Secondary	Bower Canal to B. Boeuf	Lafourche
14	Lafourche P. Housing A. Lafourche Housing Proj.	LA0066290-WP0818	0.013	Secondary	80 Arpent Canal	Lafourche
15	Lucky Hit #2	na	0.07	10\15	Baker Canal to Des Allemands	Assumption
16	Magnolia Subdivision	na	0.025	20/20	Baker Canal to Des Allemands	Assumption
17	Raceland Jr. high	na	0.03	20/20	Bowie Canal to Bayou Boeuf	Lafourche
18	Raceland Lower Elem.	na	0.017	Secondary	Bowie Canal to Boyou Boeuf	Lafourche
19	Sixth Ward Elem.	na	0.015	Secondary	B. Chevreuil	St. James
20	St. James High	na	0.15	Secondary	B. Chevreuil	St. James
21	St. James Jr. High	na	0.013	Secondary	B. Chevreuil	St. James
22	St. James Parish Housing A. Baytree Housing Pro	LA0068136-WP1105	0.019	Secondary	St. James Canal	St. James
23	St. James Parish Housing A. Hymel Hous. Proj. W	LA0046922-WP0594	0.01	Secondary	St. James Canal	St. James
24	St. James Sugar Corp., Inc. St. James Sugar Mil	LA0002984-WP0441	0.005	Secondary	B. Chevreuil	St. James
25	Twelve Cedars Severage Corp. Twelve Cedars Subd	LA0068965	0.0105	Secondary	80 Arpent Canal to L. Boeuf	Lafourche
26	Vacherie Courthouse Annex	na	0.007	Secondary	Webre Steib Canl to Lac Des Allemands	St. James
27	Vacherie Elementary	na	0.01	Secondary	Lac Des Allemands	St. James
28	Vacherie Primary	na	0.005	Secondary	Lac Des Allemands	St. James
29	West St. James Hospital	na	0.009	Secondary	Vacherie Relief Canal30 to Brogan Tie in canal	St. James
30	**MUNICIPALITY 0202**					
31	Dixieland Subdiv.	na	0.04	20/20	Drainage Canal to marsh	St.Chrles.
32	Edgard Housing Project	na	0.012	20/20	Scully Canal to Little Lake	Lafourche
33	Greenwood Landing Assoc. Greenwood Apts. Thibod	WP0111	NA	NA	80 Arpent Canal	Lafourche
34	Home Place Subdivision	na	0.075	10\15	St. Charles Canal to Providence Canal	St.Chrles.
35	J.B. Martin J. High	na	0.012	Secondary	Drainge Canal to marsh	St.Chrles.
36	Pecan Oaks Subsiv. Treatment Plant	na	0.015	Secondary	Lac Des Allemands	St.Chrles.
37	St. Charles Parish Council Hahnville STP	LA0073521	0.4	10\15	Providence Canal to 80 Arpent Canal to Lac Des	St.Chrles.
38	St. James Parish Housing Auth. Bacherie Housing	LA0046914-WP0593	0.018	Secondary	Bayou Lasseigne to DA	St. James
39						
40	**MUNICIPALITY 0203**					
41	Boute Oxidation	NA	1	hdiv. Analys	George Cousin canal	St.Chrles.
42	Lafourche Parish Housing A.- West 21st street(L	LA0047694	NA	na	Intracoastal Waterway	Lafourche
43	Paradise Apts. Partnership Paradin Apts.	NA	0.05	10\15	Crawford Canal to Bayou Gauche	St.Chrles.
44	St. Charles Parish Council-Ana heights Subdiv.	WPOO61	NA	na	Lanaux Canal	St.Chrles.
45	St. Charles Parish Council-B. Gauche STP Des Al	LAOO73504-WP0815	0.15	10\15	Bayou Gauche	St.Chrles.
46	St. Charles Parish Council-Paradis STP-(Paradis	LA0073512-WP0814	0.125	10\15	Paradis Canal	St.Chrles.
47	St. Charles P. Severage Dist. #3-Sewage Oxidati	LA0032131	1	hdiv. Analys	George Cousin Canal	
48						
49	**MUNICIPALITY 0204**					

	A	B	C	D	E	F
1	APPENDIX 3: BARATARIA BASIN MUNICIPAL DISCHARGERS					
2	Facility	Permit #	Capacity	Limits	Discharge to:	Parish
50	Assumption High School	NA	0.03	20/20	Bayou Lafourche	Assumption
51	Aucoin's Sewer Util. Serv.-Bon Service Shopping	WG022265	0.0234	30/30	Bayou Lafourche	Lafourche
52	Aucoin's Sewer Util. Serv.-Elmfield Subdiv.	WG020065	0.004	30/30	Bayou Lafourche	Assumption
53	Aucoin's Sewer Util. Serv.-Kingston Subdiv.	WG020059	0.018	30/30	Unnamed ditch to Bayou Lafourche	Assumption
54	Aucoin's Sewer Util. Serv.-Labedie Estates Subd	WG020054	0.0176	30/30	Bayou Napoleon to Bayou Lafourche	Assumption
55	Aucoin's Sewer Util. Serv.-Lucky Hit Shoppin Ce	WG020066	0.0155	30/30	Bayou Napoleon to Bayou Lafourche	Assumption
56	Aucoin's Sewer Util. Serv.-Magnolia Subdiv.	WG030005	0.0352	20/20	Bayou Napoleon to Bayou Lafourche	Ascension
57	Aucoin's Sewer Util. Serv.-Aucoin's Trailer Par	WG020064	0.012	30/30	Bayou Napoleon to Bayou Lafourche	Ascension
58	Aucoin's Sewer Util. Serv.-Lucky Hit Subdiv.	WG020053	0.0192	30/30	Bayou Lafourche	Assumption
59	Bayou Lafourche Academy	NA	0.013	Secondary	Bayou Lafourche	Ascension
60	Kingston E. Subdivision	NA	0.018	Secondary	Bayou Lafourche	Assumption
61	La. Dept. of Trans. and Develop.B. Lafourche Br	WG010038	0.0003	45/45	Bayou Lafourche	Lafourche
62	La. Dept. of Trans. and Develop.B. Lafourche Br	WG010040	0.0003	45/45	Bayou Lafourche	Lafourche
63	La. Dept. of Trans. and Develop. Intracoastal (	WG010039	0.0003	45/45	Intracoastal Waterway	Lafourche
64	Labadieville Middle School	NA	0.007	Secondary	Bayou Lafourche	Assumption
65	Labadieville Primary School	NA	0.004	Secondary	Bayou Lafourche	Assumption
66	Lafourche p. Housing A. Lafouche H. Proj. Hwy 3	LA0066303-WP0819	0.012	Secondary	Bayou Lafourche	Lafourche
67	Larose Bon-Service Shopping Center	NA	0.01	Secondary	Bayou Lafourche	Lafourche
68	Pal's Fried Chicken Restaurant of Larose	WG010009	0.001	45/45	Bayou Lafourche	Lafourche
69	Sako Nursing Home	NA	0.009	Secondary	Bayou Lafourche	Lafourche
70	St. Philomena School	NA	0.007	Secondary	Bayou Lafourche	Assumption
71						
72	MUNICIPALITY 0205					
73	Jefferson P. Dept. of Util. Sludge Lagoon	LA0058813	NA	NA	Saule Canal	Jefferson
74	Lafourche P. HOUsing A. East 69th St.\LA-80-48	LA0047678	NA	NA	Breton Canal	Lafourche
75						
76	MUNICIPALITY 0206					
77	Belle Chase State School	NA	0.05	10\15	Planter's Canal	Plaqumns.
78	Belle Chase, city of	NA	3	hdiv. Analys	Unnamed streeam	Plaqumns.
79	Creole Enterprises	NA	0.205	10\15	Intracoastal Canal	Plaqumns.
80	New Orleans Sewerage and Water Board-Westbank S	LA0038105-WP2109	10	10\15	Orleans Canal to Intracoastal Waterway	Orleans
81	Shady Oaks Mobile Home Park-(Marrero)	LA0064122-WP0287	NA	NA	Bayou Des Familles	Jefferson
82	U.S. Dept. of the Army-Naval Air Station Bachel	LA0047384	NA	NA	Outfall canal (Barataria Bay Basin)	Plaqumns.
83	U.S. Dept. of the Army-Naval Air Station Enlist	LA0047376	NA	NA	Outfall canal (Barataria Bay Basin)	Plaqumns.
84	Wash Me Carwash -(Marrero)	LA0059447	NA	NA	Bayou Des Familles	Jefferson
85						
86	MUNICIPALITY 0207					
87	Barataria Tavern	NA	0.007	Secondary	Goose Bayou to Barataria Bay	Jefferson
88	Fisher High School	NA	0.005	Secondary	Baratarea Bay	Jefferson
89	Jefferson Parish Dept. of Util-Marrero Oxidatio	LA0041998	NA	NA	Bayou Boeuf	Jefferson
90	Westwego, city of	LA0038059-WP1148	3	10\15\3\5\	Bayou Segnette	Jefferson
91						
92	MUNICIPALITY 0208					
93	Bayou Bend Enterprise Inc. Bayou Oaks Subdiv (C	LA0036111-WP0703	0.042	20/20	Scully canal to Little Lake	Lafourche
94	E. 22nd St. Housing Project	NA	0.025	20/20	Scully Canal to Little Lake	Lafourche
95	Lafitter Trailer Park	LA0079651-WP1200	NA	NA	Barataria waterway	Jefferson
96	Lafourche Parish Housing Authority (Larose)	LA0047708	NA	NA	Bayou Pognard	Lafourche

	A	B	C	D	E	F
1	**APPENDIX 3: BARATARIA BASIN MUNICIPAL DISCHARGERS**					
2	**Facility**	**Permit #**	**Capacity**	**Limits**	**Discharge to:**	**Parish**
97	Windmill II Mobile Home Park (Alliance)	WP0890	NA	NA	Ollie Drainage	Assumption
98						
99	**MUNICIPALITY 0209**					
100	Tampon Heights Plaza	NA	0.1	10\15	Breton Canal to Barataria Bay	Lafourche
101	South Lafourche High School	NA	0.01	Secondary	Breton Canal to Barataria Bay	Lafourche
102	East 69th Street Housing Project	NA	0.025	20/20	Scully Canal to Little Lake	Lafourche
103						
104	**MUNICIPALITY 0210**					
105	Exxon Company Port Sulphur H.Q.Office	WG010010	0.00024	45/45	Unnamed ditch to marsh to Bay Lenaux	Plaqumns.
106						
107	**MUNICIPALITY 0211**					
108	Citrus Lands of La., Inc. (Myrtle Grove)	LA0066907-WP0493	NA	NA	Barataria Bay	Plaqumns.
109	Grand Isle, town of Grand Isle community Center	WG010011	0.002	45/45	Unnamed ditch to Grand Isle Drainage System to	Jefferson
110	Martin's Marina Apts. (Grand Isle)	LA0046647	NA	NA	Bayou Rigaud	Jefferson
111	Pirates Cove Marina (Grand Isle)	WP0920	NA	NA	Bayou Rigaud	Jefferson

VITA

Andree M. Breaux was born in New Orleans, LA, USA on October 31, 1954. She graduated from the Academy of the Sacred Heart in Grand Coteau, LA in 1972. She received a Bachelor of Arts in History from the University of California, Berkeley in 1976. She lived in Oxford, England from 1977-1979 where she taught English as a foreign language. In 1980 she accepted a research position at the Survey Research Center, University of California in Berkeley, where she worked on the internal political structure of environmental organizations. In 1989, she received a Master of Science degree, with a concentration in wildlife and water resource policy, from the School of Forestry and Environmental Studies at Yale University. In that same year, she entered the PhD program in the Department of Oceanography and Coastal Sciences at Louisiana State University as a Board of Regents fellow, and was awarded the degree in 1992. The primary focus of her studies has been on wetland science.

DOCTORAL EXAMINATION AND DISSERTATION REPORT

Candidate: Andree M. Breaux

Major Field: Oceanography and Coastal Sciences

Title of Dissertation: The Use of Hydrologically Altered Wetlands to Treat Wastewater in Coastal Louisiana

Approved:

Major Professor and Chairman

Dean of the Graduate School

EXAMINING COMMITTEE:

Date of Examination:

June 26, 1992