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Agency

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September 1993

Constructed Wetlands for Wastewater Treatment and Wildlife Habitat

17 Case Studies

The symbol on the cover of this report was developed in Washington State by a group of state and federal agencies working in cooperation with a private real estate firm, Port Blakely Mill Company. It is available free of charge for use in any program dealing with wetland preservation and enhancement. To date, organizations in 33 states are using the symbol. For more information, contact:

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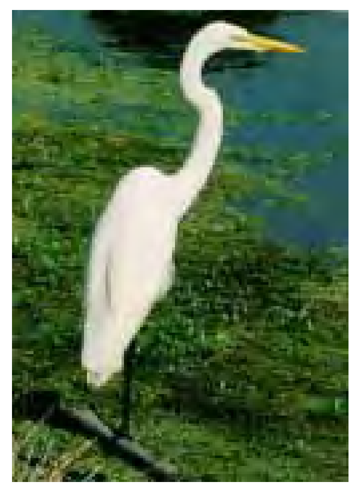

- Orlando, FL (Orlando Easterly Wetlands Reclamation Project)
- Lakeland, FL
- Incline Village, NV
- ShowLow, AZ (Pintail Lake & Redhead Marsh)
- Pinetop/Lakeside, AZ (Jacques Marsh)
- Fort Deposit, AL
- West Jackson Co., MS
- Hillsboro, OR (Jackson Bottom Wetlands Preserve)
- Des Plaines River, IL
- Concerned Citizen Questionaire

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The operational experience and research results reported in the available literature suggest that the growing interest in the use of constructed wetlands as a part of water treatment offers considerable opportunity for realizing sizable future savings in wastewater treatment costs for small communities and for upgrading even large treatment facilities.

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Jackson Bottom Wetlands Preserve

In addition, insights on the habitat value and wildlife usage of many of the facilities described were provided by field data collected and summarized by the EPA Environmental Research Lab., Corvallis, OR, in cooperation with ManTech Environmental Technology Inc.; the Cooperative Fish & Wildlife Research Unit, Dept. of Wildlife & Range Sciences, University. of Florida-Gainesville; and the Nevada Department of Wildlife.

The case studies were not subject to the Agency's peer and administrative review. Mention of specific case studies does not constitute endorsement or categorical recommendation for use by the U.S. EPA. While EPA believes that the case studies may be very useful to the reader, EPA does not select or endorse one alternative technology over other approaches to treat or reuse wastewater effluents.

Foreword

Extensive research efforts have provided considerable insight into the design, operation and performance of natural and constructed wetlands treatment systems.

Intensive studies carried out for over 5 years at Santee, CA, evaluated the performance of constructed wetlands experimental units planted with reeds, cattails, and bulrush..

Wastewater treatment is a problem that has plagued man ever since he discovered that discharging his wastes into surface waters can lead to many additional environmental problems. The Clean Water Act (P.L.92-500 passed in 1972 and its more recent amendments) led to the construction of many new wastewater treatment facilities across the country to help control water pollution. In the future add-on processes will be needed to upgrade many of these treatment facilities. In addition, more attention will need to be given to controlling the many small volume, point sources as well as the numerous non-point sources of water pollution if the water quality objectives of the Clean Water Act are ever to be fully realized.

Today, a wide range of treatment technologies are available for use in our efforts to restore and maintain the chemical, physical, and biological integrity of the nation's waters. During the past 20 years, considerable interest has been expressed in the potential use of a variety of natural biological systems to help purify water in a controlled manner. These natural biological treatment systems include various forms of ponds, land treatment and wetlands systems. As a result of both extensive research efforts and practical application of these technologies, considerable insight has been gained into their design, performance, operation and maintenance. Much of this experience has been summarized in project summaries, research reports, technical papers and design guidance.

Some of the earliest investigations to explore the capabilities of various wetland and other aquatic plant systems to help treat wastewater were undertaken in various European countries by Seidel, Kickuth, de Jong and others. Related studies were eventually undertaken by Spangler, Sloey, Small, Gersberg, Goldman, Dinges, Wolverton, Reddy, Richardson and others in numerous locations across the U.S.

Kadlec, Odum and Ewel, Valiela, Teal, and others have undertaken long-term assessments of the capabilities of several types of natural wetlands to handle wastewater additions. Funding provided by the National Science Foundation, U.S. Department of the Interior, National Aeronautics and Space Administration, Environmental Protection Agency, U.S. Army Corps of Engineers, U.S. Department of Agriculture and others has played an important role in stimulating the development of the available information and guidance on constructed wetland treatment systems in the U.S.

Long-term observations and studies of northern wetlands receiving wastewater effluents have followed the impact of changes in nutrient loadings and hydrology on vegetation and wildlife use at projects such as the Drummond Bog in Northern Wisconsin.

The operational experience and research results reported in the available literature suggest that the growing interest in the use of constructed wetlands as a part of water treatment offers considerable opportunity for realizing sizable future savings in wastewater treatment costs for small communities and for upgrading even large treatment facilities. At the same time, as is demonstrated by the 17 wetland treatment system case studies located in 10 states that are presented in this document, these systems can provide valuable wetland habitat for waterfowl and other wildlife, as well as areas for public education and recreation. Clearly such systems create an opportunity to contribute to the Nation's efforts to restore, maintain and create valuable wetland habitat.

Michael B. Cook, Director
Office of Wastewater Management

Robert H. Wayland III, Director
Office of Wetlands, Oceans, and Watersheds

Constructed wetlands are being effectively used to help protect the quality of urban lakes by improving the quality of stormwater runoff in urban areas such as at the Greenwood Urban Wetland, a former dump site, in Orlando, Florida.

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Introduction

The potential for achieving improved water quality while creating valuable wildlife habitat has lead to a growing interest in the use of constructed wetlands for treating and recycling wastewater. While land intensive, these systems offer an effective means of integrating wastewater treatment and resource enhancement, often at a cost that is competitive with conventional wastewater treatment alternatives. This document provides brief descriptions of 17 wetland treatment systems from across the country that are providing significant water quality benefits while demonstrating additional benefits such as wildlife habitat. The projects described include systems involving both constructed and natural wetlands, habitat creation and restoration, and the improvement of municipal effluent, urban stormwater and river water quality. Each project description was developed by individuals directly involved with or very familiar with the project in a format that could also be used as a stand-alone brochure or handout for project visitors.

Many of the same values associated with natural wetlands can also be realized by wetlands constructed for wastewater polishing.

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Background

Natural wetlands (e.g., swamps, bogs, marshes, fens, sloughs, etc.) are being recognized as providing many benefits, including: food and habitat for wildlife; water quality improvement; flood protection; shoreline erosion control; and opportunities for recreation and aesthetic appreciation. Many of these same benefits have been realized by projects across the country that involve the use of wetlands in wastewater treatment.

In the Southeast alone, over 500 natural wetlands such as this cyprus strand in Florida receive discharges from POTWs and other point sources.

Many freshwater, brackish, and saltwater wetlands have inadvertently received polluted runoff and served as natural water treatment systems for centuries. Wetlands, as waters of the U.S., have been subjected to wastewater discharges from municipal, industrial and agricultural sources, and have received agricultural and surface mine runoff, irrigation return flows, urban stormwater discharges, leachates, and other sources of water pollution. The actual impacts of such inputs on different wetlands has been quite variable.

However, it has only been during the past few decades that the planned use of wetlands for meeting wastewater treatment and water quality objectives has been seriously studied and implemented in a controlled manner. The functional role of wetlands in improving water quality has been a compelling argument for the preservation of natural wetlands and in recent years the construction of wetlands systems for wastewater treatment. A growing number of studies have provided evidence that many wetlands systems are able to provide an effective means of improving water quality without creating problems for wildlife. However, in some cases evidence has shown a resulting change in wetland community types and a shift to more opportunistic species.

There remain, however, concerns over the possibility of harmful effects resulting from toxic materials and pathogens that may be present in many wastewater sources. Also, there are concerns that there may be a potential for long-term degradation of natural wetlands due to the addition of nutrients and changes in the natural hydrologic conditions influencing these systems. At least in part due to such concerns, there has been a growing interest in the use of constructed wetlands for wastewater treatment.

Constructed wetlands treatment systems are engineered systems that have been designed and constructed to utilize the natural processes involving wetland vegetation, soils, and their associated microbial assemblages to assist in treating wastewater. They are designed to take advantage of many of the same processes that occur in natural wetlands, but do so within a more controlled environment. Some of these systems have been designed and operated with the sole purpose of treating wastewater, while others have been implemented with multiple-use objectives in mind, such as using treated wastewater effluent as a water source for the creation and restoration of wetland habitat for wildlife use and environmental enhancement.

A recently expanded Subsurface Flow constructed wetland system serves the small community of Monterey in Highland Co., Virginia.

Constructed wetlands treatment systems generally fall into one of two general categories: **Subsurface Flow Systems** and **Free Water Surface Systems**. Subsurface Flow Systems are designed to create subsurface flow through a permeable medium, keeping the water being treated below the surface, thereby helping to avoid the development of odors and other nuisance problems. Such systems have also been referred to as "root-zone systems," "rock-reed-filters," and "vegetated submerged bed systems." The media used (typically soil, sand, gravel or crushed rock) greatly affect the hydraulics of the system. Free Water Surface Systems, on the other hand, are designed to simulate natural wetlands, with the water flowing over the soil surface at shallow depths. Both types of wetlands treatment systems typically are constructed in basins or channels with a natural or constructed subsurface barrier to limit seepage.

Constructed wetlands treatment systems have diverse applications and are found across the country and around the world. While they can be designed to accomplish a variety of treatment objectives, for the most part, Subsurface Flow Systems are designed and operated in a manner that provides limited opportunity for benefits other than water quality improvement. On the other hand, Free Water Surface Systems are frequently designed to maximize wetland habitat values and reuse opportunities, while providing water quality improvement.

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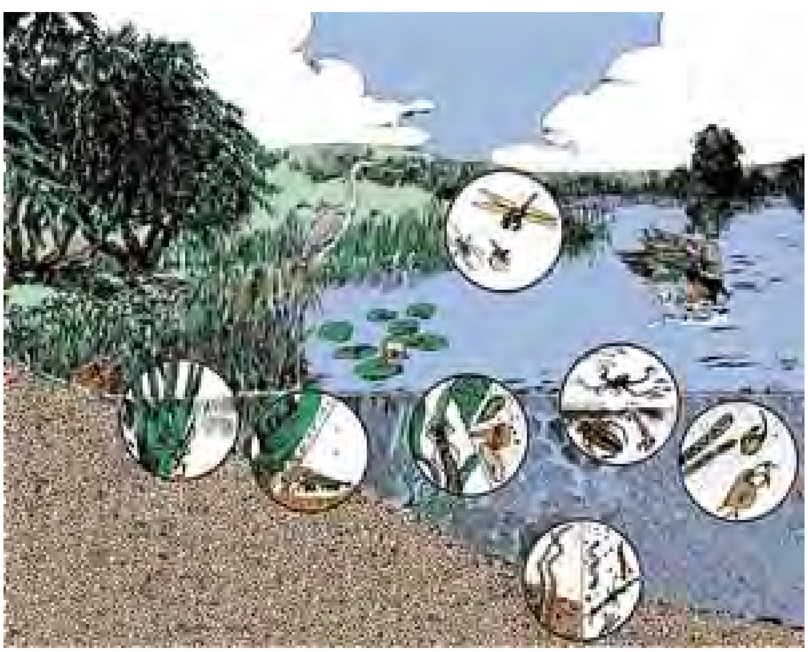
Free Water Surface Constructed Wetlands Systems

"The wide diversity of organisms coupled with the high level of productivity makes a marsh a hot bed of biological activity. The most striking improvement is the removal of suspended solids. Suspended solids in the Arcata STP are algae which supply oxygen in their secondary treatment ponds. These algae solids become entrapped, impacted, and isolated in small quiescent areas around the stems and underwater portions of aquatic plants as the water moves through marshes. The algal solids in these quiescent areas become food sources for microscopic aquatic animals and aquatic insects. This predation plays an important part in removing the solids and in moving energy through the food chain in the wetland. Over time, wetlands continue to separate and deposit suspended solids building deltas comprised of organic matter. At some point this detrital layer in the bottom of the marsh along with dead aquatic plants may need to be removed. Based on Arcata's experience this maintenance requirement is not expected until at least 8-10 years of operation at design loads."

Just how do constructed wetlands, in this case free water surface systems, remove pollutants from the wastewater effluent? These systems affect water quality through a variety of natural processes that occur in wetlands. An explanation of the major processes involved are effectively described by Robert A. Gearheart in a paper contained in the proceedings of a conference on wetlands for wastewater treatment and resource enhancement at Humbolt State University in Arcata, CA, during 1988 [1]:



Dissolved biodegradable material is removed from the wastewater by decomposing microorganisms which are living on the exposed surfaces of the aquatic plants and soils. Decomposers such as bacteria, fungi, and actinomycetes are active in any wetland by breaking down this dissolved and particulate organic material to carbon dioxide and water. This active decomposition in the wetland produces final effluents with a characteristic low dissolved oxygen level with low pH in the water. The effluent from a constructed wetland usually has a low BOD as a result of this high level of decomposition.

Aquatic plants play an important part in supporting these removal processes. Certain aquatic plants pump atmospheric oxygen into their submerged stems, roots, and tubers. Oxygen is then utilized by the microbial decomposers attached to the aquatic plants below the level of the water. Plants also play an active role in taking up nitrogen, phosphorus, and other compounds from the wastewater. This active incorporation of nitrogen and phosphorus can be one mechanism for nutrient removal in a wetland. Some of the nitrogen and phosphorus is released back into the water as the plants die and decompose. In the case of nitrogen much of the nitrate nitrogen can be converted to nitrogen gas through denitrification processes in the wetland."

Free Water Surface constructed wetlands treatment systems and related natural systems used as a part of treatment systems have been successfully used across the country. Many of these systems have been designed and operated to not only improve water quality, but to also provide high quality wetland habitat for waterfowl and other wildlife. Many of the systems are operated as wildlife refuges or parks as well as a part of wastewater treatment, reuse or disposal systems. In some cases these systems also provide an area for public education and recreation in the form of birding, hiking, camping, hunting, etc.

U.S. Bureau of Reclamation/Eastern Municipal Water District Wetlands Research Facility, San Jacinto, California. This site is a popular spot for local schools to tour and study wetlands ecology. One of the multi-purpose elements of the project is public education and recreation.

The operational experience and research results reported to date suggest that the growing interest in managing constructed wetlands systems as a part of wastewater treatment and habitat creation/maintenance efforts offers considerable opportunities for the future. The technical feasibility of implementing such projects has been clearly demonstrated by full-scale systems in various parts of the country. However, it is also clear that there is still a long way to go before such systems will be considered for routine use. While existing projects have demonstrated the potential for future use of constructed wetlands systems, there is an obvious need for further study to improve our understanding of the internal components of these systems, their responses and interactions, in order to allow for more optimum project design, operation and maintenance.

[1] *Allen, G.H. and R.A. Gearheart (eds.). 1988. Proceedings of a Conference on Wetlands for Wastewater Treatment and Resource Enhancement. Humbolt State Univ., Arcata, CA.*

Case Studies

Descriptions of 17 carefully selected projects located in 10 states (see Figure 1) are provided that help describe the full range of opportunity to treat and reuse wastewater effluents that exist across the country today. They include systems involving both constructed and natural wetlands, habitat creation and restoration, and the improvement of municipal wastewater effluents, urban stormwater and river water quality. Many of the projects received Construction Grants funding and several were built on Federal lands. All experience extensive wildlife usage, some providing critical refuge for rare plants and animals. Several are relatively new projects while others have been operating for 15-20 years. There are projects involving as few as 15 acres and several with more than 1,200 acres of wetland habitat. Among those described in this document are projects which have received major awards such as the ASCE Award of Engineering Excellence, the ACEC Grand Conceptor Award, and the Council Award, the ESA Special Recognition Award, and the Ford Foundation Award for Innovation in a Local Government Project.

The case studies demonstrate that wastewater can be effectively treated, reused and recycled with free water surface wetland systems in an environmentally sensitive way. They also demonstrate that wastewater treatment and disposal can be effectively integrated into recreational, educational, and wildlife habitat creation/wetland restoration efforts so as to enhance the value of a city's capital investment in wastewater treatment facilities. Greater recognition of these model projects may help lead to projects of high quality being developed in the future.

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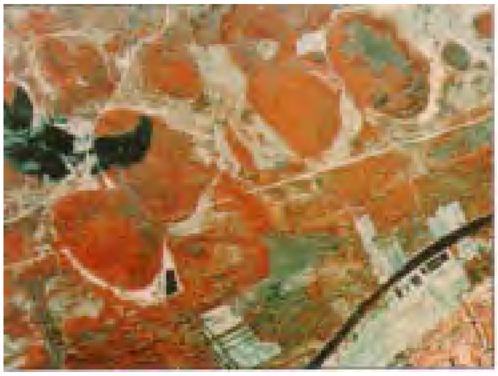
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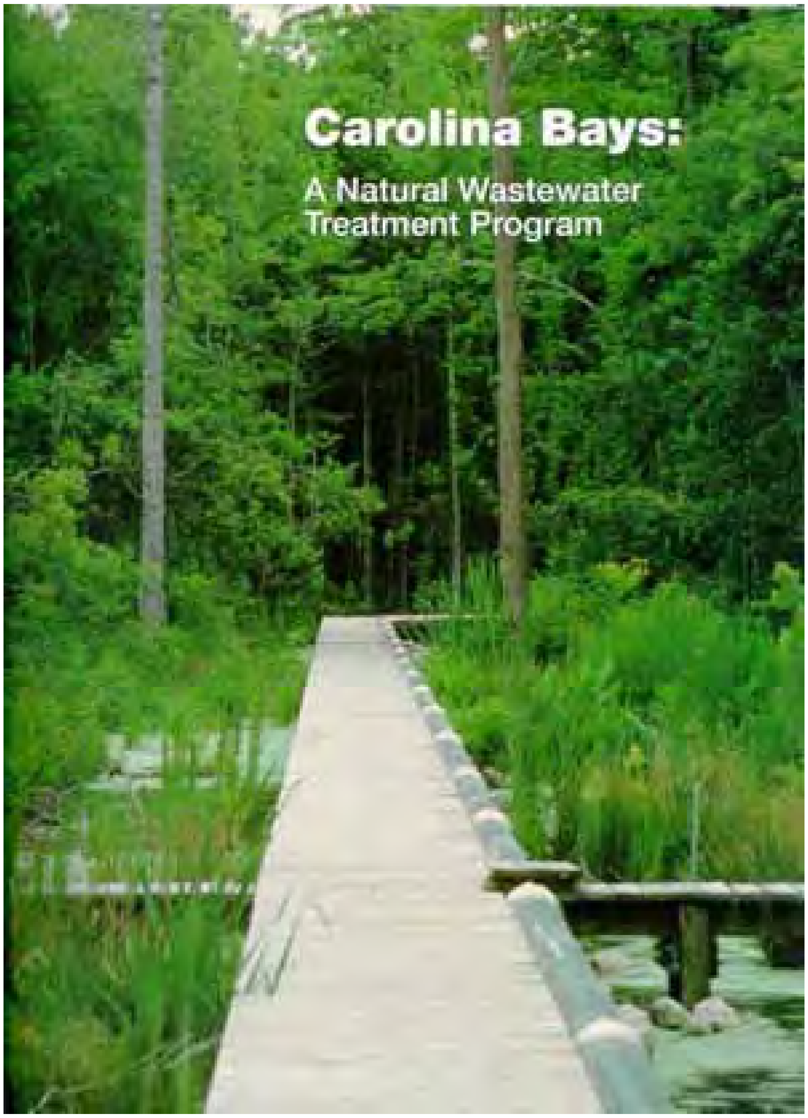
Bottles with representative samples (taken from the influent [on left] to final [on right] sample stations) from the Houghton Lake, MI, wetland treatment system which has been in operation since 1978.

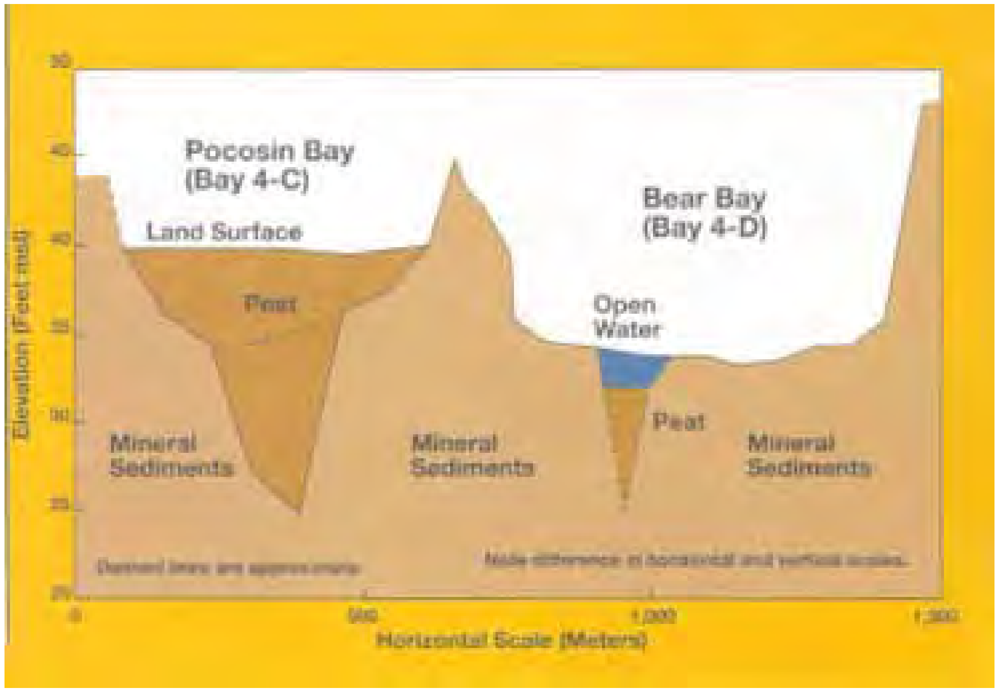
Note: This information is provided for reference purposes only. Although the information provided here was accurate and current when first created, it is now outdated.

Disclaimer: The information in this website is entirely drawn from a 1993 publication, and has not been updated since the original publication date. Users are cautioned that information reported at that time may have become outdated.

Carolina Bays: A Natural Wastewater Treatment Program



Background



In cross section, Carolina bays are shallow, bowl-shaped depressions, often filled with peat and surrounded by sandy ruins.

Carolina bays are mysterious land features often filled with bay trees and other wetland vegetation. Because of their oval shape and consistent orientation, they are considered by some authorities to be the result of a vast meteor shower that occurred thousands of years ago. Others think the natural forces of wind and artesian water flow caused the formation of lakes, which later filled with vegetation.

Whatever their origin, over 500,000 of these shallow basins dot the coastal plain from Georgia to Delaware. Many of them occur in the Carolinas, which accounts for their name. Most Carolina bays are swampy or wet areas, and most of the hundreds present in coastal Horry County, South Carolina, are nearly impenetrable jungles of vines and shrubs. Because of population growth and increased tourism in Horry County, expansion of essential utility operations was required. The regional water utility, the Grand Strand Water & Sewer Authority (GSWSA), retained CH2M HILL in the late 1970s to evaluate wastewater treatment and disposal options.

Locations to dispose of additional effluent were extremely limited because of sensitive environmental and recreational concerns. The slow-moving Waccamaw River and Intracoastal Waterway, into which existing facilities discharged, could not assimilate additional loading without adverse effects on water quality and resulting impacts on tourism and recreational activities.

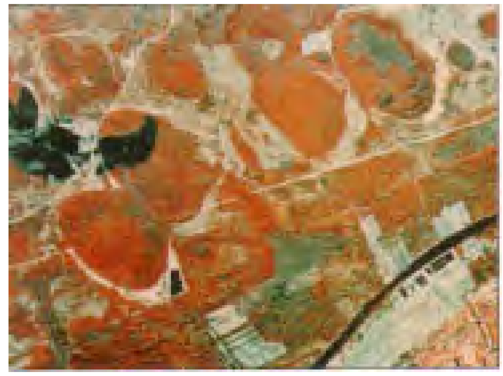
On the basis of extensive research and pilot studies, CH2M HILL recommended discharging effluent from a new 2.5 million gallon per day (mgd) wastewater treatment plant to four nearby Carolina bays.

The U.S. Environmental Protection Agency (EPA) considers the use of wetlands to be an emerging alternative to conventional treatment processes. As a result, EPA Region IV and the South Carolina Department of Health and Environmental Control awarded an Innovative /Alternative Technologies funding grant for the Carolina bays treatment project, enabling GSWSA to provide expanded collection, treatment, and disposal services at affordable costs.

This grant was used for planning, pilot testing, design, and construction of the full-scale Carolina Bay Natural Land Treatment Program.

Site Description

After 5 years of intensive study to evaluate viable treatment and disposal alternatives, four Carolina bays were selected as treatment sites. Site selection criteria focused on three primary factors: 1) distance from the wastewater source, 2) available treatment area, and 3) environmental sensitivity. The bays chosen for the GSWSA treatment complex had been previously affected by man and were the least environmentally sensitive of the bays considered.



Fourbays covering 700 acres make up the Carolina Bay Natural Land Treatment System. Plant succession in these bays is naturally controlled by fire as seen in Bay 4B (second from left).

Carolina Bays 4-A and 4-B are joined along a portion of their margins and encompass about 390 acres of dense, shrubby plant communities with scattered pine trees. This plant association is called "pocosin" after an Indian word describing a bog on a hill. A powerline right-of-way bisects Bay 4-A and also cuts through the southern end of Bay 4-B.

The 240-acre Pocosin Bay (Bay 4-C) is also dominated by pocosin vegetation and is filled with up to 15 feet of highly organic peat soils. This bay had received the least amount of prior disturbance and is being used only as a contingency discharge area. Bear Bay (Bay 4-D) covers 170 acres and is dissimilar from the other bays because it is densely forested by pine and hardwood tree species. A large portion of this Carolina bay was cleared for forestry purposes in the mid-1970s but has since been revegetated with a mixture of upland and wetland plant species.

Carolina Bay Project Summary

George R. Vereen WWTP

Design flow = 2.5 mgd
Pretreatment by aerated lagoons in
parallel trains, one completely
suspended lagoon and three partially
suspended lagoons per train
Lagoon total area = 4.4 acres
Total aeration = 192 hp
Disinfection by contact chlorination

Carolina Bays

Average hydraulic loading rate = 1 in./week Effluent distribution system

7,000 feet of 10-inch aluminum piping 30,000 feet of elevated boardwalks

Final effluent permit limits

BOD5 monthly average 12 mg/l
TSS monthly average 30 mg/l
NH3 summer (Mar-Oct) 1.2 mg/l
NH3 winter (Nov-Feb) 5.0 mg/l
UOD summer (Mar-Oct) 481 lb/day
UOD winter (Nov-Feb) 844 lb/day

Total treatment area = 702 acres

Bay 4A
combined = 390 acres
Bay 4B
Bay 4C (Pocosin Bay) = 142 acres
Bay 4D (Bear Bay) = 170 acres

Biological criteria (allowable % change)

	Bay			
	4A	4B	4C	4D
Canopy cover	15	15	0	50
Canopy density	15	15	0	50
Subcanopy cover	15	15	0	50
Plant diversity	15	15	0	50

Project Cost Summary

Pilot system $411,000
Vereen WWTP 3,587,000
Effluent distribution system
(including land) 2,490,000
Engineering (pilot and
full scale) and monitoring 1,332,000

Total cost $7,820,000

Operations and Management

The carefully planned and monitored use of Carolina bays for tertiary wastewater treatment facilitates surface water quality management while maintaining the natural character of the bays.

High-nutrient water in the bays increases plant productivity.

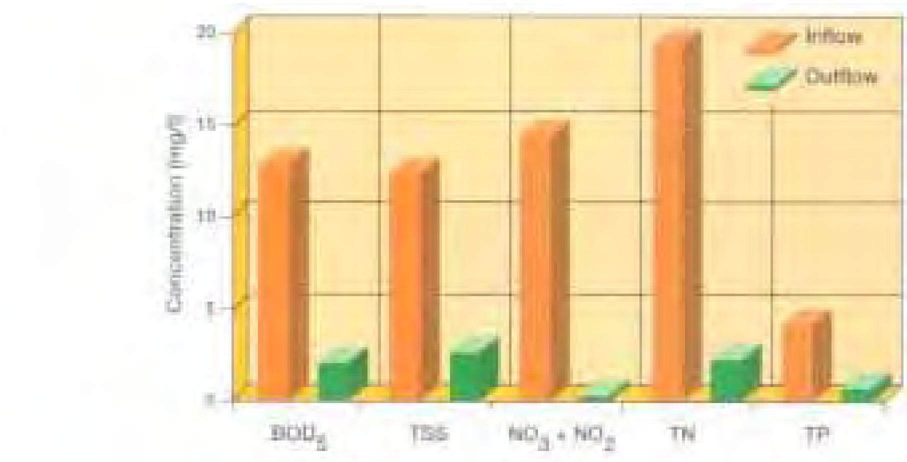
Aluminum pipes distribute the treated effluent.

After undergoing conventional primary and secondary treatment processes at the George R. Vereen Wastewater Treatment Plant, the wastewater is slowly released into a Carolina bay for tertiary treatment, rather than directly to recreational surface waters of the area. The plants found in the Carolina bays are naturally adapted to wet conditions, so the addition of a small amount of treated water increases their productivity and, in the process, provides final purification of the wastewater.

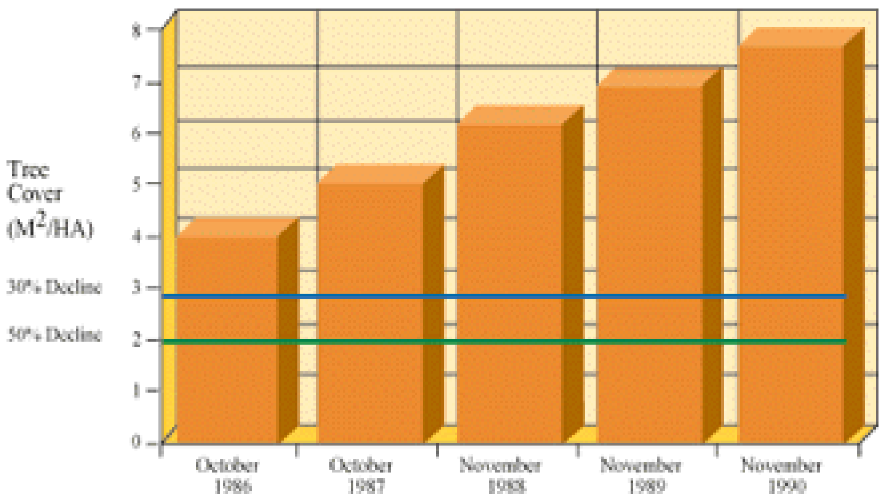
The treated effluent can be distributed to 700 acres within the four selected Carolina bays through a series of gated aluminum pipes supported on wooden boardwalks. Wastewater flow is alternated among the bays, depending on effluent flow rate and biological conditions in the bays.

Water levels and outflow rates can be partially controlled in Bear Bay through the use of an adjustable weir gate. Natural surface outlets in the other three bays were not altered by construction of the project.

Performance



Compliance with biological criteria protects the Carolina Bay plant communities from undesirable changes.



Operational water quality since 1987 indicates significant assimilation of residual pollutants is occuring in Bear Bay.

In 1985, after site selection was completed and before wastewater distribution began, baseline studies were conducted on the hydrology, surface water, and groundwater quality and flora and fauna of Bear Bay. Treated effluent was first discharged to the bay in January 1987, and monitoring was continued to measure variations in the water quality and biological communities. By March 1988, the pilot study had been successfully completed and the Carolina Bay Natural Land Treatment Program was approved for full-scale implementation by EPA and South Carolina regulatory agencies.

In October 1990, the Carolina Bay Natural Land Treatment System was dedicated as the Peter Horry Wildlife Preserve and began serving the wastewater treatment and disposal needs of up to 30,000 people.

Ongoing monitoring indicates that significant assimilation is occurring in Bear Bay before the fully treated effluent recharges local groundwater or flows into downstream surface waters. Biological changes have been carefully monitored, with the main observed effect being increased growth of native wetland plant species.

Variations in the water quality of Bear Bay are closely monitored.

Ancillary Benefits

The Carolina Bay Natural Land Treatment Program not only serves wastewater management needs but also plays an important role in protecting the environment. Although the Carolina bays have been recognized as unique, 98 percent of the bays in South Carolina have been disturbed by agricultural activities and ditching. The four bays in the treatment program will be maintained in a natural ecological condition. These 700 acres of Carolina bays represent one of the largest public holdings of bays in South Carolina.

Wetland plan communities easily adjust to changing conditions

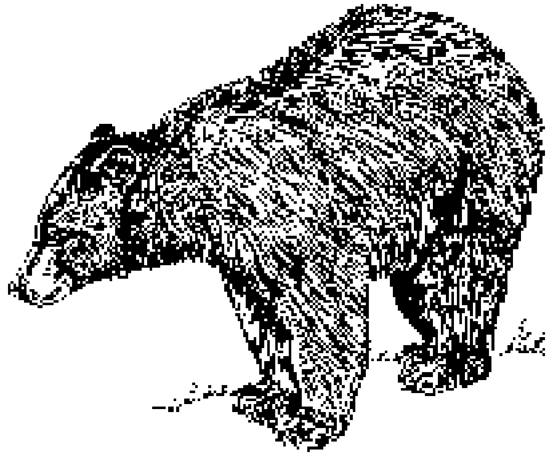
The use of wetlands for treatment can significantly lower the cost of wastewater treatment because the systems rely on plant and animal growth instead of the addition of power or chemicals. Also, the plant communities present in the wetlands naturally adjust to changing water levels and water quality conditions by shifting dominance to those species best adapted to growing under the new conditions.

Pitcher plants occur naturally in the Carolina bays.

Carolina bays provide a critical refuge for rare plants and animals. Amazingly, black bears still roam the bays' shrub thickets and forested bottom lands just a few miles from the thousands of tourists on South Carolina's beaches. Venus flytraps and pitcher plants, fascinating carnivorous plants that trap trespassing insects, occur naturally in the Carolina bays. In addition, the bays are home to hundreds of other interesting plant and animal species.

The Carolina Bay Nature Park, to be managed by GSWSA, is currently being planned. The focal point of the park will be an interpretive visitor center open to the public. This simple structure will be designed and built in harmony with its surroundings on a sand ridge overlooking two Carolina bays. The center will feature displays about black bears and Venus flytraps as well as theories on the origin of the Carolina bays, their native plant associations, including the associated sandhill plant communities, and their use for natural land treatment.

The visitor center will be the hub for three hiking trails, including a 5-minute walk through an adjacent cypress wetland; a 45-minute trail though Pocosin Bay and associated titi shrub swamp and long-leaf pine uplands; and a one-hour walk through a heavily forested Carolina bay and its adjacent sandhill plant communities.



Combined with the interpretive nature center, the hiking trails and boardwalks will provide public access, scientific research, and educational opportunities that were previously unavailable.

The designation of the Peter Horry Wildlife Preserve in October 1990 was the first step in establishing this park.

An interpretive visitor center is planned as the focal point of the Carolina Bay Nature Park.

Awards

In 1991, the Carolina Bay Natural Land Treatment Program won the Engineering Excellence Award, Best of Show, from the Consulting Engineers of South Carolina.

The American Consulting Engineers Council (ACEC) Grand Conceptor Award, considered the highest national honor in the consulting engineering field, was awarded to CH2M HILL in 1991 for its implementation of the Carolina bays project. ACEC selected the project from a field of 127 national finalist entries, each of which had earlier won in state or regional engineering excellence competitions.

Acknowledgements

Numerous individuals and organizations have shared the vision necessary to implement the Carolina Bay Natural Land Treatment Program. Some of the key organizations and individuals include the following:

Grand Strand Water and Sewer Authority

George R. Vereen, Former Chairman
Sidney F. Thompson, Chairman
Douglas P. Wendel, Executive Director
Fred Richardson, Engineering Manager
Larry Schwartz, Environmental Planner

South Carolina Department of Health and Environmental Control

Samual J. Grant, Jr., Manager, 201 Facilities Planning Section
G. Michael Caughman, Director, Domestic Wastewater Division

Ron Tata, Director, Waccamaw District

U.S. Environmental Protection Agency

Harold Hopkins, Former Chief, Facilities Construction Branch, Region IV
Robert Freeman, 201 Construction Grants Coordinator, Region IV
Robert Bastian, Office of Wastewater Management

CH2M HILL

Richard Hirsekorn, Project Administrator
Robert L. Knight, Project Manager and Senior Consultant
Douglas S. Baughman, Project Manager

South Carolina Coastal Council

H. Stephen Snyder, Director, Planning and Certification

South Carolina Wildlife and Marine Resources Department

Stephen H. Bennett, Heritage Trust Program
Ed Duncan, Environmental Affairs Coordination

U.S. Fish and Wildlife Service

Harvey Geitner, Field Supervisor

U.S. Army Corps of Engineers

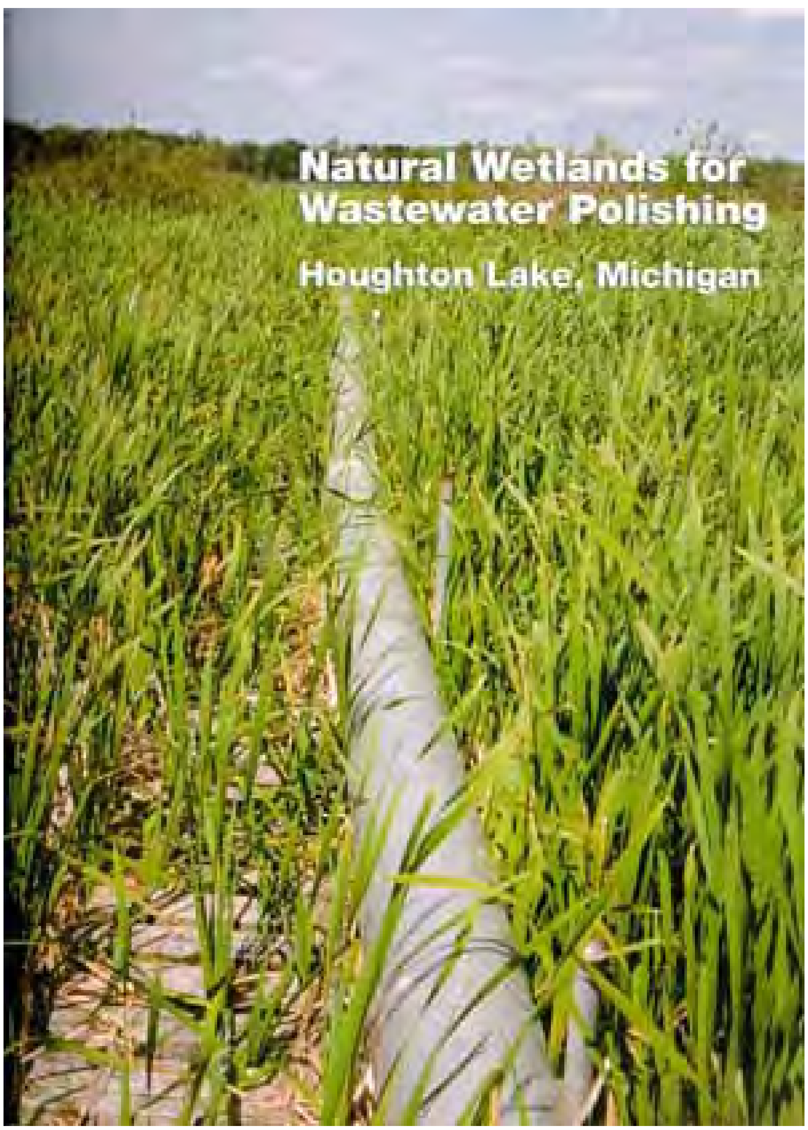
Don Hill, Director, 404 Section

This brochure was prepared by CH2M HILL for the U.S. Environmental Protection Agency.

Note: This information is provided for reference purposes only. Although the information provided here was accurate and current when first created, it is now outdated.

Disclaimer: The information in this website is entirely drawn from a 1993 publication, and has not been updated since the original publication date. Users are cautioned that information reported at that time may have become outdated.

Natural Wetlands for Wastewater Polishing, Houghton Lake, Michigan



- System Description
- History
- Hydrology
- Water Quality
- Soils and Sediments
- Vegetation
- Public Use
- Animals
- Permits
- Operator Opinions
- Awards
- People
- Literature

System Description

The wetland treatment site is located southwest of the lake. The land belongs to the State of Michigan and is dedicated to public and research uses. Dots indicate water monitoring stations.

The community of Houghton Lake, located in the central lower peninsula of Michigan, has a seasonally variable population, averaging approximately 5,000. A sewage treatment plant was built in the early 1970's to protect the large shallow recreational lake. This treatment facility is operated by the Houghton Lake Sewer Authority (HLSA). Wastewater from this residential community is collected and transported to two 5-acre aerated lagoons, which provide six weeks detention. Sludge accumulates on the bottom of these lagoons, below the aeration pipes. Effluent is then stored in a 29-acre pond for summer disposal, resulting in depth variation from 1.5 feet (fall) to 10.0 feet (spring). Discharge can be to 85 acres of seepage beds, or to 85 acres of flood irrigation area, or to a 1500 acre peatland. The seepage beds were used until 1978, at which time the wetland system was started up. The wetland has been used since that time, with only occasional discharges to seepage or flood fields. The average annual discharge is approximately 120 million gallons. Secondary wastewater is intermittently discharged to the peatland during May through September, at the instantaneous rate of 2.6 mgd.

Provisions for chlorination are available, but have not been used, because of low levels of fecal coliform indicator organisms. Water from the holding pond is passed by gravity or pumped to a 3-acre pond which would provide chlorine removal in the event of the necessity of its use. Wastewater from this pond is pumped through a 12-inch diameter underground force line to the edge of the Porter Ranch peatland. There the transfer line surfaces and runs along a raised platform for a distance of 2,500 feet to the discharge area in the wetland. The wastewater may be split between two halves of the discharge pipe which runs 1,600 feet in each direction. The water is distributed across the width of the peatland through small gated openings in the discharge pipe. Each of the 100 gates discharge approximately 16 gallons per minute, under typical conditions, and the water spreads slowly over the peatland. The branches are not used equally in all years.

The peatland irrigation site originally supported two distinct vegetation types. One called the sedge-willow community included predominantly sedges (Carex spp.) and Willows (Salix spp.). The second community was leatherleaf-bog birch, consisting of mostly Chamaedaphne calyculata (L.) Moench and Betula pumila L., respectively. The leatherleaf-bog birch community also had sedge and willow vegetation, but only in small proportions. The edge of the peatland contained alder (Alnus spp.) and willow. Standing water was usually present in spring and fall, but the wetland had no surface water during dry summers. The leatherleaf-bog birch cover type generally had less standing water than the sedge-willow cover type. Soil in the sedge-willow community was 3-5 feet of highly decomposed sedge peat; while in the leatherleaf-bog there is 6-15 feet of medium decomposition sphagnum peat. The entire wetland rests on a clay "pan" several feet thick.

The wetland provides additional treatment to the wastewater as it progresses eventually to the Muskegon River eight miles away. Small, natural water inflows occur intermittently on the north and east margins of the wetland. These flows are partially controlled by beaver. Interior flow in the wetland occurs by overland flow, proceeding from northeast down a 0.02% gradient to a stream outlet (Deadhorse Dam) and beaver dam seepage outflow (Beaver Creek), both located 2-3 miles from the discharge (Figure 1.) Wastewater adds to the surface sheet flow. Hydrogeological studies have shown that there is neither recharge or discharge of the shallow ground water under the wetland.

The original leatherleaf-bog community also had sedge and willow vegetation in small proportions, and very low abundance of cattail.

The treated wastewater arriving at the peatland is a good effluent which contains virtually no heavy metals or refractory chemicals. This is due to the absence of agriculture and industry in the community. Phosphorus and nitrogen are present at 3-10 ppm, mostly as orthophosphate and ammonium. BOD is about 15 ppm, and solids are about 20 ppm. Typical levels of chloride are 100 ppm, pH 8, and conductivity 700 mmho/cm. The character of the water is dramatically altered in its passage through the wetland. After passage through ten percent of the wetland, water quality parameters are at background wetland levels. The system has operated successfully in the treatment of 1900 million gallons of secondary wastewater over the first sixteen years.

History

The Porter Ranch peatland has been under study from 1970 to the present. Studies of the background status of the wetland were conducted during the period 1970-74, under the sponsorship of the Rockefeller Foundation and the National Science Foundation (NSF). The natural peatland, and 6m x 6m plots irrigated with simulated effluent, were studied by an interdisciplinary team from The University of Michigan. This work gave strong indications that water quality improvements would result from wetland processes.

Subsequently, pilot scale (100,000 gal/day) wastewater irrigation was conducted for the three years 1975-77. This system was designed, built and operated by the Wetland Ecosystem Research Group at The University of Michigan. NSF sponsored this effort, including construction costs and research costs. The pilot study results provided the basis for agency approval of the fullscale wetland discharge system.

The full scale system was designed jointly by Williams and Works, Inc. and the Wetland Ecosystem Research Group at The University of Michigan. Construction occurred during winter and spring, 1978, and the first water discharge was made in July, 1978. Compliance monitoring has been supplemented by full scale ecosystem studies, spanning 1978 to present, which have focussed on all aspects of water quality improvement and wetland response. Those studies have been sponsored by NSF, and in major part by the Houghton Lake Sewer Authority.

This wetland treatment system has functioned extremely well for nutrient removal over its sixteen year history.

Table 1. Economics

Capita (1978 Dollars)

Holding Pond Modification	$38,600
Decholorination Pond	153,200
Pond-Wetland Water Transfer	83,600
Irrigation System	112,800
Monitoring Equipment	9,700
Total	$397,900

Annual Operating Costs (1991 Dollars)

Pumping	$2,000
Monitoring	800
Maintenance	500
Research	12,000
Total	$15,300

Hydrology

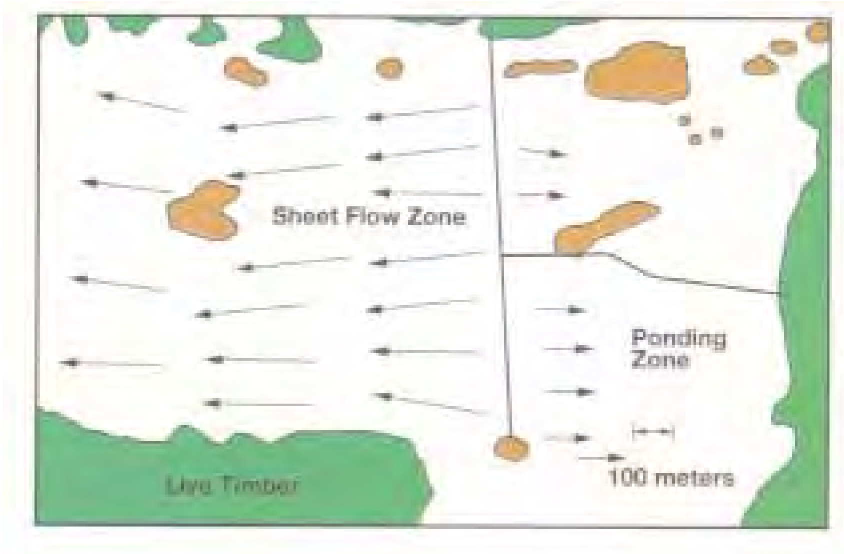


Figure 2

Water moves at about 30-100 m/d with a depth of about 20 cm.

On average, most of the water added to the wetland finds its way to the stream outflows. But in drought years, most of the water evaporates; and in wet years, rainfall creates additions to flow. During most of the drought summers of 1987 and 1988, all the pumped water evaporated in the wetland.

Water flow is strongly depth dependent, because litter and vegetation resistance is the hydrologic control. Doubling the depth causes a ten-fold increase in volume flow. Therefore, when the pump is turned on, water depths rise only an inch or two. For similar reasons, a large rainstorm does not flood the peatland to great depths.

There are no man-made outlet control structures, but both man and beaver have relocated the points of outflow, via culvert and dam placements. Inflows at E1 and E2 have ceased (see Figure 1). The point of principal stream outflow has changed from E8 to E9; and E9 has been relocated three times, twice by beaver and once by man.

The soil elevations in the discharge area were originally extremely flat, with a gentle slope (one foot per mile) toward the outlet. There has developed a significant accumulation of sediment and litter in the irrigation area, which has the effect of an increased soil elevation. This acts as a four-inch-high dam. As a consequence, the addition of wastewater along the gated irrigation pipe gives rise to a mound of water with the high zone near and upstream of the discharge pipe; in other words, there is a backgradient "pond". Depth at the discharge is not greater, but depths are greater at adjacent up and downstream locations. There is a water flow back into the backgradient pond, which compensates for evaporative losses there. But most water moves downgradient, in a gradually thinning sheet flow. (see Figure 2)

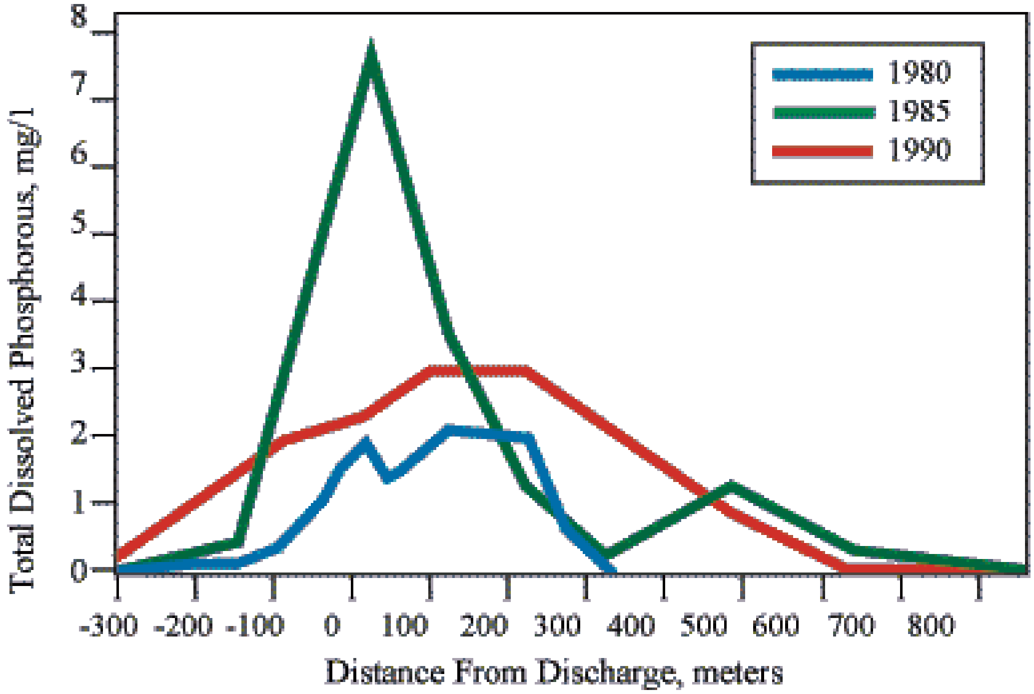
The hydroperiod of the natural wetland has been altered in the zone of discharge: dryout no longer occurs there, even under drought conditions.

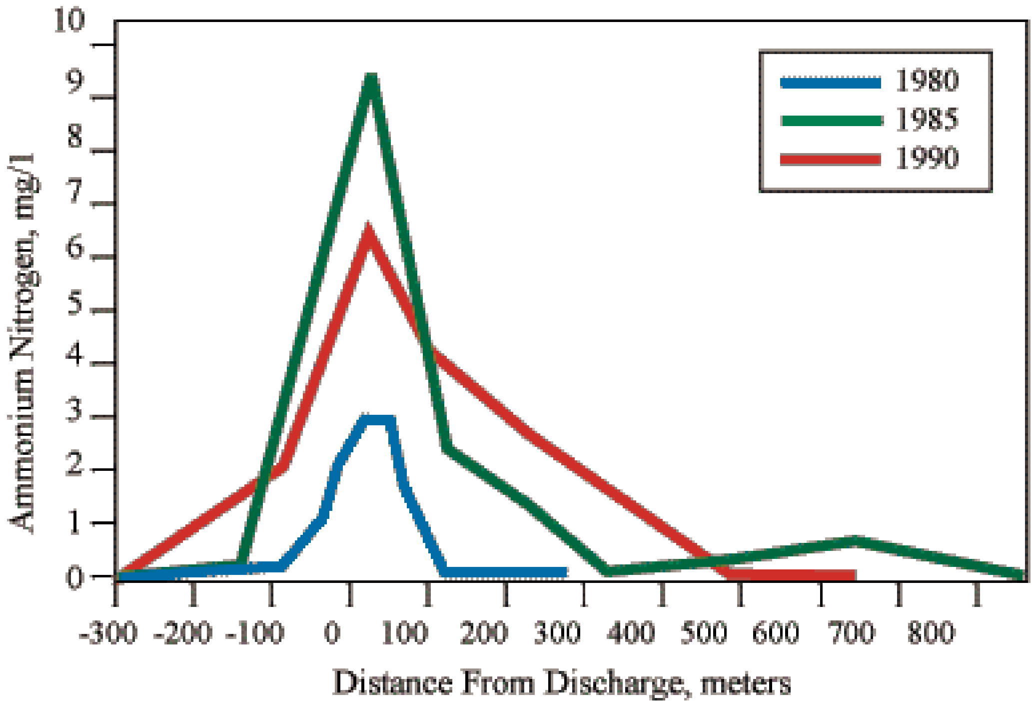
Table 2. Summary of Water Budgets.

Thousands of m3, 1.0 km2 zone. Inventory change not shown
The interval is the pumping season, typically May1-September 14.

Year	Precipitation minus Evapotranspiration	Wastewater Addition	Watershed Runoff	Outflow	Outflow Percent
1978	80	240	0	135	56
1979	-4	384	18	333	87
1980	-137	407	0	304	75
1981	99	455	30	558	123
1982	-38	404	20	386	96
1983	-110	485	132	487	100
1984	-24	546	73	602	110
1985	44	379	0	347	92
1986	-11	465	0	412	89
1987	-273	347	0	74	21
1988	-311	425	0	114	27
1989	-153	672	0	522	78
1990	-43	622	0	628	101
1991	-100	724	0	624	86
1992	-250 (est)	719	0	469	65
Averages	-82	485	18	400	80

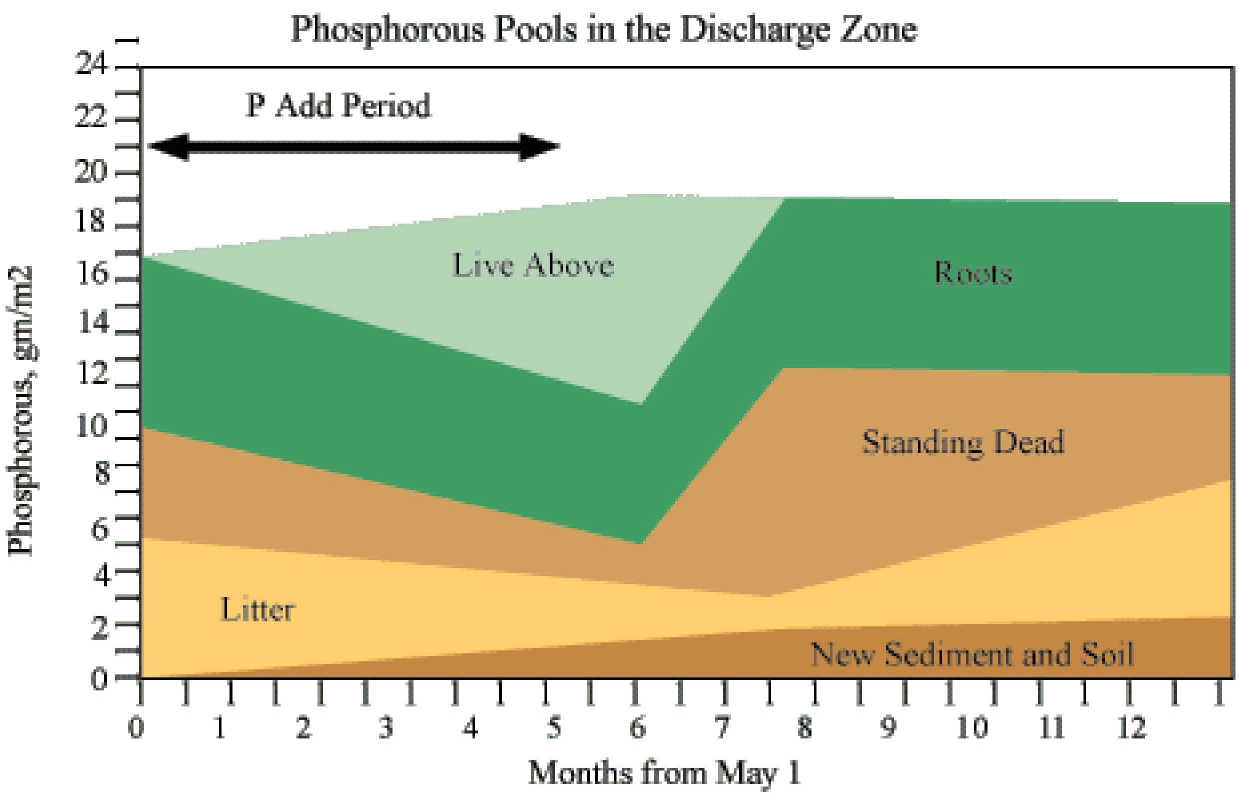
Water Quality





The phenomena interior to the irrigation zone lead to gradients in the concentrations of dissolved constituents in the direction of water flow. As the water passes through the ecosystem, both biotic and abiotic interactions occur which reduce the concentration for many species, including nitrogen, phosphorus and sulfur. Surface water samples from the wastewater irrigation area are collected and analyzed throughout the year. The changes in water chemistry as a function of distance from the discharge point are monitored by sampling along lines perpendicular to the discharge pipe, extending to distances up to 1000 meters. Such transects are made in the former sedge-willow area, along the central axis of the wetland.

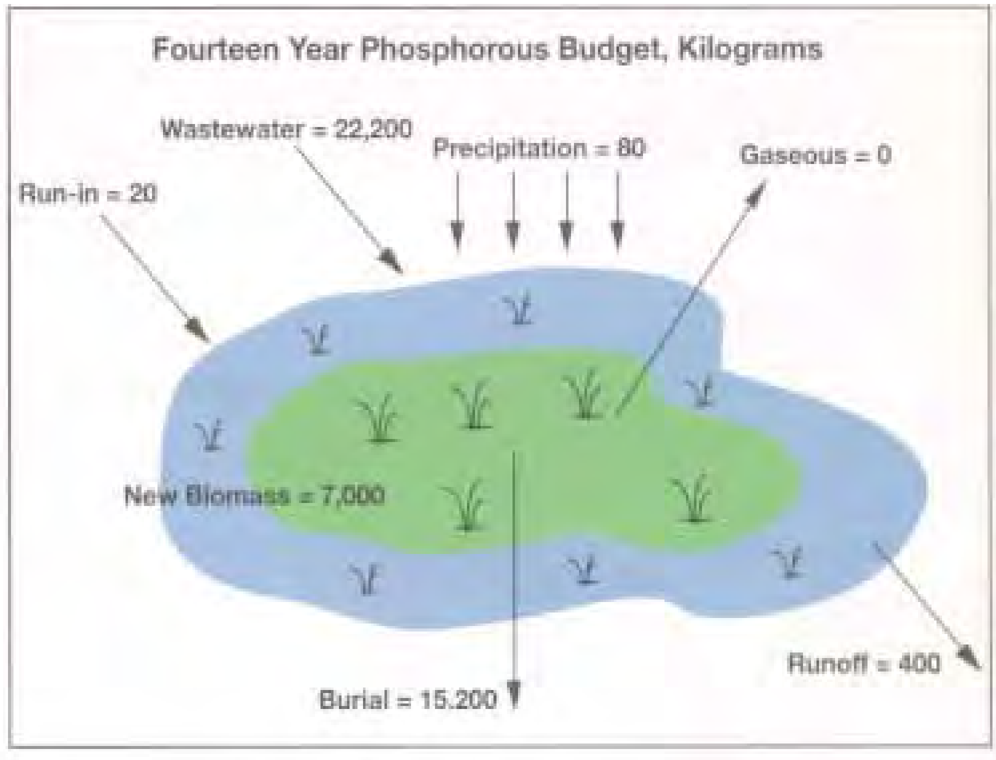
The transect concentration profiles are all similar. Water flow carries materials a greater distance in the downgradient (positive) direction than in the upgradient direction. Through the early years of operation, the zone of concentration reduction increased in size; background concentrations are now reached at distances of about 500 meters downstream of the discharge. The advance of nutrient concentration fronts during the application of wastewater is illustrated by tracking the location of phosphorus drop-off. Concentrations in excess of 1.0 mg/liter were confined to within 440 meters of the discharge point in 1990. It appears that nutrient removal processes are stabilizing.



Nitrogen species include organic, ammonium and nitrate/nitrite nitrogen. The wetland micro-organisms convert nitrate to nitrogen gas. Other bacteria convert atmospheric nitrogen to ammonium, which is in short supply; both for the natural wetland and for the fertilized zone. Large amounts are incorporated in new soils and in extra biomass.

Because the irrigation zone is imbedded in a natural wetland of larger extent, care must be taken in the definition of the size of the treatment portion of this larger wetland. A zone extending 300 meters upstream and 700 meters downstream, spanning the entire 1000 meter width of the wetland, encompasses the treatment zone with room to spare. Nutrient removal is essentially complete within this zone; some background concentrations will always be present in outflows.

The reductions in dissolved nutrient concentrations are not due to dilution, as may be seen from the water budgets. There are summers in which rainfall exceeds evapotranspiration, but on average there are evaporative losses, which would lead to concentration increases in the absence of wetland interactions.



It is possible to elucidate the mechanisms by which water-borne substances are removed in this freshwater wetland ecosystem. There are three major categories of removal processes: biomass increases, burial, and gasification. The production of increased biomass due to nutrient stimulation is a long-term temporary sink for assimilable substances. Accretion of new organic soils represents a more permanent sink for structural and sorbed components. A few species, notably nitrogen, carbon and sulfur compounds, may be released to the atmosphere, and thus are lost from the water and the wetland. Mass balance models have been constructed that adequately characterize these processes on both short and long term bases.

Some substances in the wastewater do not interact as strongly with the wetland as do nutrients. Chloride, calcium, magnesium, sodium and potassium all display elevated values in the discharge affected zone. Chloride, especially, moves freely through the wetland to the outlet streams.

Oxygen levels in the pumped water are good, approximately a 6 mg/l average. In the irrigation zone, levels are typically 1-2 mg/l in surface waters. The surrounding, unaffected wetland usually has high DO, representing conditions near saturation. The zone of depressed oxygen increased in size as the affected area increased, as indicated by the advance of an oxygen front both upgradient and downgradient. In addition, the diurnal cycle appeared to be suppressed in the irrigation zone.

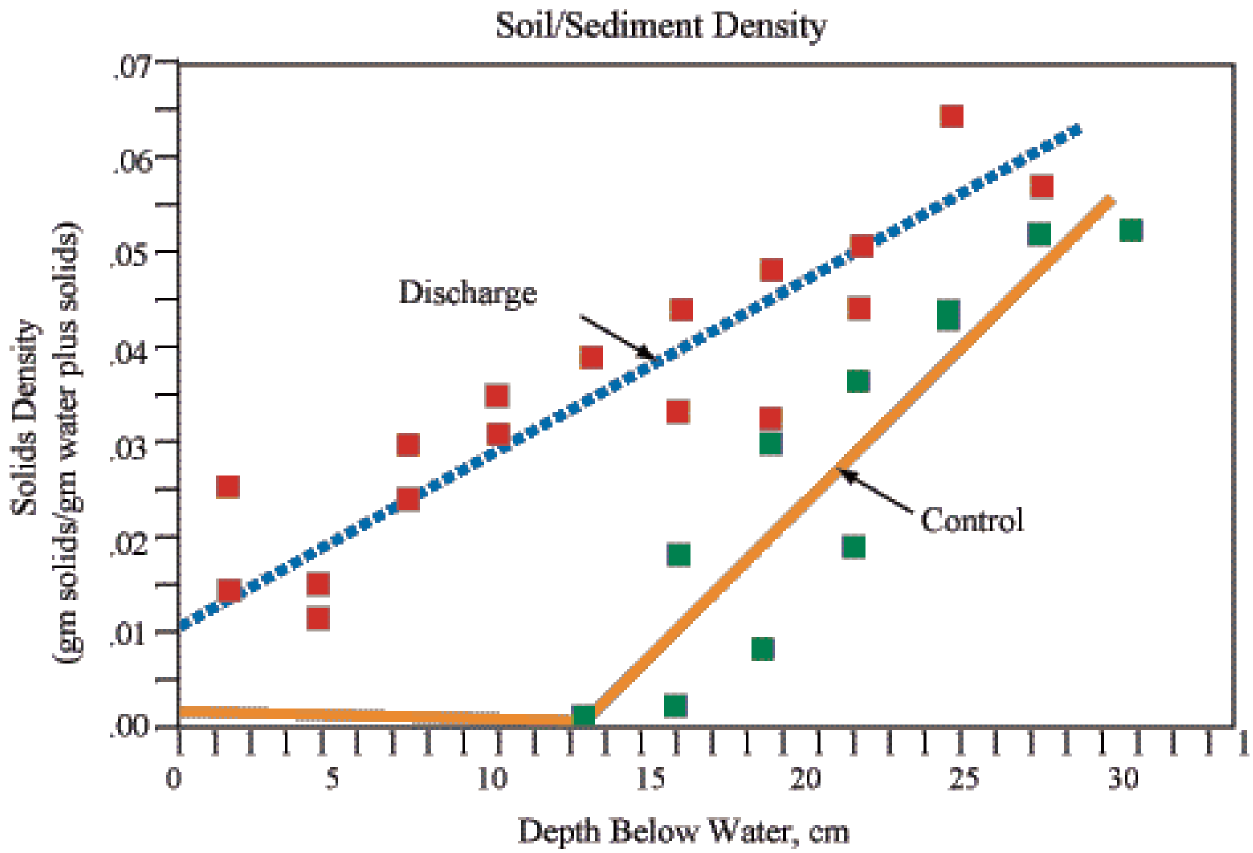
Redox potentials indicate that the sediments are anaerobic in the irrigation area, even at quite shallow depths. Steep gradients occur, leading to sulfate and nitrate reduction zones, and even to a methanogenesis zone, only a few centimeters deep into the sediments and litter.

Treatment Area and Nutrient reductions

DIN = Dissolved Inorganic Nitrogen = Nitrate plus Ammonium Nitrogen TP = Total Phosphorus.

	Area, ha		DIN, mg/l			TP, mg/l	
Year		In	Out	Reduction %	In	Out	Reduction %
78	10	0.56	0.10	82	2.85	0.063	97
79	13	3.68	0.10	97	2.87	0.047	98
80	17	3.22	0.10	97	4.41	0.068	97
81	24	2.83	0.094	97	2.83	0.088	96
82	30	5.85	0.093	98	3.27	0.064	98
83	55	3.76	0.148	96	2.74	0.066	97
84	50	10.04	0.078	99	4.52	0.079	97
85	48	7.64	0.194	98	4.11	0.099	97
86	46	9.63	0.176	98	5.26	0.063	99
87	46	4.26	0.244	94	2.90	0.074	97
88	61	6.26	0.080	99	2.66	0.086	97
89	54	8.13	0.156	98	1.66	0.047	97
90	67	8.14	0.119	99	2.93	0.112	96
91	76	7.80	0.122	99	2.59	0.147	94
AVERAGES:		**5.69**	**0.129**	**96**	**3.31**	**0.074**	**97**

Soils and Sediments

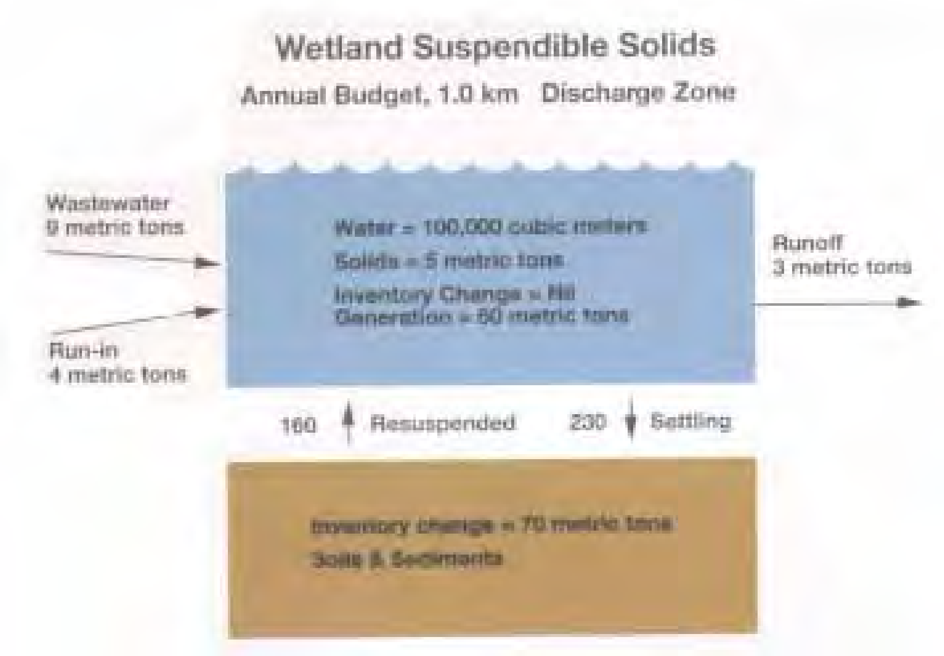


Wastewater solids are relatively small in amount and deposit near the discharge. Incoming suspended solids average about 25 mg/l, and the wetland functions at levels of about 5-10 mg/l. But internal processes in both natural and fertilized wetlands produce large amounts of detrital material, thus complicating the concept of "suspended solids removal".

Some fraction of each year's plant litter does not decompose, but becomes new organic soil. It is joined by detritus from algal and microbial populations. Such organic sediments contain significant amounts of structural components, but in addition are good sorbents for a number of dissolved constituents. The accretion of soils and sediments thus contributes to the effectiveness of the wetland for water purification. The natural wetland accreted organic soils at the rate of a two to three millimeters per year, as determined from carbon-14 and cesium-137 radiotracer techniques. The wastewater has stimulated this process to produce a net of ten millimeters per year of new organics in the discharge area. The maximum accumulation rate is located a short distance downflow from the discharge.

After more than a decade, sediment and litter accumulation total about 15

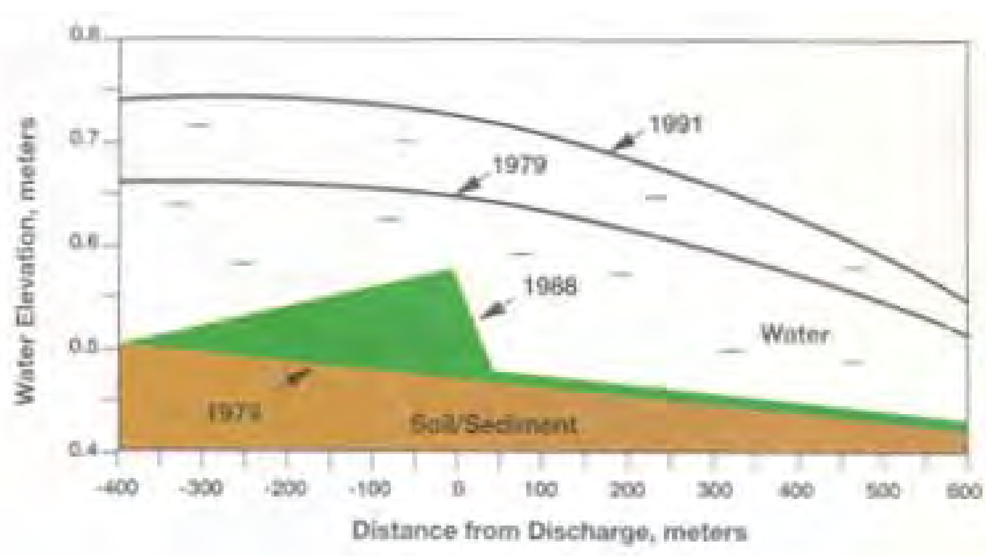
Sediment fall in the discharge area totals several millimeters per cm.



year, and this combines with wetland leaf litterfall to produce a large amount of large and small detritus. The majority of this detritus decomposes each year, but there is an undecomposable fraction. The result of continued generation and deposition of sediments, combined with the accumulation of the mineralized fraction of leaf and stem litter, is the accretion of new organic soil.

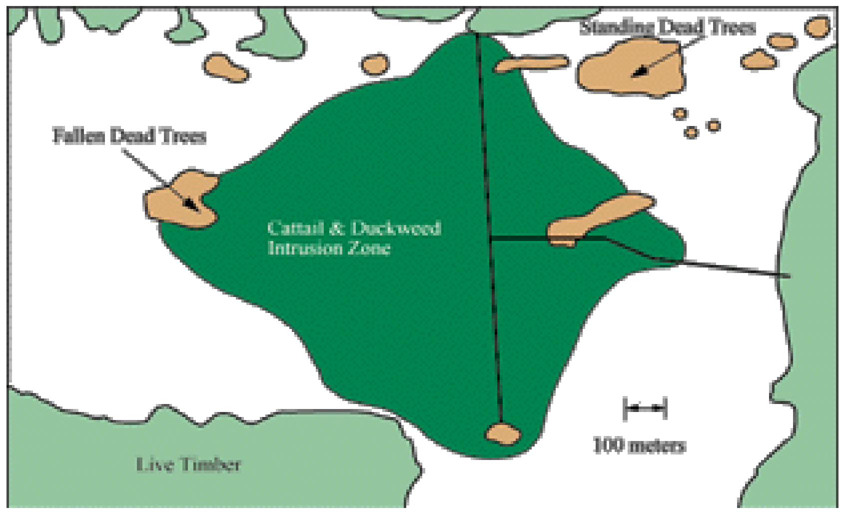
Part of the sediments are suspendible, and are transported by the flowing water. The rate of travel caused by sequential suspension and sedimentation is much slower than the rate of water flow; solids move only some tens of meters per year.

Estimated mass balances for particulate, transportable solids indicate the large internal cycle superimposed on net removal for the wetland.



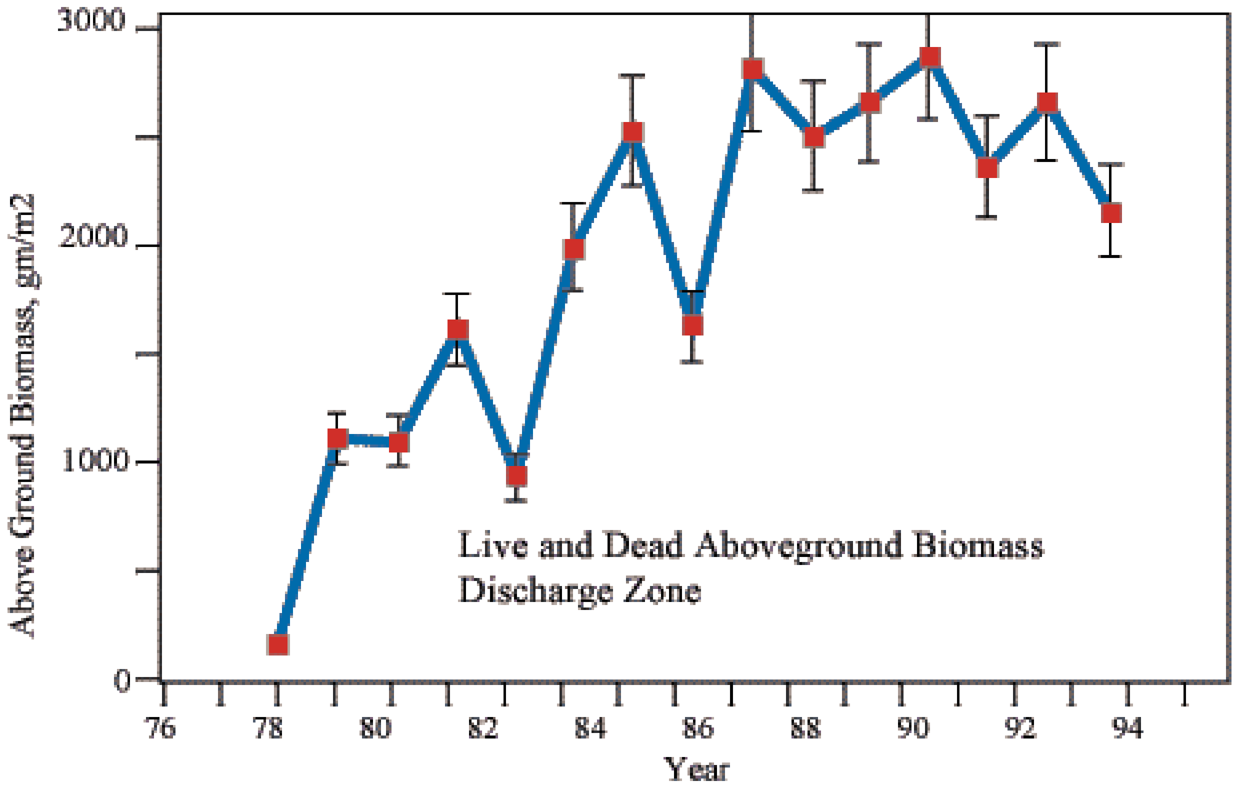
Vegetation

Many changes have occurred in the composition, abundance and standing crops of the wetland plants in the zone of nutrient removal. There are two observable manifestations of the wastewater addition: elevated nutrient concentrations in the surface waters, and alterations of the size, type and relative abundance of the aboveground vegetation. Vegetative changes occur in response to changes in hydraulic regime (depth and duration of inundation) and to changes in water nutrient status. The treatment area is taken to be the greater of these two measurable areas for each year.



When a wetland becomes the recipient of waters with higher nutrient content than those it has been experiencing, there is a response of the vegetation, both in species composition and in total biomass. The increased availability of nutrients produces more vegetation during the growing season, which in turn means more litter during the non-growing season. This litter requires several years to decay, and hence the total pool of living and dead material grows slowly over several years to a new and higher value. A significant quantity of nitrogen and phosphorus and other chemical constituents are thus retained, as part of the living and dead tissues, in the wetland. This response at the point of discharge in the Houghton Lake wetland has been slow and large. Below ground biomass responded differently from above ground biomass, however. Original vegetation required greatly reduced root biomass in the presence of added nutrients; 1500 gm/m2 versus 4000. However, the sedges initially present were replaced by cattail, which has a root biomass of 4000 gm/m2.

Approximately 65 hectares of the wetland have been affected in terms of visual vegetative change. Some plant species - leatherleaf and sedge—have been nearly all lost in the discharge area, presumably due to shading by other species and the altered water regime. Sedges in the discharge zone went through a large increase followed by a crash to extinction. Species composition within the discharge area is no longer determined by earlier vegetative patterns; cattail and duckweed have totally taken over. Cattail has extended its range out to about 600 meters along the central water track.



The cattail cover type did not exist in enough abundance (1.76% of the peatland area) to warrant study in pre-irrigation years, but was present in many locations (17% of all test plots). The early years of wastewater addition produced a variable but increasing annual peak standing crop of cattail. This change has been completed in the irrigation area, and there is no space for more plants, nor can they grow any larger.

The willows and bog birch are decreasing in numbers in the irrigation area. The fraction standing dead is low because the dead shrubs are pulled down by the falling cattail. Nonetheless, a high fraction of the standing stems are now dead. Further, the number of surviving clumps of stems is decreasing.

The aspen community near the pipeline completely succumbed in 1983. A second aspen island, located 500 meters downgradient, had also totally succumbed by 1984. The aspen on the edges of the peatland have died in backgradient and side locations where the shore slopes gradually. The alteration of the water regime has caused tree death along much of the wetland perimeter, in a band up to 50 meters wide at a few locations. Long-dead timber at these locations indicates that similar events may have occurred naturally in the past.

Public Use

The project was not designed for purposes of public use, but a set of regular users has evolved. The site serves several organizations as a field classroom. Each year, the sixth grade science classes from the Houghton Lake School pay visits—and ask the best questions. Ducks Unlimited and the Michigan United Conservation Clubs also schedule trips to the wetland. The Michigan Department of Natural Resources includes field trips to the system as part of their annual training course. And, Central Michigan University conducts a portion of its wetlands course at the site.

Many visitors, some from as far as New Zealand, come to inspect the treatment facility to learn of its performance.

The authorized operating period is set to allow deer hunting: the discharge is stopped in September to permit the wetland to "relax" from the influence of pumping. The bow-and-arrow season in October, and the rifle season in November, both find numerous hunters on and near the wetlands. Those hunters receive a questionnaire, which has demonstrated nearly unanimous acceptance of the project. The only complaint is that the boardwalk allows too easy access to the wetlands.

Duck hunting and muskrat trapping have occurred on an intermittent basis. These activities are new to this wetland, which was formerly too dry to support waterfowl and muskrats.

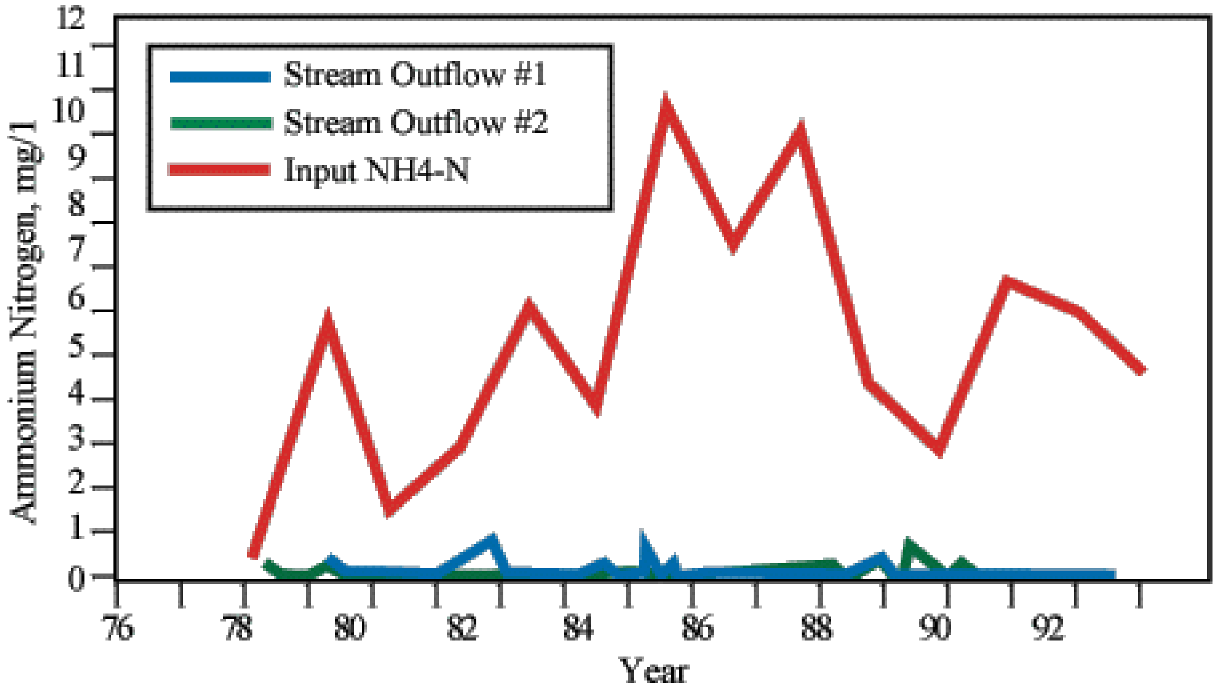
Animals

In addition to game species, coyotes, bobcats and raccoons frequent the wetland. Small mammals include a variety of mice, voles and shrews. The relative numbers have shifted with time in the discharge area; generally there are now fewer and different small mammals. The number of muskrats has increased greatly in the irrigation zone.

Bird populations have also changed. The undisturbed wetland (1973) contained 17 species, dominated by swamp sparrows, marsh wrens and yellowthroats. In 1991, the irrigation zone had 19 species, dominated by tree swallows, red wing blackbirds and swamp sparrows.

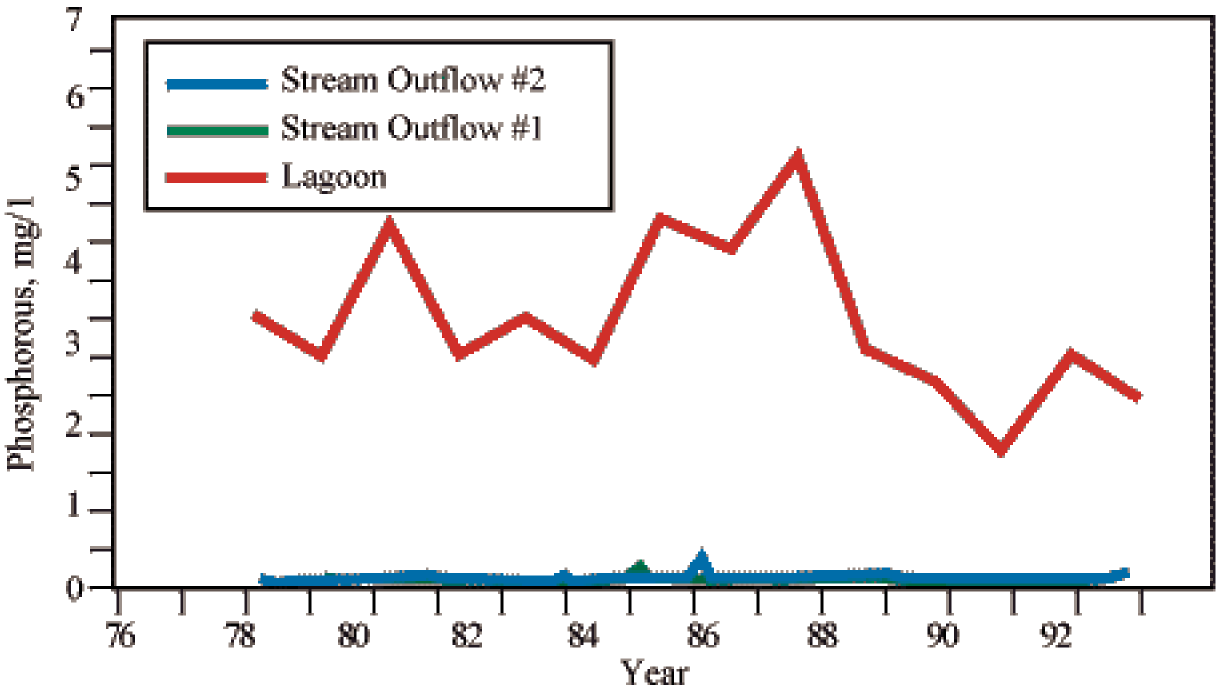
Insect species and numbers fluctuate from year to year, with no discernible pattern. In some years there are fewer mosquitoes near the discharge; in other years they are more numerous there. There are typically more midges in the discharge zone, and fewer mayflies, caddisflies and dragonflies.

Permits



The project operates under two permits: an NPDES permit for the surface water discharge, and a special use permit for the wetlands.

The Michigan Water Resources Commission issues the NPDES permit in compliance with the Federal Water Pollution Control Act. Both the irrigation fields and the wetlands are permitted. The wetlands part of the permit establishes three classes of sampling locations: the effluent from the storage or dechlorination ponds, a row of sampling stations approximately 800 meters downgradient from the discharge pipeline in the wetland (Figure 1), and steamflows exiting the wetland. Lagoon discharges are monitored weekly; interior points and stream outflows are measured monthly. Each location has its own parameter list (Table 3). The interior wetland stations are the early warning line. Background water quality was established in pre-project research. Target values are set which are the basis for assessing the water quality impacts at the interior stations.



The special use permit is issued by the Wildlife Division of the Michigan Department of Natural Resources. Under this permit, the Roscommon County Department of Public Works is granted permission to maintain a water transporting pipe across State-owned lands, maintain a wooden walkway on the peatlands to support a water distribution pipe, and to distribute secondarily treated effluent onto the peatlands. Under the terms of this permit, if circumstances arise that are detrimental to plant and animal life, the project comes under immediate review. Detrimental circumstances include detection of toxic materials, excessive levels of pathogenic organisms and excessive water depths. There has not been such an occurrence. This permit also requires monitoring of plant and animal populations, hydrology and water quality.

Water samples were collected for analysis at the points of input and output from the wetland for purposes of compliance monitoring. Water chemistry data for these inflows and outflows shows no significant increases in the nitrogen or phosphorus in the wetland waters at these exit locations.

Table3. Permit Monitoring Points and Target Values

L = Lagoon Discharge **I** = Wetland Interior **O** = Stream Outflow

Parameter	*Location*	*Background Value*	*Target Value*
Chloride	L, I, O	28 mg/l	
pH	I, O	7.0SU	8.0 SU
Ammonium Nitrogen	L, I, O	0.7 mg/l	3 mg/l
Nitrate Nitrogen	L, I, O	0.04 mg/l	0.12 mg/l
Nitrite Nitrogen	L, I, O	0.008 mg/l	0.1 mg/l
Total Phosphorus	L, O		
Total Dissolved Phospohorus	L, I, O	0.05 mg/l	0.5 mg/l
BOD5	L, O		
Suspended Solids	L		
Fecal Coliforms	L		

Operator Opinions

Mr. Brett Yardley, operator of the facility, believes "It is a great system. It has low maintenance, and is good for the community." Importantly, he feels that the regulators (Michigan DNR) are "on my side." The comments he receives are all positive.

Awards

Clean Waters Award 1974, 1985

Michigan Outdoor Writers Association

Award of Merit 1977

Michigan Consulting Engineers Council

Award for Engineering Excellence 1977

American Consulting Engineers Council

State of Michigan Sesquicentennial Award 1987

Michigan Society of Professional Engineers

People

The treatment facility is operated by:

Mr. Brett Yardley
Houghton Lake Sewer Authority
P. O. Box 8
1250 S. Harrison Road
Houghton Lake, MI 48629

Wildlife and land use considerations are coordinated by:

Mr. Rich Earle
Research/Surveys Section Head
Houghton Lake Wildlife Research Station
Box 158
Houghton Lake Heights, MI 48630

Research is conducted and archived by: Dr. Robert H. Kadlec

Wetland Ecosystem Research Group
Department of Chemical Engineering
Dow Building
The University of Michigan
Ann Arbor, MI 48109-2136

Literature

Several thousand pages of documentation exist for this project. The principal categories of documents are:

* **Annual reports.** Each operating year: compliance monitoring results; research results for vegetation, hydrology, internal water chemistry; and research results for all types of animals, insects, and invertebrates.

* **Research reports.** Background studies and pilot system performance are contained in several reports and monographs.

* **Technical papers.** Forty published papers appear in a wide variety of literature sources, and involve many authors.

* **Dissertations.** Fourteen MS and PhD theses have originated from the project.

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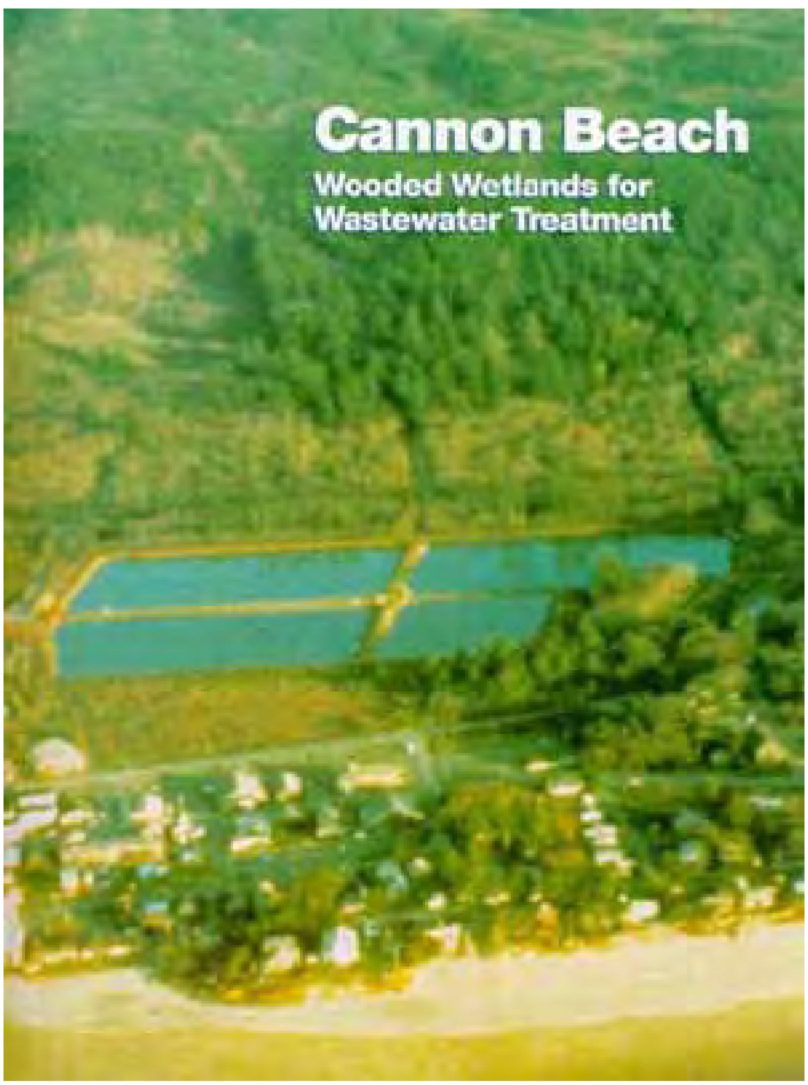
Cannon Beach, OR - Wooded Wetlands for Wastewater Treatment



The History of the Project

Design

Construction and Operation

Costs and Benefits

A Nature Study Guide

The History of the Project

Ducks, geese, elk? These are not usual inhabitants of a wastewater treatment system. But in Cannon Beach, Oregon, particularly in the fifteen acres of the wooded wetlands cells of the system, they are a common sight. How did this come to pass?

Confrontation led to a City commitment to pursue a biological solution instead of more high-tech treatment units to upgrade the treatment system.

Let's look a little closer. The City of Cannon Beach had a problem--how to treat and dispose of its wastewater. With much citizen involvement, a cost-effective ecologically-interactive wastewater treatment facility was created. This Environmental Protection Agency (EPA) funded "Innovative/Alternative" treatment system uses an existing wooded wetland to provide the final stage of the treatment process.

Effluent structures during winter flooding (when wetlands are typically not operated).

Here's the story. The three-celled sewer lagoon complex in existence at the time of the passage of the Clean Water Act of 1972 could not meet the more stringent effluent quality standards set by the Oregon Department of Environmental Quality (DEQ). In response to this situation, the City began a Facilities Plan. The completed plan recommended options for system upgrading which met with considerable community opposition.

At this point in 1977, a Sewer Advisory Board was formed. The City of Cannon Beach is a resort community and during the tourist season the population swells from a permanent size of 1,200 to many times that number. Any design considered by the Sewer Advisory Board would have to be able to accommodate these large fluctuations in wastewater flows.

Confrontation led to a City commitment to pursue a biological solution instead of more high-tech treatment units to upgrade the treatment system. The bureaucratic struggle that ensued lasted eight years and the remarkable result of these meetings was the consolidation of a set of ideas which emerged as yet another facility plan addendum. The issues deliberated included: the use and integrity of the wetlands, elk habitat, chlorination, point of discharge, birdlife, the extent of ecological upset, berming and baffling, fencing costs, and the risks of using new treatment techniques. It is a tribute to the professionals representing the various agencies involved in these meetings that, in spite of diverse and sometimes disparate responsibilities and divergent goals, negotiations took place in a spirit of cooperation and compromise sufficient to allow development of an approvable treatment scheme.

This scheme, the wetlands marsh wastewater treatment system, appeared in draft Facilities Plan Addendum No. 2 in October, 1981 and became final in March, 1982. The Plan subsequently was adopted by the City Council and approved by all the appropriate agencies through the State Clearinghouse review process. Shortly thereafter, a grant application was completed and submitted to the DEQ and EPA and approval of funding for the project was granted in September, 1982.

Typical vegetation in the majority of the wetlands (brush, sedges, and ferns).

Design

1998 Dry Weather Design Population, Flows and Loading

Population Equivalents		4085
Lagoons		
	Flow	0.68 mgd
Ave. Detention Time		7-15 days
	BOD	817 lbs/day
	TSS	817 lbs/day
Wooded Wetland		
	Flow	0.42 g/ac/day
	BOD	14 lbs/ac/day
	TSS	18 lbs/ac/day

How does the treatment facility work? Contrary to popular belief, raw sewage, or wastewater as engineers prefer to call it, is over 99% pure water. About half of it comes from toilets and most of the rest is from kitchen sinks, showers, bathtubs, and washing machines. The Cannon Beach treatment system consists of a four-celled lagoon complex followed by two wooded wetland cells which serve as a natural effluent polishing system.

The objective of the wetland treatment is to meet water quality requirements with minimal disturbance to the existing wildlife habitat. Dikes, containing water control structures, formed the wetland cells, constituting the only physical alteration to the natural wetland. The fifteen acres of wetlands are primarily red alder, slough sedge and twinberry, including the remnants of an old growth spruce forest. These wetlands act as a natural filter to complete the treatment process, and the wildlife is not disturbed.

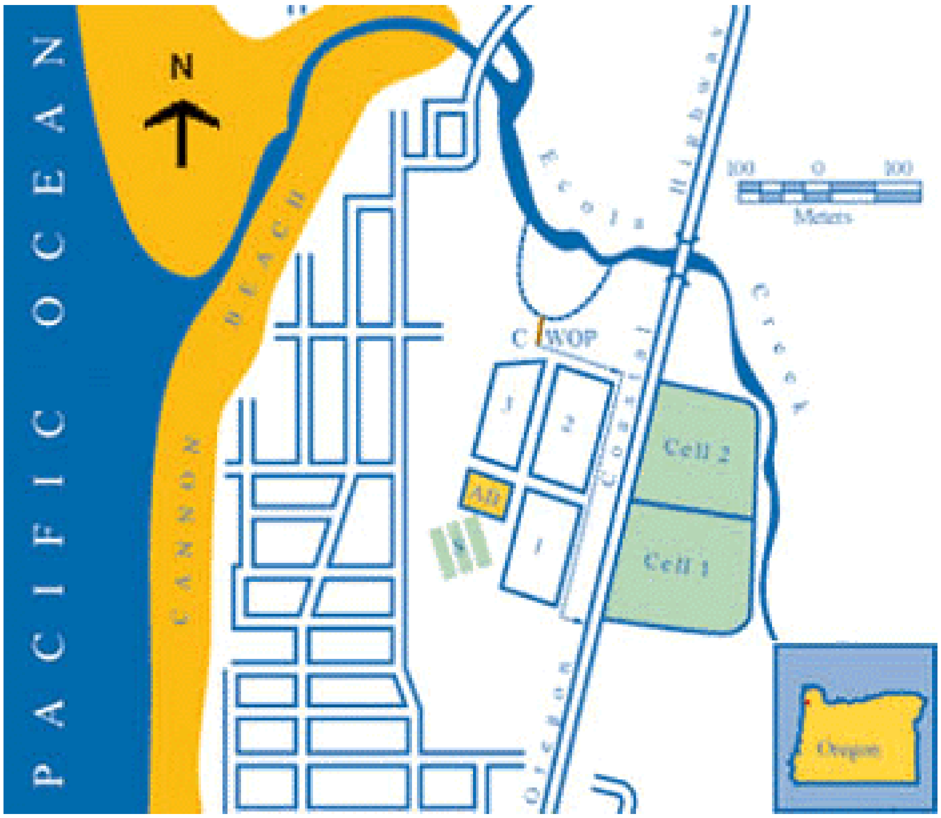
Design of the wooded wetland wastewater treatment system, along with improvements to the existing lagoon system, began in December, 1982. The design of treatment system improvements and the wetland system centered around meeting stringent effluent limitations imposed by the DEQ. Technically speaking, the wastewater treatment focuses primarily on the reduction of both biochemical oxygen demand (BOD) and suspended solids (TSS). The average monthly limitations were 10 mg/l of BOD and TSS during dry weather and 30 mg/l of BOD and 50 mg/l of TSS above Ecola Creek background levels during wet weather.

The principal mechanisms in achieving BOD and TSS reductions in wetland systems are sedimentation and microbial metabolism. Absence of sunlight in the canopy covered wooded wetland contributes to significant algae die-off and subsequent decomposition. The two-celled wetland system was designed with multiple influent ports into the first cell, multiple gravity overflow into the second cell, and a single discharge from the second cell to Ecola Creek. Each cell was designed with approximately 8.0 acres surface area to be operated in series.

Improvements to the existing lagoon system were to provide capacity through the design year of 1998. They centered around three major improvements: upgrading the hydraulic capacity of the system; decreasing the loading to the facultative lagoon system with the addition of an aerated lagoon; and adding a chlorine contact chamber to provide adequate disinfection before discharging to the wetland marsh system.

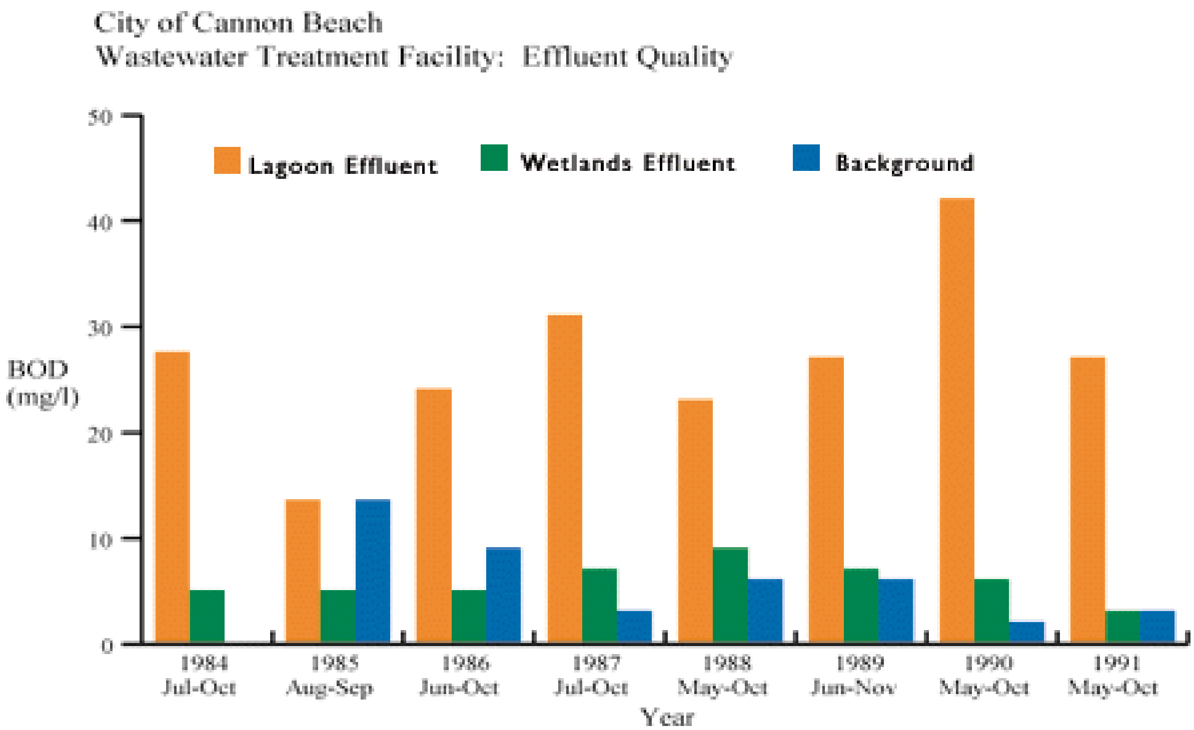
The operational strategy developed around: 1) operating the upgraded facultative lagoon system during the wet weather period of the year, and 2) operating the aerated/facultative lagoon system along with the wooded wetland system during the dry weather season.

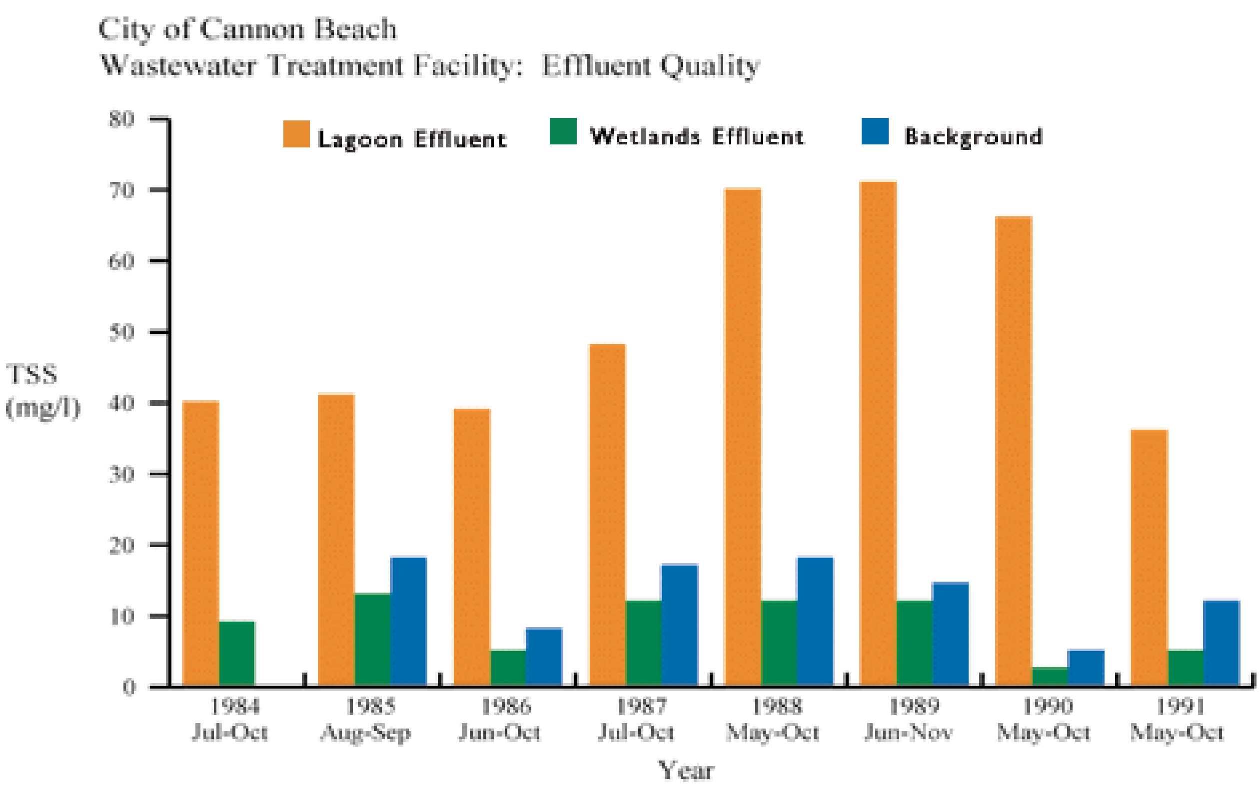
Effluent structures and vegetation l$ in north dike.



AB	Aeration Basin	C	Chlorine contact chamber
1, 2, 3	Facultative Lagoons	WOP	Winter outfall pipe
S	Sludge disposal pits	Cell 1, Cell 2	Wetland treatment cells

Construction and Operation





Construction of the wastewater facility improvements began in July 1983 and the facility officially began operation in June 1984 when flows from the facultative lagoons were initially pumped into the wetland. The system was initially operated with the aerated lagoon effluent flowing in series to the three facultative lagoons, with chlorinated effluent pumped to the wetland cells which were operated in series. The discharge from the system into Ecola Creek is approximately 25% to 50% of the influent flow with the remainder lost through evapotranspiration and seepage. The wetlands cells were initially operated at an approximate average depth of one foot and a detention time of 10-14 days.

Lagoon effluent BOD and TSS have averaged 27 mg/l and 51 mg/l respectively, while the wetlands effluent BOD and TSS averaged 6 mg/l and 11 mg/l respectively. Background water quality in Ecola Creek has averaged 6 mg/l BOD and 13 mg/l TSS. The wetland removes an average of 12% of the influent BOD while removing 26% of influent TSS. Operating efficiency has improved over time with respect to BOD and TSS. In 1991, an average of only 3 mg/l of BOD was discharged. For TSS, the past two years have shown average discharge concentrations of 2 and 5 mg/l respectively. These rates were significantly lower than those of five out of the first six years of operation.

Costs and Benefits

Elk browse on their long-time path to Ecola Creek, along the edge of the wooded wastewater wetland, just 700 feet from downtown Cannon Beach. Click on picture for larger image.

The system has been a success. Performance of the system has exceeded expectations as the effluent has come close to meeting the 10/10 effluent limitations without considering the background water quality. The City has met its monthly permit requirements with only one exception with respect to concentrations in the first eight years of operation. The water quality impact on the creek has been significant, only 25% of the mass discharge loading directly reaches the creek.

The capital costs of the total system improvements were $1.5 million in 1983. Of that, approximately 40% was classified innovative and alternative under the provisions of the Federal Clean Water Act, thus higher funding was provided by EPA. The City received an approximate 80% grant from the EPA. A significant portion of the City's share has been financed through a loan from Farmers Home Administration.

The total Sewer Department's 1992-1993 budget is approximately $600,000. The total operational costs of the pond/wetland treatment facility represents approximately 12% of this figure. Staff includes one full-time operator who devotes approximately half of his time to plant operation and laboratory work, a weekend public works utility person, and a summer student intern.

Sewer billings are based on water usage, using a base rate of $7.50 for the first 600 cubic feet and $1.25 for each additional 100 cubic feet. This rate has remained unchanged since 1983. A 10% across-the-board increase is currently under consideration.

A Nature Study Guide

Treatment of facultative lagoon effluent through the use of a natural wooded wetland has been demonstrated as an effective method over the eight years of operation. The City's direct discharge to Ecola Creek has been reduced and it's quality has been improved resulting in improved water quality for the creek. The capital, operation, and maintenance costs utilizing the wetland treatment system are significantly less than alternative systems. The treatment lagoons and wetland cells are a physical reality and an integral part of the City. Involvement in this sewerage project has resulted in a heightened awareness of the physical setting in which we live, the biological processes of which we are a part, and the society in which we function.

Within the site, the stream flows, trees and plants grow, and animals and birds come and go.

The City has cooperated with the school system in setting up a partnership. Educational materials that integrate social studies and science have been developed cooperatively using a City liaison person and resource teacher. As well as serving as a nature study site, the treatment marsh has been the focus of programs devised by Citizen Education. Waterfowl have been monitored by citizen effort. Tours are conducted for environmentally oriented classes, for groups of teachers, for sewer operators, for those seeking wastewater treatment solutions for their communities and for local citizens, as well as any interested individuals.

The organic nature of the sewerage facilities, the lack of offensive odor and the open layout of the facility contribute to a land use scheme that has a minimal disruption to the environment. Very few visitors realize that the City's sewerage facilities are just 700 feet from the downtown shopping area! Within the site, the stream flows, trees and plants grow, and animals and birds come and go. Numerous species of wild ducks can be seen on the lagoons, elk can be seen in the wetlands area, fishing, walking, and bird watching take place here.

This brochure is dedicated to the memory of Don Thompson, "The Thinker and the Doer of the Cannon Beach Sewer."

Contributors--Dan Elek, Jerry Minor and Francesca Demgen

Produced by--Woodward-Clyde Consultants

Graphic Design--Chris Dunn

EPA Project Manager--Robert Bastian

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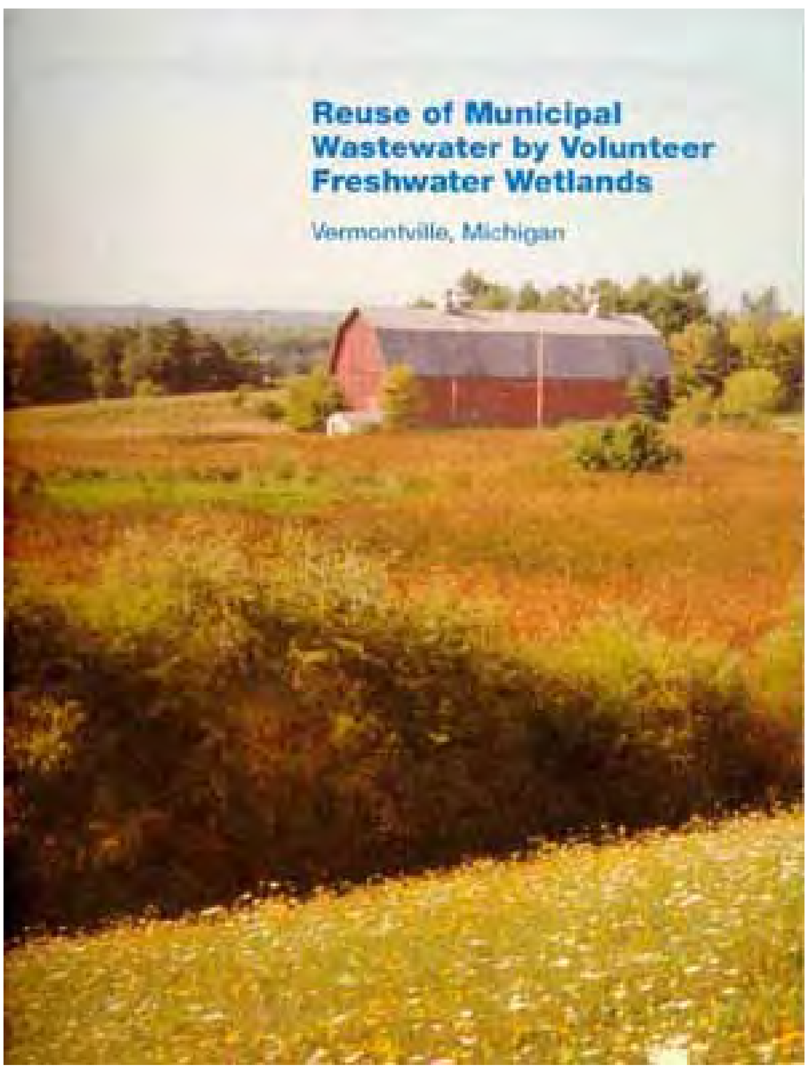
Vermontville, Michigan - Reuse of Municipal Wastewater by Volunteer Freshwater Wetlands



Introduction

Vermontville is a rural community located 25 miles southwest of Lansing. The local maple syrup industry is active; each year a festival brings thousands of visitors to this community of 825 residents. Vermontville considers itself “the sweetest little town in Michigan.” There is no evidence of the high growth and bustle of more urban areas; in fact the local Amish folk tie up their horses and buggies on Main Street. Mayor Beverly Sue Billanueva runs the town and its only restaurant.

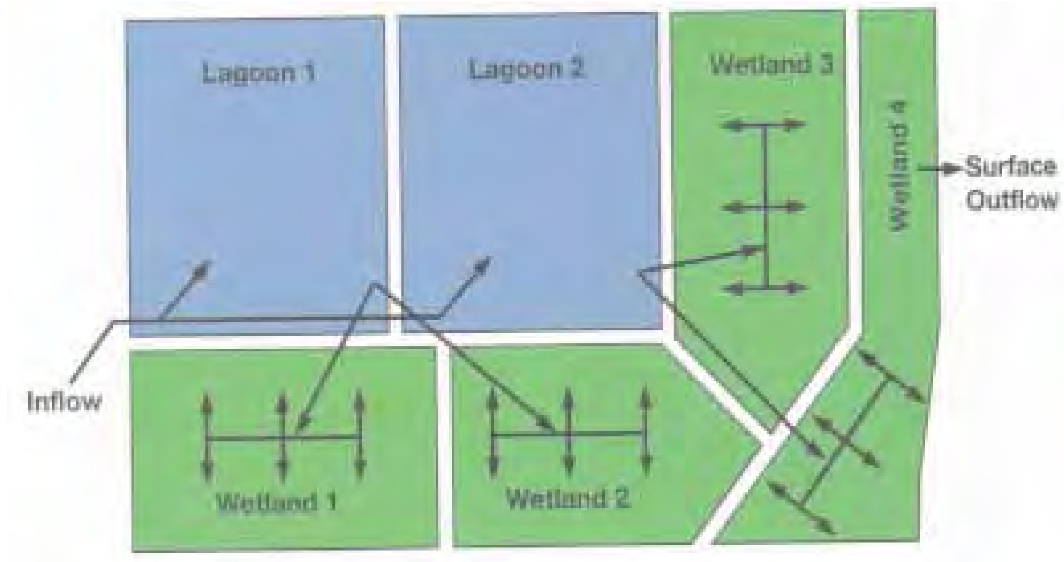


Figure 1

Layout of the Vermontville wastewater treatment system. Inflow may be directed to either of the two lagoons. The lagoons are discharged into wetlands 1-3. Wetland 4 no longer receives a direct discharge; but seepage water from the uphill units re-emerges into wetland 4.

The Clean Water Act of the early 1970’s dictated that Vermontville upgrade its wastewater treatment capabilities. In common with many other small communities, Vermontville could not afford to own or operate a “high tech” physical-chemical wastewater treatment plant. But it was situated to utilize the land-intensive natural systems technology, and decided to do so. In 1972, they opted for facultative lagoons followed by seepage beds. Those seepage beds unexpectedly became wetlands, a system which works remarkably well and is liked by the operators.

System Description

The municipal wastewater treatment system at Vermontville, Michigan consists of two facultative stabilization ponds of 10.9 acres (4.4 ha), followed by four diked surface (flood) irrigation fields of 11.5 acres (4.6 ha) constructed on silty-clayey soils. The system is located on a hill with the ponds uppermost and the fields at descending elevations (Figure 1). After 1991, the nineteenth year of operation, the fields are totally overgrown with volunteer emergent aquatic vegetation, mainly cattail. The system was designed for 0.1 MGD and a life of twenty years. It is presently operated at about three-quarters of design capacity.

The Vermontville system was intended, in the conceptual stages, to provide phosphorus removal both by harvesting of terrestrial grasses and by soil-water contact as wastewater seeps downward from the irrigation fields. Up to four inches of water applied over several hours time once each week would flood the fields briefly until the water seeped away. The upper pond (Lagoon 1, Figure 1), has separate discharge lines into fields 1 and 2, and the lower pond (Lagoon 2) has separate discharge lines into fields 3 and 4. Fields 1-4 have all been colonized by volunteer wetland vegetation, and are now eutrophic emergent marshes.

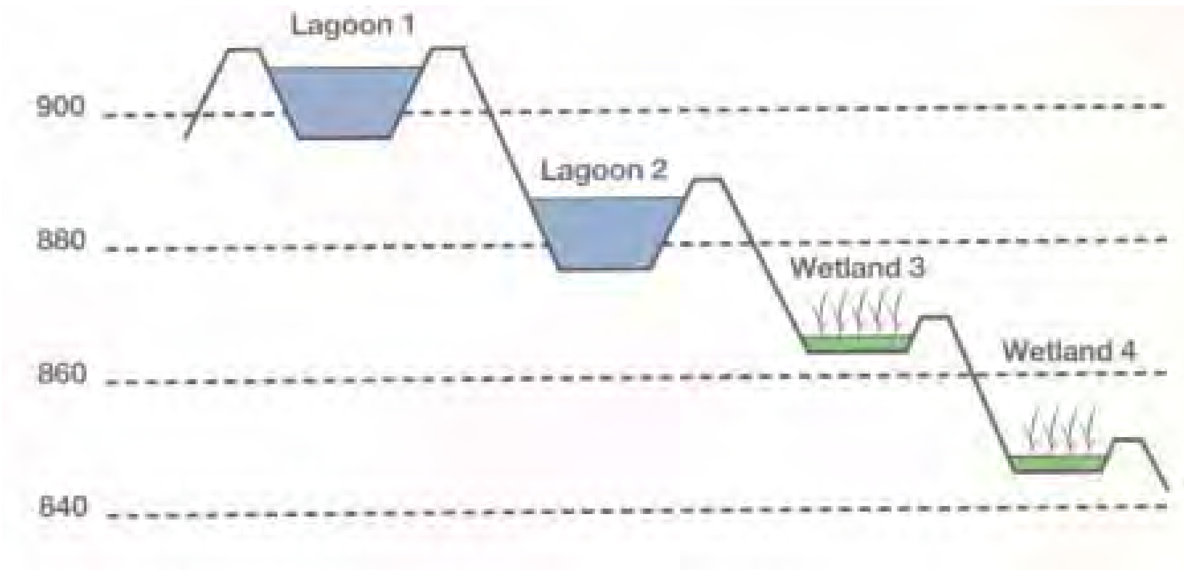


Figure 2

Cross section of the Vermontville wastewater treatment system. The units are set on a steep hillside, with large driving forces for hte gravity flow from lagoons to wetlands. Elevations shown on the left are in feet above sea level. Overflow occurs out of wetland 4 to the right.

Pond-stabilized wastewater is released into each wetland by gravity flow through 10-in. (0.25 m) main and 8-in (0.2m) manifold pipe having several ground level outlets in each wetland. The lagoons and wetlands are terraced on a steep hillside (Figure 2), providing ample driving force for gravity flow. Should the water level exceed 6 in. (15.2 cm), water would overflow to the next wetland by means of standpipe drain. All applied water would seep into the ground before leaving the treatment area.

The system is operating nearly in this manner today. There is a constant surface overflow from the final wetland, made up of ground-recycled wastewater which enters the final field at springs. The direct surface overflow from wetland 3 has been taken out of service. Essentially, the system is a seepage wetland complex and very similar to a conventional flood irrigation facility. The vegetation and relatively small surface overflow from the final wetland provides an established system in which to evaluate the treatment aspects of seepage combined with lateral flow-through wetlands, the potential nutrient removal and wildlife values of these strictly voluntary wastewater wetland, and the economics of the system.

A thorough study of water quality and other aspects of system was conducted in 1978, by Dr. Jeffrey Sutherland of Williams and Works and Professor Frederick Bevis of Grand Valley University. This work was sponsored by The National Science Foundation.

Hydrology

During 1990, approximately 29 MG of wastewater was introduced into the lagoons. This was a dry year. Evaporation exceeded rainfall and snowmelt, leaving only about 22 MG to discharge to wetlands 1, 2, and 3. There was no lagoon discharge to wetland 4. About 7 MG were lost to evaporation in the wetland cells, 13 MG infiltrated to groundwater, and 2 MG overflowed from wetland 4 to the receiving stream.

Wetland 4 receives its water from interior springs fed by the groundwater mound under the upgradient wetlands, most importantly wetland 3. The direct discharge to wetland 4 was discontinued, since it was in close proximity to the system outflow point, and was clearly short-circuiting water across wetland 4. Effluent discharged from the system has therefore passed through the lagoons, then through the upper wetlands, the soils under the site, and finally through the last wetland.

Permits

The facility operates under an NPDES Permit issued by Michigan DNR. The outflow from wetland 4 is to an unnamed tributary of the Thornapple River, which is protected for agricultural uses, navigation, industrial water supply, public water supply at the point of water intake, warm water fish and total body contact recreation. There are presently no industrial dischargers. The discharge limitations from the treatment wetlands

Table 1. Discharge limitations for the Vermontville wastewater treatment facility.

Parameter	Dates	Daily Minimum	Daily Maximum	30-Day Average	7-Day Average
CBOD5	4/15-4/30		25 mg/l	17 mg/l 14 lb/d	21 lb/d
	5/1-9/30		10 mg/l	5 mg/l 4.2 lb/d	8.3 lb/d
	10/1-10/31		16 mg/l	11 mg/l 9.2 lb/d	13.3 lb/d
TSS	4/15-4/30			20 mg/l	30 mg/l
	5/1-10/31			30 mg/l	45 mg/l
NH4-N	4/15-4/30			7 mg/l	
	5/1-9/30			2.2 mg/l	
	10/1-10/31			5 mg/l	
TP	All Year			1.0 mg/l 0.83 lb/d	
DO	4/15-4/30	5 mg/l			
	5/1-9/30	6 mg/l			
	10/1-10/31	5 mg/l			
pH	All Year	6.5	9.0		

Water Quality

Compliance Monitoring

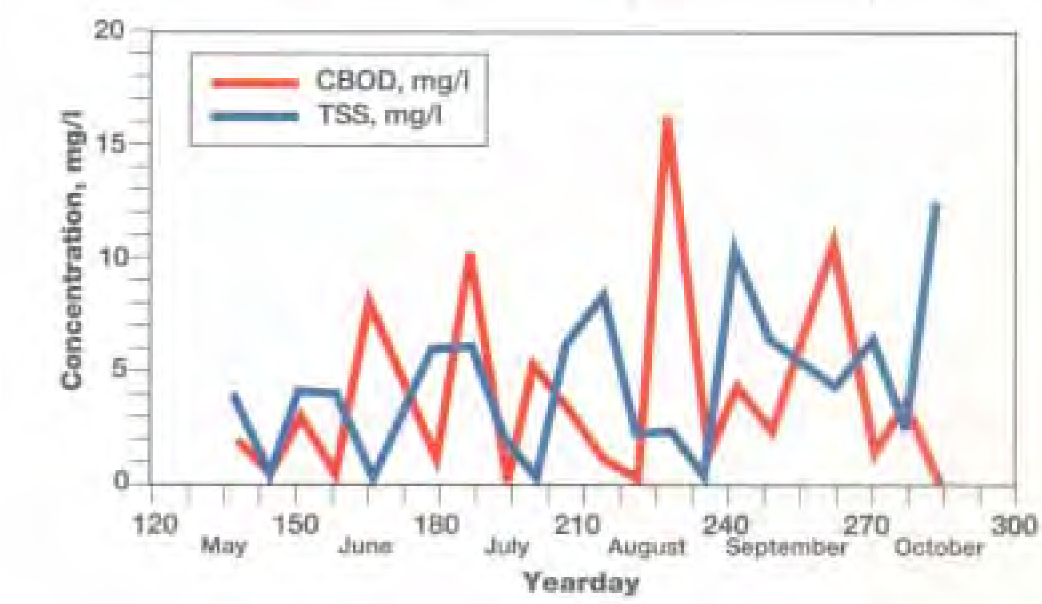


Figure 3

Both CBOD and TSS fluctuate in the outflow from the wetlands, but the seasonal averages are quite low; 3.5 mg/l for CBOD; 4.2 mg/l for TSS. (Data are for 1990)

The overflow from final wetland field 4 contains a fairly constant volume of effluent which has seeped from the higher elevation wetlands, flowed through the ground, and entered field 4 springs. This treated effluent is of high quality, as is the ground water recovered from the project's monitoring wells. The outflow is monitored weekly. Total suspended solids (TSS) was well within permit limits at all times during 1990 (Figure 3), indicating that the wetlands had effectively filtered and settled particulate material.

Carbonaceous biological oxygen demand (CBOD) also remained within 30-day average permit limits in 1990, and there was only one excedance of the seven-day permit limit of 5 mg/l. The CBOD load in the surface discharge was less than 10% of that allowed by the permit.

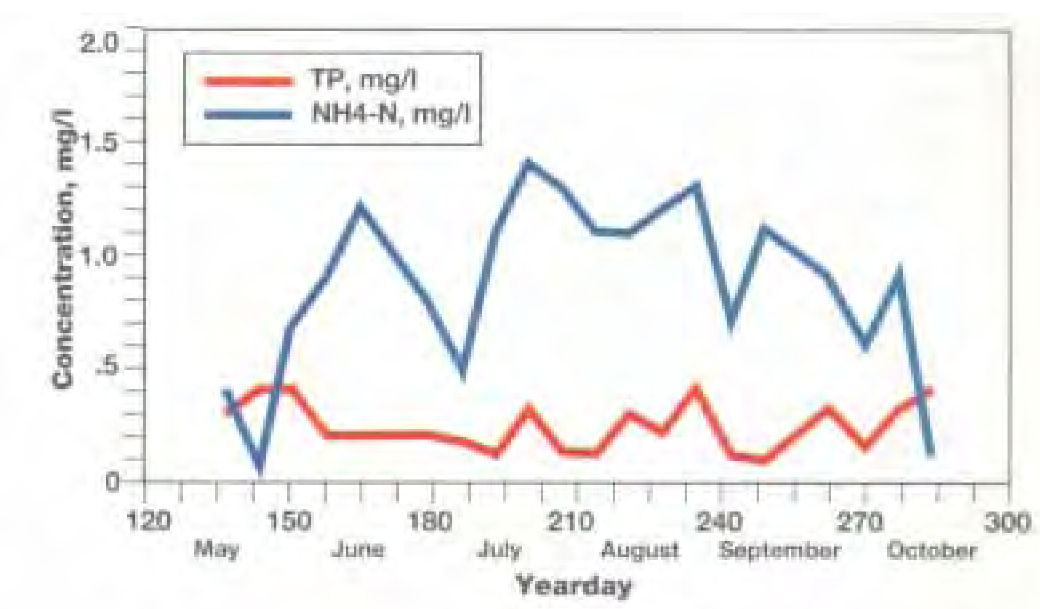


Figure 4.

The nutrients phosphorus and ammonium nitrogen were well within limits in the

Total phosphorus in the surface discharge was also well within permit limits, with an average 1990 value of 0.24 mg/l compared to the permit level of 1.0 mg/l (Figure 4). The same was true for ammonium nitrogen, which averaged 0.86 mg/l compared to the 2.2 mg/l permit requirement. Both phosphorus and nitrogen display considerable variability, which is characteristic of many wetland systems. The *wetland outflow in 1990. The seasonal average total phosphorus was 0.24 mg/l; ammonium nitrogen averaged 0.86 mg/l.*

seasonal trends in ammonium nitrogen—an increase followed by a decrease—have been observed at other sites, and are therefore probably real. They are likely due to the changing processes of plant uptake and decomposition. Figure 3. Both CBOD and TSS fluctuate in the outflow from the wetlands, but the seasonal averages are quite low; 3.5 mg/l for CBOD; 4.2 mg/l for TSS. (Data are for 1990) Dissolved oxygen averaged 7.0 mg/l in 1990, with a range from 5.4 to 9.4, which included a four excedances of minor nature. pH ranged from 6.6 to 7.2, well within the permit range. Fecal coliform counts (Figure 5) are within limits for surface water discharges, but are higher than at other comparable wetland sites.

Research Results

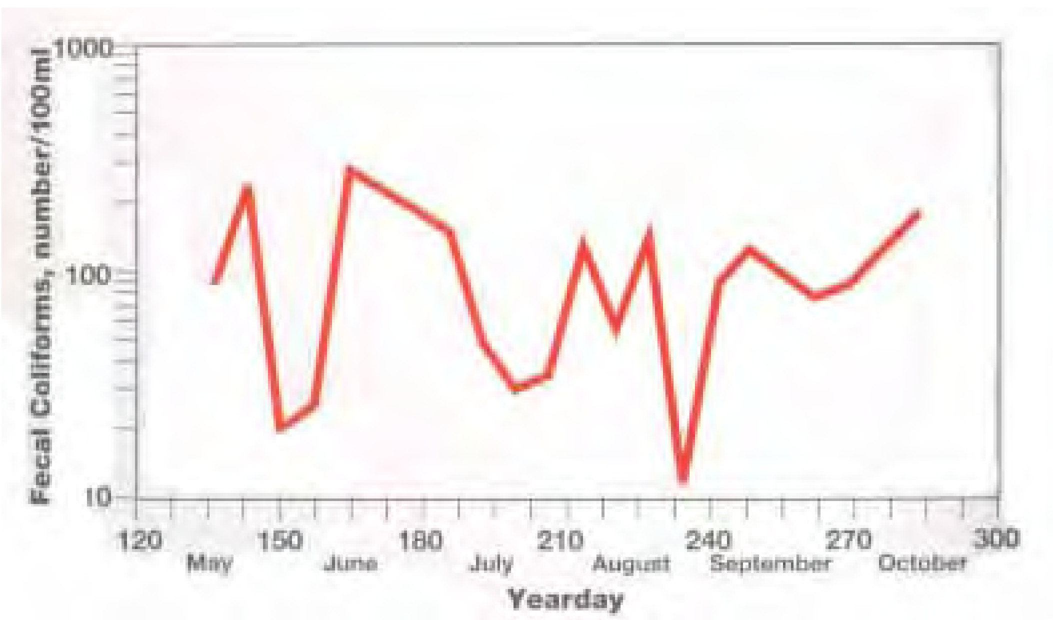


Figure 5

Fecal coliform bacteria counts also fluctuate in the outflow from the wetlands, but the seasonal average is quite low; the geometric mean value was 77 (Data are for 1990).

Some of the more detailed water quality results for 1978 are summarized in Figure 6. Greater than two-fold dilution across the system was evident in the decreasing chloride concentration from 280 mg/l in the effluent to 124 mg/l in the ground water. Pond effluent was 25% diluted with respect to influent. Although a few inches of precipitation in excess of evaporation from the ponds occurred during the summer, the 25% dilution was more importantly due to excessive snow and ice meltwater added to the ponds in spring 1978. The 25% dilution between the pond effluent and the water standing in the wetlands was due principally to a large number of sampling dates coinciding with significant rainfall. Greater than 20 inches (50.8 cm) of rain fell in the 4 1¼2 months from June to mid October, which was approximately 50% higher than the normal rate. The decrease in concentration between irrigation fields and ground water was due to mixing of wastewater with more dilute ambient ground water.

Phosphorus was removed to the extent of around 97% between the wetland fields and the ground water, which was sampled from monitoring wells placed at depths ranging from roughly 10 ft. to 25 ft. (3.0 m to 7.6 m) below the wetland floors. Most removal of phosphorus occurs in the upper 3 ft. (0.9 m) of soils judging from a small number of lysimeter samples which averaged 0.11 mg/l total P and 0.06 mg/l ortho-P, with ranges of 0-0.3 mg/l and 0-0.2 mg/l, respectively. The average removals of phosphorus effected in the upper 3 ft. (0.9 m) of soils were approximately 95%.

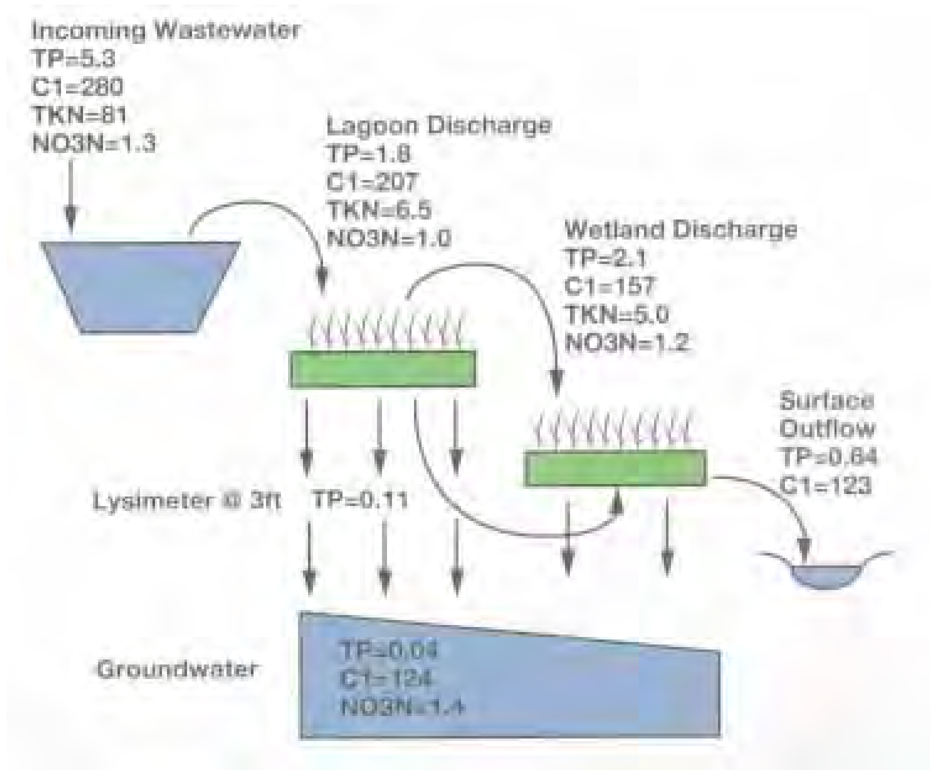


Figure 6

Profiles of water quality in 1978. Lagoons and wetlands and soils are functioning to remove nutrients in this system. During the early life of the facility, there were lagoon discharges directly to wetland 4; and there was surface overflow directed from wetland 3 to wetland 4. This resulted in some short-circuiting to the surface outflow; and consequently higher phosphorus numbers than in the present mode of operation.

Levels of nitrate-nitrogen increased approximately 60% between the pond discharge and the wetland standing water, indicating that aerobic bacteria were at work in the wetland waters. On the other hand, the sediments were anaerobic as evidenced in the fetid odor which evolved when they were disturbed. Loss of some of the nitrate by denitrification was apparently occurring. Lysimeter samples showed nitrate-nitrogen ranging from 0.0 to 0.9 mg/l, which suggested that denitrification of approximately 60% of the nitrate occurred in the shallow wetland soils. The ambient ground water contained higher levels of nitrate-nitrogen than did the seeping wastewater, perhaps indicating some further nitrification during passage through the soil.

Levels of TKN and ammonia-nitrogen seemed not to change much between the pond discharge and the wetland waters. But this constancy was likely only apparent, with organic nitrogen and ammonia probably being produced through anaerobic decomposition in the wetland sediments and being consumed in the aerobic wetland waters.

Vegetation

The wetlands were observed to contain eight plant communities in 1978. These included areas dominated by grassland, duckweed, cattail and willow. In 1991, the grassland and duckweed communities were no longer significant. The wetlands are now dominated entirely by cattail and willow shrubs and trees.

Standing crops (above ground plant parts) for the wetlands varied from a minimum of 830 to over 2,200 gm/m2 in the wetlands in 1978. Visual estimates in 1991 indicate that the standing crops are presently somewhat higher than that maximum, and more uniform. There appears to be approximately 3,000 gm/m2 at all locations, not counting trees. Because the wetlands are located on an exposed hillside, winds can and do blow down the cattails. The result is a patchy stand of cattail, about three meters in height where it is erect, and flat on the surface elsewhere.

The phosphorus in the prevailing cattail standing crop is significant compared to the phosphorus released into the wetlands. Cattail harvesting would therefore be a means of reducing effluent phosphorus. But harvesting is not needed for phosphorus removal in seepage wetland settings where subsurface soil types and volumes are adequate to effect phosphorus removal before effluent ground water reaches receiving streams. The expense and difficulty of harvesting further preclude its use at Vermontville.

Wildlife

Casual observation reveals the wastewater-grown wetlands have significantly added to the acreage of suitable, adequately isolated habitat for waterfowl and other wildlife in the Vermontville area. Natural, interrupted zones of attached aquatic plant life fringe the nearby Thornapple River, but these are narrow, small and easily accessible to fisherman and other recreationists. The wastewater wetlands are part of a restricted public access area.

The Vermontville volunteer wetland system created marshland habitat suitable for waterfowl production otherwise not present in the immediate area. Many other types of birds also nest in the marshes, including red-wing blackbirds, American coot, and American goldfinch. Waterfowl (blue-winged teal and mallard), shorebirds (gallinule, killdeer, lesser yellow-legs, and sandpiper) and swallows use the wetland pond system for feeding and/or resting during their migration. Great blue heron, green heron, ring-neck pheasant, and American bittern have also been seen frequenting the wetlands.

These volunteer wetlands are also important habitat for numerous amphibians and reptiles. These include snapping and painted turtles, garter and milk snakes, green and leopard frogs, bullfrogs and American toads. Muskrats inhabit the wetlands, while raccoon, whitetail deer, and woodchuck are seen feeding in the wetlands.

Operating and Maintenance Activities

Very little wetland maintenance has been required at Vermontville. The berms are mowed three or four times per year, for aesthetic reasons only. Water samples are taken on a weekly frequency at the surface outflow. The discharge risers within the wetlands are visited and cleaned periodically during the irrigation season. There is essentially nothing to be vandalized, and there have been no repairs required.

The dikes are monitored for erosion, which has not been a significant problem. Muskrats build lodges and dig holes in the dikes; and woodchucks also dig holes in the berms. Therefore, a trapper is allowed on the site to remove these animals periodically. The operator also periodically tears the muskrat lodges apart.

Wetland number two contains more and larger willows. Together with the narrow leaved cattail, these two species dominate the wetland.

There are no bare soil (tilled) areas to be plugged through siltation caused by rain splash, spray irrigation, or flood-suspension of inorganic soils. The Vermontville wetlands showed buildup of three or four inches (0.1 m) or organic residues largely in the form of cattail straw after six irrigation seasons (1972-78). That litter mat is still of the same thickness today, but is accompanied by a small accretion of new organic sediments and soils. There was one attempt to burn the accumulated detritus, which proved to be difficult, and of no value in the system operation or maintenance. The amounts of this material have not compromised the freeboard design of the embankments over the system’s 19+ year operational period. Tree control has not been practiced at Vermontville, and the wetlands now contain willow trees up to several meters in height. No hydraulic problems have been experienced due to these trees, or any other cause.

Costs

The Vermontville ponds and wetlands cost $395,000 to build in 1972. Much of this expense was incurred for grading, because of the uneven topography of the site.

The operating and maintenance costs associated with the wetlands portion of the treatment system are quite low. In 1978, these were approximately $3,500 per year, of which $2,150 was labor and field costs, and the balance for water quality analytical services. In 1990, these same costs totalled about $4,200, including $3,400 for labor and field costs.

Contacts

The treatment system is under the supervision of Mr. Tony Wawiernia, Superintendent, Department of Public Works, 121 South Main Street, Vermontville, MI 49096. Phone (517) 726-1429.

The designers and engineers for this facility were Williams and Works, Inc., 611 Cascade West Parkway S.E., Grand Rapids, MI 49506.
Phone (616) 942-9600.

The ponds at Vermontville are set into a hillside that drops off more than 70 feet. This view of lagood 2 shows the high and wide berms that this relief necessitates. In late summer, these are covered with a profusion of wildflowers.

Professor Fred Bevis visits the site with his students on a regular basis, and collects information on vegetation and other aspects of the ecosystem. Fred is Chairman of the Department of Biology, Grand Valley State University, Allendale, MI 49401.
Phone (616) 895-3126.

Performance

The 1978 research work is detailed in a report to The National Science Foundation under Grant No. NSF ENV-20273, May 1978. This report is available from the National Technical Information Service. Conference reprints summarizing the work were prepared, and may be obtained by contacting Professor Bevis:

> Applied Ecology Group 11628 104th Ave. West Olive, MI 49460-9632

Sutherland, J. C. and F. B. Bevis, 1979. *Reuse of Municipal Wastewater by Volunteer Fresh-Water Wetlands. IN:* Proceedings of Wetland Reuse Symposium, Vol. 1, p. 762-781. AWWA Research Foundation, Denver, CO.

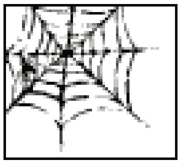
Bevis, F. B., 1979. "Ecological Considerations in the Management of Wastewater-Engendered Volunteer Wetlands," presented at the Michigan Wetlands Conference, MacMullan Center, Higgins Lake, MI.

A brief summary description also may be found in:

> Sutherland, J. C., 1982. "Michigan Wetland Wastewater Tertiary Treatment Systems,"
> Chapter 16 in: *Water Reuse*,
> E. J. Middlebrooks, ed., Ann Arbor
> Science Publishers, Inc., Ann Arbor, MI.

EPA United States Environmental Protection Agency
Office of Water

Constructed Wetlands for Wastewater Treatment and Wildlife Habitat



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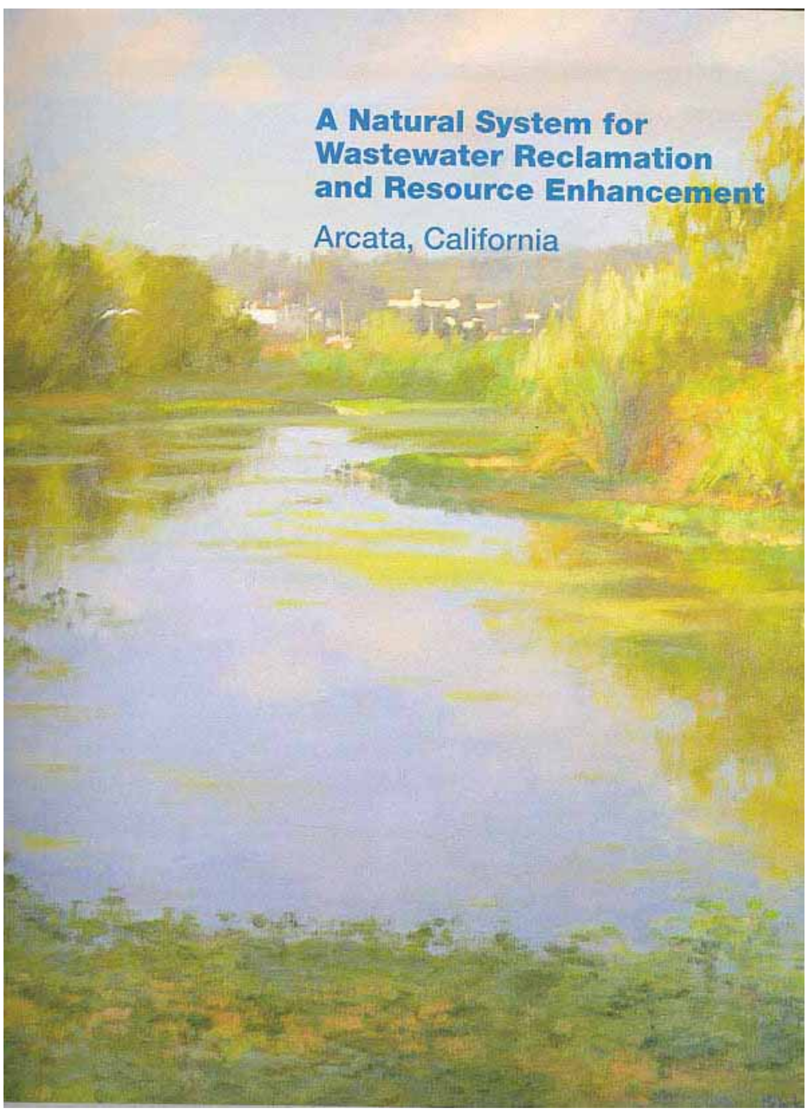
Arcata, California - A Natural System for Wastewater Reclamation and Resource Enhancement



Introduction

...a constructed wetland system can be a cost efficient and environmentally sound wastewater treatment solution.

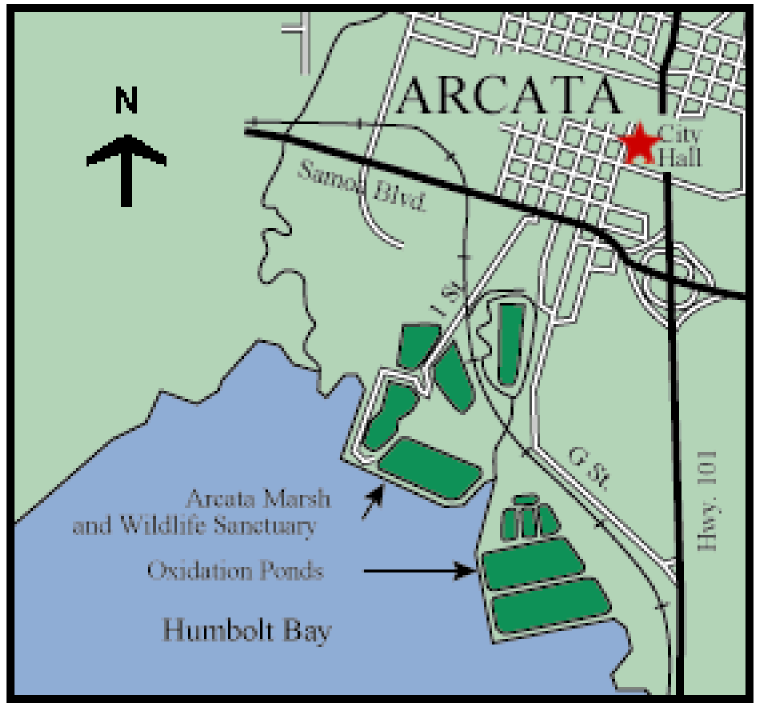
The constructed wetland system is the cornerstone of Arcata's urban watershed renovation program. This program includes major urban stream restoration, log pond conversion to a swamp habitat, pocket wetlands on critical reaches of urban streams, and an anadramous wastewater aquaculture program to restore critical commercial recreational and ecological important populations. The Arcata project is a demonstration of wastewater reuse, ecological restoration, and reuse of industrial, agricultural and public service land.

Arcata Site Plan

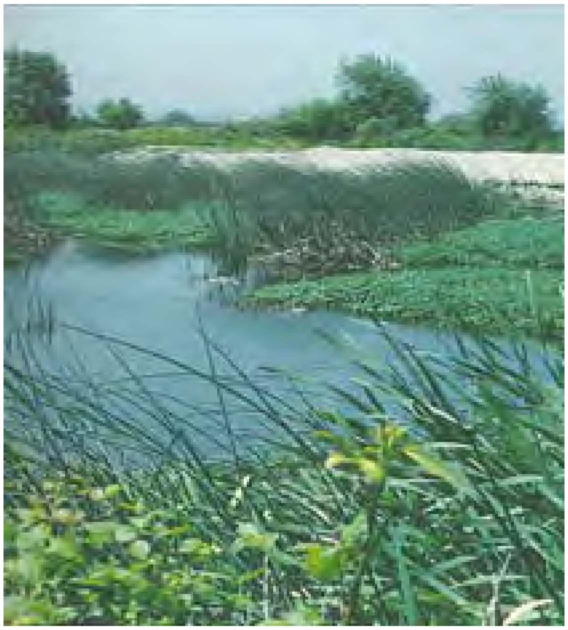
Situated in the heart of the redwood country and along the rocky shores of the Pacific Northcoast, the City of Arcata is located on the northeast shore of Humboldt Bay in Northern California, 280 miles north of San Francisco. Arcata, with a population of approximately 15,000, is a diverse community whose resourcefulness and integrity has demonstrated that a constructed wetland system can be a cost efficient and environmentally sound wastewater treatment solution. In addition to effectively fulfilling wastewater treatment needs, Arcata's innovative wetland system has provided an inspiring bay view window to the benefits of integrated wetland enhancement and wastewater treatment.

What is the Arcata Marsh and Wildlife Sanctuary?

Arcata is a small town located on the north-eastern side of Humboldt Bay, about 280 miles north of San Francisco. Humboldt Bay is a focal point where timber resources and marine resources cross paths as they struggle to sustain Humboldt County's economy. Resource management is a practice that receives high priority and expert advice in this scenic niche of the Pacific Northcoast. Arcata, with a population of approximately 15,000, is a diverse community whose resourcefulness and integrity has served to lead the city down a successful path marked by innovative decisions and maintained by pride. So, when the city faced making a change in their wastewater treatment methods, they demonstrated that a constructed wetland system can be a cost efficient and environmentally sound wastewater treatment solution. In addition to effectively fulfilling wastewater treatment needs, Arcata's innovative wetland system has provided an inspiring bay view window to the benefits of integrated wetland enhancement and wastewater treatment.



How did the project evolve?



Arcata established its innovative treatment system as a result of extensive community involvement and a series of political events. In the early 1970's, Arcata's active wastewater treatment plant discharged unchlorinated primary effluent into Humboldt Bay. In 1974 the State of California enacted a policy which prohibited discharge of wastewater into bays and estuaries unless enhancement of the receiving water was proven. In response to this policy the local Humboldt Bay Wastewater Authority proposed the construction of a state sponsored regional wastewater treatment plant that would serve all the communities in the Humboldt Bay vicinity. The plant was to have large interceptors around the perimeter of the bay with a major line crossing under the bay in the region of active navigation. The proposed treatment facility was energy intensive, with significant operational requirements. Effluent from the proposed plant was to be released offshore into an area of shifting sea bottom and heavy seas during winter storms. As the scale of the regional treatment plant grew, the costs and difficulties of incorporating other communities became apparent

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Arcata established its innovative treatment system as a result of extensive community involvement and a series of political events.

Recognizing the constraints of the local environment and criteria for wastewater treatment, the City of Arcata began exploring the design of a decentralized system which employed constructed wetlands. Wastewater aquaculture projects at the City of Arcata started as early as 1969 and had been successful in raising juvenile Pacific Salmon and Trout in mixtures of partially treated wastewater and seawater. This project demonstrated that wastewater was a "resource" that could be reused and not simply to be viewed as a disposal problem. With this philosophy a city Task Force on Wastewater Treatment determined that the natural processes of a constructed wetland system could offer the city an effective and efficient wastewater treatment system. From 1979 to 1982 the city, and associated proponents of alternative wastewater treatment, experimented with partially treated wastewater and the natural processes of wetland ecosystems. These experiments demonstrated that constructed freshwater wetlands could be utilized to treat Arcata's wastewater and at the same time enhance the biological productivity of the wetland environment into which treated wastewater was discharged. The Task Force determined that a constructed wetland system was extremely cost effective. Moreover, a successful system offers the city a vital wetland ecosystem that could be used for the rearing of salmon and steelhead as well as offer the community a unique site for recreation and education.

With the aid of the Arcata City Council and political representatives in the state capital, the city received authorization in 1983 to develop the constructed wetland system and incorporate its use at the original Arcata Wastewater Treatment Plant. The wetland system that exists today was completed in 1986. Since that time the natural ability of marsh plants, soils and their associated microorganisms has successfully been utilized to meet the need for a cost-effective and environmentally sound wastewater treatment technology that meets federal and state mandated water quality requirements.

Who cares and what are the benefits?

At the same time that wetland wastewater technology has been used to successfully meet water quality criteria, it has also aided in restoring a degraded urban waterfront. Prior to the installation of its wetland treatment system, the City of Arcata's waterfront was the site of an abandoned lumbermill pond, channelized sloughs, marginal pasture lands, and a closed sanitary landfill. Today, Arcata's waterfront has been transformed into 100 acres of freshwater and saltwater marshes, brackish ponds, tidal sloughs and estuaries. Because of the wetland communities and wildlife habitats that the waterfront now supports, the area in its entirety has come to be known as the Arcata Marsh and Wildlife Sanctuary (AMWS.) The AMWS's three freshwater wetlands are Gearheart, Allen and Hauser Marshes. They were constructed to receive treated wastewater, thereby treating the wastewater further and enhancing the receiving water at the same time. These enhancement marshes are a host of aquatic vegetation that, in association with Klopp Lake and the adjacent estuaries and ponds, have further provided an extraordinary habitat for shorebirds, waterfowl, raptors and migratory birds.

As a home or rest stop for over 200 species of birds, the AMWS has developed a reputation as one of the best birding sites along the Pacific North Coast. The Redwood Region Audubon Society uses the site on a regular basis for its weekly nature walks. For the past 10 years, docents trained by the Society have explained the role the wetlands play in attracting birds and mammals, as well a s their role in managing the water quality of Humboldt Bay. The beauty and uniqueness of the AMWS has served as inspiration to many artists, whose products range in form from plays and poems to photographs and paintings.

Arcata has become an international model of appropriate and successful wastewater reuse and wetland enhancement technologies. Over 150,000 people a year use the AMWS for passive recreation, bird-watching, or scientific study. Visitors from around the world have come to Arcata to investigate its success in wastewater management. Students of all ages and institutions use the AMWS for scientific study. In 1987, the City of Arcata was selected by the Ford Foundation to receive an award for this wastewater wetlands project as an innovative local government project. This award included a $100,000 prize to be used to fund the establishment of the Arcata Marsh Interpretive Center. The Center focuses on the historical, biological and technical aspects of the AMWS, and attempts to meet the informational and educational demands of the wastewater treatment system.

Today, Arcata's waterfront has been transformed into 100 acres of freshwater and saltwater marshes, brackish ponds, tidal sloughs and estuaries.

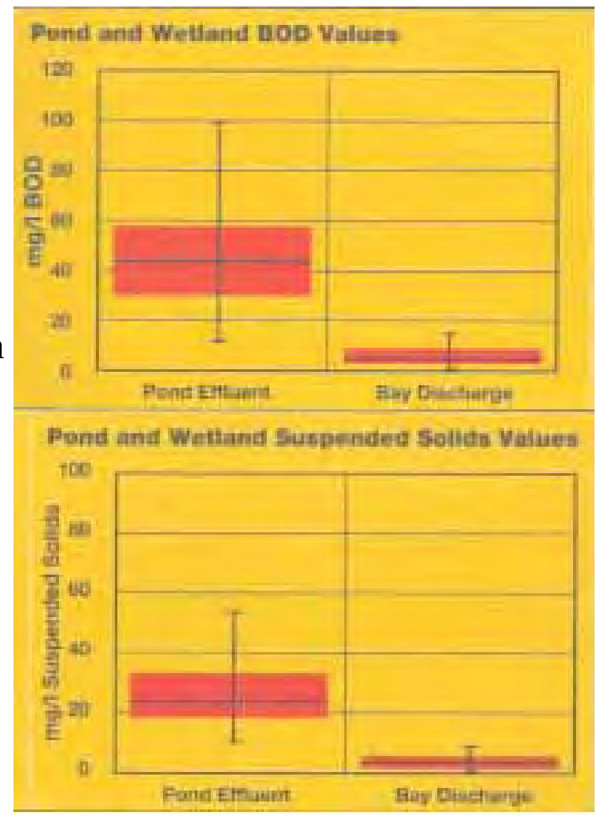
Take a look at some of the living environments of the Arcata resources. *(JPG format, 39KB)*

Stage in Treatment Plan

Take a look at the Stage in Treatment Plan

Arcata's present wastewater treatment plant consists of seven basic components. These are the headworks, primary clarification, solids handling, oxidation pond, treatment marshes, enhancement marshes and disinfection. Each one of these components will be detailed as follows.

Headworks: The "headworks" component of Arcata's wastewater treatment plant is the first phase in the treatment of raw sewage and consists of technologies aimed at removing inorganic materials from the raw sewage. The technologies include two screw pumps that lift the sewage fifteen feet and pass it through bar screens, a parshall flume (for flow measurement) and grit separators before it enters the clarifiers.



Primary Clarification: Two clarifiers are used to settle out any remaining suspended material that passes through the headworks. The liquid form of sewage that results from clarification flows to the oxidation ponds, completing primary treatment. The solids that settle out in the clarifiers are pumped to the digesters.

Sludge Pumping and Stabilization/Cogeneration: The sludge from the clarifiers is pumped first to the primary digester and then the secondary digester. The digestors mix the sludge by recirculating methane gas with compressors. The digestors were designed in conjunction with a methane recovery and cogeneration system. The cogeneration component is designed burn the methane gas and utilize the heat to aid in the digestion process.

Oxidation Pond: The oxidation ponds efficiently remove approximately 50 percent of the BOD and suspended solids that remain after primary treatment. Long detention times and natural processes (see diagram showing plant and animal roles) accomplish these reductions.

Treatment Marshes: The treatment marshes reduce the levels of suspended solids and BOD concentrations that remain in the oxidation pond effluent. The three, two-acre treatment marshes in operation are located north of the oxidation ponds. They were created by subdividing the previous oxidation ponds. All treatment marshes were planted with hardstem bulrush (Scirpus acutus), a freshwater marsh plant native to the Humboldt Bay area. This plant's effectiveness as a treatment species was shown by Marsh Pilot Project data. The treatment marsh's effluent is combined at a pump station where it is pumped to the disinfection facility.

Enhancement Marshes: After the first chlorination, wastewater is directed to the enhancement marshes, which are located northwest of the oxidation ponds. The three enhancement marshes cover a total of 31 acres. These marshes are managed to maintain the greatest diversity of aquatic plant species and to maintain or improve water quality. Flow is directed through the enhancement marshes with sluice gates and wooden stop-log weirs. After disinfection, the wastewater flows into George Allen Marsh, then Robert Gearheart Marsh, and finally Dan Hauser Marsh. The effluent from Hauser Marsh is pumped back to the disinfection facility.

Disinfection: Chlorine gas is used to disinfect Arcata's waste water before it is discharged to the enhancement marshes and again before it is discharged into Humboldt Bay. Because of this “double™ chlorination” two chlorine contact basins are necessary. These basins are built as one unit, which is located immediately south of the headworks. Any free chlorine remaining in the final effluent after the 60 minute contact time is removed with sulfur dioxide.

Arcata Marsh and Sanctuary: Points of Interest

1 Robert Gearheart Marsh: Completed in 1981, this marsh was built from pastureland and now uses treated wastewater as the sole water source.

2 George Allen Marsh: Also completed in 1981, this marsh was built on an abandoned log deck and is enhanced with wastewater.

3 Dan Hauser Marsh: The final marsh to be irrigated with treated wastewater before returning to the treatment plant for disinfection and release into to the bay. This marsh was a barrow pit for the closure of the adjacent landfill.

4 Mount Trashmore: This grassy hill has been reclaimed from a sealed sanitary landfill that operated during the 1960's and 70's.

7 Arcata Boat Ramp: The only concrete boat ramp maintained in Arcata Bay, this serves as an access point for sport boating, duck hunting, and sport shellfish harvesting.

11 Butcher’s Slough: Butcher’s Slough is a restored estuary receiving feed from Jolly Giant Creek, the principal watershed in Arcata. A California Coastal Conservancy Project returned the estuary to its original alignment and ecological value. This slough serves as home to the Coastal Cutthroat Trout.

12 Butcher's Slough Marsh: An old log pond restored to provide swamp-like habitat in the Arcata Marsh and Wildlife Sanctuary.

16 AMWS Interpretive Center: This is the site where the AMWS Interpretive Center is built. This center will attempt to meet the educational demands of the treatment system.

5 Frank Klopp Lake: This brackish lake was also a barrow pit for the closure of the landfill and is now a popular loafing area for shorebirds, a feeding area for diving birds and river otters, and a place for artificial-bait-only sport fishing.

6 Treatment Marshes: Three 2.5 acre constructed wetlands which process oxidation pond effluent to secondary standards prior to release to the Arcata Marsh and Wildlife Sanctuary.

8 Wastewater Aquaculture Project: Fish hatchery and ponds where salmon, trout and other fish are raised in a mixture of wastewater and seawater.

9 Marsh Pilot Project: These ten 20’ X 200’ marsh cells have been used since 1980 to demonstrate the effectiveness of constructed wetlands to achieve water quality and habitat goals.

10 Oxidation Ponds: These 45 acres of ponds, built in the late 1950’s, treat Arcata’s wastewater to secondary standards.

13 Arcata Bay: This bay produces more than half of the oysters grown in California and is home to a variety of other aquatic animals.

14 Headworks Facility: This is the place where the influent to the treatment system is received.

15 Discharge Point: This is the point where a mixture of treatment of marsh effluent and enhancement marsh effluent is discharged into the Arcata Bay side of Humboldt Bay.

Specifications

Design Population..19,056
Average Annual Flow....................................2.3 mgd
Maximum Monthly Flow................................5.9 mgd
Peak Flow..16.5 mgd
BOD's Load..4100 lbs/day
TSS Load..3400 lbs/day

Headworks

Mechanically Cleaned
Bar Screens.................................2 at 5 mgd each
Gravity Grit Removal.....................................144 ft.2

Primary Treatment

2 Primary clarifiers ....26 ft. diam./60 ft. diam
Retention time at design flow............................3.8 hrs.
Retention time at max. monthly flow..................1.4 hrs.

Treatment Marshes

Total area..7.5 acres
Ave. Depth..2 ft.
Total detention time at design flow..................1.9 days

Chlorination/Dechlorination

Volume..185,400 gallons
Retention time at design flow............................58 min.
Retention time at max. monthly flow..................30 min.

3 Enhancement Marshes

Total area..31 acres
Ave. depth...1.5 ft.
Retention time at ave. flow..................................9 days

Acknowledgments - Elected Officials
Lynne Canning
Elizabeth Lee
Bob Ornelas
Sam Pennisi
Victor Schaub *Mayor*

City Staff
Frank Klopp *Director of Public Works*
Steve Tyler *Deputy Director of Public Works*
David Hull *Aquatic Resources Specialist*

Supporting Organizations
California Coastal Conservancy
California State Water Resources Control Board
California Coastal Commision
California Department of Fish and Game
Humboldt State University
Redwood Regional Audubon Society
U.S. Environmental Protection Agency

Cover Painting--Jim McVicker

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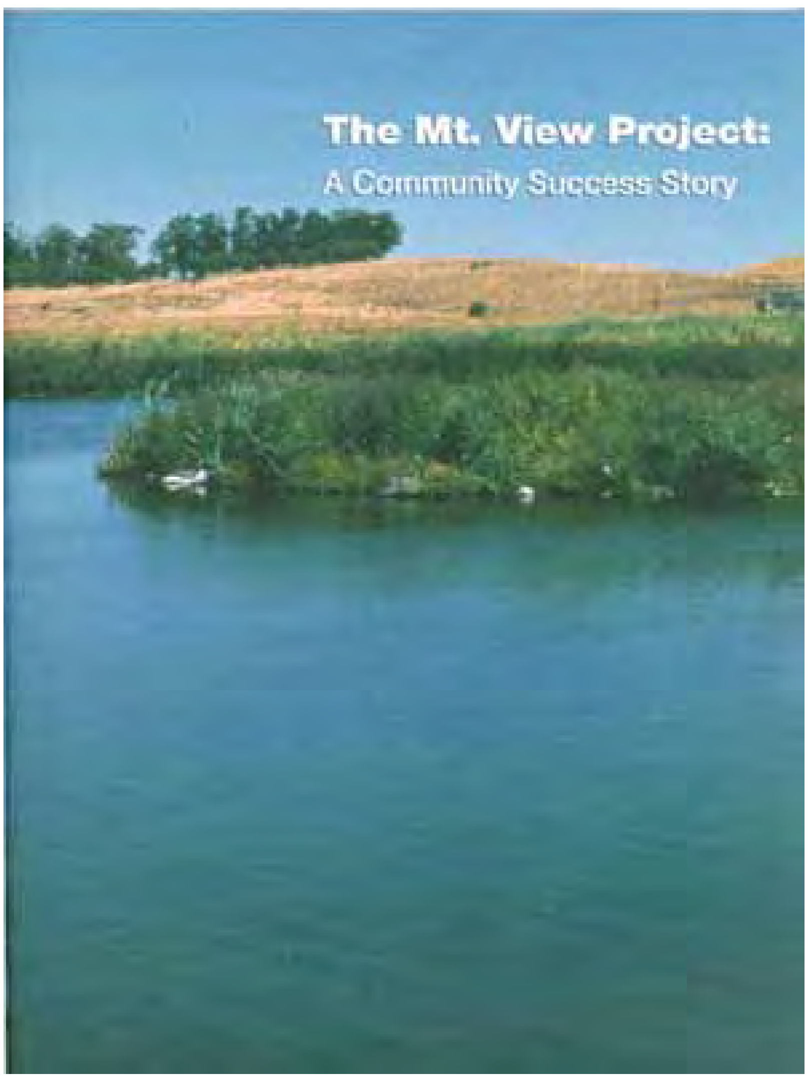
Martinez, CA - The Mt. View Project: A Community Success Story



The Mt. View Project: A Community Success Story

Mt. View Sanitary District (MVSD) provides wastewater treatment for approximately 16,000 people living in and around Martinez, California. This community, led by an independent-minded Board of Directors and a forward-thinking engineer, created the first wastewater wetlands on the West Coast. The project saved the rate payers millions of dollars and established a valuable wildlife habitat in the process. This is the story of how Mt. View Sanitary District created a wastewater wetland for the enrichment of both the community and wildlife.

Sewage treatment plants, by their very nature, are often located at the fringe of development. The year Mt. View Sanitary District was established —1923, it was located outside the City of Martinez, in rural Contra Costa County, California.

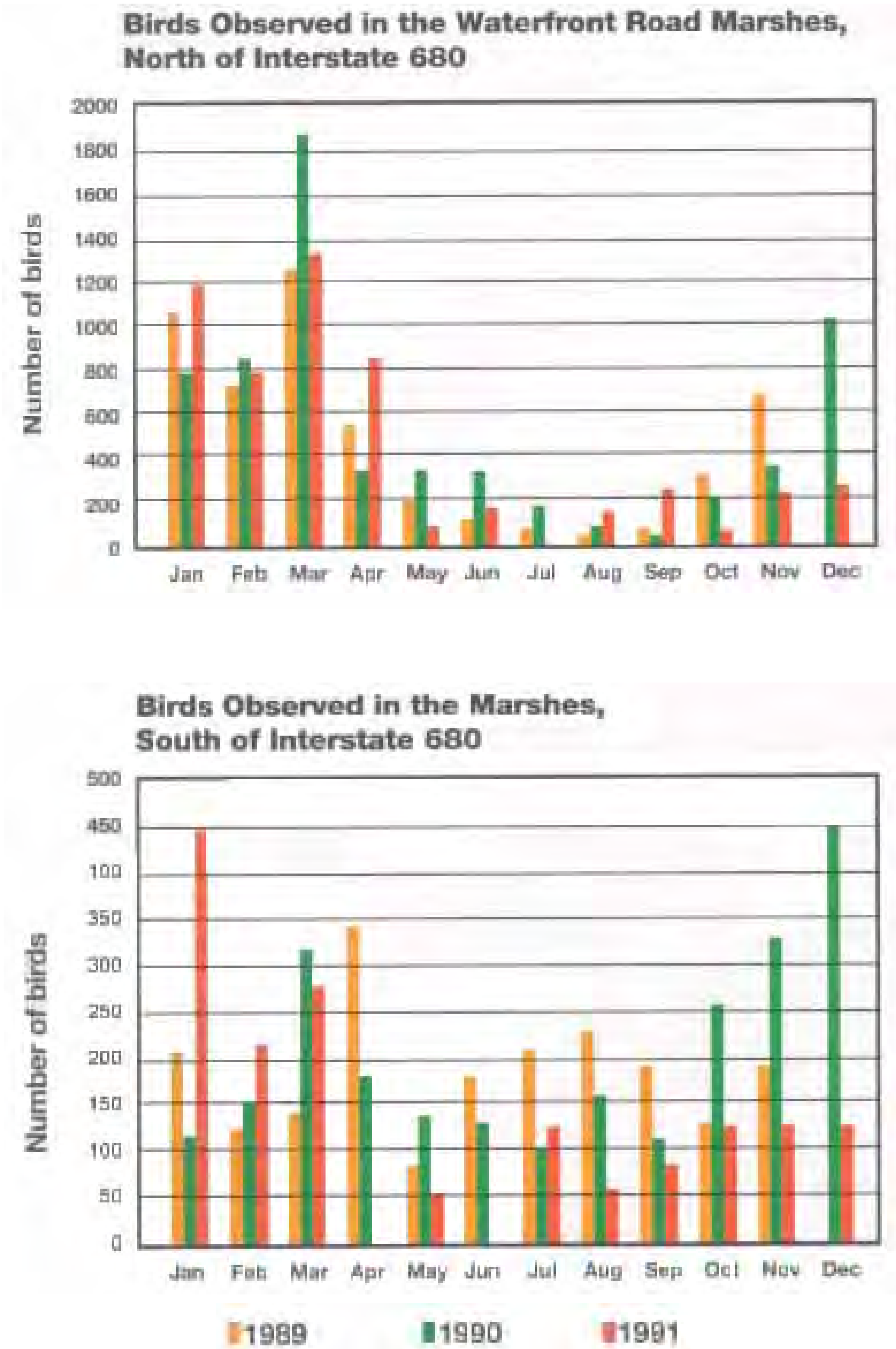
Mt. View Sanitary District Wetlands are located adjacent to large industrial facilities.

Mt. View was created as a special district to treat the wastewater from the rural portions of the county surrounding Martinez and was to be governed by a board of five publicly elected directors.

The board was an independent group and did not easily accept the Regional Water Quality Control Board's (RWQCB) idea in the late '60s of consolidating all of the small treatment facilities into a large regional plant. The result would have required pumping MVSD's wastewater to a neighboring facility to be treated, effectively dissolving their district. Not only would it have usurped their control, but it also was going to cost over $6 million. The District decided to search for an alternative.

MVSD tried to sell its water to neighboring industrial plants and to the highway department for irrigation. The District considered constructing its own deep-water diffuser in nearby Carquinez Straits, at a cost of $2.38 million. Warren Nute, the District's engineer at the time, observed that the regulations the RWQCB were using stated that if the treated effluent was creating an environmental benefit, then the District would not have to remove its effluent discharge from Peyton Slough, a small creek, influenced by tidal action along part of its length, that delivers the District's effluent to Carquinez Straits and San Francisco Bay. The District then set about creating the first wetland on the West Coast using secondary treated effluent, to provide environmental benefits.

The Marsh Began to Grow



Bird usage from 1989-1991 in Mt. View Sanitary District Wetlands

In 1974 the District began with a simple 10-acre wetland divided into two sections. The area that was created by scraping away the topsoil became a shallow, open-water pond. The other area, whose topsoil was not disturbed, was quickly colonized by emergent vegetation, such as cattails.

In 1977 the marsh was expanded to include 10 more acres of land divided into three marsh areas. One was constructed as an open-water pond with islands to provide protected nesting habitat for waterfowl.

A second marsh was seeded with plants to provide food for waterfowl, such as water grass and alkali bulrush *(Echinochloa crusgalli and Scirpus robustus).* The third area was designed in a serpentine fashion to provide maximum water/plant contact to enhance treatment effectiveness.

The Mt. View Sanitary District marshes are located in an urban environment and the marsh is bisected by an interstate highway. The next 22 acres, added to the marsh system in 1984, were located across the interstate to the north. This area had been seasonally flooded and the District merely had to make minor changes to water control structures to allow the marsh's inclusion in the system. The most recent addition to the wastewater wetland complex is a 43-acre section that also is located to the north of the interstate and adjacent to the previous 22 acres.

A variety of habitat types and controlled public access promote wildlife use of the wastewater wetland.

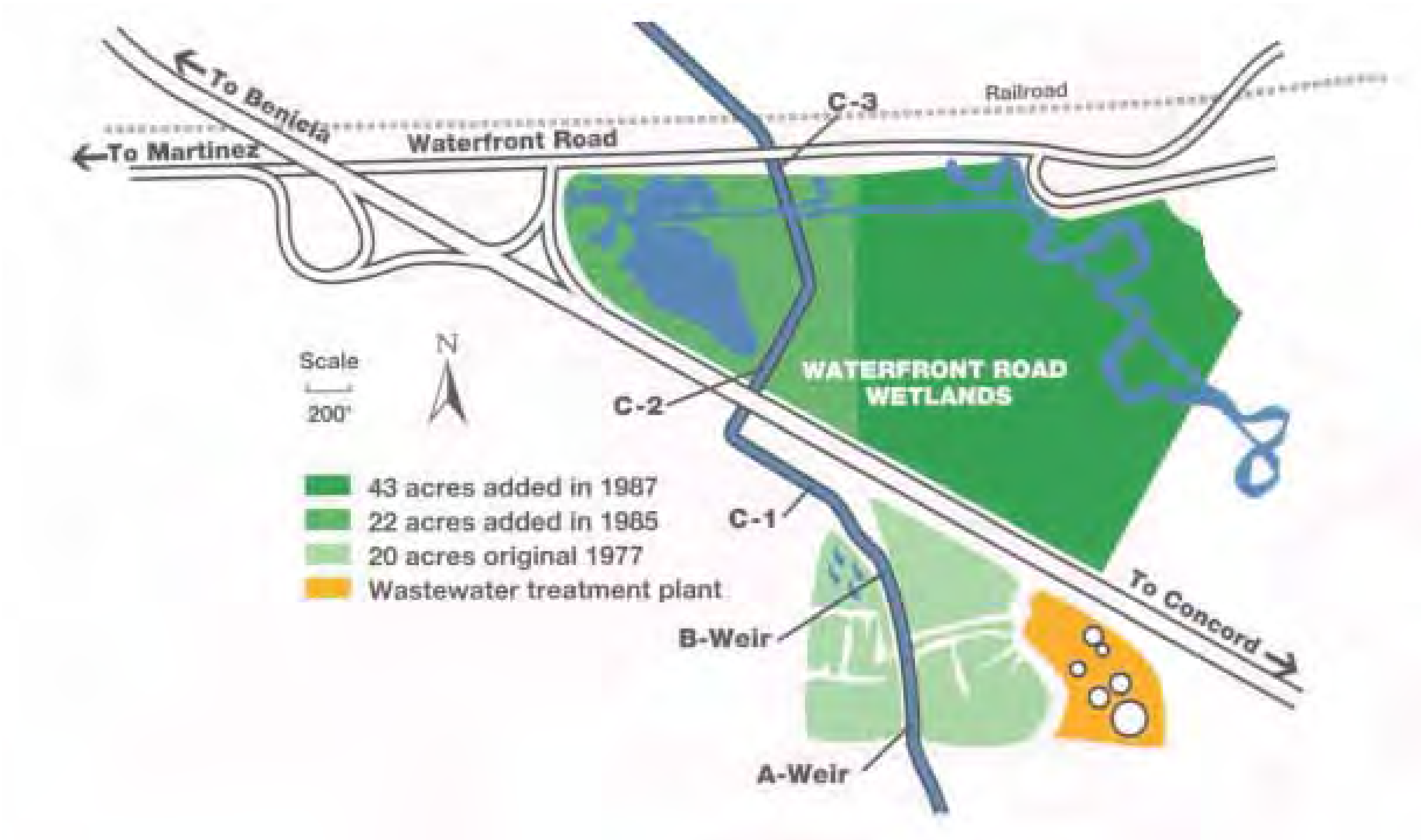
The wetlands area totals 85 acres. This bountiful wildlife habitat includes plants, animals, fish and invertebrates. Some of the animals are permanent residents of the marshes, while others are temporary visitors that stop along their migratory journey. Plants grow in the marshes as well as on the levees surrounding the marshes and a riparian corridor is beginning along Peyton Slough. There are emergent plants rooted in the bottom muds as well as submerged plants.

Wetland plants provide food and shelter for marsh biota and improve water quality. Birds, mammals, reptiles and amphibians eat plant leaves, seeds and roots of the more than 70 species of marsh and riparian vegetation. Dense growths of marsh bulrushes provide nesting sites for songbirds as well as ducks.

The most visible animals at the marshes are the more than 123 species of birds. The diversity of aquatic habitats attracts mallard and cinnamon teal to rest and feed in the open-water areas; avocets and black-necked stilts to probe for invertebrates in the mudflats; and red-winged blackbirds to nest among the cattail stands. There are resident birds in the wetland, such as song sparrows and American coot, in addition to migrant birds, as exemplified by sandpipers and pintail.

There are more than 15 species of birds that nest in the wetland. The area provides valuable nesting sites for waterfowl, shorebirds and songbirds. The wetland is also important because fresh drinking water is a requirement for ducklings. Later, as the ducklings mature, they develop salt glands that allow them to drink saline water. However, until that time, they must be reared in a freshwater environment. In an area such as San Francisco Bay, which has lost nearly all of its freshwater wetlands, appropriate nesting habitat is a valuable resource provided at the Mt. View wastewater wetland.

Fish also inhabit Peyton Slough and the marshes. Small fish eat midge and mosquito larvae to help keep the marsh free of these nuisance insects, and in turn they are preyed upon by herons and egrets. The discarded carapace of a crayfish is evidence of the raccoon's evening meal. Other marsh wildlife includes everything from pond turtles to striped skunks and an occasional river otter. A total of 34 species of fish, mammals, reptiles and amphibians have been observed at the wetland.



Schematic of the Mt. View Sanitary District marsh creation project.

Where Does the Water Come From?

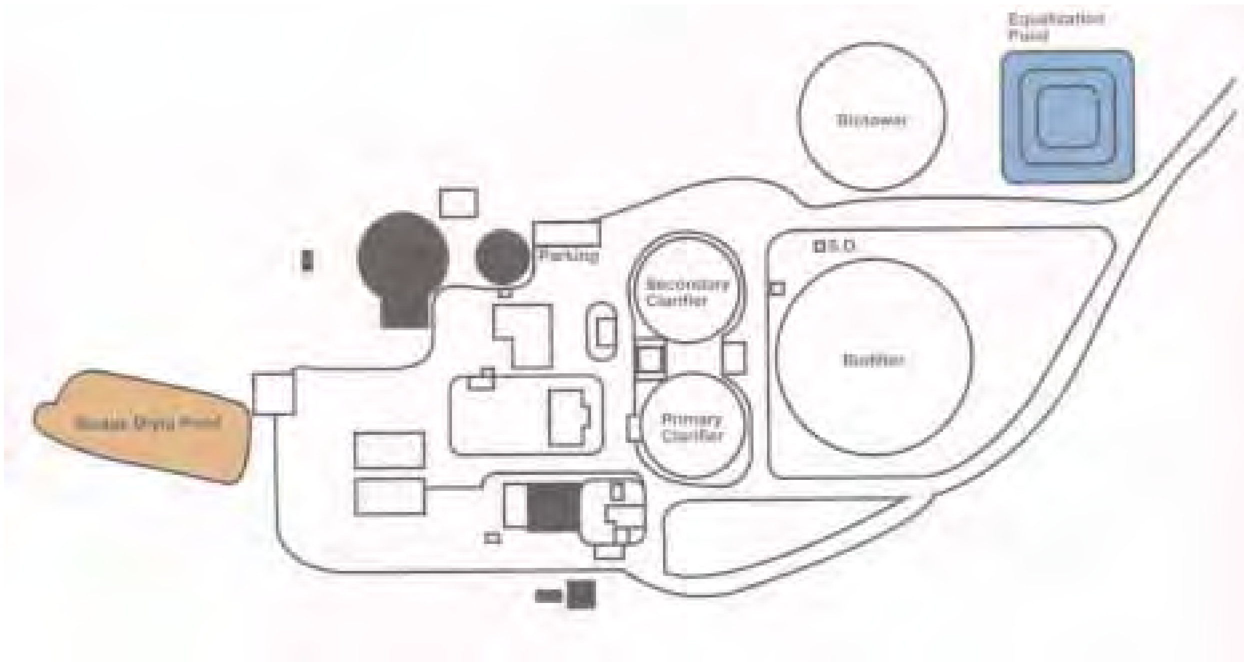
Mt. View Sanitary District provides secondary treatment to approximately 1.3 million gallons per day of wastewater from approximately 16,000 residents in the Martinez, Calif., area. Although there is some light industry and commercial development within the District's service area, the primary source of the wastewater is residential. The District maintains strict pretreatment standards and prohibits the discharge of heavy industrial waste into its sewerage system.

The treatment train includes comminution, primary sedimentation, biological treatment by a two-stage, high-rate trickling filter, a biotower for ammonia removal, secondary sedimentation, effluent chlorination, dechlorination with sulphur dioxide, and sludge processing. A flow equalization basin assists in equalizing storm flows to the treatment plant to maximize efficiency.

Monitoring is conducted on the treatment plant influent, effluent, marsh discharges and the receiving water. Although the primary purpose for constructing the wetland is to create wildlife habitat, it also improves water quality for some parameters. There are numerous processes by which plants contribute to water quality improvements, including direct uptake of nutrients by algae and some rooted vegetation. The plants foster settling of particulate matter by slowing water movement and greatly increase the contact with microorganisms that live on the surfaces of emergent plants. These microorganisms metabolize pollutants, decreasing their dissolved concentrations in the water. Monitoring shows that wetland nutrient concentrations follow a stable seasonal cycle that varies little from month to month, but clearly shows a difference between the cold, wet season (November through April) and the warm, dry season (May through October).

The concentration of nitrates decreases in the wetland during the summer months. There is limited evidence to suggest that the wetland is removing cadmium, copper, silver and zinc. In addition, periodic special monitoring studies are undertaken to answer specific questions concerning the processes or biota within the wetlands. Studies at the marsh have included an ammonia study and a fisheries and benthic invertebrate study.

Doubtless the largest special study, however, occurred after the 1988 spill of 440,000 gallons of crude oil into the marsh from an adjacent refinery. The cleanup efforts included picking up oily water by vacuum trucks, rototilling of contaminated soils and hand-cutting vegetation in less inundated areas of the marsh. The recovery of the marsh's vegetation and soils was monitored closely and eight months later this section of the wetland resumed operation.



Mt. View Sanitary District treatment plant.

Keeping the Wetland Wet

In 1974 MVSD created its wetland and, as with other man-made environments, routine operations and maintenance are required. Tasks required on a weekly or monthly basis include removing debris that collects behind weirs, examining levees for erosion and inspecting for animal burrows that could lead to levee failure.

The frequency of vegetation harvesting in the shallow marsh areas has proven to be related to its surface. Smaller marsh plots need to be harvested more frequently than larger areas. Marsh A-1 is approximately one acre and has had vegetation removed a number of times during the past 18 years. Similarly, a three-acre marsh plot that had internal levees subdividing it into smaller waterways also was in need of harvesting and levee rearranging after 10 years. Whereas the larger Marsh A-2, approximately four acres, is only now ready to be harvested after 18 years of operation.

Early maintenance activities included stocking the marshes with mosquito fish as predators for mosquito larvae. The mosquito fish population became self-sustaining after the first few years. There were so many of the small fishes that for a period of time, the MVSD marshes supplied fish to a local natural history museum to feed their live exhibits. The original 10-acre marsh construction project cost only a few thousand dollars, and the first 10-acre expansion cost $85,000. The District already owned the land for these segments of the marsh creation project. The first 22 acres to the north of the interstate were acquired by the California State Department of Fish and Game and is managed by MVSD. The 43 acres acquired in 1985 were purchased for $204,887. It is likely that more acreage will be added to the wetland in the future as a result of the settlements from the oil spill. The annual operation and maintenance budget includes labor for marsh monitoring, special research studies, vegetation harvesting and levee repair. These costs average $30,000-$50,000 annually.

The total cost of the marsh over the past 18 years is less than one-third the cost ratepayers would have had to contribute to the neighboring treatment plant's deep-water diffuser.*

Not only has the experiment been cost effective, but the marsh itself boasts a long list of contributions to the community. Visitors spend hundreds of hours enjoying the marsh and its wildlife. Bird watching and nature photography are favorite pastimes of local, regional and international visitors. Students from elementary through college come to observe and do research projects at the wetland.

The wetland provides open space in a rapidly developing county. The freshwater habitat is a link on the Pacific Flyway used by migratory birds. The effluent is viewed as a resource creating wildlife habitat and maintaining a small, freshwater surface inflow to San Francisco Bay, which has lost most of its freshwater tributaries.

The creation of Mt. View Sanitary District's wetland system is a community success story. The independent District was willing to question regional policy makers and in so doing pioneered the creation of wetland habitat using secondary treated effluent, saving local citizens millions of dollars.«

The wetland serves as an outdoor laboratory for learning. Students from local elementary schools as well as college students are interested in the marsh.

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* This brochure is dedicated to the memory of J. Warren Nute, who pioneered the development of wastewater wetlands on the West Coast.

« This brochure was created with funding from the U.S. Environmental Protection Agency. Requisition No. A22190

Robert Bastian---
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Photography

United States Environmental Protection Agency
Office of Water

Constructed Wetlands for Wastewater Treatment and Wildlife Habitat

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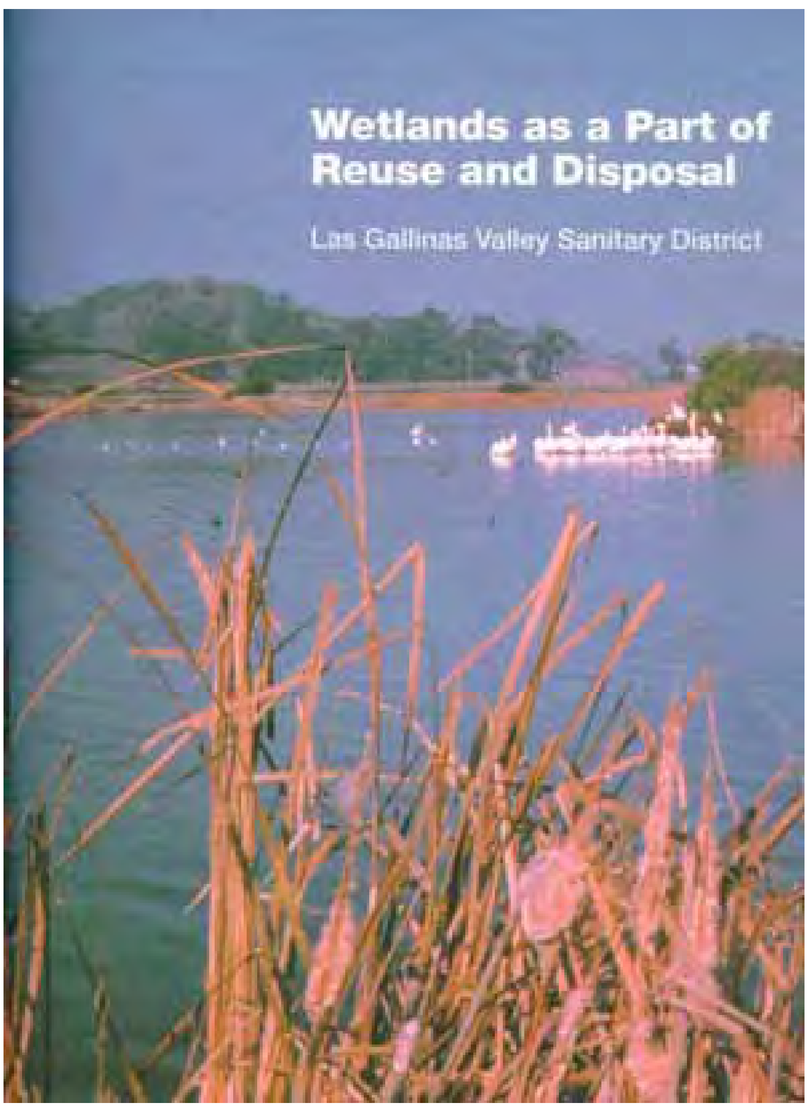
Marin Co., CA - Wetlands as a Part of Reuse and Disposal: Las Gallinas Valley Sanitary District



Introduction

Where can you find herons roosting in trees and 31/2 miles of public access trails on the edge of San Pablo Bay? The answer is at Las Gallinas Valley Sanitary District's Wastewater Reclamation Project in Marin County, California. The District has created a multi-faceted reclamation project that includes a freshwater marsh, irrigated pasture, storage ponds, a saltwater marsh and miles of trails for hiking, biking and bird watching.

The District has created a multi-faceted reclamation project that includes a fresh-water marsh, irrigated pasture, storage ponds, a saltwater marsh and miles of trails for hiking, biking and bird watching.

History

A regional planning effort for eastern Marin and southern Sonoma counties began in the early 1970's. The goal of the planning was to improve effluent water quality to meet the increased requirements of the Clean Water Act. The best apparent alternative identified in 1977 was to discharge treated effluent to the shallow waters of the Bay, but only on high tides, and to begin reclamation for landscape irrigation.

The agencies determined that this did not afford the shallow waters of San Pablo Bay, the northern most portion of San Francisco Bay, enough protection. They decided to require an elimination of any discharge of treated wastewater effluent to the shallow fringes of the Bay and its tributary creeks during the summer months.

The planners were frustrated by the moving target, but they went back to the drawing boards and developed a plan for treatment and disposal that would meet all of the requirements. In order to meet a requirement of no summer discharge the plan needed to include storage capacity and alternative disposal options. So they developed a project that included many forms of reuse and disposal.

Las Gallinas' wastewater reclamation project is a 385 acre complex including 200 acres of irrigated pasture, 40 acres of storage ponds, a 20 acre freshwater wetland, a 10 acre salt marsh, and landscape irrigation. The District has an agreement with the local water agency for reclamation of up to 350 million gallons of treated effluent per year for landscape irrigation.

Las Gallinas Valley Sanitary District was formed in 1954 by residents who were faced with serious health problems from failing septic tanks and pollution in Gallinas Creek. The District now serves a community of approximately 30,000 people in northern Marin County. The District's influent is predominantly residential including discharges from some commercial and light industry sources. The treatment facility has a design capacity of 2.9 million gallons per day.

The planners were frustrated by the moving target, but they went back to the drawing boards and developed a plan for treatment and disposal.

Treatment and Reclamation

The treatment plant was expanded and upgraded in 1984, when the reclamation project was constructed. The project received state and federal Clean Water Grant funds for 87.5% of the costs. The treatment consists of grit removal, clarification, two stage biofiltration, ammonia removal, filtration, chlorination, and dechlorination. The treated effluent goes to a combination of the marsh, the creek, or the storage ponds, depending on the time of year. For nine months out of the year the effluent from the marsh is discharged to Miller Creek and San Pablo Bay. During June, July, and August, the discharge is stored in 40 acres of ponds and used to irrigate the pasture and for the water agency's recycling program.

Las Gallinas Valley Sanitary District Design Criteria

Design Year................................2001

Population..................................34,711

Average Dry Weather Flow.........2.69 mgd

Peak Dry Weather Flow..............4.3 mgd

BOD Loading..............................5434 lbs/day

TSS Loading...............................5738 lbs/day

Irrigated Pasture...........................200 acres

Marsh/Pond................................20 acres

Storage Ponds.............................40 acres

Irrigated Landscaping...................20 acres

The 200 acres of pasture is subdivided into sections so that it may be irrigated on a rotating schedule. The irrigation must be done in June, July, and August to dispose of the effluent, however depending on the weather and the needs of the pasture, it is usually irrigated through November. The irrigation schedule rotates among the fields with a goal of the disposal of a target number of gallons per month.

Marin County is located on a narrow peninsula north of San Francisco. The County’s drinking water reservoirs have relatively small watersheds and under extreme draught conditions have been nearly emptied. In seeking to develop new sources of water, the water district approached Las Gallinas to discuss the potential for reclamation. The agreement that was developed allows the water district to purchase up to 350 million gallons of Las Gallinas’ effluent per year. The effluent receives further treatment and is then sold for landscape irrigation, helping the limited potable water supply to stretch further.

The 20 acre freshwater marsh/pond was designed to incorporate a number of different wildlife habitat types into a single unit. This is accomplished by varying the depths of the water and the types of vegetation that colonize each area. The central area is the deepest, more than six feet under normal operation. The deep central area is ringed by a two foot deep zone that was designed to become inhabited by emergent vegetation such as tall thin bulrushes. There is an overflow zone that is only inundated during winter rains and when the marsh/pond is needed occasionally to store additional effluent near the end of the summer. The five islands are the final physical component of the marsh.

The most important part of the marsh/pond is not its physical configuration but its biological inhabitants.

The wide variety of plants and animals make the area interesting to the many visitors that walk, jog, or bike around the perimeter. There are many regular bird watchers that keep track of the resident and migratory populations that use the reclamation project. Members of the Marin Audubon Society have observed over 147 species of birds in the reclamation project areas.

There are over 40 species of plants in the marsh/pond ranging from submerged pond weeds to emergent cattails. There are willow trees and acacias on the islands, grasses, and shrubs on the banks. The grasses on the islands produce seeds that are eaten by small rodents and serve as cover for waterfowl nesting. Mallards, coots, and Canada geese nest and raise their young at the marsh/pond. A portion of one of the islands is barren and has a gentle slope up from the water. This area is a favorite resting place for the cormorant.

The island's trees provide roosting habitat for a wide variety of birds including snowy and great egrets, black-crowned night heron and the great blue heron. Occasionally there is even competition for roosting space among the tree branches. A long-eared owl rested not so peacefully in a willow tree one February afternoon when a red-shouldered hawk perched barely 3 feet above its head in the same tree and screeched incessantly, trying unsuccessfully to get the owl to move.

The wading herons and egrets and the diving pelicans and cormorant are probably attracted to the wetland not only for resting but to feed on the plentiful small fish in the pond. The flock of dozens of large white pelicans that frequent the marsh are a favorite of visitors. There are small mosquito fish as well as carp that grow to fourteen inches in length. Many other animals use the marsh/pond including noisy bullfrogs, snakes that shed their old skins intertwined among the tall grasses, raccoon, jack rabbits, deer and muskrat. The muskrats aren't always welcomed by the wetland manager because they tend to dig tunnels in the levees.

The salt marsh restoration project was completed to diversify the types of wildlife habitat. The salt marsh is fed by water from the Bay and does not receive any treated effluent.

Water Quality

The Las Gallinas Valley Sanitary District produces a high quality, advanced secondary effluent. The average flow in 1992 was 2.7 million gallons per day, during the months when the effluent is discharged to Miller Creek and the Bay. The purpose of the treatment plant and reclamation project is to keep as much of the pollutant load from entering the environment as possible. In 1992 the plant removed 95% of the organic material that would enter the creek and bay. These biochemical oxygen demanding substances would use oxygen to complete decomposition. It is this oxygen that is needed by fish and other aquatic organisms for their survival. The concentration of ammonia in the effluent is reduced substantially, to a level that is not harmful to fish in the marsh/pond or the creek.

Las Gallinas Valley Sanitary District
Effluent Water Quality, 1992 Averages

Parameter	Monitoring Frequency	Average Concentration
Biochemical Oxygen Demand	3x/wk	9.9mg/L
Total Suspended Solids	3x/wk	14mg/L
Oil and Grease	1 mo	<5mg/L
Settleable Solids	daily	0.06m/l/L/hr
pH	daily	6.6 units
Ammonia Nitrogen	1/mo	2.3mg/L
Arsenic	1/mo	<2ug/L
Cadmium	1/mo	<1ug/L
Chromium	1/mo	<2ug/L
Copper	1/mo	18ug/L
Cyanide	1/mo	<10ug/L
Lead	1/mo	<2ug/L
Mercury	1/mo	0.3ug/L
Nickel	1/mo	3.5ug/L
Silver	1/mo	2.3ug/L

Zinc	1/mo	75ug/L
Phenols	4x/yr	<50ug/L

Costs and Benefits

The reclamation project was constructed in 1984 for a cost of $6.5 million dollars, including the land acquisition. Approximately 87.5% of the project funding was from state and federal Clean Water Grant funds administered by the Environmental Protection Agency. The project was recognized for Engineering Excellence in a competition sponsored by the Consulting Engineers Association of California and indeed the residents of the District are proud of the treatment system and enjoy the benefits of the reclamation project. Each and every day people can be seen walking dogs, gazing through binoculars at their favorite birds, and jogging around the marshes.

Developed by Woodward-Clyde Consultants
Project Manager---Francesca Demgen
EPA Project Manager---Robert Bastian
Graphic Design---Chris Dunn

This brochure was created with funding from the U.S. Environmental Protection Agency. Requisition No. A22190.

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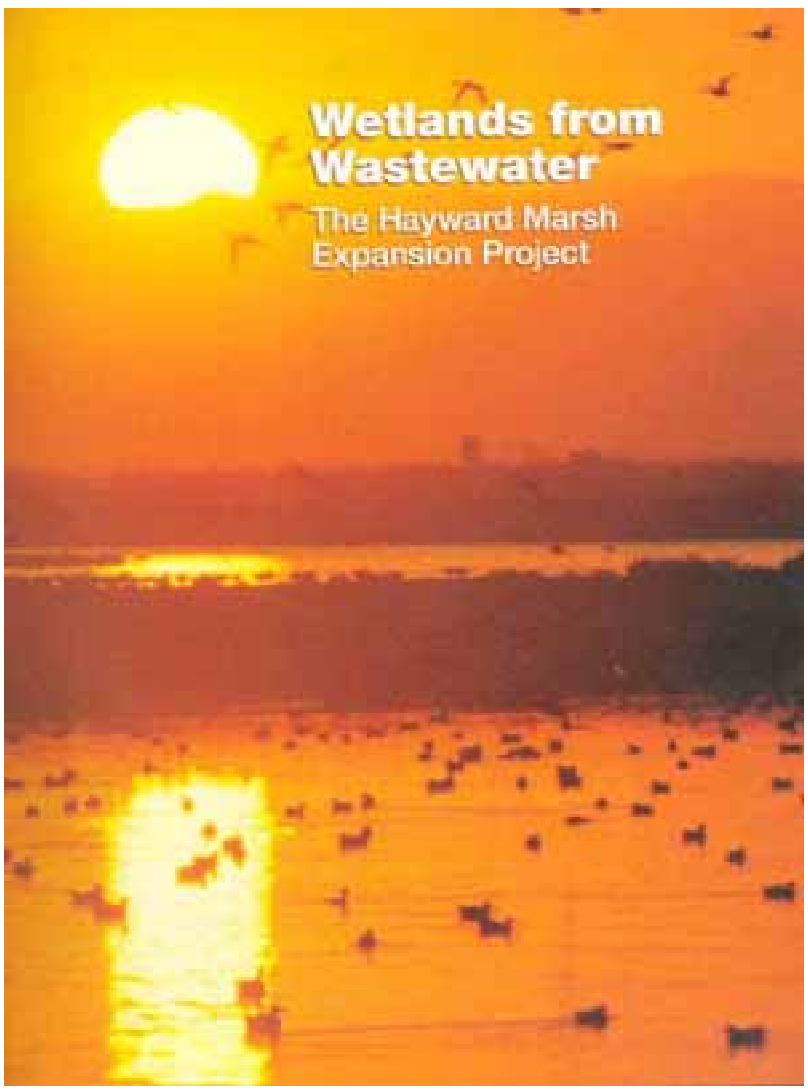
Hayward Marsh, CA - Wetlands from Wastewater: The Hayward Marsh Expansion Project



The Hayward Marsh Expansion Project: Wetlands From Wastewater

Can treated sewage effluent be used to enhance and create wetlands? This brochure documents the innovative and effective use of secondary wastewater on wetlands in a northern California coastal community. The community, Hayward, is on the eastern shore of San Francisco Bay. The project, Hayward Shoreline Marsh Expansion Project, is a part of a larger marsh restoration and enhancement plan.

The Hayward Shoreline Marsh Expansion Project addresses two growing urban issues: the restoration and enhancement of declining wetlands areas in the United States, and the additional treatment and beneficial uses that can be achieved from the utilization of wastewater. The shoreline and marsh in this case are roughly 172 acres of a 400-acre restoration and enhancement area. The source of the wastewater is primarily residential and light industry.

Biodegradable mesh was laid on banks near inlet and outlet structures during construction.

The History of the Project, Marsh and Shoreline

In 1971 the Hayward Area Shoreline Planning Agency was formed by five groups to restore about 1,800 acres of Hayward shoreline. The five included: the City of Hayward, Hayward Area Recreation District, East Bay Regional Park District (EBRPD), and the Hayward and San Lorenzo Unified School Districts. The 1,800-acre area had been a part of the Bay area salt-and-brackish-marsh system until the later part of the 19th century. At that time the marsh was eliminated by creation of a dike to hold out tidal action to allow for commercial salt production. Salt production ceased in the 1940s, but the area was not returned to marshland until more than 40 years later.

The Two Phases


A 27-acre corner of Hayward Marsh has been set aside as a preserve for the salt marsh harvest mouse.

The restoration and enhancement of the diverse 400-acre marsh—part of the 1,800 acres of Hayward shoreline-was planned in two phases. The first phase was completed in 1980 when extensive grading and breaching of the dikes allowed tidal action to be restored to approximately 200 acres. This created the conditions necessary for natural restoration of a tidal cord grass and pickleweed salt marsh. The second phase, the Hayward Shoreline Marsh Expansion Project, involved restoring 172 acres to fresh and brackish marshes. Using existing and newly created channels and dikes, a five-basin marsh system was formed. This second phase of newly created fresh and brackish marshes began operation in April 1988 and relies on secondary treated wastewater as its freshwater source.

Funding for the 172-acre marsh expansion totaled $713,570 and has come from four sources: the U.S. Fish and Wildlife Service for designs and specifications; City of Hayward for design, contract documents and permits; the EBRPD's appropriation from the 1980 California Parklands Act for marsh enhancement and recreational facilities; and a grant from the State Coastal Conservancy for the major portion of construction.

EBRPD and the East Bay Dischargers Authority (EBDA) are the joint holders of the National Pollution Discharge Elimination System (NPDES) permit for the marsh. Flow to the marsh, primarily from Union Sanitary District, is diverted from EBDA’s forcemain, which runs along the eastern edge of the Bay and discharges effluent from six municipal wastewater treatment plants to the deep waters of San Francisco Bay. The anticipated success of the Hayward Marsh may provide EBDA and its member agencies with the opportunity to develop other constructed wetlands along the Bay.

EBRPD has acquired control of the site, including the 400 acres designated for marsh restoration, by purchase of 495 acres and by long-term lease with other agencies. EBRPD is responsible for the operation and maintenance of the marsh. When completed, the Hayward Marsh will be the largest restoration and enhancement project on the West Coast to date.

The 172-acre area is actually divided into six sections: the five basins mentioned earlier and a preserve set aside for the salt marsh harvest mouse, an endangered species. The five basins include three freshwater basins and two brackish water basins.

Basin 1 receives the treated, chlorinated

Vegetation begins to colonize Basin 2A, a newly created freshwater marsh.

Schematic of the Hayward Shorline Marsh Expansion Project.

secondary effluent. The water that enters the marsh meets standards for both biochemical oxygen demand and suspended solids, as well as for coliform bacteria. Residual chlorine is allowed to dissipate in this basin. Basin 1 is about 15 acres and is operated at a depth of between 5 and 8 feet. From Basin 1 the water is discharged to a channel leading to Basins 2A and 2B.

Basins 2A and 2B are identical 35-acre freshwater marshes with internal channels and islands. The marshes were designed to have a range of depths: there are shallow areas of two feet or less and the perimeter and internal channels are six feet deep. Basins 3A and 3B are brackish and receive a combination of approximately 25 percent bay water and 75 percent effluent from Basins 2A and 2B. These two basins are each 30 acres and also have internal channels and islands.

The 27-acre mouse preserve, on the southeastern corner of Hayward Marsh, is an area of pickleweed marsh set aside specifically as habitat for the salt marsh harvest mouse. This area receives storm water runoff, but not treated effluent.

Wastewater: Resource Versus Liability

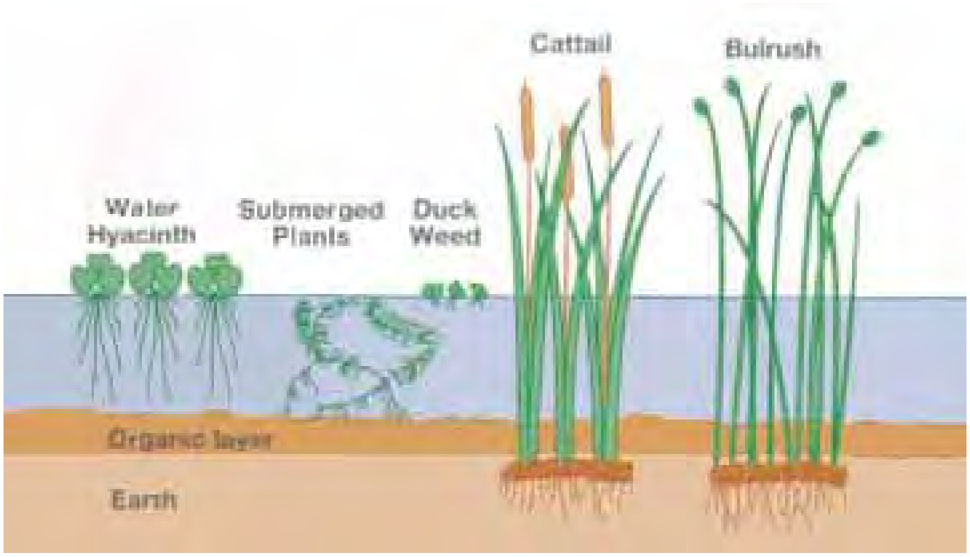
Wastewater has been treated and reused successfully as a water and nutrient resource in agriculture, silviculture, aquaculture and golf course and green belt irrigation. By regarding wastewater as a resource rather than a liability, it is now being viewed as water pollution control with positive benefits.

The Hayward Shoreline Marsh Expansion Project has three main objectives: creation of a diversified marsh system using secondary effluent; maximization of public benefits including wildlife habitat, preservation of open space, and creation of educational, research and aesthetic opportunities; and meeting NPDES requirements.

The marsh system removes pollutants from the treated wastewater it receives, so its final discharge to the bay is water of higher quality.

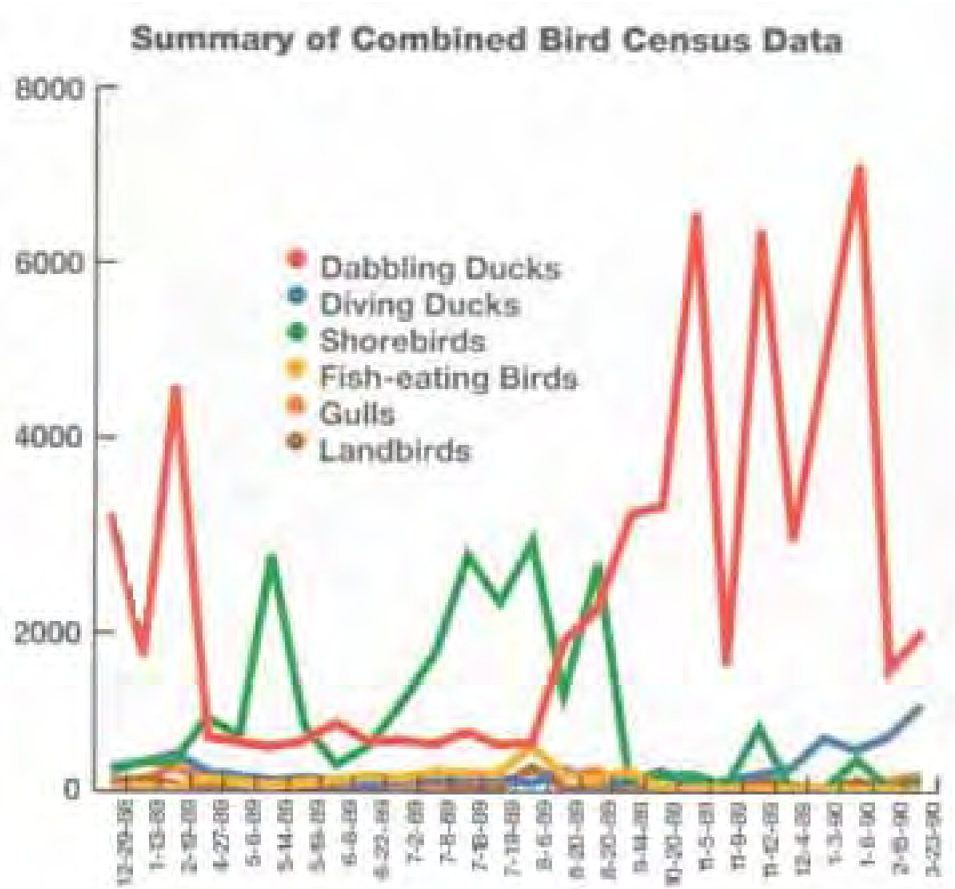
The increased interest in wastewater wetlands treatment systems can be attributed to three factors: recognition of the natural treatment functions of aquatic plant systems and wetlands, particularly as nutrient processors and buffering zones; emerging or renewed application of aesthetic, wildlife and other incidental environmental benefits associated with the preservation and enhancement of wetlands; and rapidly escalating costs of construction and operation associated with conventional treatment facilities. Constructed wetlands have become attractive as a treatment and disposal alternative for secondary wastewater for several reasons: they physically entrap pollutants through adsorption in the surface soils, in organic litter and on suspended particulates; through their utilization and transformation of pollutants by microorganisms; and because of their low-energy and low-maintenance requirements to attain consistent treatment levels.

Flora and Fauna



The first plants to emerge at Hayward Marsh were grasses, fat hen and pickleweed which had colonized the levees prior to project construction. Recolonization by plants has been slowed somewhat because of residual soil salinities from earlier commercial salt production and because topsoil was disturbed during construction.

Planting efforts have met with varying degrees of success. Seeds of alkali bulrush (Scirpus robustus) and watergrass (Echinochloa crusgalli) were eaten by ducks. Shoots of other bulrush species were eaten by waterfowl and geese or were dislodged by high winds. Subsequent planting efforts have been more successful due to protective cages that exclude predators and help block the wind. Once the plants become well established the cages will be removed.



The fauna that use the marsh include waterfowl, shorebirds, small mammals, amphibians, reptiles and fish. As many as 94 species of birds have been recorded using the site for feeding, nesting, hunting, foraging or as a refuge during high tide. Hayward Marsh is strategically located on the bird migration route known as the Pacific flyway. On any given day during the winter migratory season,

There are 3 main species of terns that forage at the marsh including the Forster's tern (pictured above). The endangered Least tern stopped thousands of ducks can be seen resting on the freshwater marshes.

at Hayward Marsh on its migratory journey and nested successfully in 1990. Efforts to provide suitable nesting habitat for the tern include covering one of the islands with crushed oyster shells.

Birds using Hayward Marsh have been categorized as follows: dabbling ducks, shorebirds, diving ducks, fish-eating birds, gulls and landbirds. Dabbling ducks include mallard, northern pintail, gadwall, cinnamon teal and the northern shoveler. Dabblers feed on or near the surface of the marsh and eat seeds and shoots of aquatic plants, aquatic invertebrates, minnows, snails, grain, grass and insects.

Shorebirds also migrate through San Francisco Bay and use the brackish water sections of Hayward Marsh during the spring and fall. Common visitors to the marsh include the American avocet, black-necked stilt, Caspian tern, Forster's tern, sandpiper, willet and killdeer.

Diving ducks have included the scaup, canvasback, bufflehead and ruddy duck. Diving ducks feed either within the water column or by diving to the bottom for mollusks, crustaceans, aquatic insects and invertebrates, crayfish and, to a lesser degree, aquatic plants.

Geese, ducks, and shorebirds produce hundreds of offspring at the marsh each year.

Fish-eating birds have included heron, egret, grebe, tern and pelican. Fisheaters either wade or dive for food. Their diet, in addition to fish, may include crustaceans, aquatic insects, frogs, small vertebrates and crayfish. It was not at all a coincidence that a large flock of opportunistic pelicans visited immediately after hundreds of pounds of Sacramento blackfish were introduced to the marshes.

Land birds at the marsh have included raptors, such as an endangered peregrine falcon that preys upon ruddy ducks and sandpipers. The marsh is within the peregrine‘s established territory. Seed-eating songbirds and insect eaters such as swallows are regular inhabitants of the marsh area.

Gathering the Data

Marsh Influent Water Quality 1990

	Range mg/l
Biochemical Oxygen Demand	5.2-22.0
Suspended Solids	10.3-22.0
Oil and Greese	3-10
Cyanide	<.01-.04
Residual Chlorine	6.0-9.3
pH (Units)	7.0-7.4
Arsenic	<.01-.002
Cadmium	<.01-.039
Chromium	<.00003-.0074
Lead	<.0002-.036
Mercury (1)	<.000025
Nickel	<.005-.13
Zinc	<.001-.14
Selenium	<.00005-.0022

(1) None of the 11 samples contained concentrations above the detection limit.

The second step is to determine the concentration of metals in the water, the sediment, and the plants and animals living in the marsh. There are 10 metals for which the marsh is being tested: arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver and zinc.

There are three methods being used to study the marsh. First, the wetland itself is being sampled. Second, a

The EBRPD, EBDA and the Union Sanitary District (USD) are the team responsible for providing the treated effluent to the marsh, monitoring the water quality within the system and managing the wetland. The team's tasks include everything from analyzing for residual chlorine to sampling fish and aquatic invertebrate populations.

One of the most beneficial aspects of the Hayward Marsh Project is that the team is encouraging and supporting research studies of the effect of effluent heavy metals on the marsh and its inhabitants. EBDA and USD have contracted with the University of California-Berkeley, Hayward State University and Woodward-Clyde Consultants to conduct a three-year research project to study heavy metals in the marsh.

Research questions and answers are complicated by the complexities inherent in a marsh. There are many chemical reactions, biological interactions and physical processes that take place every day in this 172-acre marsh. The research project first has to identify all of the major biological organisms that live in the marsh. This means counting birds and their nests, digging up worms and other invertebrates that live in bottom muds, and identifying the plants that grow in, on, and right up through the water.

Wetland Design Criteria

Average Daily Flow (1)	9.68 mgd
Maximum Daily Flow (2)	25.92 mgd
Minimum Daily Flow (3)	0
Bay Inflow (4)	2.5 mgd
Total Wetland Area	172 acres

mesocosm or small-scale marsh located adjacent to Hayward Marsh is being used to create and test future conditions that will occur in the marsh. And third, laboratory experiments mimicking sediments, water and phytoplankton are being used to isolate and analyze specific metal-uptake processes that occur in the field. This extensive research program is partially funded by an $80,000 grant from the U.S. Environmental Protection Agency with the remainder of the total research costs of $539,000 supported by EBDA and USD. The park district supports the research efforts with in-kind services.

Trace amounts of heavy metals are a normal occurrence in our environment. The key questions research will answer include: 1) Are the metals being concentrated in the wetland? and 2) Are the metals having an adverse effect on the marsh's biota? To predict potential effects to the wildlife, the concentrations of metals in the organisms will be measured and then compared with published values for metals that have been found harmful to wildlife.

Detention Time.............................14 days

Basin 1.......................................15 acres

Marsh 2A....................................35 acres

Marsh 2B....................................35 acres

Marsh 3A....................................30 acres

Marsh 3B....................................30 acres

Mouse Preserve...........................27 acres

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(1) This is Union Sanitary District treated effluent.

(2) Maximum flows may be used as a management tool, such as to flush waterfowl disease bacteria out of hte system.

(3) The ability to shut off the flow facilitates maintenance.

(4) Bay water mixes with the treated effluent in Marshes 3A and 3B.

Water Quality Analyses

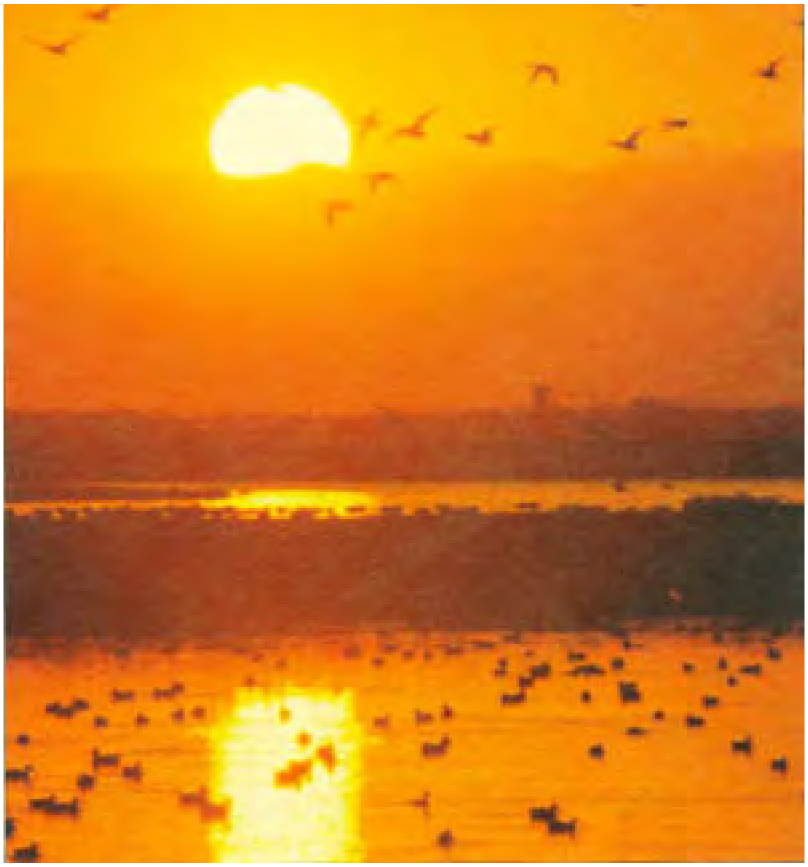
Parameter	**Daily** Basin 1	**Weekly** Basins 2A, 2B, 3A, 3B &	**2x/week** Basins 1, 2A 2B Receiving Water	**Monthly** Basin Effluents 1, 2A, 2B, 3A, 3B & Receiving Water	**Biweekly** 12 Stations in Marsh
Dissolved Oxygen	*	*			*
Temperature	*	*			*
pH	*	*			*

MPN Coliform Bacteria	*			
Ten Metals			*	
Total Ammonia		*	*	*
Un-ionized Ammonia		*	*	*
Nitrites		*	*	*
Nitrate		*		
Salinity			*	
Chlorophyll a			*	
PAHs			*	
Suspended Solids			*	
Avian Census			*	
Fish Bioassay			* (1)	

Ten Metals Analysis: Analysis for 10 metals is being performed twice on multiple samples of sediments, fish, emergent and floating vegetation, phytoplankton, addled eggs, acquatic invertebrates and benthic invertebrates in both Hayward Marsh and the mesocosm.

(1) Effluent only

The Promise of Wastewater Wetlands



Growing numbers of communities around the country have created wetland projects to create wildlife habitat and to further treat secondary effluent as a low-cost, energy-efficient disposal alternative. This method is especially suitable for smaller communities with available land.

A wastewater wetland created as a treatment facility will be designed differently than one built primarily to enhance wildlife habitat. The differences may be in design depths, basin configurations, flow rates and vegetation types. But a wetland built as a treatment facility may also yield other benefits. It may be useful for some wildlife and may provide recreational trails. Likewise, a wastewater wetland created for wildlife habitat may also improve the quality of water that flows through it to the sea.

The Hayward Marsh Expansion Project is a case-in-point of innovative engineering and science applied to the conversion of secondary wastewater effluent into a resource; a project that holds great promise for a growing environmental problem.

This brochure was created with funding from the U.S. Environmental Protection Agency. Requisition No. A22190.

Robert Bastian, U.S. EPA
Project Officer

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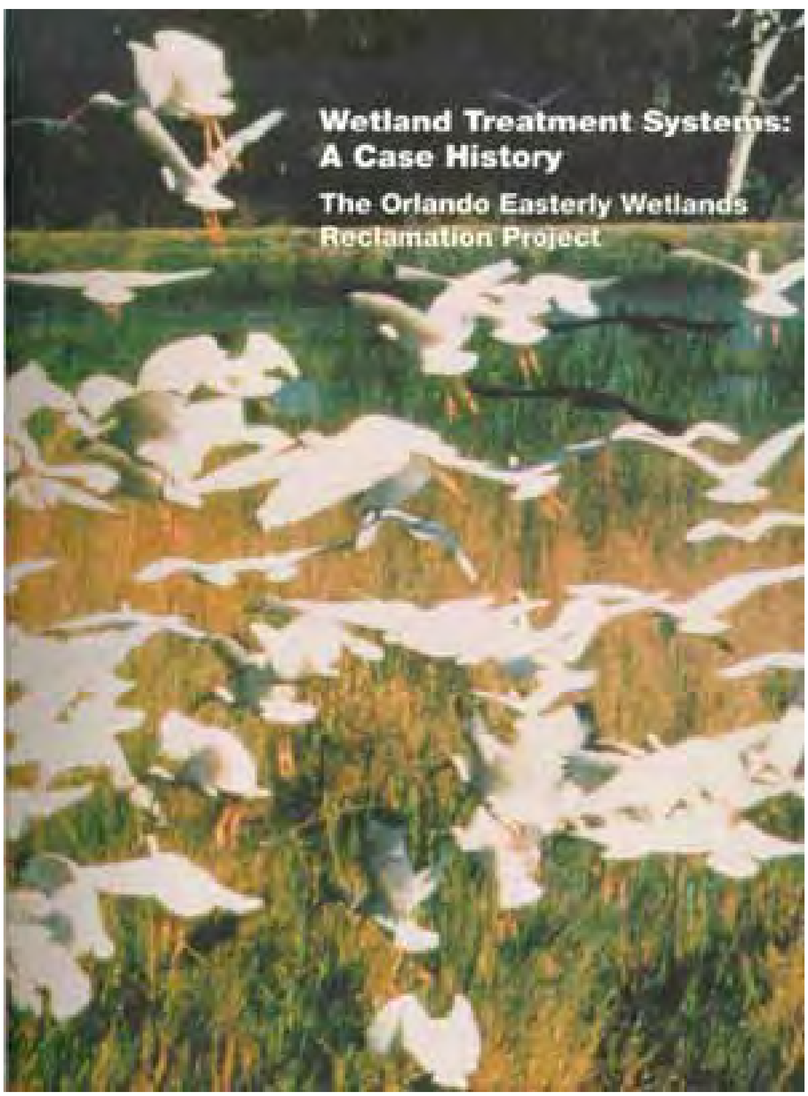
Note: This information is provided for reference purposes only. Although the information provided here was accurate and current when first created, it is now outdated.

Disclaimer: The information in this website is entirely drawn from a 1993 publication, and has not been updated since the original publication date. Users are cautioned that information reported at that time may have become outdated.

Orlando, FL - Wetland Treatment Systems: A Case History - The Orlando Easterly Wetlands Reclamation Project



A Case History: Orlando Easterly Wetlands Reclamation Project

Introduction

Wetlands have been the victim of progress in America. Research indicates that less than half of the 215 million acres of wetlands originally present in the United States prior to settlement remained by the mid 1970s. Much of this loss is due to the conversion of wetland areas into farmland.

Project Location.

Today, wetlands are recognized as a valuable natural resource. They help maintain the quality of our environment; provide habitat for a variety of plants and animals, including rare and endangered species; and offer a number of socio-economic benefits, ranging from flood protection to recreation opportunities.

In operation since 1987, the Orlando Easterly Wetlands Reclamation Project has demonstrated its successs as a treatment facilility, reuse project, and wildlife habitat.

The critical role which wetlands can play in reclaiming valuable freshwater resources is also recognized. Unlike the technology of the late 1960s and 1970s, which focused on the disposal of wastewater effluents as quickly and efficiently as possible (usually through discharge into streams, lakes, or oceans), wetlands treatment technology involves passing wastewater effluent or stormwater runoff through a wetland system. By acting as a natural filter for the pollutants that remain even in advanced treated wastewater effluent, wetland systems can polish the effluent so that it can be safely returned to fresh water sources.

One of the largest constructed wetland treatment systems built to date is the Orlando Easterly Wetlands Reclamation Project. Post, Buckley, Schuh & Jernigan, Inc. (PBS&J) served as design engineers for the City of Orlando, Florida. Background issues, special considerations, and performance results from this award-winning facility are discussed next.

Project Background

The Little Econlockhatchee (Little Econ) is a primary tributary to the Econlockhatchee River (Econ), which in turn is a primary tributary to the St. Johns River (SJR). The SJR system drains portions of the middle and upper east coast of Florida to the Atlantic Ocean. Over the years, much of the floodplain around both the SJR and the Econ system has been altered by drainage systems and subsequently converted to grazing lands for cattle. By 1980, 16 wastewater treatment plants (WWTPs) in the eastern Orange County area, discharged either primary or secondary effluent to the Little Econ.

The Orlando Easterly Wetlands was constructed on pasture land in an area which had been a natural wetland prior to human settlement and cattle grazing

The effects of these WWTP discharges on the Little Econ included decreased dissolved oxygen levels and the occurrence of Eichhornia crassipes (water hyacinth), Hydrilla verticillata, Najas guadalupensis, the duckweeds, and Panicum spp. which at times completely covered sections of the channel in the Econ system, and also contributed to frequent algae blooms in Lake Harney, a node within the SJR. (Located about one mile downstream of the confluence with the Econ, Lake Harney serves as a key indicator of water quality conditions in the Econ watershed.)

As part of a commitment to improve water quality conditions in the Little Econ, the City of Orlando began construction of an advanced wastewater treatment (AWT) plant which would replace a number of the existing package plants. By 1980, Phase I of the Iron Bridge Regional Water Pollution Control Facility (WPCF) was underway.

Iron Bridge WPCF Original Permit Conditions

BOD5	5 mg/L	(1001 lb/d)
TSS	5 mg/L	(1001 lb/d)
TN	3 mg/L	(600 lb/d)
TP	1 mg/L	(200 lb/d)

Permit regulations imposed on the Iron Bridge WPCF by the U.S. Environmental Protection Agency (USEPA) and the Florida Department of Environmental Protection (FDEP) were very stringent. Limitations for both effluent concentrations and loadings were based on the Phase I flow rate of 24 MGD. This meant that the capacity of future expansions to the treatment plant would be severely limited by the allowable effluent loading criteria in the USEPA National Pollutant Discharge Elimination System (NPDES) and FDEP permits, or the City would have to find an alternative discharge point.

Faced with a growing population and the need for additional wastewater treatment capacity, the City sought alternative effluent disposal options. An analysis of potential options was completed in 1984. The overall scope of the study included an investigation of such disposal options as deep well and aquifer injection, spray irrigation, moving the discharge point to another sub-basin of the SJR system, water hyacinth treatment, and both natural and constructed wetlands treatment.

The conclusions of this study ranked the construction of a wetland for effluent disposal adjacent to the floodplain of the SJR as the number one alternative. Selection criteria included economics, restoration of previously lost wetlands, and creation of a wild-life habitat.

Siting Considerations

Critical to the successful design of the City's wetland system was the selection of an appropriate location. The site selected was about 1,640 acres in size and located about two miles west of the main channel of the SJR. Review of historical data, including surveys conducted in the late 1850s, indicated that much of the site was previously part of the wetland system adjacent to the SJR. An elaborate series of ditches had been used to drain the site when it was converted to pastureland shortly after the turn of the century . Since this conversion, it had been operated as a cattle ranch. Using this site meant that more than 1,200 acres of land would be restored to its natural wetland state.

Soil characteristics were another important consideration in site location. The surficial soils at the City's wetland system are generally fine sands underlain by clayey soils. The depth of the clayey soils range from the surface to several feet below the soil surface, and tend to restrict water movement downward to the groundwater.

A hydraulic gradient that exists across the site directs groundwater flows toward the east, away from residential wells located west of the site.

At the time the City acquired the site, most of the on-site surface waters were routed to a main canal that drained to a backwater area of the SJR. The course of the main canal bisected a natural wetland owned by the St. Johns River Water Management District (SJRWMD) known as Seminole Ranch. This canal formed part of a stormwater management system on the SJRWMD land that altered the natural wetland such that transitional and upland vegetation were invading the site.

Berms divide the 1,220-acre wetland system into treatment cells which provide additional nutrient removal to treated effluent passing through the site.

By using the discharge waters from the City's wetland treatment system, wetland hydrology on about 600 acres of the Seminole Ranch is being restored. Today, the water discharged from the City's wetland moves by sheet flow through Seminole Ranch prior to discharge into the SJR.

Existing topography was also a key consideration in selecting the project site. With a topographic gradient of about 15 feet across the site, the land slopes downward from the west to the east. The wetland design used this gradient to divide the site into seventeen cells such that the average drop in elevation across each cell was limited to approximately three feet. This allows each treatment cell within the wetland system to be operated at dry season and wet season water depths that could range from sheet flow to a maximum depth of three to five feet.

Permitting Considerations

Fluctuating water levels are critical for the maintenance of desired plant communities within wetland treatment systems. The primary objective in designing the City's system was to use macrophytic communities to facilitate additional nutrient removal for up to 20 mgd of treated effluent from the Iron Bridge WPCF. The original permit issued by FDEP limited flow to 8 mgd, due in part to the untested nature of the system. Flow increases of about 3 to 5 mgd to a maximum of 20 mgd are being permitted by FDEP as the system demonstrates its ability to operate successfully at each increase. The current system is operating at a flow rate of 13 mgd, and the City has received approval from FDEP to increase flow to 16 mgd.

Anhingas and other bird species find the Orlando Easterly Wetlands to be a safe haven for raising their young.

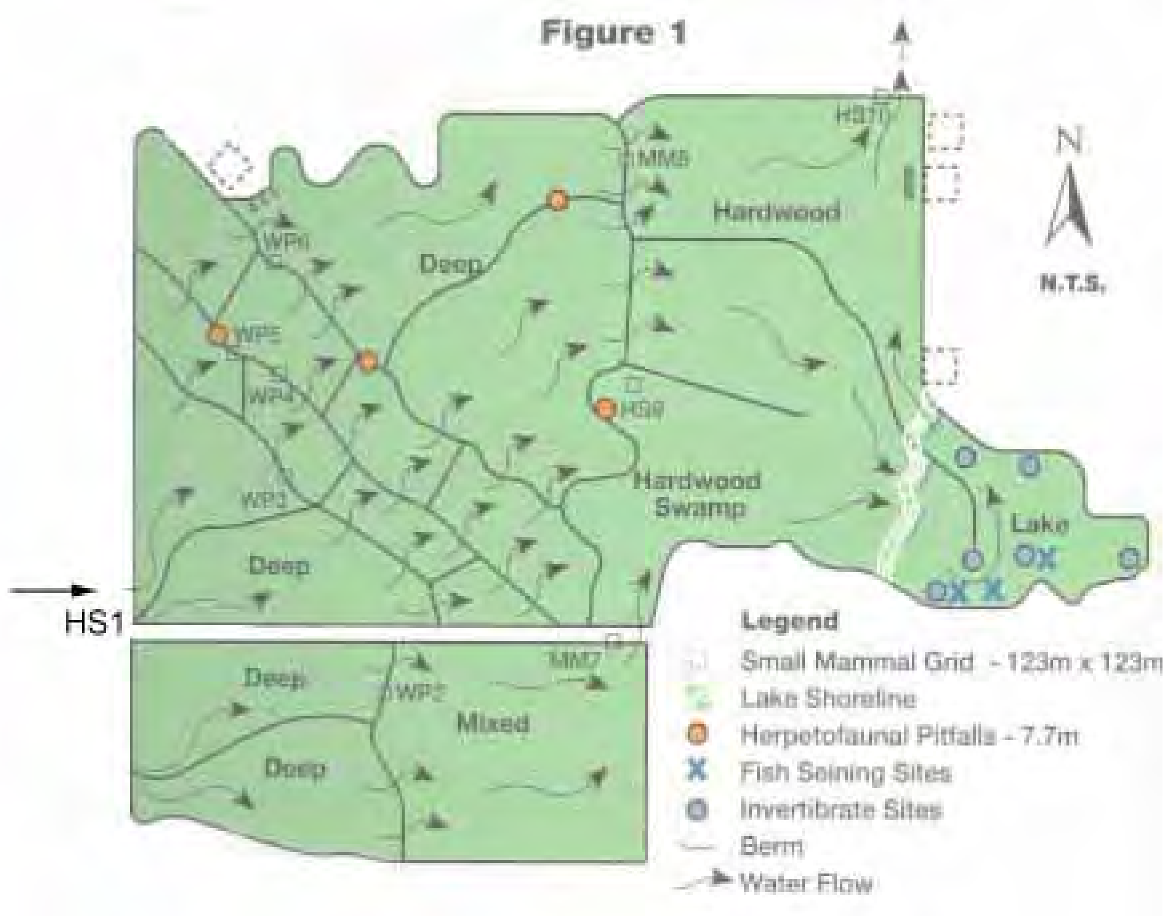
FDEP and USEPA did not allow the City to use existing permit conditions or wasteload allocations as the basis for nutrient limitations of the wetland discharge. This situation was largely due to the continued degradation of water quality conditions in Lake Harney. The USEPA NPDES and FDEP permits require that the wetlands' discharge meets existing background water quality conditions in nearby natural wetlands as well as complies with the loadings established under the wasteload allocation for discharges to the Little Econ.

The City conducted a 2.5-year water quality study in conjunction with the SJRWMD and FDEP to estimate the nitrogen and phosphorus limits for the wetland's operating permits. The nitrogen and phosphorus permit limits generated by this study are 2.31 mg/L and 0.2 mg/L, respectively.

Wildlife Considerations

A secondary objective of the Orlando Easterly Wetlands project was the creation of a wildlife habitat. During the conceptual design phase, the wildlife management area was thought of as a function of the wetland treatment process rather than as a specific plan for specific wildlife species. However, as permitting and design proceeded, wildlife issues shifted from simple descriptions of potential species occurrences in the general area of the wetland to the design of specific habitat types. This inclusion of areas designed as a wildlife habitat within the City's wetland system allows the project to serve as a valuable wildlife refuge and opens up the site for other uses in addition to wastewater treatment and disposal.

Developing the Wetlands



Approximately 1,220 acres of the project site were developed into the Orlando Easterly Wetlands project. The system is divided into seventeen cells oriented across the site so that the first twelve cells comprise about one-third of the total project area. The mixed marsh includes three cells that also comprise about one-third of the total area. The remaining two cells form the hardwood swamp. The cells were defined by constructing a series of earthen berms and were planted using about 2.1 million aquatic wetland plants. Vegetation originally planted in the wetland are shown in Figure 2.

All fill material used to construct the berms was excavated from a borrow pit (shown as the lake in Figure 1) located in the eastern part of the site. The habitat potential of the lake is enhanced by the use of an irregular shoreline, the varied slope of the littoral zone, the varied water depths (e.g., the rim ditch used to de-water the site was left in place and now averages up to 45 feet deep), and the placement of construction debris within the lake for fisheries habitat.

The system began operation in September 1987. AWT effluent is pumped about 7 miles from the Iron Bridge WPCF to a three-way splitter box at the wetland system, after which the water flows by gravity to the outfall structure. Rectangular weir structures are used to control the flow internally; two-inch flash boards are removed or inserted as needed. The berm design includes a three-foot freeboard capacity for storage of stormwater inputs. This design allows the operators to control the flows into and out of any given cell without influencing the operation of the remaining areas of the wetland treatment system. The average travel time through the Orlando Easterly Wetlands varies from about 21 days during the dry season to about 65 days during the rainy season.

Wetland Components

Water enters the Orlando Easterly Wetlands system through the 12 cells that form the deep marsh. The deep marsh cells generally have an average depth of 3 to 3.5 feet and were planted with cattails (Typha spp.) and bulrush (Scirpus spp.). These areas were planned as cattail communities at the conceptual design stage, because the scientific literature at the time provided more information about using this species than any other species for wastewater treatment.

Bulrush and Cattail communities remove and store most of the nutrients from effluent entering the wetland system.

Because cattails are potentially capable of competitively eliminating other native plant species and consequently reducing the diversity of the emergent plant communities in the SJR basin, the SJRWMD voiced concern about the formation of such a large cattail community so near to the SJR. In response, PBS&J designed a large-scale in-situ experiment for the City to test the treatment capabilities and competitive effects of cattail versus bulrush communities. As a result, the first 12 cells of the City's system are planted with either cattails, bulrush, or a combination of the two.

To date, the results indicate there are subtle differences between the two plant species relative to water quality improvement. The bulrush cells appear to have a slightly

Figure 2
Orlando Easterly Wetlands Reclamation Project Species Planted

Red Maple (Acer rubrum)

Water hyssop (Bacopa caroliniana)

Canna (Canna flaccida)

Sawgrass (Cladium jamaicense)

Spikerush (Eleocharis cellulosa)

Pop ash (Fraxinus caroliniana)

Dahoon Holly (Ilex cassine)

Blue flag (Iris hexagona)

Soft rush (Juncu s effusus)

Sweet gum (Liquidambar styraciflua)

Sweet bay (Magnolia virginica)

Stone wort (Nitella sp.)

Cow lily (Nuphar luteum)

Water lily (Nymphaea odorata)

Black gum (Nyssa sylvatica)

Maidencane (Panicum hemitomon)

Knot grass (Paspalum distichum)

Smartweed (Polygonum punctatum)

Pickerelweek (Pontederia cordata)

Pondweed (Potamogeton illinoensis)

Swamp laurel oak (Quercus laurifolia)

Arrowhead (Sagittaria graminae)

Arrowhead (Sagittaria lancifolia)

greater nutrient uptake capacity than the cattail cells. The bulrush also have proven to be more tolerant of water level fluctuations than the cattails. The deep marsh cells are designed to take advantage of the microbial communities associated with the littoral zones within the cattail and bulrush communities to remove and store most of the nutrients entering the wetland system.

Three-square bulrush (Scripus americanus)

Giant bulrush (S. Californicus)

Soft stem bulrush (S. Validus)

Pond cypress (Taxodium ascendens)

Thalia (Thanlis geniculata)

Cattail (Typha domingensis)

Cattail (T. latifolia)

Tapegrass (Vallisneria americana)

The deep marsh cells are followed by three mixed marsh cells. The mixed marsh is designed as a transition point between the water treatment aspects of the wetland treatment system and those associated more closely with wildlife habitat. Approximately 30 plant species were planted in the mixed marsh cells, and approximately 100 other species have become self established from the seed bank or off-site wetlands since system start-up.

More than 200 animals species use the Orlando Easterly Wetland as habitat today.

Overall, the vegetative communities within the mixed marsh cells provide a very diverse habitat structure. The mixed marsh cells act as a nutrient polishing step to the deep marsh cells and maintain nitrogen and phosphorus concentrations at lower levels than those found in the deep marsh. An apparent difference in the nutrient removal processes in the deep marsh and mixed marsh cells is that the former relies more on bacterial uptake while algae are more dominant in the latter.

The final component of the Orlando Easterly Wetlands system is the hardwood swamp. This area is specifically designed as a wildlife habitat area. About 160,000 trees were planted throughout the cells, intermixed with an understory similar to that typical of the mixed marsh. In addition, an existing cypress (Taxodium spp.) head was preserved, and the lake, developed from the borrow pit, was located within these cells. Although the hardwood swamp cells were not expected to play a significant role in the nutrient uptake before system start-up, they have since proven to produce a net release of phosphorus back into the water column. This release of phosphorus can be partially attributed to the number of rookeries located within these cells. The nesting bird species typically found in the rookeries include several heron and egret species.

Measuring Success

Wetland system designers included an operational plan for maintaining target communities and refuges for forage species.

In 1984, at the conclusion of the initial study which examined disposal alternatives, the City established the goal of creating a wetland treatment system that would provide both effluent polishing and a wildlife management area. Since system start-up, the performance of the Orlando Easterly Wetlands relative to nitrogen and phosphorus uptake and storage has been better than originally predicted by the design (see Table 1).

The data in Table 1 show that the Orlando Easterly Wetlands project has consistently discharged a water quality that is better than the permit requirements. The discharge has, in fact, been statistically equal (æ < 0.05) to the water quality conditions in the SJR, both upstream and downstream of the discharge point (see Table 2). These data indicate that the system has acted to recover a resource-- fresh water--that now is being used to hydrologically restore the SJRWMD wetland site.

The annual performance of the system is shown by the data in Tables 3 and 4, with reference to Figure 1 for the station locations. These data indicate the system has performed very well for the first four years of operation. This can be partially attributed to the level of commitment by the City of Orlando to operate the system as a treatment process and as a wildlife habitat area. Operational procedures, such as varying water depths, employed by the project have attempted to minimize nutrient releases while maximizing the ability of the wetland treatment system to remove and store nutrients. The data in Table 4 also show that phosphorus concentrations are reduced to about 0.05 mg/L at the discharge point from the mixed marsh.

Water quality data are only one indication of the success of the Orlando Easterly system. Another measure of success is the diversity of the system and the array of wildlife species attracted by this diversity.

Table 1

TN and TP Discharge Concentrations*

	Flow (mgd)	TN (mg/L)	TP (mg/L)
FDEP	13.00	2.31	0.200
1988	10.00	0.84	0.095
1989	13.33	0.92	0.076
1990	13.28	0.93	0.090
1991	12.90	0.80	0.087

* This table compares the first four years of compliance data for the Orlando Easterly Wetlands project with the current FDEP permit criteria for TN and TP discharges. Flows shown represent influent discharges to the wetland system.

Figure 4

Orlando Easterly Wetlands Reclamation Project Observed State and Federally Listed Animal Species

Roseate spoonbill
Limpkin
Gree-backed heron
Little blue heron
Snowy egret
Tricolored heron
Peregrine falcon
Florida sandhill crane
Woodstork
Everglades snail kite
American alligator
Eastern indigo snake

The system has demonstrated that if properly managed, a constructed wetland can be used for water treatment, water quality improvement, and diverse wildlife habitat. In fact, data collected to date indicate that the system may attract more species than surrounding natural wetlands and generally may support a higher resident population than similar natural habitat areas (see Figure 3). The latter can be directly attributed to the higher productivity rates within the system.

The design of the Orlando Easterly Wetlands includes the preservation of upland areas around the site. Maintenance of the upland/wetland ecotone has increased the value of the potential habitat for wetland-dependent species.

The design also included an operational plan, i.e. managing water depths for maintaining the hydroperiod (optimal water depths and duration) for targeted vegetative communities in the system. This plan addresses procedures for maintaining the refuges for the forage species, which ultimately will lead to stabilizing the habitat of higher wildlife species such as birds, alligators, and otters.

Another measure of the Orlando wetlands success is the number of listed species which use the site (shown in Figure 4). To date, 145 bird species have been observed on site and 10 of these species are state or federally listed and are currently utilizing the system as part of their habitat. The sandhill crane and Everglades kite have successfully nested in the wetlands and fledged young during the third and fourth years of operation. This usage pattern of the wildlife habitat also serves as an on-going natural bioassay of the system, showing that the water quality goals have been met in full.

Table 2

Comparison of TN and TP Discharge Concentrations with the Annual Averages of Receiving Waters

(First Four Years)

	TN (mg/L)				TP (mg/L)			
	1988	**1989**	**1990**	**1991**	**1988**	**1989**	**1990**	**1991**
HS10	0.84	0.92	0.93	0.80	0.095	0.076	0.090	0.087
SJR1	0.87	0.88	1.08	1.05	0.137	0.074	0.098	0.053
SJR5	0.87	0.89	0.89	1.09	0.149	0.071	0.084	0.116
SR	0.95	1.00	1.09	1.06	0.117	0.070	0.080	0.067

HS10 = Orlando Easterly Wetlands Reclamation Project Discharge

SJR1 = Station in the St. Johns River Upstream of HS10

SJR5 = Station in the St. Johns River Downstream of HS10

SR = Average Annual Concentration for Seminole Ranch Monitoring Stations

Table 3

Comparison of TN Annual Averages Through the Orlando Easterly Wetlands Reclamation Project

(First Four Years)

	Nitrogen (mg/L)				
Station (1)	**1988**	**1989**	**1990**	**1991**	**Area (2)**
WP1	4.18	5.52	2.83	2.44	0
WP3	1.53	1.92	0.98	2.20	11
WP4,5	1.51	1.74	1.00	1.02	16
WP6	1.27	1.59	1.09	1.11	32
MM8	0.96	1.22	1.19	1.25	67
HS10	0.84	0.92	0.93	0.90	100

(1) These stations include influent and effluent samples in addition to four internal strat.

(2) Area equals the percent of wetland area upstream of the listed sample station.

Table 4

(First Four Years)

Station (1)	Phosphorus (mg/L) 1988	1989	1990	1991	Area (2)
WP1	0.572	0.720	0.41	0.23	0
WP3	0.103	0.080	0.16	0.37	11
WP4,5	0.102	0.065	0.14	0.12	16
WP6	0.106	0.070	0.11	0.11	32
MM8	0.091	0.050	0.05	0.06	67
HS10	0.095	0.076	0.09	0.087	100

(1) These stations include influent and effluent samples in addition to four internal strat.

(2) Area equals the percent of wetland area upstream of the listed sample station.

Community Acceptance

Orlando Easterly Wetlands Reclamation Project Awards	
1987	PBS&J Project Excellence Award
1988	Florida Institue of Consulting Engineers Excellence Award ACEC Excellence in Engineering Award
1990	FDEP Secretary's Award, Florida Department of Environmental Regulation
1990	State of Florida Governor's Environmental Award
1992	Water Environment Federation Outstanding Achievement Award (included with other City achievements) over the past 10 years

Orlando Easterly Wetlands Reclamation Project Costs

Land Acquisition.........$4,411,000
Wetlands Development
Structural...........4,232,000
Vegetation.............750,000

Force Main...................8,491,000
Effluent Pump Station....1,982,000
Engineering....................1,659,000

Total.........................$21,525,000

The success of the Orlando Easterly Wetlands Reclamation Project is attributed not only to its success as a wastewater treatment facility and reuse project, but also to the benefits it offers surrounding communities. For visitors who wish to enjoy the beauty of Florida wildlife in a natural habitat, a portion of the project functions as a wilderness park with nature trails and seasonal camping facilities which are open from mid-January through September.

For area schools with environmental educations programs, it serves as a natural laboratory and research facility. The result is a project which exemplifies the current trend toward socially responsible environmental management.

Figure 3
Comparison of Wildlife Diversity

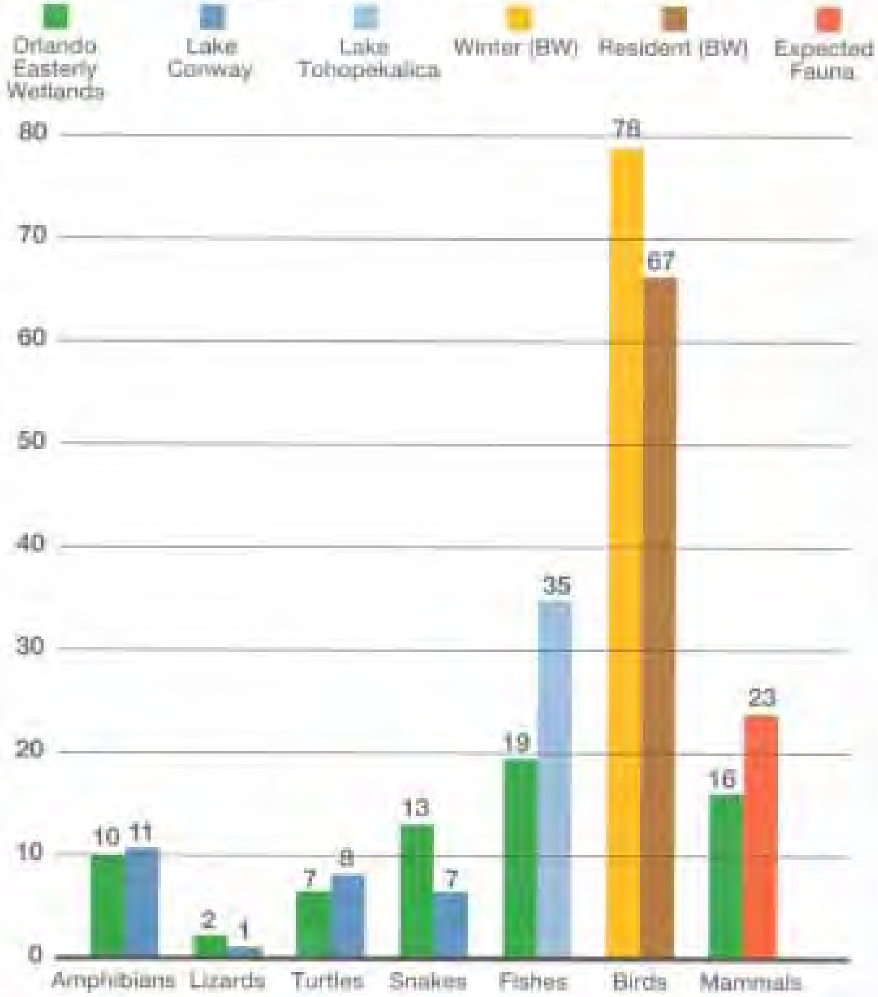


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Photo courtesy of Seth Blitch

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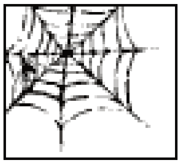
Constructed Wetlands for Wastewater Treatment and Wildlife Habitat



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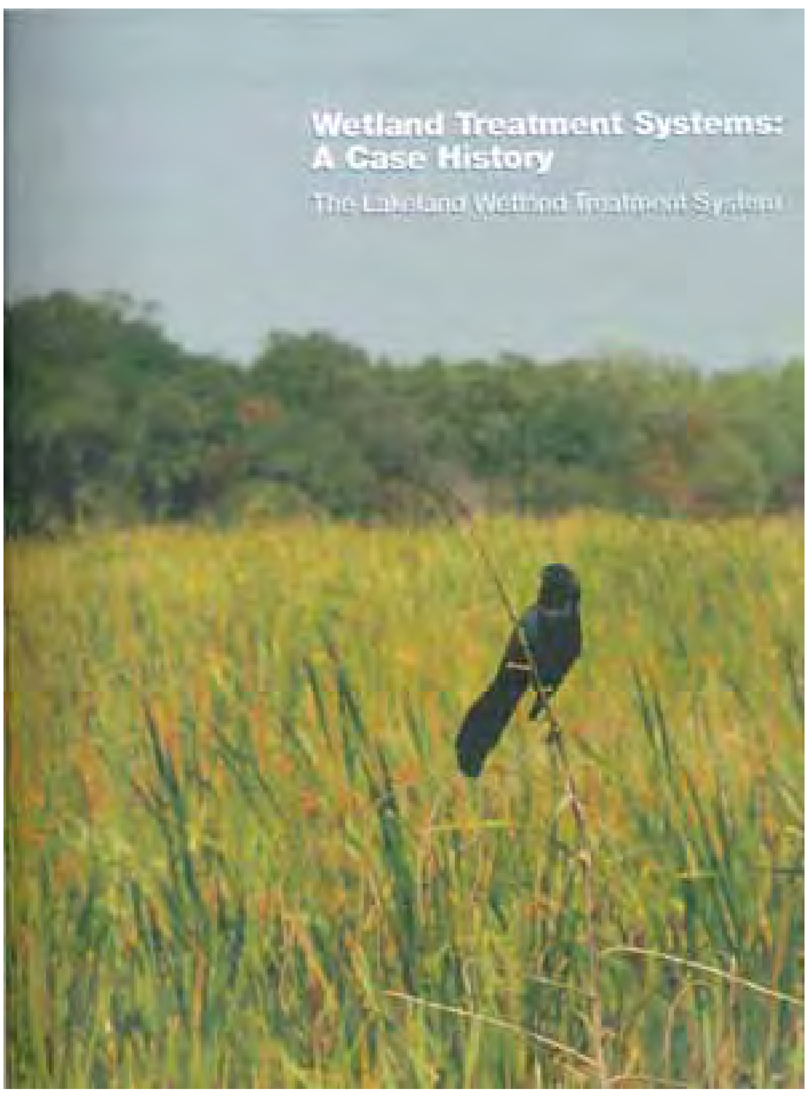
Lakeland, FL - Wetland Treatment Systems: A Case History - The Lakeland Wetland Treatment System



A Case History: Lakeland Wetland Treatment System

Introduction

The City of Lakeland (City) operates a 1,400 acre wetland treatment system located just |east of the town of Mulberry, Florida. The wetland system serves as the final treatment process for the City of Lakeland's 10.8 mgd Glendale Wastewater Treatment Plant and their 4.0 mgd Northside Wastewater Treatment Plant. These treatment plants serve a combined population of approximately 79,000 people within the city limits, as well as portions of the unincorporated areas of Polk County.

Figure 1
Plan view of the site showing the relative locations of the internal cells.
Click on picture for larger image.

Many of the natural upland and wetland communities within Polk County and the surrounding counties have been replaced by agricultural and industrial development. Citrus and phosphate mining industries have altered the landscape around Lakeland to a greater extent than any other development activity. The phosphate mines have provided the most dramatic changes to the lands in Polk County by not only eliminating the natural ecosystems, but also by significantly altering the topographic nature of these areas.

Restoration efforts within most of the abandoned mine sites have been limited in scope at best, since no real efforts generally are made to restore the original topography and vegetative communities. Instead, upland areas are normally replanted as monoculture pine forests, while most aquatic areas are comprised of lakes formed in unfilled mine pits. Most emergent wetland communities are restricted to the littoral zones of the lakes or are usually dominated by monoculture stands of cattails (Typha spp.) and/or Carolina willow (Salix caroliniana).

Project Background

Originally, the City began treating wastewater on the Glendale site in 1926 using a 2.5 mgd primary treatment plant. This plant began discharging effluent to Banana Lake via Stahl Canal, a practice that continued for more than 65 years. In 1939 the City upgraded the treatment plant with trickling filters to achieve secondary treatment. In the late 1950's and 1960's, the City rebuilt the trickling filters and expanded the facility to 10 mgd. The City began diverting up to 5.5 mgd of effluent from the Glendale treatment plant to the newly constructed C.D. McIntosh Jr. Power Plant for use as cooling water. In 1981 effluent pumped to the power plant was further treated on the power plant site and discharged (rapid infiltration) to the surficial aquifer adjacent to Lake Parker, thereby reducing the flows and loadings to Banana Lake. In 1988, the City expanded the wastewater treatment system to include its newly constructed 4.0 mgd Northside plant. When the Northside plant went on-line, it became the primary source of cooling water for the power plant.

The sustained effluent discharge to Banana Lake, along with agricultural development in the Banana Lake watershed, severely degraded the water quality of the lake and down stream waterways. Early in 1983, the Florida Department of Environmental Protection (FDEP) indicated that the City's discharge permit to Banana Lake would not be renewed due to water quality problems in the lake. For this reason, both FDEP and the U.S. Environmental Protection Agency (USEPA) negotiated compliance schedules with the City to cease discharging effluent to Stahl Canal and Banana Lake.

One of the lakes located at the downstream end of the wetlands.

Faced with compliance schedules to cease discharging to Banana Lake, the City retained Post, Buckley, Schuh & Jernigan, Inc. (PBS&J) to develop and evaluate viable effluent disposal alternatives. Analysis of these alternatives indicated that disposal via an artificial wetland system would be the most cost effective method of effluent disposal for the existing Glendale plant. The Glendale facility has since been rerated to 10.8 MGD. The wetland site selected includes 1,600 acres that were formally used by W.R. Grace Inc. as a phosphate settling area. The site is characterized by a series of seven cells surrounded by levees. (See Figure 1.) Process waters from the previous mining operation were recycled through the cells to settle solids out of the water column. Overflow from the recycle system is discharged to the Alafia River. This process created a soil gradient across the cells where course-grained sands settled on the influent side of cells 1, 2, and 3, while fine clayey sediments settled on the effluent side of the cells. The settling process also created a significant topographic gradient in the first three cells that slope downward from the influent to effluent sides of the cell. The sediments in cells 4 through 7 are predominately nearly level fine clayey soils. A shallow lake still exists on the downstream side of Cell 5, while cells 6 and 7 remain as deep lakes.

Figure 2. *The influent structure aerates the water as it enters the wetland.*

Wetland Design

Weirs located along berms covered with grout-filled fabric revetments distribute flow into the cells 2 and 3.

Since 1987, approximately 1,400 acres of the project site have been used as part of the wetland treatment system. This area provides a permitted treatment capacity of 14 mgd of secondary effluent, although the current flows average approximately 8.0 mgd. Effluent is pumped from the Glendale plant polishing ponds through 6.4 miles of force main to the wetland system. In 1989, the influent to the wetland system was augmented by the inclusion of blow down waters from the Unit No. 3 cooling tower at the McIntosh Power Plant, along with periodic discharges from the ash ponds. Blow down waters from the power plant are mixed with effluent from the wastewater treatment plants at the Glendale plant and are then pumped to the wetland.

The H-flume outlet structure controls flows leaving the wetlands.

The introduction of the cooling waters and the ash pond effluent has significantly increased the total dissolved solids concentrations to the wetland. As an example, the average annual influent conductivity levels have increased.

The influent enters the wetland through a cascade inlet structure, as shown in Figure 2. The inlet structure is designed to aerate the influent waters through turbulent fall down the structure's 13 steps. The flow is split at the inlet structure between two Fabriform lined ditches that lie along the eastern boundary (influent side) of Cell 1. Water is discharged from the distribution ditches through weirs located every 100 feet along the ditch. Flow rates through individual weirs can be controlled by the addition or removal of flashboards. Once the water passes through the cell it is collected and discharged to Cell 2. This general pass through and collection system is repeated in cells 2 and 3. These three cells have the greatest change in topography. This system helps better distribute flow in these cells.. Cells 4 through 7 do not have distribution ditches. An H-flume outlet structure located at the south end of Cell 7 is used to monitor and control flows leaving the wetland site. A meteorological station provides data to assist in the preparation of annual water budgets for the wetland.

Site Conditions

In operation since 1987, the Lakeland Wetland Treatment System offers wildlife a natural habitat.

When the City assumed control of the wetland site, much of the interior of cells 1 through 4 were covered by cattails and Carolina willow. Upland islands within the cells generally were vegetated by undesirable grass/herbaceous species, and in some areas by pine (Pinus spp.) and live oak (Quercus virginiana) tree species. Vegetation in the upstream areas of Cell 5 was a mixture of cattails and Carolina willow, while the downstream half of the cell was a shallow lake system that was ringed by a dense population of water hyacinths (Eichhornia crassipes). Densities of algal populations in this lake often created a lime green color in the open water areas.

Although minimal disruption of the existing wetland vegetation within the treatment cells resulted from the construction activities, restoration grant monies received by the City from the Florida Department of Natural Resources were used to plant trees including black gum, red maple, sweet bay, swamp laurel oak, bald cypress, dahoon holly, and pop ash, within certain areas of cells 1 through 5. Secondly, the water hyacinths were removed from Cell 7 in response to concerns, voiced by the Polk County Environmental Services Division, that operation of the wetland system would increase mosquito production in areas covered by water hyacinths.

The areas along the eastern sides of cells 1 and 2 were originally barren sands or sparsely covered by upland grass species. These were the only areas planted with herbaceous wetland vegetation during construction. In both cells the pre-construction vegetation was cleared to allow the site to be graded. Initially, the highly permeable sandy soils made it difficult to establish wetland vegetation in these areas. However, after five years of operation both areas now support dense communities of wetland vegetation.

Operational Results

The original design objectives for the wetland treatment system were to improve the City's effluent quality beyond the secondary level (shown in Table 1 as Original Goals). Since start-up of the wetland system, state legislation was enacted that required the wetland to meet even more advanced wastewater treatment levels (also shown in Table1 as Existing Permit Conditions). Table 1 provides a summary of the influent BOD, TSS, TN & TP concentrations, water quality after passing through the first two cells (represented by station G3) that are primarily emergent wetlands, and the final effluent discharge structure. The average annual concentrations for the first four years of operation are presented, as well as the FDEP and USEPA permit limits. As shown, the wetland effluent quality has consistently met the permit limits, with the exception of TSS for 1990 and 1991. This can be at least partially attributed to increased algal populations in the last four cells within the wetland. Cell 7 previously was covered by water hyacinths, which served to limit the concentration of algae near the effluent structure. The removal of the water hyacinths in response to county concerns has allowed the algal concentrations to increase which appears to interfere with the wetlands ability to maintain TSS concentrations below permit limits. The City currently is working with FDEP, USEPA, and PBS&J to lower water levels in cells 3 through 6, and to increase the density and distribution of macrophytic vegetation in cells 4 through 7. Increased densities of macrophytic vegetation in the latter four cells should help limit the density of algae in these cells and, consequently, reduce their contribution to TSS in the effluent.

The wetland also has provided habitat for a

Table 1.

Water quality results for the first four years of operation

	Parameter			
	BOD (mg/L)	**TSS (mg/L)**	**TN (mg/L)**	**TP (mg/L)**
Influent	3.88	5.60	10.36	9.05
G3	1.14	1.74	2.79	6.54
Effluent	3.12	4.70	1.99	4.22
Original Goals	5.0	10.0	3.0	Exempt
Existing Permit Conditions	5.0	5.0	3.0	mpt

* Effluent phosphorus limits are exempted due to the high background phosphorus levels in the receiving stream.

Project Capital Costs

variety of wildlife species. Most notable are the large rookeries formed by wood storks (*Mycteria americana*), white pelicans (*Pelecanus erythrorhynchos*), cormorants (*Phalacrocorax auritus*) anhingas (*Anhinga anhinga*), white ibis (*Eudocimus albus*), and several egret and heron species on the upland islands within cells 5, 6, and 7. In addition, there are several bobcat (*Felix rufus*) and otter (*Lutra canadensis*) families now living within the boundaries of the wetland.

Wetland	$3,100,000
Pipeline	$2,800,000
Pump Station	$780,000
Total	$6,680,000

The wide variety of wildlife inhabitint the wetlands includes anhinga and numerous other waterfowl.

Acknowledgements

Numerous individuals have contributed to the success of the Lakeland Wetland Treatment System. Listed below are some of the key groups and individuals.

City of Lakeland
John K. Allison, *former Public Works Director*
Virgil Caballero, *Wastewater Superintendent*
David Hill, *Project Biologist*

FDEP
Edward G. Snipes Jr. , *Permit Coordinator*
G.J. Thabaraj, *Engineer*
Bhupendra Vora, *Grants Coordinator USEPA*

PBS&J
R. Morrell, *Project Director*
M. Walch, *Project Manager*
K. Keefer, *Project Engineer*
J. Jackson, *Project Engineer*

USEPA
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Office of Wastewater Management
Washington, D.C.

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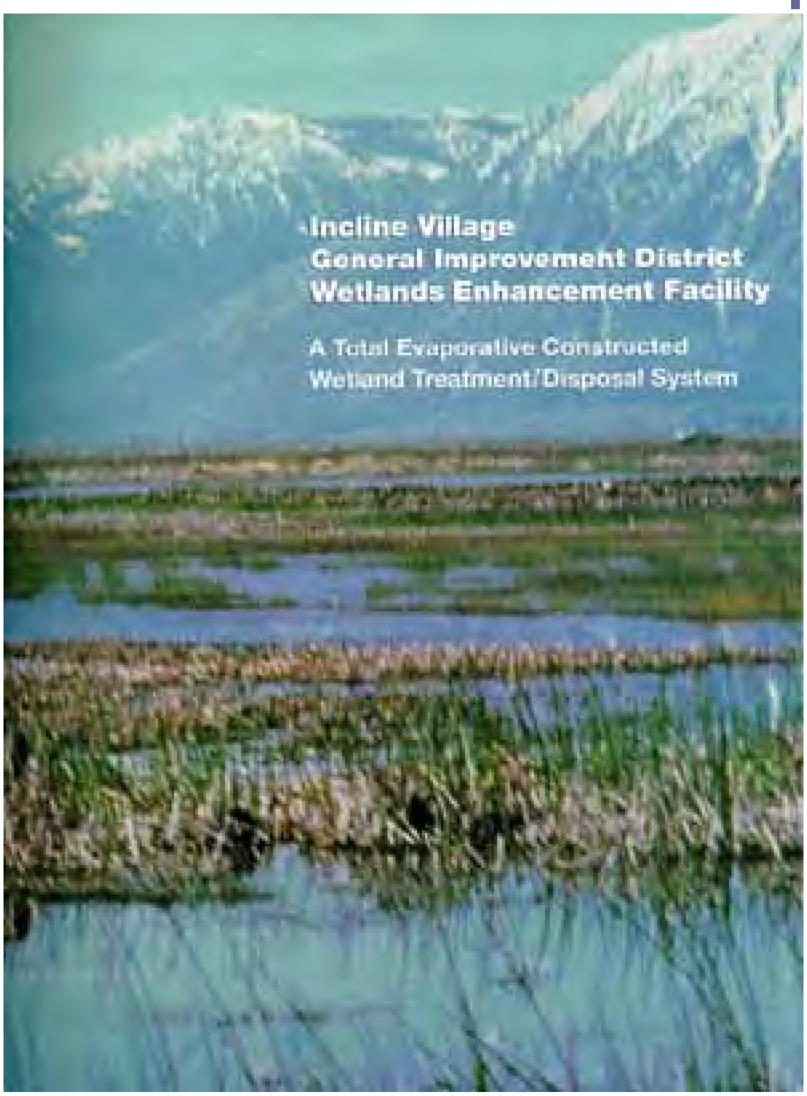
Incline Village, NV - Incline Village General Improvement District Wetlands Enhancement Facility: A Total Evaporative Constructed Wetland Treatment/Disposal System



Background

Incline Village, Nevada, uses a constructed wetland for disposal of secondary effluent. Starting with an existing, mineralized, warm-water wetland near Minden, Nevada, the Incline Village General Improvement District developed a system which uses natural processes both to renovate wastewater and benefit wildlife. With this system, Incline Village can meet several goals to protect the environment:

- dispose of treated effluent effectively and economically
- expand the existing wetland habitat for wildlife
- provide an educational experience for visitors

Until 1975, effluent treated at the Incline Village General Improvement District's 3.0-mgd activated sludge plant was exported from the Lake Tahoe Basin and discharged into the Carson River during the winter and used for irrigation of hay fields during the summer.

The Incline Village Wetlands Enhancement Facility is located south of Carson City, Nevada, about 10 miles east of Lake Tahoe.

A discharge permit issued in 1975 required either more stringent treatment standards or a year-round, land-based disposal system. In 1979, a facility plan funded by the U.S. Environmental Protection Agency (EPA) and prepared by CH2M HILL recommended meeting a zero surface discharge standard by using land application during the growing season and constructed wetland enhancement during the remainder of the year. Local agency reviews and public hearings were held, and the wetland concept was finally approved in 1982. The project was designed by the environmental engineering firm, Culp·Wesner·Culp, with technical assistance from Dr. Robert Kadlec of the Wetlands Research Group. The design was completed in 1983 and construction was finished in November 1984.

A 20-mile pipeline carries the treated effluent from the treatment plant to the Wetlands Enhancement Facility. Constructed wetland cells, berms, a flood dike, and a distribution ditch are the main components of the system. The 770-acre site is made up of several distinct areas:

A resident population of Canada geese use the berms and islands for nesting.

- constructed wetlands
- natural warm-water wetlands
- seasonal storage/waterfowl areas
- effluent storage area
- upland area

Eight constructed wetland cells are the primary disposal area for the treated effluent. There is no surface discharge from the wetland disposal area because of evaporative water losses. Each cell has a deep channel down its center that discourages growth of emergent vegetation and furnishes a landing area for waterfowl. Islands within this channel serve as nesting sites.

Wetland treatment cells with islands were constructed around the existing warm-water wetlands.

The natural warm-water wetland provides a natural habitat for plants and animals and is not part of the disposal process.

The seasonal storage/waterfowl areas store excess water during periods of low evaporation and high rainfall. They are dry during summer and fall, except for a small ponded area fed by warm-water springs. Three islands in this area provide nesting habitat for waterfowl. Each of the islands was planted to provide food, screened areas, and trees for birds.

The 2.8-million-gallon effluent storage area is used only during high flows or heavy rainfall. The 200-acre upland area is used to dispose of effluent by spray irrigation during extended rainy weather.

Operations and Management

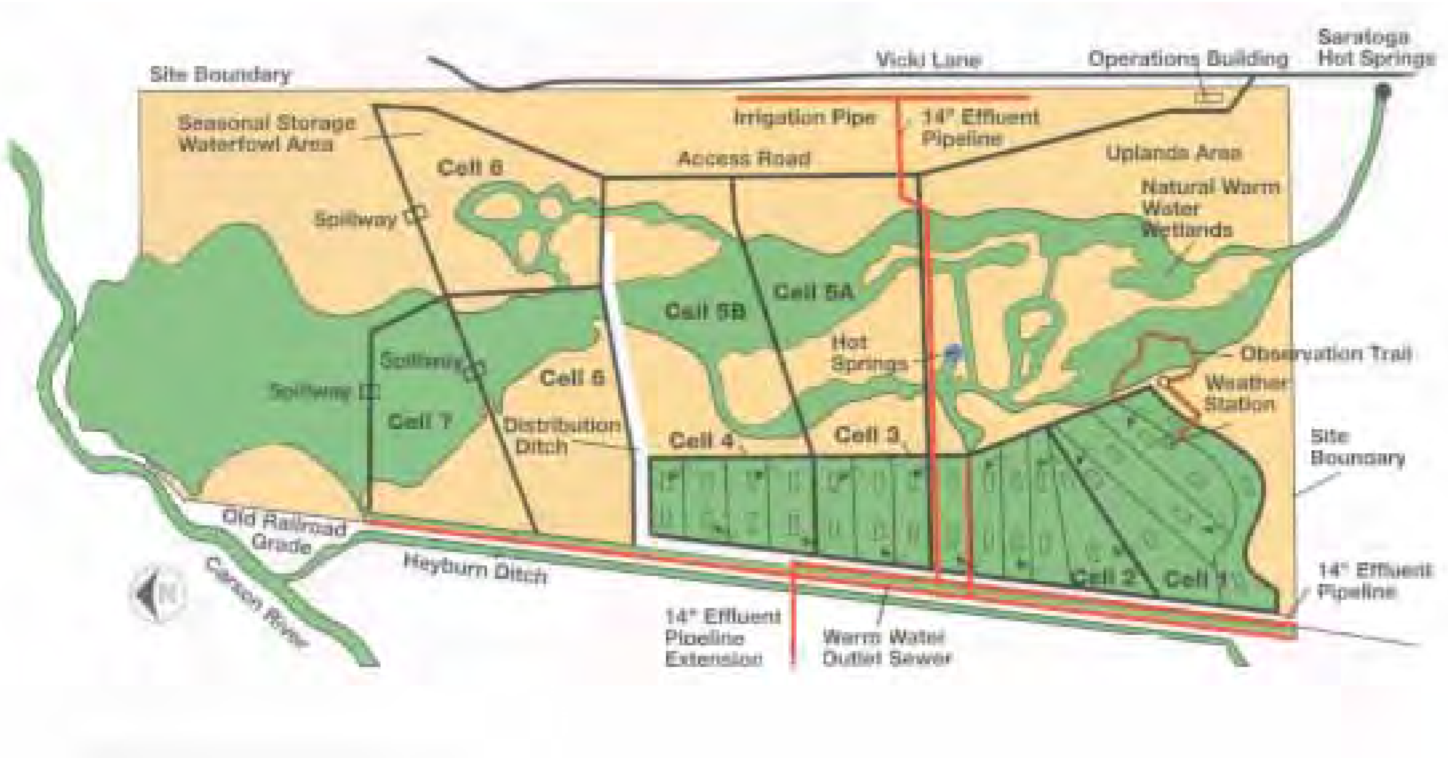
The treated effluent passes through the 390-acre system of wetland cells and is disposed of through evaporation, transpiration (evaporation through plants), and percolation (seepage through soil). The system works in harmony with the existing warm-water wetlands, adapts well to year-round fluctuations in weather and temperature, and meets state and EPA water-quality requirements while avoiding surface discharge to the Carson River.

Effluent flows from Cell 1 through Cells 2, 3, and 4 before overflowing to the distribution ditch. Overflows from Cells 3 and 4 are diverted to Cell 5 for storage and evaporation. Water that must be stored is held in Cells 6, 7, and 8.

Using weather instrumentation and monitoring equipment, plant operators determine rainfall, evapotranspiration and percolation rates, and groundwater quality. These data are used to estimate the evaporation rates at the site and to determine compliance with groundwater quality standards.

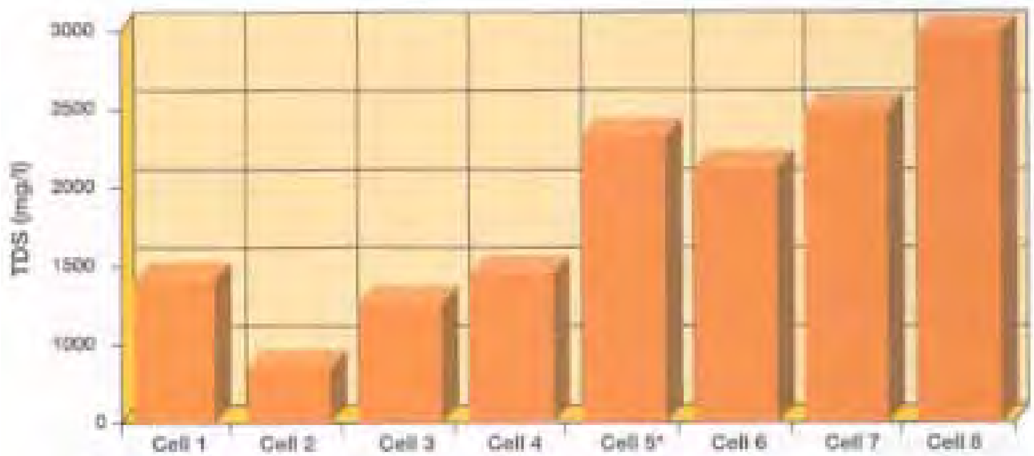
The size of the constructed wetland needed for evapotranspiration and percolation of effluent was determined by calculating several water balances for the site. Evaporation rates were estimated with the Penman method and were based on limited data available for the area. Subtracting the evapotranspiration and percolation from the rainfall yielded the net water loss from the site. Dividing the net water loss into the effluent volume gave an estimate of the required acreage.

Percolation is critical to successful operation of the project. At least 1.1 inches of percolation per month is required at the projected flow rate. If percolation occurs at this rate, only 175 acres are needed to treat the effluent. If percolation does not occur, as much as 450 acres would be required.

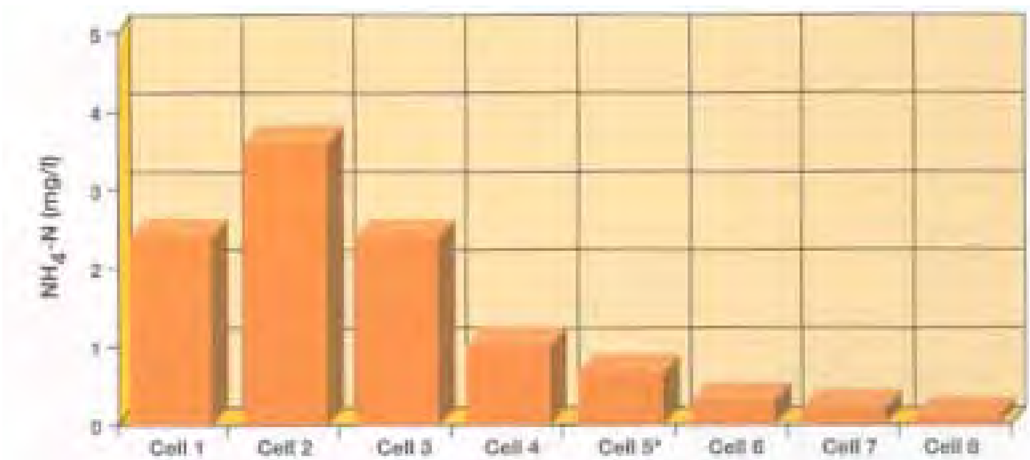


The Incline Village Wetlands Enhancement Facility includes a total of 770 acres of wetlands and uplands.

Performance



The concentration effect of evaporation can be seen in the increase of total dissolved solids as water moves through the cells.



The concentration of ammounium nitrogen is reduced as the water flows through the cells.

Because there is zero discharge to surface waters from the Incline Village Wetlands Enhancement Facility, no surface water quality criteria must be met. However, many parameters of regulatory interest are monitored in the wetland cells. Even though all surface water evaporates or is lost to percolation, water quality improvements can be observed as the water passes through the cells in a serial pattern.

For seven years, nitrogen and phosphorus levels have been reduced in the water, even during the winter. Nutrients in the last cells display only 2 to 3 percent of the concentration values in the incoming wastewater effluent.

The effect of evaporation can be seen in the increases of total dissolved solids (TDS) and chloride ion as water moves through the cells. The evaporites in the original desert soils are rearranged by water movement, with increases in concentrations in the downstream cells. However, there is no evidence of a continuing buildup of these ions in the downstream cells. Apparently, transport of solutes from upstream to downstream cells has reached a balance with other processes.

Wetlands Design Criteria

Flow, Average Annual......................1.66 mgd

Flow, Maximum Daily.......................2.68 mgd

Influent Quality

Suspended Solids...................20 mg/l

BOD5....................................20 mg/l

TDS.......................................240 mg/l

Total Phosphorus as P............6.5 mg/l

Total Nitrogen as N................25 mg/l

Constructed Wetland Area

Cell 1......................................37.9 acres

Cell 2......................................33.2 acres

Cell 3.......................................27.3 acres

Cell 4.......................................23.4 acres

Cell 5 (overflow area)................117.3 acres

Cell 6 & 7 (floodplain area).......105.6 acres

Cell 8 (seasonal storage)................42.5 acres

Wetland Depth

Emergent Marsh......................................0.5 feet

Open Water......................................2.0-3.0 feet

Ancillary Benefits

Plant Communities

Vegetation is essential to the success of the wetland. Plants increase evapotranspiration by as much as 20 percent in the summer and improve water quality. Wetland vegetation includes rush meadow, threesquare bulrush, tule cattail, and willow thickets. Upland vegetation consists primarily of sagebrush, rabbitbrush, greasewood, and salt grass, which tolerate the alkaline soils. Floodplain vegetation includes rabbitbrush and salt grass, plants which can exist in saline, silty loam, and clay soils.

Project implementation has allowed existing plant species to flourish. Careful planting of hundreds of trees and bushes added a new component to the ecosystem, with taller vegetation providing new perching and nesting areas for hawks and eagles.

The yellow-headed blackbird prefers nesting in the emergent marsh areas.

Wildlife Habitat

Migratory trumpeter swans find winter habitat at the wetlands enhancement facility.

The wetlands provide three types of wildlife habitat: permanent wetlands, seasonal wetlands, and uplands.

Many types of aquatic and nonaquatic wildlife coexist at the site. Aquatic invertebrates such as insects, worms, snails, and crayfish eat algae and other plants and serve as food for larger organisms. Fish such as largemouth bass, black bullhead, green sunfish, mosquito fish, and carp were identified before construction and were transferred to several areas within the site.

Birds occupying the site include ducks and geese, shore birds, raptors (hawks and eagles), and passerine (such as blackbirds). Many migratory species travel through the Carson Valley and nest on the islands in the seasonal storage/waterfowl area or the grassy areas along the edges of the cells. Animals common to the area include deer, coyote, skunk, mink, muskrat, rabbit, squirrel, chipmunk, and the western yellow-bellied racer.

Recreational Uses

An observation area is provided at the operations building in the southeast corner of the site to encourage the public to enjoy and learn about man's use of his natural environment. Observation trails traverse the warm-water wetlands and created wetlands so that visitors may experience the diverse wildlife and vegetation at the site and see how the project operates.

The natural warm-water wetlands provide a year-round habitat when the constructed wetland cells are dry.

Acknowledgements

Incline Village General Improvement District

Elected Trustees
Robert Wolf, *Chairman*
Pamela T. Wright, *Vice-Chairman*
Roberta Gang, *Secretary*
Jane Maxfield, *Trustee*
Greg McKay, *Trustee*

Professional Staff
Robert A. Hunt, *General Manager*

John F. Shefchik, *District Engineer*

Don N. Richey, *Sr., Operations Superintendent*

Grant Funding
U.S. Environmental Protection Agency, 9
Nevada Division of Environmental Protection, Construction Grant Section

Design Team
CH2M HILL
    Facilities Plan and Conceptual Design

Robert Chapman, *Project Engineer*

Richard Mishaga, *Environmental Scientist*

Culp$#183;esner$#183;, *Design*

Wetlands Ecosystem Research Group, *Wetlands Consultation*

Robert Kadlec, *Senior Consultant*

This brochure was prepared by CH2M HILL for the U.S. Environmental Protection Agency.

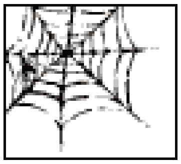
Project Cost

Description	Amount
Engineering/Inspection	$423,493
Land	$772, 503
Construction	$3,568,000
Total Project	$4,963,996

Innovative/Alternative grants funded 85 percent of the project.

EPA United States Environmental Protection Agency
Office of Water

Constructed Wetlands for Wastewater Treatment and Wildlife Habitat



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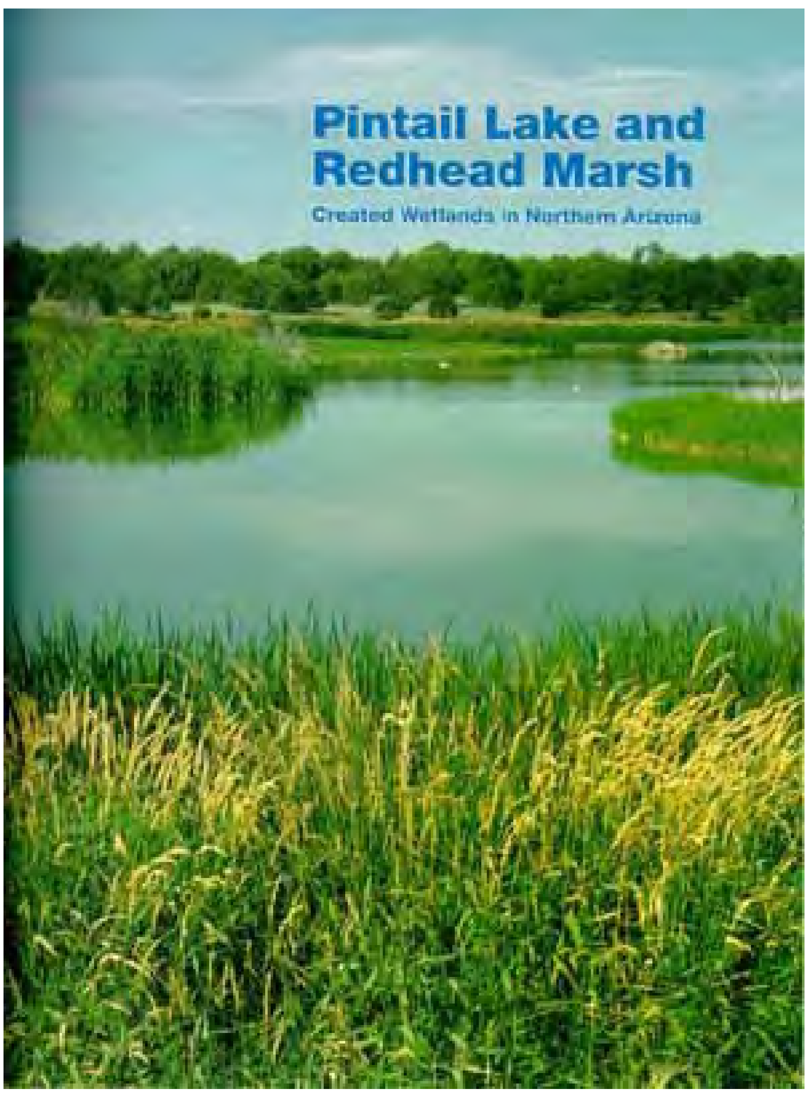
ShowLow, AZ - Pintail Lake and Redhead Marsh: Created Wetlands in Northern Arizona



Background/History

Treated municipal wastewater is being used in N.E. Arizona to create some very interesting wetlands. Wildlife response to this new habitat has been dramatic with over 120 species of birds using them. The local community is justly proud of this example of environmental innovation and cooperation.

The City of Show Low built its first wastewater collection and treatment system in 1958. It consisted of sewer lines, serving the original townsite and contiguously built up areas of the city, and two stabilization ponds for treatment. Effluent was discharged directly into Show Low Creek, adjacent to the treatment plant, eventually reaching Fool Hollow Lake. Nutrient loading resulted in accelerated lake eutrophication, algae blooms, and resulting fish kills.

In 1970, with the cooperation of the U.S. Forest Service, wastewater discharge into the creek was halted. The effluent was pumped two miles north to a natural depression known as Telephone Lake where it contributed to the development of wildlife habitat. In 1977, due to increasing population and resulting effluent flows, the treatment system was expanded to include additional natural depressions to the East which became known as Pintail and South Lake Marshes. In Pintail Lake the U.S. Forest Service began to construct islands to enhance waterfowl reproduction.

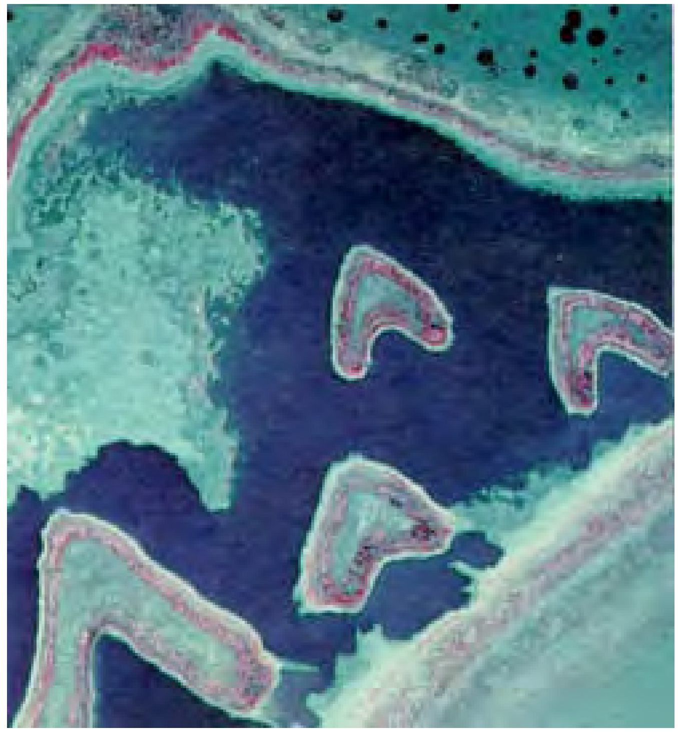
By 1982 wastewater flows exceeded the treatment plant's design capacity. Discharges directly into Show Low Creek and decreased quality of effluent delivered to the marsh treatment areas resulted in degraded habitat quality and sharply decreased waterfowl populations. In 1985 the City began to work on a long term solution to the problems of treatment plant capacity and providing high quality effluent to the created wetlands.

The solution selected was to deepen and improve the existing treatment lagoons by adding aeration, increase pumping capacity, add stabilization ponds for secondary treatment, increase the capacity of Telephone Lake for effluent storage, and add additional marsh capacity for final treatment and reuse.

Pintail Lake in winter.

Treatment Facility

The City of Show Low wastewater treatment facility now consists of two aerated lagoons that may be operated in series or parallel, a lift station with two 1,150 gpm pumps, four biological stabilization ponds that may also be operated in series or parallel, a chlorination contact chamber, effluent storage and clarification in Telephone Lake, nutrient removal in constructed riparian areas, and eventual reuse in constructed waterfowl marshlands.



Aerial view.

Site Description

The created wetlands at Pintail Lake and Redhead Marsh are located 4 miles north of the City of Show Low, Arizona. This is in the high country of northeastern Arizona. The wetlands are on National Forest Service Lands administered by the Apache/Sitgreaves National Forests.

Weather Summary

Month	Average High Temp.	Average Low Temp.	Historic Record Low	Average Precip.
Jan	44.2°F	17.7°F	-25°F	1.40"
Feb	48.3°F	21.0°F	-11°F	.96"
Mar	53.8°F	25.4°F	-7°F	1.25"
April	63.9°F	32.1°F	11°F	.60"
May	73.0°F	38.5°F	14°F	.31"
Jun	82.8°F	47.6°F	27°F	.50"
Jul	85.5°F	55.5°F	42°F	2.47"
Aug	82.9°F	54.1°F	37°F	2.25"
Sept	79.4°F	47.6°F	25°F	1.22"
Oct	68.5°F	35.7°F	10°F	1.46"
Nov	55.3°F	24.8°F	-9°F	1.06"
Dec	45.6°F	18.9°F	-16°F	1.87"

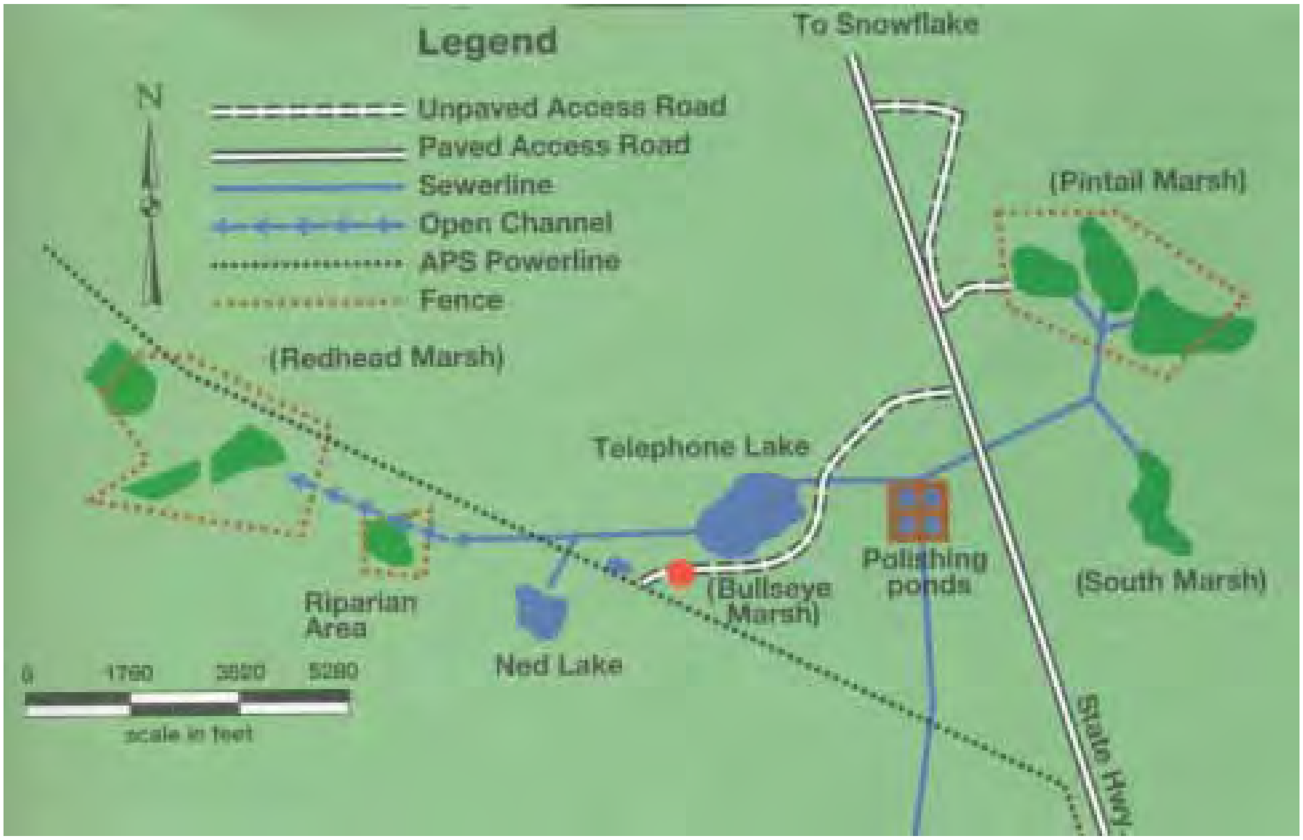
The climate has a dominant influence on the functions of the created wetlands. This area has four definite seasons. Spring is very windy with gusts over 50 mph. This can cause severe bank erosion if vegetation isn't established. Net evaporation can exceed 12 inches per month in May and June. Summer is characterized by the onset of a monsoon type pattern with frequent showers and high night time temperatures. Fall is ushered in as the rainfall diminishes and nights get colder. Winter is marked by colder temperatures and the wetlands freeze over. Ice may occur 1 to 2 months of winter. Snow depths of 3 to 12 inches are common.

Water control structure at Redhead Marsh.

The soils of this area are heavy clays with low water permeability. The natural vegetation is typical pinyon-juniper woodland. This is a very common vegetation type in this area. The topography is flat to moderately sloping with some natural basins which form Pintail and Telephone Lakes. The elevation above sea level is 6,350 to 6,380 ft.

Evaporation from wetland surfaces is a key factor affecting their functions. Total evaporation exceeds precipitation by 48 inches per year. The evaporative loss is greatest during the months of May and June which account for one half of the year's total. During winter months evaporation is near zero, so ponds fill up and total storage capacity becomes a concern.

Design and Layout



Since the construction of the first wetland at Pintail Lake in 1978, there has been a gradual evolution of the wetlands. In 1985 a major expansion occurred with the construction of Redhead Marsh. This surge of construction was required as effluent volumes produced began exceeding treatment and disposal capacities. The present system is designed to handle 1.42 million gallons of wastewater per day to serve a population of 13,500.

Size of Wetlands

Telephone Lake..........45 acres

Pintail Lake.................57 acres

South Marsh...............19 acres

Redhead Marsh..........49 acres

Bullseye Marsh.............1 acre

Ned Lake...................15 acres

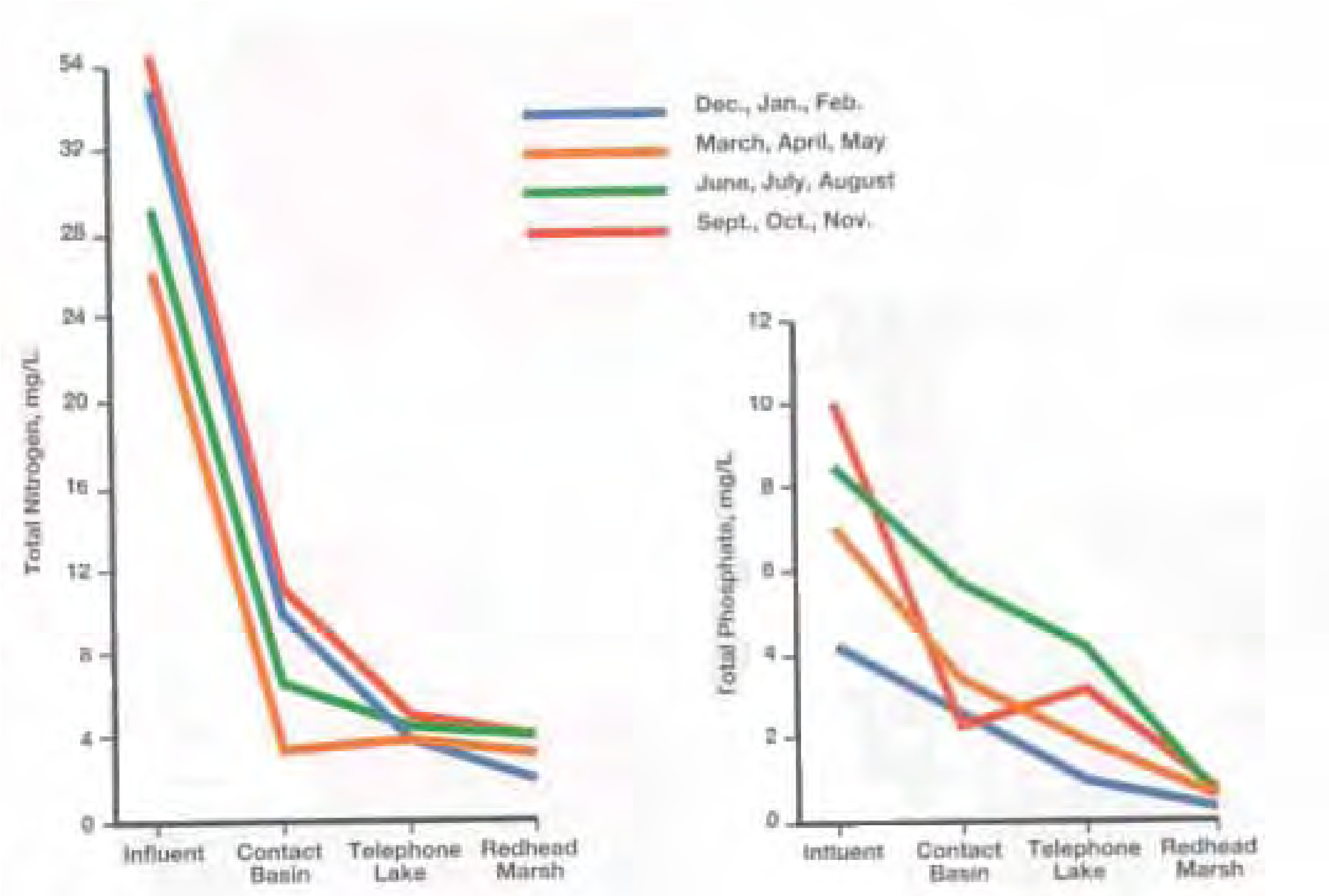
Riparian Area..............15 acres

Total Acres = 201 acres

The system was designed to integrate several lakes and marshes into an effective wetlands complex. Flexibility in management options was built in to accommodate changes from year to year. The water delivery system was designed to provide additional treatment before the effluent reaches Redhead Marsh.

Operation and Monitoring

The



main techniques used in operating the wetland complex involve the management of the water. The quantity, quality, and delivery routes are varied to manage the wetland habitat. The flexibility designed into the system allows a variety of management options. For example, water control structures with adjustable water boards are used to hold water levels at desired levels. Water can be diverted away from some ponds to allow them to dry up. This is desired to allow for maintenance and to accomplish vegetation management goals.

Monitoring of the wetlands is conducted in accordance with the requirements of the Arizona Department of Environmental Quality by the City of Show Low. Additional monitoring is conducted by the Arizona Game and Fish Department and the U.S. Forest Service.

As water progresses through the system, water quality improves. For example, secondary effluent coming from the polishing ponds flows into Telephone Lake, then into an open channel which delivers it to the riparian area. After the riparian area, the water flows into another open channel and is finally delivered to pond one of the Redhead Marsh. During this delivery process the water quality greatly improves. The following charts show the removal rates for nitrogen and phosphorus as water moves through the system.

Response

Pintail Lake and Redhead Marshes have exceeded the original objectives and expectations. What started out as a project to favor waterfowl has developed into a complex of wetland ecosystems with a wide range of benefits. Similar projects in other areas have been developed as a result of the success here.

Vegetation

Experience has shown that the addition of water to these previously arid sites brings on dramatic vegetation changes. A prime objective has been the establishment of a vigorous vegetative cover. Cattail, water grass, spike rush, and various sedges have become established naturally in the created wetlands while others such as hardstem, softstem, and alkali bulrushes and sego pondweed have been successfully planted.

Animal

The response of animals to the new wetlands has been exciting. After 3 years of data collection on Pintail Lake, L. Piest (1981) stated: “The response of breeding waterfowl has been dramatic. I estimated that 1,544 ducklings or 76.4 ducklings per hectare (30.93 per acre), were produced in 1981.” The response of other birds has been similar with the establishment of cormorant and black-crowned night heron rookeries in the new wetlands.

To date ten bird species which are classified as endangered, threatened, or sensitive have been seen using the wetlands. These include the bald eagle, peregrine falcon, osprey, northern goshawk, snowy egret, belted kingfisher, American avocet, sora rail, black-crowned night heron, and the double-crested cormorant. Four of these species (the avocet, sora rail, blackcrowned night heron, and cormorant) have been found nesting here. A survey done in 1991 to document total bird use on a weekly basis found 120 different species of birds using the created wetlands. Some of the birds are predators, feeding on fathead minnows, a small fish that inhabits part of this wetland system. Other animals found in the wetlands include rocky mountain elk, mule deer, pronghorn, black bear, coyote, raccoon, and various kinds of amphibians.

Shorebirds using Telephone Lake.

People are also attracted to these wetlands for a variety of reasons— to relax and watch animals is probably the intent of most people. Facilities were provided to improve wildlife viewing at Pintail Lake. School groups often use these wetlands for environmental field trips. The concepts of wastewater cleanup and recycling have more meaning after experiencing the created wetlands.

Acknowledgements

Since the first wetland was built at Pintail Lake in 1978 to the present, the wetlands have been a cooperative effort. The "core team," which started the project and continues to make it successful today, include the City of Show Low, the Arizona Game and Fish Department, and the U.S. Forest Service.

Other groups have also played a major role. The U.S. Environmental Protection Agency has provided guidance and funding for this innovative wastewater treatment project. The Arizona Department of Environmental Quality is involved in the monitoring and operational permitting process.

The wetland project is also supported by the local communities. This includes the local schools with their field trips. The White Mountain Chapter of the Audubon Society with the field trips and work projects.

Newly established cormorant rookery.

References

L. Piest, 1981. "Evaluation of Waterfowl Habitat Improvements on the Apache/Sitgreaves National Forests, Arizona." USDA/Forest Service. 119pp.

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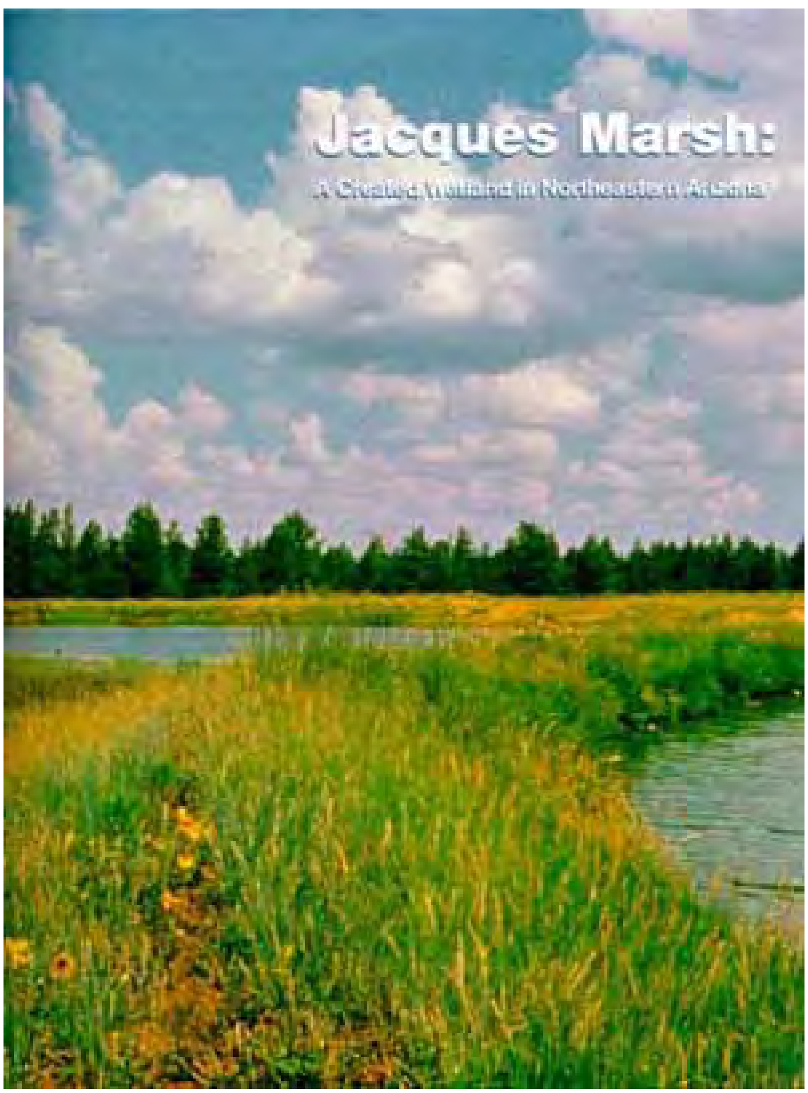
Pinetop/Lakeside, AZ - Jacques Marsh: A Created Wetland in Northeastern Arizona



History

Cooperation between public agencies and nature can have amazing result. The innovative decision to use treated municipal wastewater to create wetland wildlife habitat continues to pay off for the local community. Like a biological magnet, the new wetlands attract a wide variety of wildlife and of course people to watch them.

Jacques Marsh is a constructed wetland that is a component of the wastewater management system of the Pinetop-Lakeside Sanitary District. It is the result of a cooperative effort between the U.S. Forest Service, Arizona Game and Fish Department, and the Pinetop Lakeside Sanitary District. The manmade marsh was constructed on National Forest Service Lands in an area with no historical ponds, lakes or wetlands. However, once established the marsh closely represents a natural wetland in terms of plants and wildlife present at the site.

The surface and groundwaters of the community were considered to be contaminated in the 1970's and the Pinetop-Lakeside Sanitary District was formed in 1973 to clean up these waters. With assistance of an EPA construction grant the wastewater collection system, a 2 million gallon per day secondary treatment plant and Jacques Marsh were completed in 1980. The 127 acres of marsh and ponds currently receive about one million gallons of treated wastewater per day.

The community is proud of its decision to construct Jacques Marsh to recycle their reclaimed water rather than discharge effluent from the treatment plant into Billy Creek which runs through the area. Many worries about pollution and human contact were eliminated and a striking wildlife area was created. The use of Jacques Marsh for recreation, outdoor education, and wildlife has been well worth the effort.

Jacques Marsh 1990.

Wastewater Treatment Facility

The wastewater treatment plant operated by the Pinetop-Lakeside Sanitary District is a 2 million gallon per day activated sludge plant. Treatment consists of comminutors, hydrostatic screens and a vortex grit system followed by aeration in a 2 million gallon oxidation channel. Organic material in the wastewater is stabilized during this part of the process.

Following aeration for 24 hours in the channel, the flow is directed into two secondary clarifiers (sedimentation tanks) for separation of the organic solids from the treated wastewater. In the secondary clarifiers, solids are settled out by gravity and recycled to the oxidation channel, or removed. The effluent is drawn from the top of the secondary clarifiers, chlorinated and pumped to the Jacques Wetlands Marsh System.

The sludge that is removed is pumped to an aerobic digester. Following digestion, the sludge is dewatered (concentrated) by Somat Dewatering Screws and pumped to an Eweson Co-Composting digester to be mixed with municipal solid waste. This 12 week process reduces 20 tons of material (14 tons of municipal solid waste plus 6 tons of sludge) to around 11 tons of marketable compost. Since this co-composting facility became operational, it has utilized 100% of the sludge from the wastewater treatment plant and 80% of the residential solid waste produced by the Town of Pinetop-Lakeside.

PLSD's on-site testing lab.

Site Description

The created wetlands at Jacques Marsh are located 1 mile north of the town of Pinetop-Lakeside, Arizona. This is in the high country of northeastern Arizona. The wetlands are on National Forest Service Lands administered by the Apache/Sitgreaves National Forests.

The climate has a dominant influence on the functions of the created wetlands. This area has four definite seasons. Spring is very windy with gusts over 50 mph. This can cause severe bank erosion if vegetation isn't established. Net evaporation can exceed 7 inches per month in May and June. Summer is characterized by the onset of a monsoon type pattern with frequent showers and high humidities. Plants respond quickly to the higher night time temperatures. Fall is ushered in as the rainfall diminishes and nights get colder. The first frosts occur during the last part of September. Winter is marked by colder temperatures and the wetlands freeze over. Ice may occur for 1 to 2 months of winter. Snow depths of 6 to 16 inches are common.

The clay soils of the Jacques Marsh site are of volcanic origin. They have low permeability to water. This is a key factor in the wetland design. The natural soils were used to form the marsh basins.

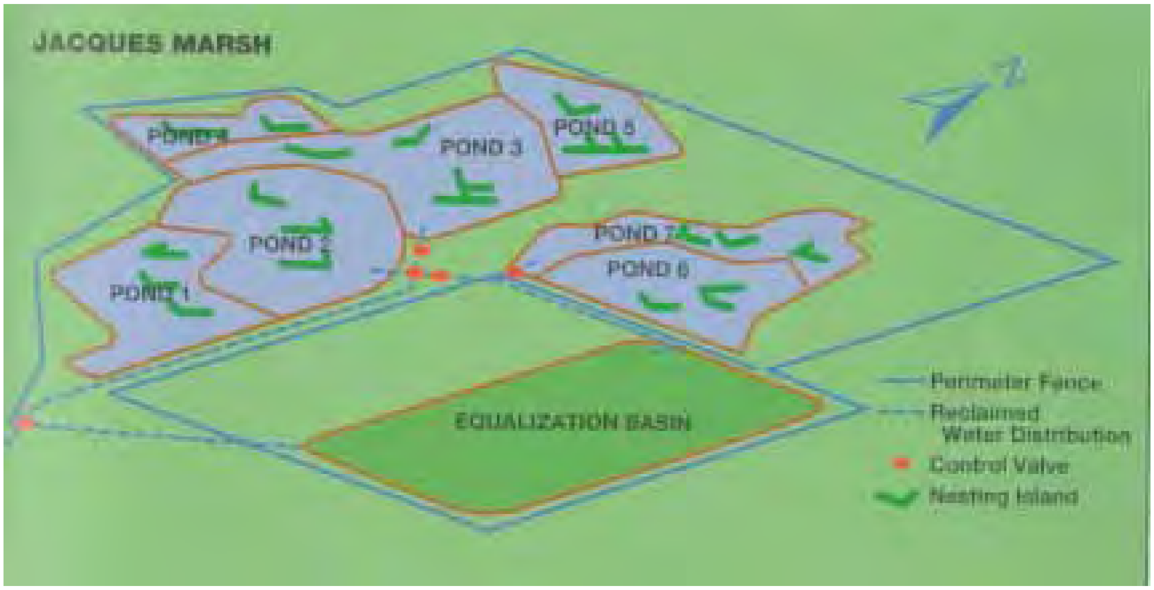
The natural vegetation of the site was ponderosa pine, Utah juniper and pinyon pine. This is a very common vegetation type in this mountain area. The animals occurring in this area include rocky mountain elk, mule deer, Merriam turkey, black bear, and coyotes. Common birds are Stellers jay, western bluebird, redshafted flicker, and raven. Waterfowl are common where water occurs. The Intermountain Biotic Province is the greatest source of waterfowl using this site.

Weather Summary

Month	Average High Temp.	Average Low Temp.	Historic Record Low	Average Precip.
Jan	44.3°F	16.0°F	-23°F	1.92"
Feb	46.1°F	18.1°F	-18°F	1.30"
Mar	50.0°F	21.7°F	-13°F	1.91"

April	59.7°F	27.9°F	0°F	.93"
May	69.0°F	33.8°F	8°F	.43"
Jun	78.1°F	40.7°F	20°F	.57"
Jul	80.5°F	49.1°F	30°F	3.13"
Aug	77.5°F	48.1°F	32°F	3.40"
Sept	74.4°F	41.6°F	21°F	1.82"
Oct	65.6°F	32.6°F	6°F	1.89"
Nov	53.6°F	23.4°F	-3°F	1.34"
Dec	46.5°F	18.2°F	-18°F	1.96"

Design and Construction



Net Evaporation

Month	Inches
Jan	+.32
Feb	-1.33
Mar	-3.75
May	-6.22
Apr	-7.62
Jun	-8.49
Jul	-4.34
Aug	-3.29
Sep	-3.74
Oct	-2.55
Nov	-1.31
Dec	+.57
Total	**-41.75**

Jacques Marsh is different than most constructed wetlands because it doesn't occupy a natural basin or drainageway. The relatively level site was selected because it has a clay soil of sufficient depth to provide material for dike construction and a low percolation rate.

Several hundred soil borings were made to map the size and thickness of the clay layer. Heavy earth moving equipment performed the necessary cut and fill to create the dikes and islands which form the physical features of the marsh.

A pipeline was installed to carry the reclaimed water which is pumped up hill from the treatment plant to the marsh. Outlets allow for water to be pumped directly into 5 of the 7 ponds. Interpond concrete structures allow water to flow from one pond into another. These structures are equipped with water boards to maintain predetermined water levels in each pond. This flexibility of managing water levels is a key factor in operating the marsh.

Pond Sizes

Pond Number	Surface Acres
1	16.36
2	21.86
3	18.56
4	4.66
5	7.70
6	10.95
7	12.08
Equalization Basin	35.0
Total	**127.17**

The "V" shaped nesting islands were designed to retard wave erosion. The points of the islands face the prevailing wind and the back sides provide back water areas for resting waterfowl. The purpose of the islands is to provide nesting sites which are safe from predators such as skunks and coyotes. The perimeter of the area was fenced to keep out domestic livestock.

Operation and Monitoring

The effluent produced by the Pinetop-Lakeside Sanitary District's treatment plant has the following characteristics:

	Range	Mo. Avg.
Biological Oxygen Demand	2-3 mg/l	2.4 mg/l
Total Suspended Solids	1-13 mg/l	6.4 mg/l
Turbidity	2.1-5.4 ntu	3.6 ntu

The treated wastewater is provided to a combination of the 7 ponds each year in accordance with the habitat management plan. Waterfowl habitat needs and plant requirements are the primary factors affecting management of the ponds and marsh.

Aerial view of treatment facility.

As water proceeds from one pond to another in the marsh, nitrogen and phosphorus are removed from the water. These nutrients are taken up by plants and animals and contribute to the overall productivity of the marsh. The following summarizes the removal rates for nitrogen and phosphorus for the months of February, March, April and May 1991:

	Total N (mg/l)	Total P (mg/l)
Effluent	20.35	7.90
Pond 1	6.23	4.10
Pond 2	5.35	4.75

In addition to monitoring surface water quality, the Pinetop-Lakeside Sanitary District samples 3 shallow wells on a quarterly basis to insure groundwater quality is not being impacted.

Response

What started out as a curiosity, putting wastewater to good use, has now become an attraction to many forms of life. Visitors are usually treated to a surprise package of sights and sounds provided by a vibrant marsh ecosystem.

In the winter bald eagles are a common sight and in the summer peregrine falcons are occasionally seen. The peak periods of waterfowl use occur during the spring and fall migration. The islands provide excellent duck nesting habitat. Elk are attracted to the marsh in the fall and winter where they consume the dry vegetation.

Of course the diversity of plants and animals attracts many human visitors. The area is popular with the viewing and hunting public. Jacques Marsh is a point of local pride. The residents of the cities of Pinetop and Lakeside have supported the project since it's inception.

A major side benefit of the created marshes has been the opportunity for interaction with the local schools. The marshes now function as outdoor classrooms where many environmental principles are taught including recycling and water cleanup. In 1989 a local group of 140 fourth graders were treated to the sight of a peregrine falcon hunting shore birds as they toured the wetland.

Elk using Jacques Marsh

Acknowledgements

Jacques Marsh is the result of many agencies and individuals working toward common goals. The U.S. Environmental Protection Agency provided much of the funding under the Clean Water Act. The Pinetop-Lakeside Sanitary District provided funding and constructed the system. The Arizona Game and Fish Department agreed to maintain the wetland after construction. The Apache/Sitgreaves National Forests provided 255 acres of land and developed the habitat. The Arizona Department of Environmental Quality provided technical guidance and operational permits for the facility.

The wetland came together as a result of dedicated effort, and a vision of the future held by several people. Adrian Hill, District Forest Ranger of the Apache/Sitgreaves National Forests, and Jack O'Neil, Game Specialist for the Arizona Game and Fish Department, worked hard at garnering their respective agencies support for the project. U.S. Forest Service Wildlife Biologists Leon Fager and James McKibben provided the technical and planning support to make the project viable. The Board of Directors of the Pinetop-Lakeside Sanitary District played a key role in obtaining the support of the local communities. This group of dedicated individuals didn't permit doubt, policy, politics, or the "but it's never been done here before" attitude to stop them. Jacques Marsh is a tribute to them and to many others who followed for the past 17 years.

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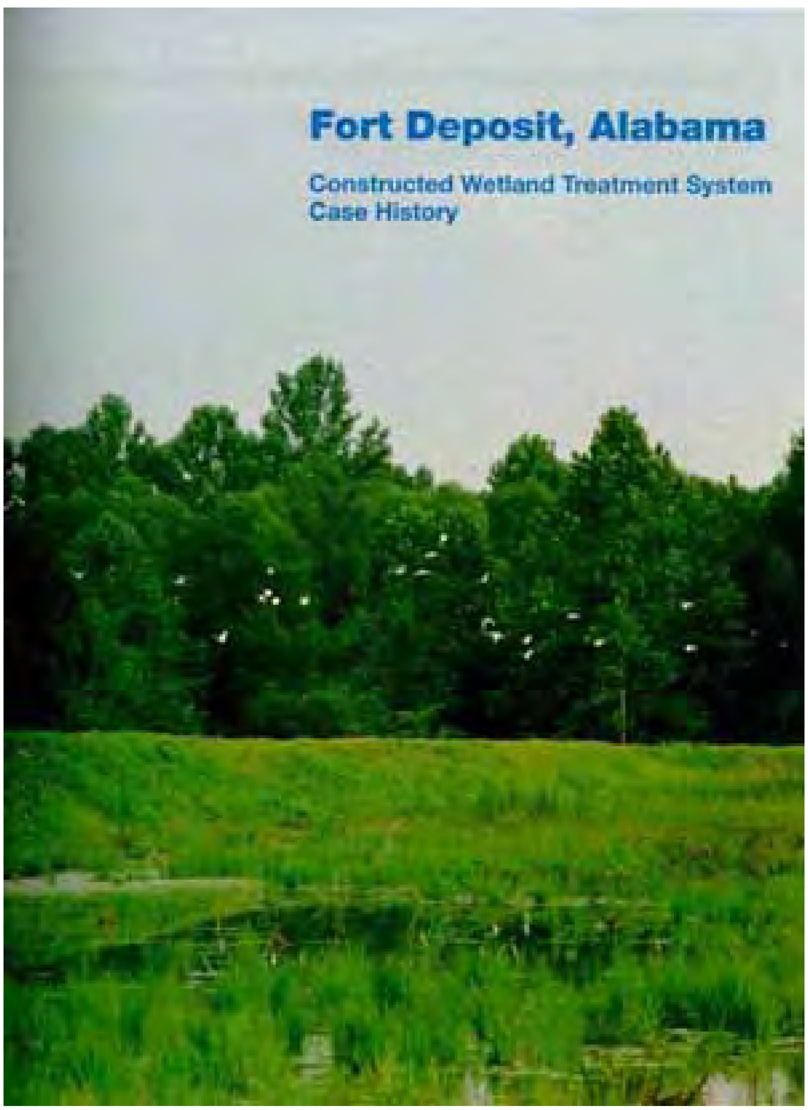
Fort Deposit, AL: Constructed Wetland Treatment System Case History



Background

Post-aeration is essential for compliance with the effluent standard for dissolved oxygen.

The town of Fort Deposit, located south of Montgomery, Alabama, has a population of slightly more than 1,500. Until 1985, the town's wastewater was treated in a 10-acre waste stabilization pond and consistently met discharge limits. In 1985, a new discharge permit was issued by the Alabama Department of Environmental Management. This permit required the town to meet more stringent standards based on water quality limitations in the receiving water. Since the town's stabilization pond was unable to meet the new standards, an administrative order requiring the town to upgrade its system was issued.

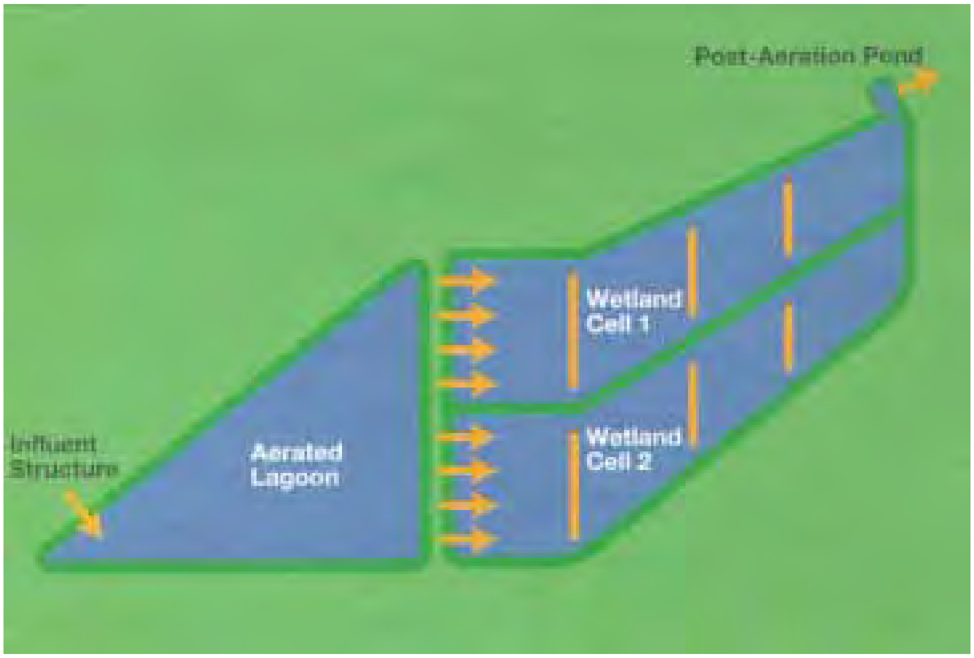
An engineering analysis of treatment alternatives was conducted by the environmental consulting firm CH2M HILL to compare a variety of conventional and innovative technologies. On the basis of an evaluation of environmental benefits, reliability, and cost, treatment by constructed wetlands was selected as the most cost-effective approach for compliance with the new permit limitations.

The use of constructed wetlands to remove impurities in wastewater and to consistently achieve treatment levels that meet permit requirements was an emerging technology in 1985. To assist with funding their new system, the town applied for and was awarded a $610,000 U.S. Environmental Protection Agency (EPA) Innovative/Alternative Technology grant for its wetland project. This additional funding, coupled with low construction and maintenance costs associated with the wetland system, reduced the financial impact of the upgrade on the community and provided it with a system that would require only slightly more maintenance than the existing stabilization pond.

System Description

As designed, the Fort Deposit wetland treatment system includes the following main components:

- An 8.9-acre aerated pond
- Two 7.5-acre constructed wetland cells
- A 0.1-acre post-aeration pond



The Fort Deposit constructed wetland treatment system uses an aerated lagoon for pretreatment followed by two parallel wetland cells.

The town's existing stabilization pond was modified to provide more effective pre-treatment. The modifications included relocating the influent and effluent points and adding floating mechanical aerators. Seven acres of the pond were aerated, leaving the remaining area to serve as a settling basin. These modifications improve 5-day biochemical oxygen demand (BOD5) and ammonia nitrogen (NH3-N) removal efficiency, reduce organic and solids loading to the wetland cells, and provide additional flexibility in the overall treatment process.

The wetland cells are configured side by side. Each cell covers 7.5 acres and has an aspect ratio (length to width) of 4.6:1. The cell floors are slightly sloped for easy draining during maintenance. Although most of the 15 acres of wetland cells are less than 2 feet deep, each cell has three "deep zones," which are 4 feet deep and about 20 feet wide. The deep zones remain free of rooted marsh vegetation, thus allowing effluent to be redistributed through the system and providing atmospheric aeration. The deeper water in these zones also furnishes year-round habitat for aquatic life, particularly mosquito fish and wetland birds.

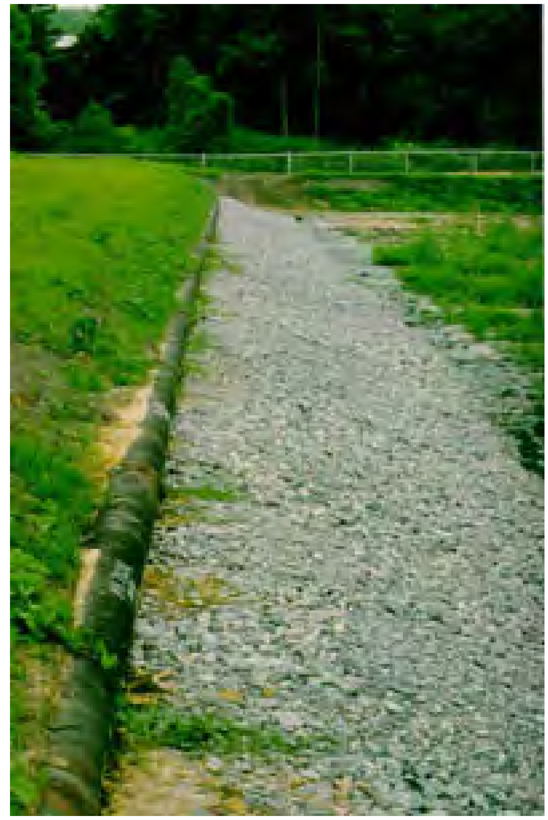
The parallel operation of the two wetland cells gives the town the ability to direct all flow through a single cell during wetland resting and maintenance periods. Moreover, the rate of flow to each cell can be varied to allow flexibility in operations and to aid in testing or research.

The treated effluent enters a post-aeration pond after passing through the wetland cells. This system component is used to meet the effluent dissolved oxygen limits specified in the permit. This 75,000-gallon earthen pond is equipped with a floating mechanical aerator. Final effluent flow rate from the post-aeration pond is continuously measured by a Parshall flume.

Operations and Management

Outlet weir structures allow water level control for adjustment of hydraulic retention time.

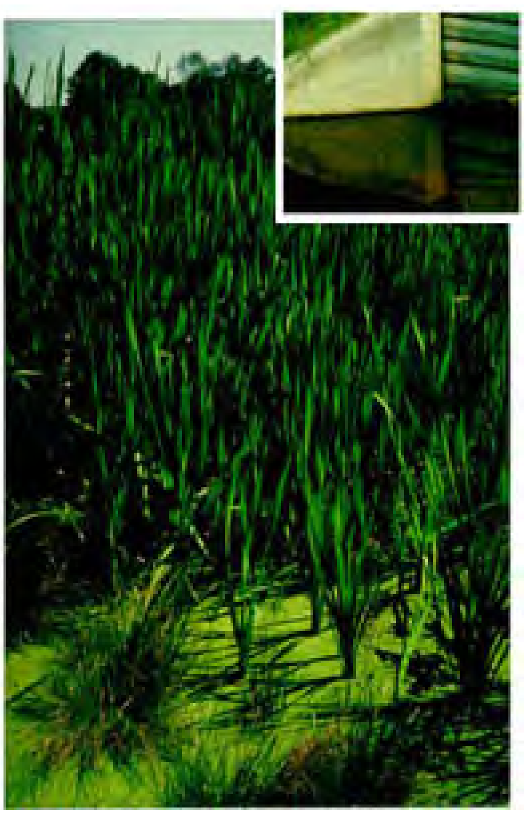
In the Fort Deposit wetland system, wastewater is treated by the naturally occurring bacteria and fungi that colonize the sediments on the bottom of the cells and the stems and leaves of the wetland vegetation below the water level. These microorganisms help transform and remove organic matter and nutrients that might otherwise degrade adjacent surface waters.



Influent distribution to the wetland cells is enhanced by perforated pipes on a rip-rap slope across the width of the wetland cells.

The vegetation in the two wetland cells was selected to simulate a natural wetland and included an initial planting of 68,000 cattail and bulrush plants.

Influent from the aerated pond is distributed to the cells by pipes with 1-inch holes drilled at 10-foot intervals.



This method of distributing influent starts the flow through the treatment system and reduces the buildup of solids at the head of the wetland cells.

The system is designed so that the effluent takes up to 30 days to flow through the wetland cells. The actual retention time varies seasonally to account for changes in the reaction rate of microorganisms in the cells. Because the microorganisms react more quickly at higher temperatures, the retention time can be decreased during the summer and still provide the required contact time for effective removal of impurities. Conversely, during the winter's colder temperatures, the reaction rate of the microorganisms is lower and the retention time is increased by raising water levels.

Aluminum stop logs, located in three outlet structures along the width of each wetland cell, control cell water depth and promote the flow of effluent through the treatment system.

Dense stands of submerged cattail stems and leaves serve as growth media for microorganisms that feed on impurities in the influent. The natural transfer of atomospheric oxygen to these microbes is essential in removing organic matter and ammonia from the wastewater.

After treatment by the wetland cells, effluent is conveyed to the post-aeration pond, where it receives supplemental aeration from a floating aerator.

Performance

Deep zones in the wetlands provide open water for ducks and wading birds, enhance flow distribution in the wetland cells, serve as a sump for settling solids, and provide additional hydraulic residence time in the wetland cells.

Construction of the cells began in June 1989, with planting starting during May 1990. By August 1990, the vegetation provided almost complete cover, and operation of the wetland cells began. Since then, with only one exception for NH3, the Fort Deposit constructed wetland treatment system has consistently achieved permit compliance and has caught the attention of others seeking a low cost, dependable natural treatment system. Because of its outstanding contribution to water resource conservation, the Fort Deposit system received several awards including the Alabama 1991 Governor's Conservation Achievement Award, the Alabama Engineering Excellence Award, and the Grand Award from the American Consulting Engineers Council.

	Month	BOD_5		TSS		Nitrogen	
		In	Out	In	Out	TKN In	NH_3 Out
1990	August	102	5	137	10	20.0	0.57
	September	27	8	101	18	11.0	0.66
	October	30	3	168	18	19.0	0.78
	November	27	3	127	10	14.0	0.93
	December	15	4	71	9	10.0	2.60
1991	January	20	5	52	10	8.0	1.10
	February	13	4	18	4	11.0	0.74
	March	26	7	40	8	19.0	0.89
	April	22	10	97	15	10.0	0.70
	May	21	9	52	20	80.0	0.35
	June	29	10	72	25	5.0	0.94
	July	33	7	69	10	21	6.43
	August	56	7	183	7	20.0	0.90
	September	24	4	87	12	10.0	0.99
	October	30	8	125	18	6.0	0.75
	November	32	4	106	7	11.0	0.21
	December	33	12	64	16	11.5	0.87
1992	January	39	4	83	19	10.0	0.38
	February	22	4	32	4	6.7	0.15
	March	34	4	58	5	10.0	0.22

April	31	4	119	3	12.0	0.51

Wetland effluent BOD5 and total suspended solids (TSS) are consistenly in compliance with permit limits despite variable inflow quality to the wetland cells. Total Kjeldahl nitrogen (TKN) is mineralized in the wetland cells to NH3 and then nitrified to achieve the low discharge limits.

Ancillary Benefits

In addition to improving the quality of the effluent discharged to the receiving stream, the creation of the Fort Deposit constructed wetland treatment system has significantly increased wildlife. This new habitat provides cover and food for various types of wetland-dependent vertebrate and invertebrate life including a variety of ducks and wading birds and their prey.

As a result of the wetland's success and the desire of others to adopt similar technology, the town is receiving visitors from other areas of the state and the nation.

The Fort Deposit wetlands continue to diversify as new plant species colonize the cells.

Fort Deposit Wetland Design Criteria

Average Daily Flow 0.24 mgd

Influent Quality	
BOD_5	40 mg/L
TSS	100 mg/L
TN	20 mg/L
NH_3-N	10 mg/L
Effluent Criteria	
BOD_5	10(18)[a] mg/L
TSS	30 mg/L
NH_3-N	2(5)[a] mg/L
pH	6-9 units
Areas	
Lagoon	10 acres
Wetland Cells (2)	7.5 acres each

( )[a] winter limits December-April

Acknowledgements

The Waterworks and Sewer Board of the Town of Fort Deposit

Henry Crenshaw, *Chairman*
Leo Goldsmith, *Board Member*
W.O. Ward, *Board Member*
David Edwards, *Manager*

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This brochure was prepared by CH2M HILL for the U.S. Environmental Protection Agency.

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West Jackson Co., MS: Constructed Wetland Treatment System Case History

Background

The West Jackson County Constructed Wetland Treatment System (CWTS) was built in two phases between 1990 and 1991 to provide additional effluent treatment and disposal capacity for the Mississippi Gulf Coast Regional Wastewater Authority's (MGCRWA) regional land treatment facility. Located north of Ocean Springs, Mississippi, the West Jackson County constructed wetlands consist of three parallel treatment systems that cover 56 acres.

The land treatment facility was originally designed to treat an annual average daily flow of 1.6 million gallons per day (mgd). Initially, this capacity was sufficient to treat the wastewater produced within the service area, which is primarily from household sources. However, following heavy rainfall events, hydraulic capacity of the land treatment facility was exceeded, and excess flow was bypassed directly into Costapia Bayou. Wetlands were constructed to increase the site's overall treatment capacity to 2.6 mgd and to eliminate this periodic bypass.

Spray irrigation is used for effluent treatment and disposal at West Jackson County during dry weather.

System Description

As designed, the West Jackson County Natural Land Treatment System includes the following main components:

- a 75-acre lagoon/storage facility
- a 380-acre land application system
- three constructed wetland treatment systems, CWTS1, CWTS2, and CWTS3, with a combined area of 56 acres
- a 0.2-acre post-aeration pond

Wastewater is conveyed to the regional land treatment facility by a pressurized force main. Initial treatment is provided as the effluent moves through the three cells of the lagoon, which remove grit and settleable solids and reduce suspended and dissolved organic materials. The effluent flows by gravity to the distribution pump station where debris is removed by two traveling screens. The effluent is then pumped to the distribution system.

The partially treated effluent is applied to crops on two sites: a 245-acre southern site, located on Mississippi Sandhill Crane National Wildlife Refuge lands, and a 170-acre northern site, located on MGCRWA-owned land. Permanent big-gun sprinklers are used to apply the effluent. Underdrains on the land treatment fields transfer excess percolate to wetland ponds on the Refuge that provide nesting habitat for the endangered sandhill cranes. These birds have also benefited from this project through their use of the spray fields as feeding habitat.

Alternatively, the effluent can be pumped to the 22-acre CWTS1 or be gravity fed to the 34-acre CWTS2 and CWTS3 sites. CWTS1 consists of two cells that operate in series. Effluent from Cell 1A flows over eight adjustable weirs into Cell 1B. From there, Cell 1B effluent flows into an open collection ditch where it flows by gravity to the post-aeration pond north of CWTS2.

CWTS2 and CWTS3 are two separate, parallel treatment trains that operate in series. CWTS2 has three cells and CWTS3 has two cells. CWTS2 and CWTS3 are directly downgradient from the lagoon; therefore, influent flows by gravity at a constant rate up to 1.0 mgd. After being measured, the influent is split between the two treatment trains by a concrete flow splitter. Approximately 65 percent of the flow goes to CWTS2, and the rest to CWTS3, resulting in a uniform loading per acre to the treatment trains even though they are different sizes.

After treatment in the three CWTS, all wetland outflows are combined in the effluent collection ditch and conveyed to the post-aeration pond, which is equipped with two floating aerators. The post-aeration pond effluent passes through a Parshall flume for flow measurement, then through the outfall pipe where it is discharged into Costapia Bayou.

Operations and Management

Constructed wetland systems can provide a high level of waste-water treatment with low operation and maintenance requirements and low energy costs. In the West Jackson County CWTS, wastewater is treated by the naturally occurring bacteria and fungi that colonize the sediments on the bottom of the cells as well as the stems and leaves of the vegetation below the water's surface. These microbes help transform and remove organic compounds and nutrients that might otherwise result in pollution of adjacent surface waters.

Cattails are the primary wetland species used for water quality treatment.

The bottoms of the CWTS cells are slightly sloped for easy draining during maintenance. Each wetland cell has three or more "deep zones," which are 5 feet deep and about 20 feet wide. The deep zones remain free of rooted marsh vegetation, allowing them to redistribute effluent through the system and provide atmospheric aeration. The deeper water in these zones furnishes year-round habitat for aquatic life, particularly mosquito fish and wetland-dependent birds such as waterfowl.

Operation of the West Jackson County CWTS is based on shallow, overland flow conditions in the first half of the wetland cells. Water depth increases to a maximum of about 1 foot at the downstream end of the cells. This operational strategy takes advantage of the fact that higher dissolved oxygen (DO) occurs in shallow, higher velocity areas of the wetland cells.

The West Jackson County CWTS was initially planted with cattail and bulrush plants. The CWTS also has been naturally colonized by 43 other wetland plant species, providing a high level of biological diversity.

Influent from the pretreatment lagoon is distributed to the wetland cells by pipes with 2-inch holes drilled at 10-foot intervals. This method of distributing influent begins the flow through the treatment system and is critical for effective use of the CWTS for water quality treatment.

The effluent flows through the cells for up to 12 days to provide a high quality effluent. To account for seasonal changes in the reaction rate of microorganisms in the cells, the retention time is varied by changing water depths. Because the microorganisms react more quickly at higher temperatures, the retention time can be decreased during the summer and still provide the required contact time for effective treatment. Conversely, during the winter's colder temperatures, the reaction rate of the microorganisms is lower; therefore, the retention time is increased by raising water levels. Deep water zones provide effective redistribution of water flows along the length of the wetland cells. Stainless steel outflow weirs control cell water depth and promote the flow of effluent through the treatment system.

After it is treated in the CWTS, effluent is conveyed to the post-aeration pond, where the flow rate and water quality are measured before final discharge.

Post-aeration is essential for consistent compliance with the dissolved oxygen permit limit of 6.0 mg/l.

Performance

West Jackson County Constructed Wetland Design Criteria

Wetland Design Flow	1.6 mgd	
Influent Quality		
BOD 5	45 mg/L	
TN	12.5 mg/L (167 lb/d)	
Effluent Criteria		
BOD5	10 (13)a mg/L	
TSS	30 mg/L	
NH3-N	2 mg/L	
pH	6-8.5 units	
DO	6 mg/L	
Fecal coliforms	2200 col/100ml	
Areas (acres)		
CWTS1	Cell A	12
	Cell B	10
CWTS2	Cell A	9.7
	Cell B	7.8
	Cell C	4.0
CWTS3	Cell A	9.2
	Cell B	3.3

a() December-April,
BOD5 = Five-day biochemical oxygen demand,
TN = Total nitrogen,
TSS = Total suspended solids,
NH3-N = Ammonia nitrogen,
DO = Dissolved oxygen

Construction of Phase I of the CWTS began in February 1990. The earthwork and planting were completed in July 1990, and startup and flows to this phase began in August 1990. Plant cover was fully established in Phase I by October 1990.

Construction of Phase II began in June 1990 and was completed about 8 months later. Influent flows to this phase began in October 1990 and planting was completed in April 1991. Plant cover was fully established in Phase II by June 1991.

Water quality measurements made since June 1991 following complete plant establishment indicate that the West Jackson County constructed wetlands will effectively reduce BOD5 and TSS concentrations to less than 8 mg/L. These reductions occur in spite of variable BOD5 and TSS inflow concentrations.

One of the key goals of the West Jackson County CWTS is ammonia nitrogen (NH3-N) reduction. Performance of the CWTS has been variable to date, with 3 out of 12 months having outflow NH3-N levels above the limit. High outflow NH3-N concentrations have been associated with either high TKN loadings (over 3 pounds per acre per day) or with high flows (over 2 mgd). Operational control of peak flows, TKN loading, and water level adjustment are currently being used to optimize this wetland system's nitrogen removal potential.

Water Quality Measurements

Month	BOD_5		TSS		Nitrogen	
	In	Out	In	Out	TN In	NH_3 Out

1991	June	28	9	40	15	7.3	1.2
	July	13	5	41	15	4.4	1.3
	August	23	4	49	10	15.2	1.0
	September	19	2.5	35	5	17.7	2.3
	October	27	4	35	4.5	14.5	3.5
	November	46	3	36	4	13.5	3.9
	December	39	4	29	7	6.9	1.3
1992	January	23	4	17	8	11.0	1.4
	February	19	5	12	4	14.5	1.6
	March	19	5	16	5	15.4	1.7
	April	28	4	18	4	12.2	1.2
	May	24	4.5	31	6.5	6.9	0.05

BOD5 outflow concentrations have remained below 5 mg/L since vegetation colonization was completed in June 1991. TSS outflow concentrations have settled to less than 8 mg/L since September 1991. NH3 outflow concentration is dependent on the mass loading of TN and has remained below 2 mg/L as long as TN loading is less than 167 lb/d (3 lb/ac/d).

Ancillary Benefits

In addition to improving the quality of the effluent discharged to the receiving stream, the creation of the West Jackson County CWTS has resulted in significant wildlife benefits. This new wetland habitat provides food and cover for various types of wetland dependent vertebrate and invertebrate life. The aquatic invertebrate populations throughout the wetlands provide food for fish and birds.

The 45 wetland plant species identified to date, combined with open water zones and shallow edge areas, have resulted in a diversity of wildlife habitats and high populations of wild-life species. Sixty-two bird species were identified in or around the wetlands during 1991. About 37 of these species are considered to be wetland-dependent. Bird populations during the winter, spring, and fall seasons are dominated by ducks, sora rails, swamp sparrows, and wading birds. Summer bird population studies indicate the presence of at least 7 nesting bird species and a total of 30 species in and around the wetlands.

Winter bird populations include ducks, rails, sparrows, coots, herons, egrets, and many other wetland species.

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Region IV

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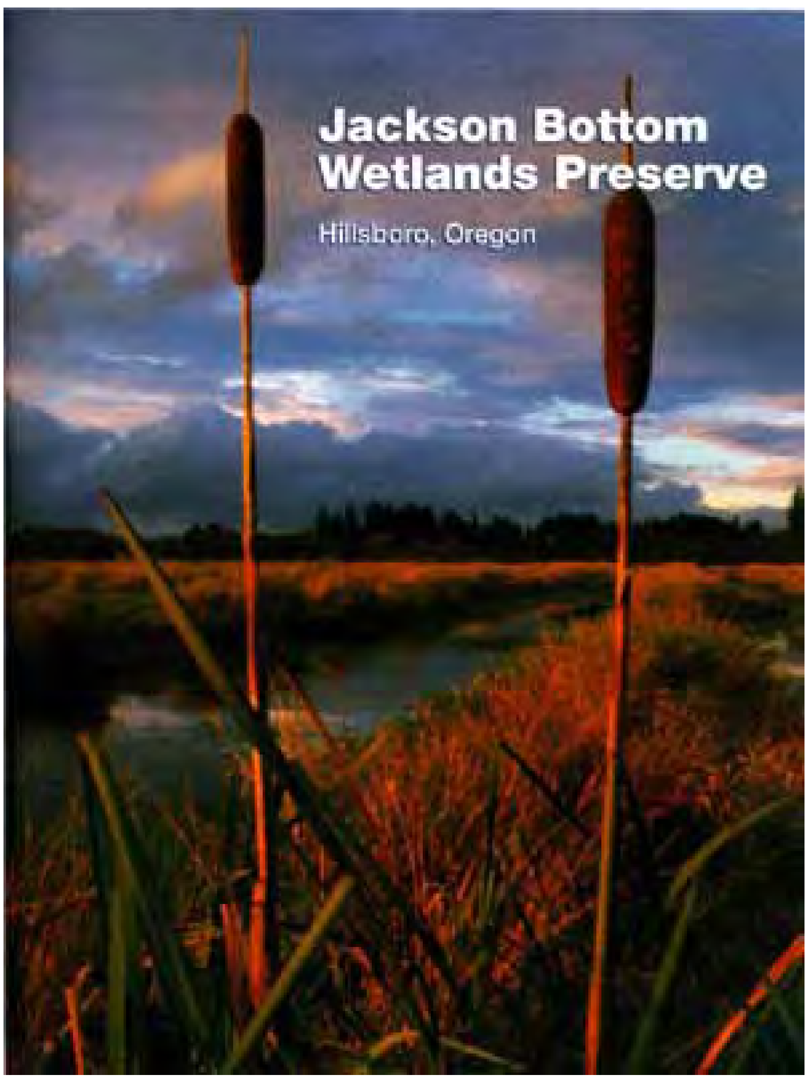
Hillsboro, OR - Jackson Bottom Wetlands Preserve



Working together for water quality, wildlife habitat, education and passive recreation.

At the south edge of Hillsboro, Oregon, lies the damp, tranquil sanctuary of the Jackson Bottom Wetlands Preserve. Nearly 650 acres of low-lying floodplain on the edge of the Tualatin River, about 80 percent of the area is classified as wetlands.

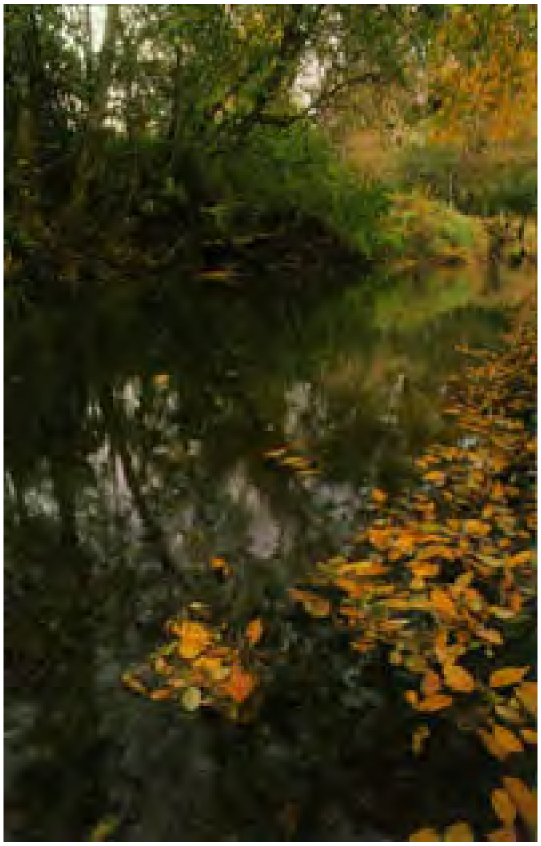
Early mapmakers dismissed the damp bottomlands as a “mirey swamp” suitable only for dredging, draining, and farming. Over the years, agricultural and sewage disposal practices created a highly degraded landscape of limited value for wildlife use, dominated by introduced grasses.

Since 1979, the Jackson Bottom Steering Committee has been working together on an innovative project aimed at changing those conditions and transforming this "mirey swamp" into a wildlife and water quality "living laboratory." The Steering Committee, made up of a unique alliance of economic interests, environmental groups and public agencies, spent the first 10 years on efforts directed primarily toward improving the area's wildlife habitat and passive recreation values.

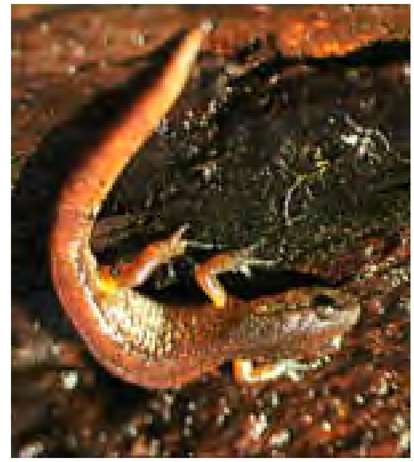
In 1989, the coalition broadened its efforts and began investigating the use of natural and constructed wetland systems for water quality management as part of the Unified Sewerage Agency's effort to improve water quality in the Tualatin River.

At the Jackson Bottom Wetlands, the Steering Committee has a unique opportunity to manage the wetland's multiple goals. Jackson Bottom provides a chance to increase the diversity of resident and transient wildlife, improve water quality, provide rich research and educational experiences, offer passive and non-consumptive forms of recreation, and attract tourists in an area of rapidly expanding urban population.

The 1989 Jackson Bottom Concept Master Plan clearly outlined the main goals of the Jackson Bottom Wetlands Preserve.



Enhancement for Wildlife: Attract a more diverse wildlife population by expanding and restoring the preserve to provide food and shelter to a variety of birds and animals.



Water Quality Management: Develop the Jackson Bottom Experimental Wetland to investigate the feasibility of using wetlands to "polish" effluent from a secondary wastewater treatment plant for the removal of phosphorus and nitrogen before discharging to the water quality-limited Tualatin River.

Passive Recreation: Provide access to areas of the wetland and the Tualatin River for hiking, bird watching, angling and other passive natural resource-associated activities.

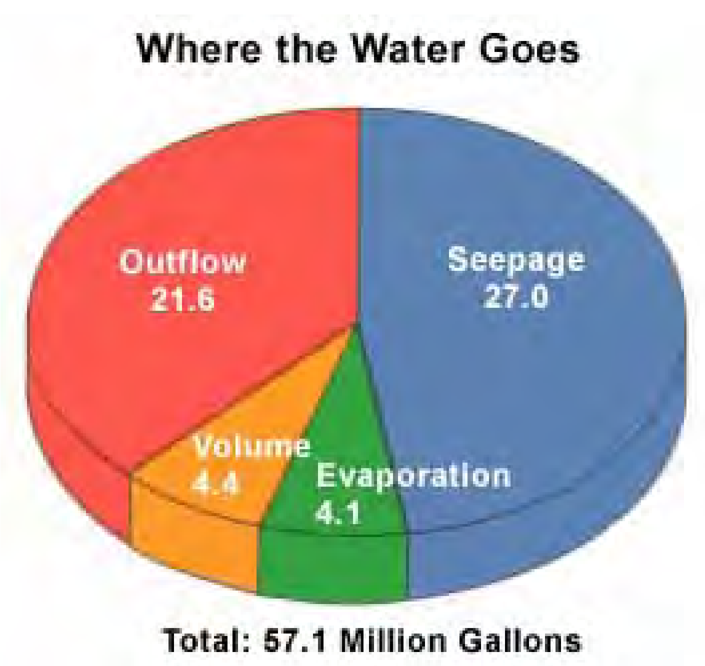
Education and Research: Encourage educational use through interpretive signs and displays, development of educational materials for schools and groups, providing site tours and assisting researchers with research projects.

The Jackson Bottom Steering Committee

- City of Hillsboro
- Unified Sewerage Agency (USA)
- Oregon Department of Fish and Wildlife
- Greater Hillsboro Chamber of Commerce
- Washington County Soil and Water Conservation District
- Portland Audubon Society
- Friends of Jackson Bottom
- Oregon Graduate Institute
- Washington County Education Service District
- The Wetlands Conservancy
- Portland Bureau of Environmental Services
- Pacific University
- U.S. Fish and Wildlife Service

Wetlands Water Source

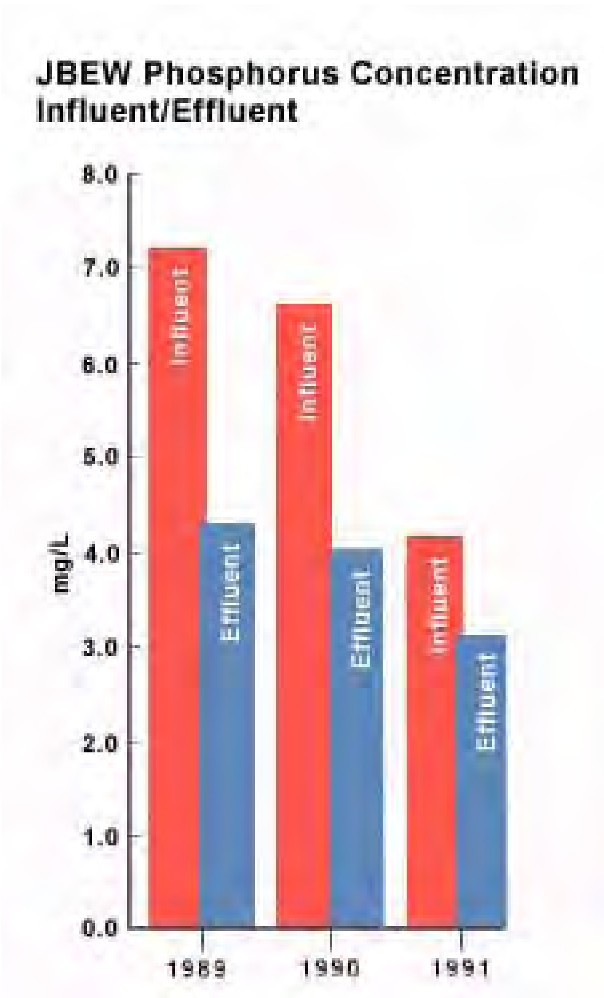
Historically, the damp landscape of Jackson Bottom owes its source of water to the regular flooding of the Tualatin River. The flooding creates the bottomland wetlands which make up the majority of Jackson Bottom.

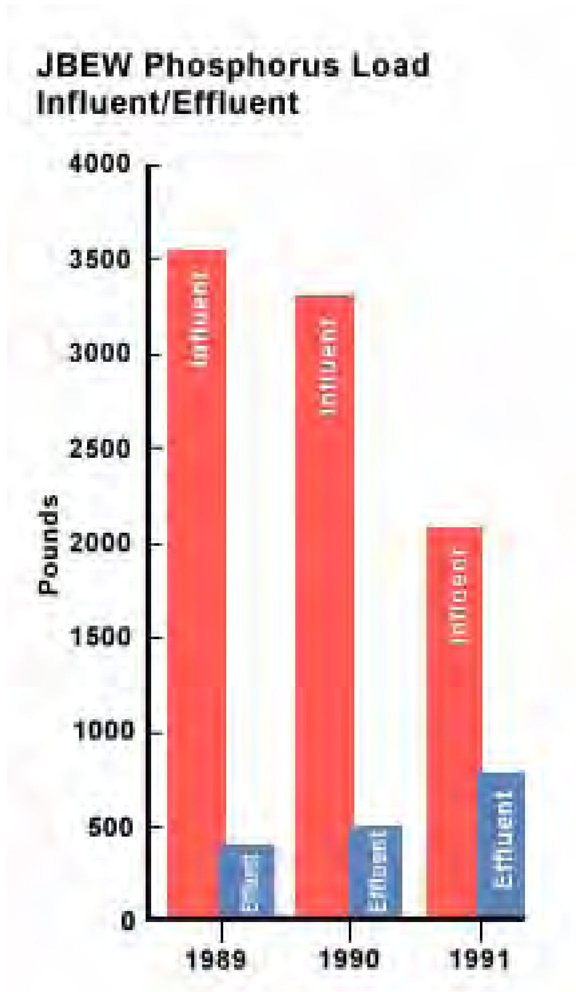


Today, water from regular winter flood is supplemented in the summer by secondarily treated effluent from a nearby Unified Sewerage Agency treatment plant. This cleaned wastewater helps to maintain the restored wildlife habitat. In return, the wetlands filter the effluent before it's returned to the river.

Since 1979, enhancement projects have created and restored several types of wetlands once typical in the basin. The additional wetland types include deep and shallow ponds, wet meadows, riparian wetlands and fresh-water marshes. Edging the east side are also forested wetlands and upland habitat.

Putting the Polish on Wetlands for Water Quality Management





Wetlands, ponds and lagoons have long played a role in wastewater treatment. In many areas, partially treated wastewater is filtered through wetlands for suspended solids (SS) and biochemical oxygen demand (BOD) removal.

The Jackson Bottom Experimental Wetland (JBEW) is taking this process one step further. Using secondarily treated effluent from the Unified Sewerage Agency's (USA) Hillsboro Wastewater Treatment Plant, USA's researchers are investigating the use of wetlands to “polish” the wastewater for removal of phosphorus and nitrogen. These nutrients are abundant in the effluent of conventional secondary treatment plants. This experimental program is part of USA“s comprehensive effort to reduce loads of phosphorus and nitrogen entering the water quality-limited Tualatin River.

Built in the summer of 1988 with operation beginning in 1989, the JBEW occupies about 15 acres on the eastern edge of the Jackson Bottom Wetlands Preserve. The Experimental Wetland is actually a series of 17 parallel cells, each built to contain effluent for varying amounts of time, with different soil types and different vegetation patterns. Since July 1989, testing has been conducted to measure the success rates of the soils and vegetation to "polish" the effluent.

Jackson Bottom Experimental Wetland Design and Operational Criteria

Cell Design Criteria; 15.6 Acre Wetland (17 Parallel Cells)

Cell	Size, Capacity	Total
Width	18.3 to 22.4 ft	
Length	1250 to 1280 ft	
Depth	46 percent at 1 ft 54 percent at 3 ft.	
Surface Area	22,000 to 30,600 sq. ft 0.5 to 0.7 acres	430,600 sq. ft 9.9 acres
Water Level	0.5 to 2.75 ft	
Volume	254,000 to 427,000 gal	4.8 mil gal.
Introduced	Cattail *(Typha latifolia)*	
Vegetation	Sago pondweed *(Potamogeton pectinatus)*	
Soil		
Cove Series	5.4 acres	
Wapato silty loam	6.2 acres	
Labish mucky clay	3.4 acres	

JBEW Operational Parameters

	1989	1990	1991
Days	77	108	118

Operational Period		July 25-Oct 17	June 25-Oct 10	June 19-Oct 10
Hydraulic Loading Rate	cm/d	7.0	4.0	5.5
	in/d	2.8	1.6	2.6
Average Flow/cell	gpm	30	19	24
Detention Time	days	5-10	5-27	4-12
Mass Loading Rates				
Phosphorus	kg/ha/da	5.2	3.4	2.4
	lb/ac/da	4.6	3.0	2.1
Nitrogen	kg/ha/da	14.9	7.7	11.0
	lb/ac/da	13.2	6.9	9.8

After three years of testing and extended research on JBEW, interesting results have surfaced . The Experimental Wetland is improving the quality of the effluent—it is lower in both phosphorus and nitrogen when it leaves the cells. Research has shown, although plants serve important functions in the filtering, the soils have proved to be the main elements in binding up the phosphorus, thereby preventing it from reaching the nearby Tualatin River.

Water quality is the focus of the JBEW, but education and wildlife have also benefited from this innovative project. The construction of the wetlands has provided food, nesting and rich habitat for many wetland species. The Experimental Wetland has also provided valuable educational opportunities for teachers, students and researchers from schools and universities throughout the region.

As research continues to determine how to best meet the state's water quality standards, the Jackson Bottom Wetlands Preserve serves as a model for improving water quality and managing multiple goals.

JBEW Outflow Data, Three Year Average

	Influent	**Effluent**
Biochemical Oxygen Demand (mg/L)	5.1	3.0
Chemical Oxygen Demand (mg/L)	42	47
Alkalinity (mg/L)	86	126
Total Solids (mg/L)	312	326
Total Dissolved Solids (mg/L)	304	316

Total Suspended Solids (mg/L)	7.7	9.6
Ammonia-N (mg/L)	8.4	3.0
Total Kjeldahl Nitrogen-N (mg/L)	11.9	4.8
Nitrate/Nitrite-N (mg/L)	7.3	0.5
Total Phosphorus	6.3	3.8
Soluble Ortho Phosphorus-N (mg/L)	5.0	3.0
Chloride (mg/L)	59	66
Enterococcus (#/100 ml)	3	75
Chlorophyll a (ug/L)	0.9	28.7

Groundwater Monitoring Data

Shallow Wells Within JBEW

	Drinking Water Std	1989	1990	1991
Nitrate/Nitrite (mg/L)	10	0.39	0.04	0.02
Chloride (mg/L)	250	102	63	49
pH	6.0-9.0	7.2	6.4	6.6

The Dynamics of a Real-World Experiment

Gathering data from a dynamic, real-world experiment presents challenges. Variables that can easily be controlled in a lab, may be unpredictable in a dynamic process.

JBEW researchers have worked to carefully control the variables within their reach, yet remain flexible enough to adjust for changes in a dynamic system. Among the impacts that have affected the JBEW are:

- **Non-native vegetation.** Planted vegetation (cattails, sago pondweed) struggled to compete with the non-native plants (reed canary grass, Lemna, Azola) that dominate much of Jackson Bottom.
- **Phosphate detergent ban.**In 1991, a region-wide phosphate detergent ban dramatically reduced the concentration of phosphorus in USA's effluent. As a result, the amount of phosphorus entering JBEW dropped as did the percent removal.
- **Plant operations.** In 1991, the Hillsboro Treatment Plant was no longer able to operate in nitrification mode due to a 25 percent increase in service area. This resulted in higher ammonia and lower nitrate effluent entering JBEW.

Enhancement for Wildlife

Jackson Bottom is part of a larger Tualatin River wildlife/wetland corridor. This rich corridor provides essential stop-over feeding and resting spots for migrating waterfowl traveling the Pacific Flyway. It is also an important habitat for other species of wildlife. Much of this habitat has been lost to agriculture and development. But with projects like the Jackson Bottom Wetlands Preserve, crucial links in this increasingly fragmented ecosystem are being reconnected, enhanced and protected.

Though degraded by past human practices, Jackson Bottom is coming alive with a newly developed diversity thanks to the dedicated efforts of Oregon Department of Fish and Wildlife, the Friends of Jackson Bottom, Ducks Unlimited and other groups. What was once a flat meadow of exotic reed canary grass, with little feeding or nesting opportunities for native species of wildlife, is now being transformed into a complex patchwork of wetlands and upland habitat. The wildlife ponds and marshes created using recycled wastewater are bordered by cattails, reeds and rushes, native willows, dogwood, ash and elderberry. This increased diversity of plants provides food and shelter for migratory waterfowl, shorebirds and other wetland wildlife. Resident populations now include Canada geese, many species of ducks, rails, herons, osprey, bald eagles, nesting red tailed hawks, harriers, and several owl species. Larger mammals include rare sightings of deer, elk, mink, beaver, coyote and fox.

Until the habitat has sufficiently recovered, nesting sites are supplemented with floating goose platforms and boxes for swallows, bats, wood ducks and kestrels. The enhancement projects offer the opportunity to become involved with wildlife agencies and provide rich habitat for wildlife.

Education, Research and Passive Recreation

From early morning walks in the thick morning fog to sophisticated research by soil scientists, there are many opportunities to enjoy and learn from this natural resource without harming it.

Research, education and passive recreation activities are a major component of the 1989 Jackson Bottom Concept Master Plan. Research efforts conducted by the Unified Sewerage Agency, the Oregon Graduate Institute and other regional colleges and universities are providing answers and posing new questions about ecosystems and their role in water quality management.

Education is a top priority, too. Spearheaded by the Wetland Coordinator and Friends of Jackson Bottom, students and teachers are learning about this astonishing natural system through tours and field work. The Friends group has developed wetlands curriculum and sponsors a variety of events year-round. In 1992, a state grant enabled Jackson Bottom to hire a part-time Wetlands Educator to coordinate a pilot educational program.

Trails, viewsites and viewing shelters offer visitors a glimpse into the workings of this rich ecosystem. The Kingfisher Marsh Interpretive Trail, designed and built by the Friends group, offers visitors a mile long walk through wetland and upland habitat along the rarely seen Tualatin River. Future plans call for more trails and improved river access.

For information on the Jackson Bottom Wetlands Preserve and the Jackson Bottom Experimental Wetlands, please contact:

Jackson Bottom
Wetlands Coordinator
City of Hillsboro
123West Main Street
Hillsboro, OR 97123
(503) 681-6206

Unified Sewerage
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155 North First Street
Hillsboro, OR 97124
(503) 648-8621

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Nest photo on page 156 and family photo on page 161 courtesy of Friends of Jackson Bottom. The salamander photo on page 157 courtesy of Audubon Society of Portland, Oregon.

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Des Plaines River, IL - The Des Plains River Wetlands Project: Wetlands for River Water Quality Improvement

System Description

Wetlands EW3 and EW4 are encircled by access roads, and bordered by US Highway 41 (bottom) and Wadsworth Road (left). Flow enters EW3 from the left, and enters EW4 from the bottom. Both discharge to a swale (top right), which is connected to the Des Plaines River. On this aerial infrared photo, water is black and cattails are dark red.

The Des Plaines River Wetlands Demonstration Project is designed to produce the criteria necessary for rebuilding our river systems through the use of wetlands and for developing management programs for the continued operation of the new structures. The research program is assessing wetland functions through large-scale experimentation, controlled manipulation of flow rates and water depths, testing of soil conditions, and the employment of a wide variety of native plant communities.

Four wetlands have been constructed near Wadsworth, Illinois, for purposes of river water quality improvement. The river drains an agricultural and urban watershed, and carries a non-point source contaminant load of sediment, nutrients and agricultural chemicals. The site is located 35 miles north of Chicago. It incorporates 2.8 miles of the upper Des Plaines River and 450 acres of riparian land. The river flows south, draining 200 square miles in southern Wisconsin and northeastern Illinois. Eighty percent of the watershed is agricultural and 20 percent urban. The river is polluted with non-point source contaminants from a variety of land use activities, and point source contaminants from small domestic treatment plants. In support of previous agricultural uses, low-lying portions of the site were drained by means of tiles. Past uses of the site included pasture and a Christmas tree farm which resulted in the demise of most of the original wetlands and associated fauna and flora.

Water is pumped from the river to the wetlands, from a point just south of Wadsworth Road. This energy intensive alternative was necessary because of site constraints, and because of the desire to explore a wide range of hydraulic conditions. Gravity diversion would be a preferred alternative in most applications of this technology. Water leaving the wetlands returns to the river via grassy swales.

Hydrology

The river is a "good old muddy midwestern stream." Shown here at average flow, it regularly floods a large amount of bottom land. In the summer of 1988, a severe drought caused it to dry to a disconnected string of pools.

The Des Plaines River enters the site from the north, passing under the Wadsworth Road bridge. It is relatively wide and shallow under normal flow conditions—100 feet wide and about 2 feet deep. This reach exhibits channel stability, primarily because of the low energy state of the river. Stream velocities average less than 1 foot per second. The gradient is 1.2 feet per mile.

About 15% of the variable stream flow is pumped to the wetlands, and allowed to return from the wetlands to the river through control structures followed by vegetated channels. Native wetland plants have been established, ranging from cattail, bulrushes, water lilies, and arrowhead to duckweed and algae. Pumping began in the 1989, and has continued during the ensuing spring, summer and fall periods. The experimental design provides for different hydraulic loading rates, ranging from 2 to 24 inches per week. Intensive wetland research began in late summer 1989, and continues to present.

The hydrology of the wetland complex has been studied extensively. Groundwater investigations showed a relatively complex local flow pattern, with some groundwater interactions with the river. Wetland EW5 leaks to groundwater, as does wetland EW5 to a minor extent. For WY 1990 (October 1989-September 1990), precipitation and evapotranspiration were equal.

Pumping occurred for all weeks in 1990, but was discontinued in winter in subsequent years. The pump is run on weekdays, for a prescheduled period. In WY 1990, it was run 10.5% of the time. Outflow from the wetlands is controlled by weirs. Thus the hydrologic regime is cyclic, with increasing water levels and flows during the few daily hours of pumping, followed by a lowering of water levels and a slowing of flows during the off hours.

Pumping creates a fountain effect at the inlet to each wetland.

WY1990 (cm/day)

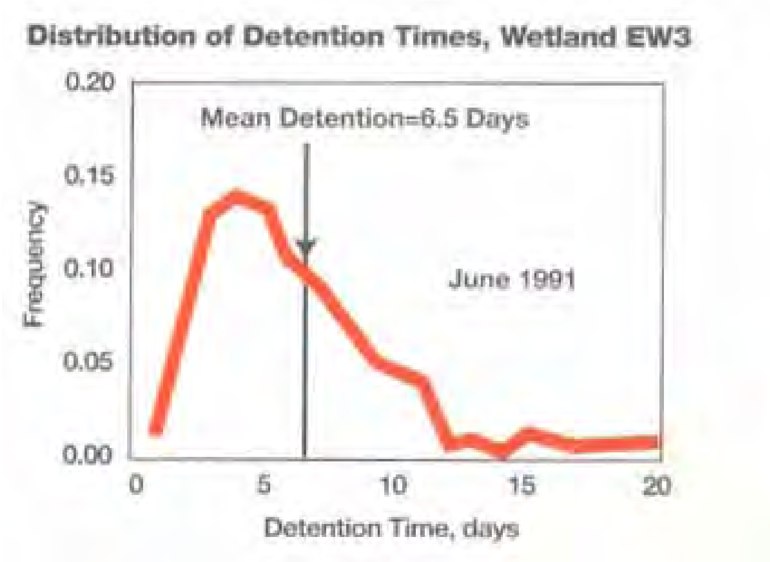
	EW3	EW4	EW5	EW6
Inflows				
Surface Inflow	5.36	1.46	5.01	2.78

Precipitation	0.26	0.26	0.26	0.26
Outflows				
Discharge	5.36	1.46	4.80	0.35
Evapotranspiration	0.26	0.26	0.26	0.26
Seepage	0.00	0.00	0.21	2.43

River enters the site from the north, passing under the Wadsworth Road bridge. It is relatively wide and shallow under normal flow conditions 100 feet wide and about 2 feet deep. This reach exhibits channel stability, primarily because of the low energy state of the river. Stream velocities average less than 1 foot per second. The gradient is 1.2 feet per mile.

System Performance

The wetland internal flow patterns are not ideal in any sense of the word. The nominal detention times in the wetlands range from one to three weeks under moderate to high flow conditions. Some of the pumped water moves quickly toward the outlet, and reaches it in about one days time. Other portions of the pumped water are trapped in the litter and floc near the wetland bottom. Still other portions are slowed by plant clumps, or blown off course by the wind. The net effect is that some water takes three times as long as the average to find its way out of the wetland.

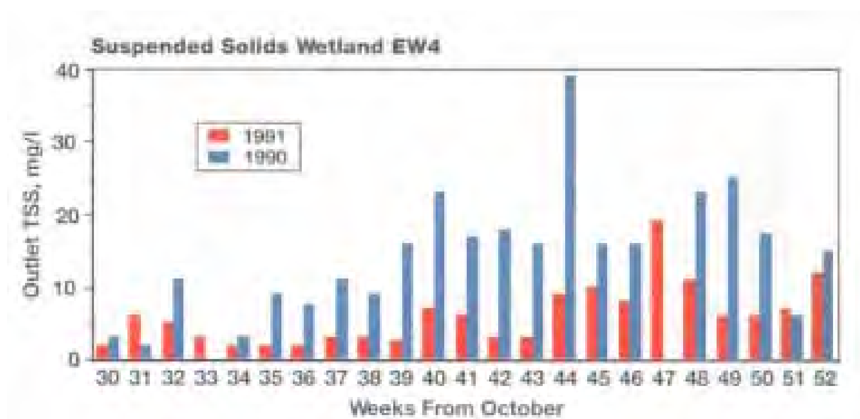


Tracer studies have been run at Des Plaines, using lithium chloride as the tracer material. A sudden dump of dissolved lithium is made into the wetland inflow. The outflow is then analyzed for the lithium, which appears at varying concentrations and at various times after the dump. These tests have established that the degree of mixing within the wetlands is higher than expected. But surprisingly, there is not a great deal of difference between wetlands, even though they differ in shape.

Suspended Solids In and Out of the Des Plaines Wetlands (mg/l)

	Inlet	EW3	EW4	EW5	EW6
FA89	8.0	2.0	2.4	2.6	3.0
WI89	7.1	5.0	3.6	4.2	3.0
SP90	24.2	5.5	4.5	2.9	3.3
SU90	47.7	5.7	14.9	4.3	13.9
FA90	50.1	10.8	7.4	5.4	4.4
SP91	63.9	5.8	7.4	2.4	6.2
SU91	123	6.0	6.8	3.2	7.8
FA91	66.0	10.8	6.7	25.8	NF
AVG	**48.8**	**6.5**	**6.7**	**4.9**	**6.1**
% Removal		**87%**	**86%**	**90%**	**87%**

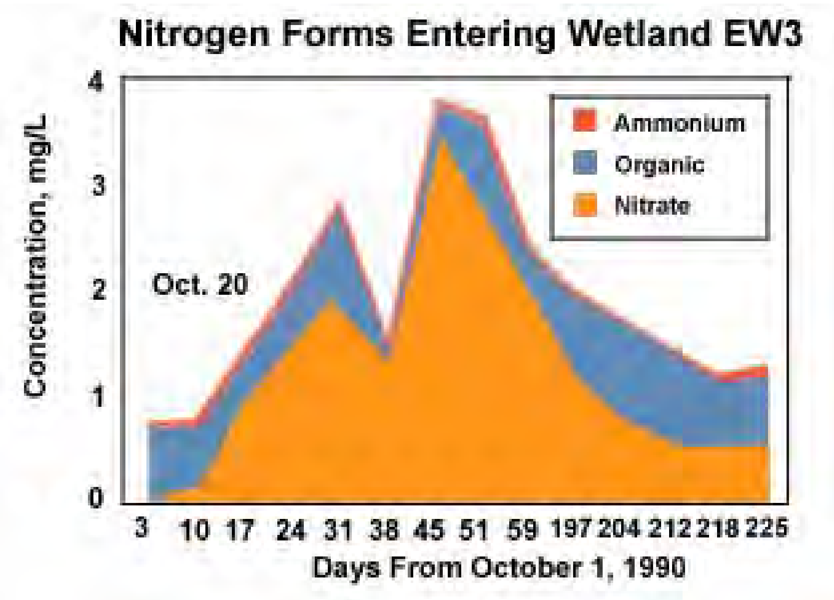
The primary water quality problem of the river is associated with turbidity. With a mean concentration of 59 parts per million, over 5,000 tons of suspended solids enter the site per year via the Des Plaines River and Mill Creek. Seventy-five percent of these solids are inorganic and 95 percent are less than 63 microns in size. Sediment removal efficiencies ranged from 86-100% for the four cells during summer, and from 38-95% during winter.

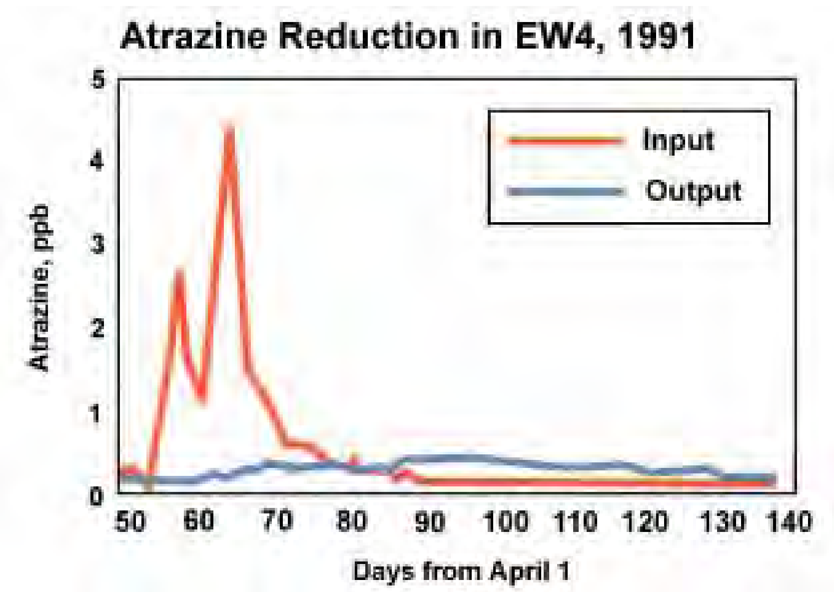


A fish story developed in 1990. The solids in the wetland effluents were steadily increasing with each passing week. The source of the problem was found: a large number of carp were growing up in the wetlands. These fish foraged in the wetland sediments, causing resuspension of solids. They entered as fry in the pumped water, and grew to 8-10 inches over the first two years of the project. The solution was to draw down the wetland water levels, in winter 1990-91, and freeze out the carp. Solids removal returned to the previous high levels of efficiency.

Carp rooted up sediments and impaired sediment removal efficiency. They were frozen out and removed.

Water Quality Responses





Other observed river water quality problems included violations of the state water quality standards for iron, copper, and fecal coliforms. These pollutants are found only occasionally, and not in dangerously high concentrations. Although not detected in amounts exceeding the federal Food and Drug Administration's criteria, dieldrin, DDT and PCBs have been found in fish flesh samples. DDT, DDE and PCBs were also found in low concentrations in the river borne sediments. The

Suspended Solids In and Out of the Des Plaines Wetlands (mg/l)

	Inlet	EW3	EW4	EW5	EW6
FA89	0.052	0.018	0.013	0.014	0.018
WI89	0.073	0.053	0.030	0.058	0.024
SP90	0.057	0.044	0.015	0.017	0.023

old pesticides are pervasive everywhere else in the environment, and so will be in these wetlands. The river bears a significant nutrient load, as evidenced by nitrate and phosphorus. These fertilizers peak seasonally, corresponding to runoff timing and land use practices within the watershed. Agricultural practices within the basin produce pollution with atrazine, at concentrations which peak in excess of the federal drinking water standard. According to the results of benthic surveys, the stream is classified as semi-polluted.

SU90	0.117	0.038	0.055	0.035	0.062
FA90	0.131	0.024	0.007	0.017	0.011
SP91	0.089	0.003	0.002	0.001	0.002
SU91	0.119	0.010	0.010	0.010	0.009
AVG	**0.091**	**0.027**	**0.019**	**0.022**	**0.021**
% Removal		**65%**	**78%**	**73%**	**75%**

Phosphorus removal efficiencies average 65–80%. However, efficiency is lower in winter and higher in summer. That is partly because the riverine concentrations of phosphorus are very low in winter, and partly because biological processes slow in the cold temperatures. Winter runoff in the watershed is overland, over frozen soils or ice and snow. The result is low phosphorus in the river in winter.

Most phosphorus enters the wetlands associated with mineral suspended solids. These solids settle quickly, and may not freely exchange their phosphorus with the wetland waters. In addition, there is a large biotic cycle of growth, death and decomposition at work, which leaves a residual of organic sedimentary material. The deposition from this cycle exceeds the deposition of incoming river solids by a wide margin. Both processes immobilize phosphorus in these wetlands. During the early years, phosphorus is also tied up in the new biomass associated with these developing ecosystems.

Nitrate Nitrogen Reduction, (mg/l)

	Inlet	**EW3**	**EW4**	**EW5**	**EW6**
FA89	2.46	1.46	0.04	1.27	0.08
WI89	2.15	0.67	0.17	1.51	0.25
1990	1.87	0.54	0.24	0.53	0.32
1991	1.22	0.23	0.10	0.18	0.18
AVG	**1.80**	**0.61**	**0.15**	**0.70**	**0.22**
AVG %		**66%**	**92%**	**61%**	**88%**

There are a variety of nitrogen forms in the river water. About 0.6 mg/l of organic nitrogen enter the wetlands, and the same amount leaves. Very low ammonium nitrogen concentrations are found in both river and wetland waters: about 0.05 mg/l. Nitrate varies seasonally in the river, in response to urban and agricultural practices. High spring and fall concentrations are echoed by similar variations in the nitrate content of the wetland effluent waters. However, in the warm seasons, a considerable amount of the incoming nitrate is removed, presumably due to denitrification. This microbially mediated process appears to be more efficient in the wetlands with lower hydraulic loading rate, which is equivalent to increased detention time since depths are comparable. Thus the overall effect of the wetlands is to control the nitrate in the water when sufficient contact time is available.

Atrazine, a triazine herbicide, exists in many streams in the upper midwestern part of the United States, including the Des Plaines River, due to use patterns in the watershed. The atrazine-wetland interaction is very complex, including removal from the area by convection in the water, loss of chemical identity by hydrolysis to hydroxytriazine and dealkylation, and sorption on wetland sediments and litter. Atrazine transport, sorption and identity loss were studied at the site, and in accompanying laboratory work. Sorption was effective for soils and sediments, but the more organic materials, such as litter, showed a stronger affinity for atrazine than the mineral base soils of the wetland cells at Des Plaines.

Atrazine was found to degrade on those sediments according to a first order rate law. Therefore, outflows from the Des Plaines wetland cells contained reduced amounts of atrazine compared to the river water inputs. During 1991, atrazine peaked in the river due to two rain events. Only about 25% of the incoming atrazine was removed in wetland cell EW3, but 95% was removed in wetland cell EW4. The explanation is that the detention time in EW4 is longer than in EW3.

Vegetation Responses

Water clarity is generally excellent at the wetland outflow.

Efforts at vegetation establishment were initially thwarted by the extreme drought conditions of 1988. The planting of white water lily (*Nymphea odorata*) showed small success, and American water lotus (*Nelumbo lutea*) did not survive.

The development of the macrophyte plant communities has been monitored from project startup. Sixteen 2m x 2m permanent quadrats were established in each wetland cell. Data were acquired on species composition and biomass for all plants in each quadrat. Plants were individually measured, and a correlation between dry weight and leaf size was developed. Thus biomass could be determined non-destructively. There was an overall increase in species as volunteer wetland vegetation replaced the terrestrial vegetation of pre-pumping.

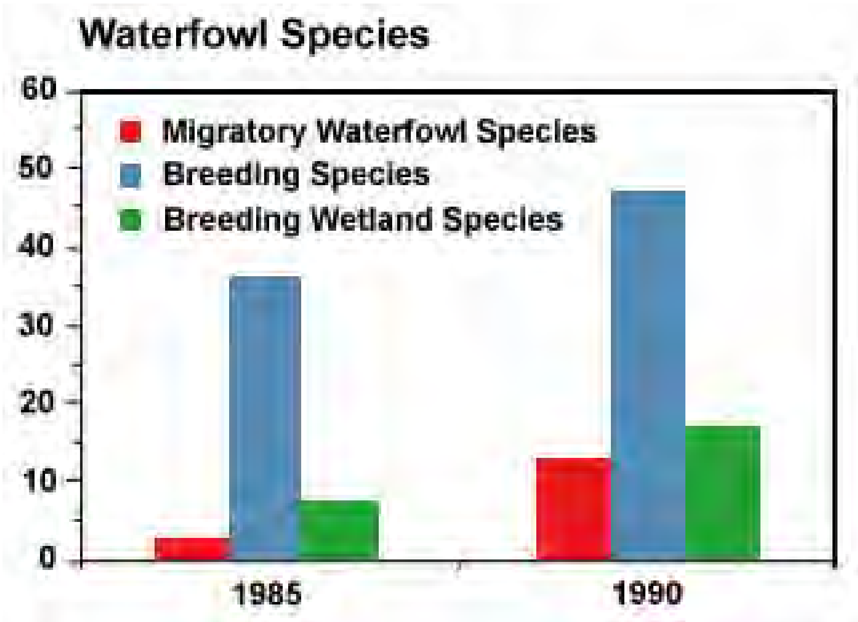
Number of Species of Wetland Plants

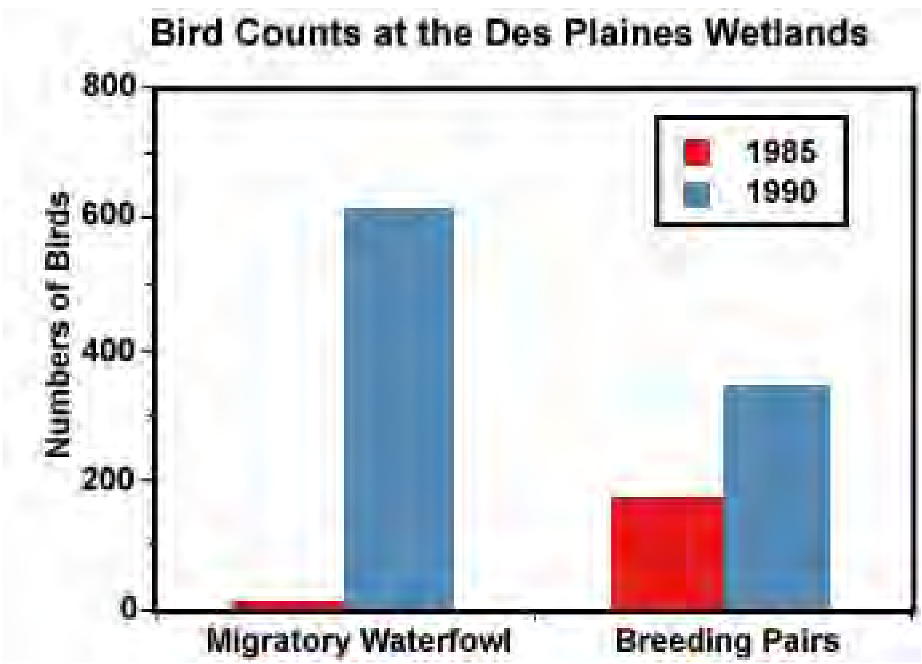
	EW3	**EW4**	**EW5**	**EW6**
1988	2	21	22	29
1989	9	19	14	17
1990	26	28	20	26
1991	25	33	22	27

Fourteen species were observed in 1990 that were not present in 1989, and ten species from 1989 did not reappear; these later being mostly upland species.

The first year of inundation caused the death of many upland species, such as cottonwood (Populus deltoides). The growing seasons of 1989, 1990 and 1991 all displayed an increase in the amount of cattail (Typha spp.). Productivity increased from 200-400 dry grams per square meter in 1989 to 600-800 in 1990. The growing season of 1990 produced extensive blooms of macrophytic algae, predominantly Cladaphora.

Wildlife Use





Bird populations have grown much larger than in the pre-wetlands period for the site. For migratory waterfowl, there has been a 500% increase in the number of species, and a 4500% increase in the number of individuals from 1985 to 1990. Forty-seven species of birds nested on the site in 1990, a 27% increase over preproject numbers.

The fall 1990 bird survey turned up a number of interesting species, including the state endangered pied-billed grebe and black-crowned night heron, and also the great egret, American bittern, and the sharp-shinned hawk. The state-endangered yellow-headed blackbird and least bittern nest successfully at the site.

Muskrats have moved in, and constructed both dwelling houses and feeding platforms. And, beaver are now resident in the wetlands. They chewed off quadrat corner posts—most of the 256 posts initially placed. They attempted to dam the wetland EW3 outflow nearly every night in 1992.

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Ecological Society of America: Special Recognition Award, 1993

Research Groups

Project research has been conducted by several organizations:

College of Lake County
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North Dakota State University
Northeastern Illinois Planning Commission
Northern Illinois University
Northwestern University
The Illinois State Water Survey
The Illinois Institute of Technology
The Illinois State Geological Survey
The Morton Arboretum
The Ohio State University
The University of Michigan
Western Illinois University

Blue horizon marker particles just after placement. As sediments accumulate, these marker particules become buried. The amount of overlying sediment may then be determined at later times.

For the project bibliography, project reports or other information, contact the not-for-profit coordinating organization:

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