The Tres Rios Hayfield Site constructed wetland demonstrates the creation of wildlife habitat using highly treated municipal effluent along the Salt River west of Phoenix, Arizona

Executive Summary

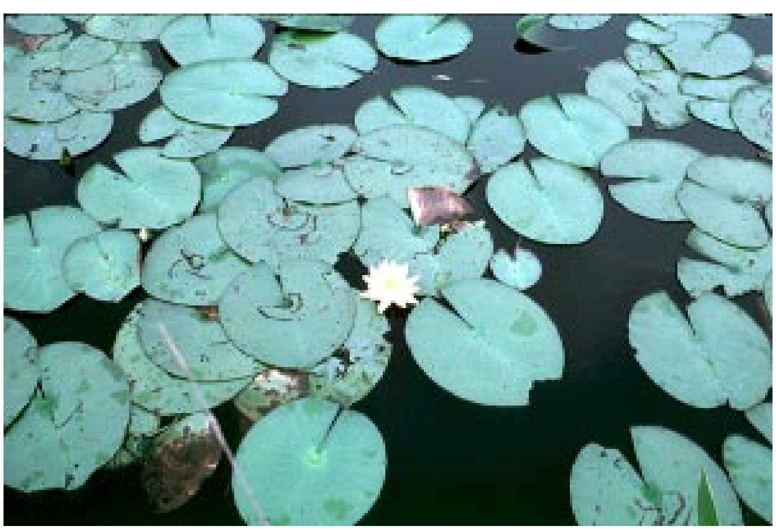
Treatment Wetland Habitat and Wildlife Use Assessment

Background

Natural and constructed wetlands are being used throughout North America and the world to improve the quality of a broad variety of wastewater types. Incidental to this water quality function, most of these wetlands have been observed to attract significant wildlife populations. In some cases these treatment wetlands are also open to the public for nature study and other forms of recreation.

Little effort has been made to collect or organize published and unpublished information concerning the habitat functions of treatment wetlands. As a result many treatment wetland systems have been designed in a manner giving little attention to achieving plant diversity and attracting wildlife. Little in the way of guidance has been issued on whether such habitat creation is even compatible with the goal of protecting wetland biota. While it is generally conceded that treatment wetlands provide habitat for wildlife, the amount and quality of that habitat has not been widely recorded. Moreover, the potential for this habitat to threaten the health of wildlife attracted to treatment wetlands has been raised, but documentation of the occurrence of undesirable side effects has been very limited. There are few definitive studies of habitat values or of ecological impacts in treatment wetlands—and when they do exist, they are not generally available.

This Executive Summary report is one output from a Environmental Protection Agency Environmental Technology Initiative (ETI) Program funded project undertaken in cooperation with the City of Phoenix and the U.S. Bureau of Reclamation. This project is concerned with developing information and guidance to facilitate treatment wetland projects that provide multiple environmental benefits. The potential benefits of treatment wetlands include improved water quality, creation of wildlife habitat, and enhancement of the public's understanding and appreciation of constructed wetlands. Other efforts under the ETI project deal with the ability of treatment wetlands to improve water quality and with policy and permitting considerations facing the technology. This Executive Summary and the companion report: *Treatment Wetland Habitat and Wildlife Use Assessment*, summarize what is known about these systems in terms of their ecological structure and function and how they are used by the public. This portion of the effort is termed the ETI Treatment Wetland Habitat Project.



Habitat diversity can be incorporated in constructed wetlands by planting a variety of aquatic plant species such as these water lilies.

Scope of This Assessment

Natural and constructed wetlands have received and treated a variety of wastewater sources for over 25 years. Hundreds of treatment wetlands exist in the United States (Bastian and Hammer, 1993; US EPA, 1993; Kadlec and Knight, 1996) and in Europe and Canada (Pries, 1994). New systems are being designed and implemented at an ever-increasing rate. This innovative technology for managing water quality has become attractive to public and private facilities, in many cases because it provides a cost-effective method for improving water quality while providing valuable wetland habitat.

Concurrent with the development and maturation of treatment wetland technology, researchers have observed that numerous secondary or ancillary benefits have resulted from some of these projects (Sather, 1989; Knight, 1992; Knight, 1997). Published observations of high usage by waterfowl and other wetland-dependent wildlife in surface flow treatment wetlands (Wilhelm et al., 1989) indicated that these secondary benefits are highly significant in some cases. Also, researchers have pointed out potential problems that might result from the use of wetlands for receiving wastewaters (Guntenspergen and Stearns, 1985; Bastian et al., 1989; Knight, 1992; Godfrey et al., 1985; Wren et al., 1997). Bioaccumulation of heavy metals or organics that are present in some wastewaters, as well as transmission of disease, might create hazards that outweigh the potential benefits of these projects.

The U.S. EPA conducted a pilot study of wildlife usage and habitat functions of constructed treatment wetlands during the summer of 1992. This study utilized a consistent rapid-assessment protocol at six constructed surface flow treatment wetlands to evaluate their habitat structure and function and the possibility of environmental hazards (McAllister 1992, 1993a, 1993b). That study represents the only known attempt to critically compare habitat and wildlife usage between treatment wetland sites with nearby "control" natural wetlands.

A recent report prepared by the Canadian Wildlife Service (Wren et al., 1997) summarizes information on wildlife usage of stormwater treatment wetlands. It identifies areas of potential concern related to accumulation of hazardous pollutants and concludes that insufficient data are available to document detrimental effects. The report recommends the need to require detailed monitoring of potential wildlife hazards in stormwater treatment wetlands in Canada.

This ETI project effort represents the first comprehensive effort to assemble the wide-ranging information concerning the habitat and wildlife use data from surface flow treatment wetlands. These data are assembled in an electronic data base format that allows researchers to take a critical look at the actual benefits and hazards that have been documented in treatment wetlands. This project involved a focused search of project reports and researcher files for qualitative and quantitative information concerning surface flow treatment wetland plant communities, animal populations, concentrations of trace metals and organics, biomonitoring results, and human use. These data have been gathered into an electronic format built upon the previous existing North American Treatment Wetland Database Version 1.0 (NADB v. 1.0) funded by the U.S. EPA (Knight et al., 1993). This Executive Summary briefly describes the format and contents of the updated database (NADB v. 2.0) and synthesizes this existing information into a summary of current knowledge and remaining questions related to habitat and wildlife use of treatment wetlands.

Gated pipes on raised boardwalks allow access to over 600 acres of treatment area in the Vereen Natural Treatment Wetland in South Carolina.

Habitat quality, wildlife population, and human usage data have been previously collected by a number of treatment wetland projects. When available, these data are typically in raw form, unpublished reports, or rarely in refereed publications. In many cases these data have not been available to other researchers to evaluate. No previous attempt has been made to assemble these types of data into a consistent format or to summarize information to compare results among treatment wetland sites.

The primary purpose of this effort was to assemble existing wildlife and habitat use data from diverse sources into a consistent format and to make these data available to regulators, designers, owners, and researchers. This Executive Summary and the companion report provide a preliminary summary of these data to begin identifying any apparent benefits or hazards. It is anticipated that others will conduct more detailed analyses of these data.

A second purpose of this effort is to establish an inventory of the types of data that are of interest when assessing the environmental and societal attributes of treatment wetlands, and to create a database format to guide the design of new studies as additional data are collected by wetland researchers. A third purpose of the effort is to provide information concerning habitat, wildlife, and human use in treatment wetlands to be used for future designs of these systems to optimize specific goals for habitat creation. The fourth purpose of this project is to identify areas of insufficient knowledge and to recommend actions that can be taken to fill those information gaps.

North American Treatment Wetland Database Version 2.0 (NADB v. 2.0)

Data Collection

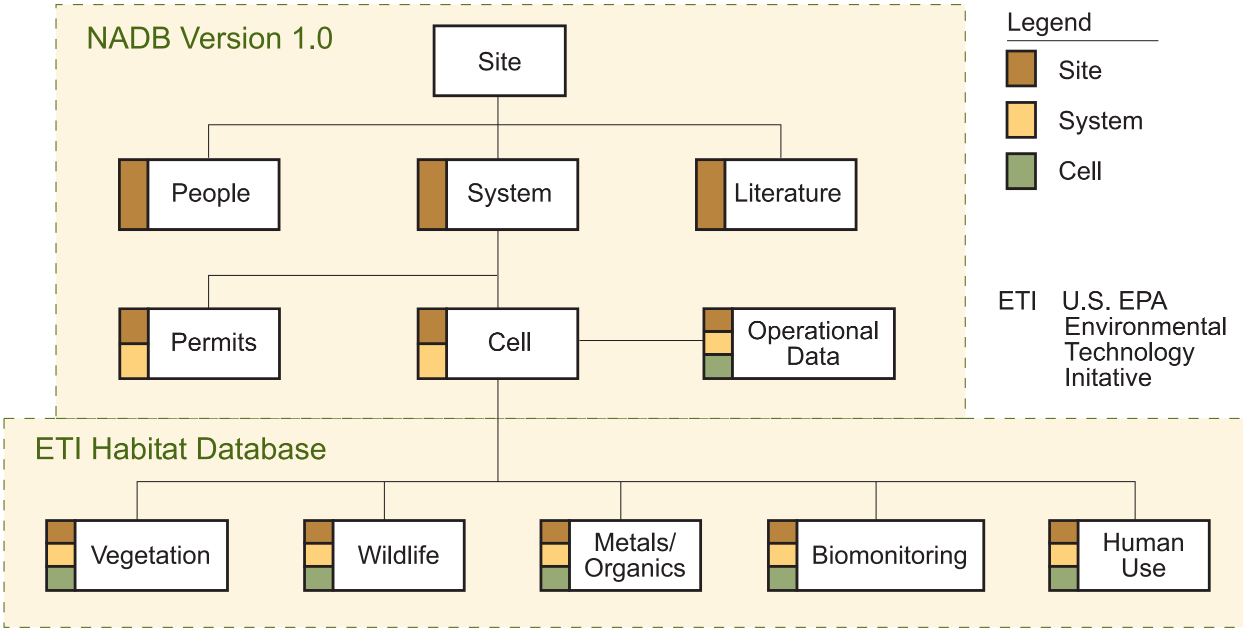
The original NADB v. 1.0 identified 179 sites where treatment wetlands were being used in North America (Knight et al., 1993). In the course of that effort, habitat and wildlife usage data sets were obtained from some of these sites. Ongoing treatment wetland monitoring projects continue to develop habitat-related data, and those data were requested by telephone and or in writing from current project owners and researchers. Data were received in various formats, including electronic spreadsheets, consultant and owner reports, daily monitoring reports, and raw data. Data were collected using a variety of methods with no differing levels of quality control/quality assurance between projects. Although this effort to obtain existing treatment wetland habitat data was extensive, it is considered likely that some relevant data sets are not included in this survey.

There was no attempt to verify or judge the quality of data collected for this database. Any use of these data to develop summary conclusions concerning the populations of flora and fauna in treatment wetlands should be considered preliminary until specific data sets are identified and their quality verified through peer-reviewed reports. The data gathered for the companion report range in quality from detailed biological and water quality research efforts to cursory qualitative estimates. For most purposes, the data summarized in the NADB v. 2.0 can be assumed to be reasonable estimates or approximations of the biological and chemical conditions in these treatment wetlands.

Database Structure

Five new database files with data pertinent to habitat quality and wildlife use of treatment wetlands were added to the existing 7 files in NADB v. 1.0 to create the ETI Treatment Wetland Habitat Project NADB v. 2.0. The structure of the five new database files follows the format of NADB v. 1.0 in their hierarchical structure. The NADB v. 2.0 also has been updated by adding treatment wetland site, design, and operational performance data from confined animal feeding operations (CAFOs) summarized by a separate project completed for the Gulf of Mexico Program with U.S. EPA funding (CH2M HILL and Payne Engineering, 1997).

Each record identifies the treatment wetland site, system, and cell, which allows links to be made between the 12 individual database files in NADB v. 2.0.



File structure of the North American Treatment Wetland System Database (NADB) Version 2.0.

The *Vegetation* database file contains qualitative and quantitative plant community data for treatment wetland sites. It provides vegetation data of cells within each system for a specified period. Data entered here include species lists, percent cover, biomass, density, basal area, and importance values.

The *Wildlife* database file contains qualitative and quantitative population data for benthic macroinvertebrates (benthos), fish, amphibians, reptiles, avifauna (birds), and mammals. Data entered here include species lists, species density, species diversity, and reproductive success for a given period.

The *Metals/Organics* database file contains data on water, sediment, plant, and wildlife tissue concentrations for trace metals and organics. Data entered into this file are identified by the sample matrix type (water, sediment, or tissue) and the sample parameter. Water sampling data are recorded as influent and effluent concentrations for each system at a given site. Sediment data are identified by the station location. Plant and wildlife tissue data are identified by species and the type of tissue.

The *Biomonitoring* database file includes information on acute and chronic toxicity tests, reproduction, and mortality tests on various test organisms. Each record identifies the sampling location (influent or effluent), dilution for each test, and the organism used.

The *Human Use* database file contains information on how the public uses wetland treatment sites for recreation, research, hunting, and other activities. Data entered include use density, number of use days, and harvest totals per site.

Summary of NADB v. 2.0 Contents

Sites and Systems

NADB v. 2.0 has information for a total of 257 sites, 367 systems, and 831 cells from treatment wetlands in North America. These numbers reflect the fact that some sites have multiple systems and some individual systems have multiple cells. Of these 257 sites, 160 of them treat municipal wastewater, 12 receive industrial effluents, 68 receive livestock wastewaters, and 17 receive other wastewater types including stormwaters. Of the systems described in NADB v. 2.0, 305 are surface flow, 54 are subsurface flow, and 8 are hybrids of these two designs.

The five new files in NADB v. 2.0 contain habitat and related data for 109 sites, 168 separate systems, and 386 individual cells from 31 states or provinces. Eighty-five percent of the sites within the five new database files are constructed treatment wetlands; the rest are natural treatment wetlands. Of the 29,960 new records in these five database files, 65 percent come from constructed treatment wetland sites.

Treatment Wetlands as Habitat

The word ***habitat*** refers to a place or environment that provides support for the needs of a plant or animal. Many plant species are typically found in wetland environments, including vascular plants, algae, mosses, ferns, and other non-vascular plant species. Wetlands also provide some or all of the habitat requirements for thousands of animal species. Some animals may live out their lives within the border of a particular wetland while other species are adapted to come and go across wetland boundaries. Wetlands provide significant habitat requirements for many of the bird species that are commonly found in North America.

For an environment to be classified as habitat for a particular organism, it must be able to provide the necessary conditions required to complete the normal life cycle of that organism and to propagate the species into the indefinite future. There must be the opportunity for reproduction, growth, adaptation, maturation, and ultimately reproduction again.

Since the habitat requirements of nearly every organism are different in some way, there is no single measure of the adequacy of habitat that can be applied broadly across many species. However, there is a relatively simple test to determine if a given area is providing suitable habitat for a species of interest. The presence of the species over a period of time that includes multiple generations indicates that the area is suitable habitat. For plant populations, this test requires that successful reproduction must occur within the plant's normal life span. This might be only once in 100 years for long-lived tree species, or it may be yearly for annual species.

This habitat test applies to organisms that breed within the habitat as well as those that may migrate through and breed elsewhere. If these migratory animals or their progeny do not return to the area then it is not providing suitable habitat. To be beneficial, habitat must provide one or more life history requirements that contribute to a species' sustainable population size. If the amount or quality of available habitat is limiting a given species' overall population size, then the addition of more habitat or the enhancement of existing habitat will lead to a higher sustainable population of that organism. While science may never have enough information to define a species' overall population size and the variable nature of that population from year to year, enough data exist for some key species that occur in treatment wetlands to make preliminary assessments of the habitat value of these engineered ecosystems. Existing knowledge can be organized by taxonomic group (vegetation and animals) and by specific attention to potential hazards to biota and humans.

Vegetation in Treatment Wetlands

Introduction

The wetland environment is generally characterized by a high diversity and abundance of plants (Mitsch and Gosselink, *Treatment Wetland Sites in the NADB Version 2.0 with Habitat Data.*

Site No.	Site Name	Origin	Area (ha)	Source of Waste Water
1	Lakeland, FL	CON	498.00	MUN
5	Orange County, FL	CON	89.00	MUN
7	Cypress Domes, FL	NAT	1.56	MUN
9	Reedy Creek, FL	NAT	82.20	MUN
11	Silver Springs Shores, FL	CON	21.00	MUN
12	Central, SC	NAT	31.60	MUN
13	Ironbridge, FL	NAT	494.00	MUN
18	West Jackson County, MS	CON	22.70	MUN
20	Poinciana, FL	NAT	46.60	MUN
22	Vereen, SC	NAT	229.00	MUN
25	Arcata, CA	CON	15.18	MUN
26	Hillsboro, OR	CON	35.70	IND
29	Santa Rosa, CA	CON	4.05	MUN
31	Waldo, FL	NAT	2.60	MUN
33	Deer Park, FL	NAT	50.60	MUN
39	Brookhaven, NY	CON	0.49	MUN
51	Hayward, CA	CON	58.68	MUN
62	Minot, ND	CON	13.58	MUN
68	Halsey (Pope & Talbot), OR	CON	2.02	IND
76	Show Low, AZ	CON	54.20	MUN
91	Hillsboro, ND	CON	33.00	IND
92	Everglades Nutr. Removal, FL	CON	1406.00	OTH
96	Columbia, MO	CON	37.00	MUN
98	Hemet/San Jacinto, CA	CON	14.16	MUN
99	Sacramento Dem. Wetland, CA	CON	8.90	MUN
102	Champion Pilot, FL	CON	1.42	IND
108	Las Gallinas San. Dist., CA	CON	—	MUN
109	Collins, MS	CON	4.47	MUN
110	Tompkins County Landfill, NY	CON	0.04	IND
111	TVA Mussel Shoals, AL	CON	0.19	IND
112	Tres Rios, AZ	CON	4.18	MUN
114	Tarrant Co, TX	CON	—	OTH
202	Biwabik, MN	NAT	40.50	MUN
204	Cannon Beach, OR	NAT	7.00	MUN
206	Des Plaines, IL	CON	10.13	OTH
209	Houghton Lake, MI	NAT	79.00	MUN
210	Kinross (Kincheloe), MI	NAT	110.00	MUN
217	Vermontville, MI	CON	4.60	MUN
302	Benton, KY	CON	3.00	MUN
303	Brillion, WI	NAT	156.00	MUN
304	Drummond, WI	NAT	6.00	MUN
310	Incline Village, NV	CON	173.28	MUN
311	Listowel Artificial Marsh, ONT	CON	0.87	MUN
312	Mt.View Sanitary District, CA	CON	37.00	MUN
314	Seneca Army Depot, NY	NAT	2.50	MUN
412	Benton, KY	CON	1.46	MUN
500	Saint-Felicien, QUE	CON	0.72	MUN
501	Essex County, ONT	CON	0.06	AGR
502	Perth County, ONT	CON	0.09	AGR
503	Simco County #1, ONT	CON	—	AGR
504	Region of Niagara, ONT	CON	0.02	AGR
505	Hamilton-Wentworth, ONT	CON	—	AGR
506	Region of Ottawa-Carlton, ONT	CON	0.02	AGR
507	Russel County, ONT	CON	0.08	AGR
508	Region of Peel, ONT	CON	—	AGR
509	Simco County #2, ONT	CON	0.03	AGR
510	Lucky Rose Farm, IN	CON	0.98	AGR

Site No.	Site Name	Origin	Area (ha)	Source of Waste Water
511	Wayne White Farm, NS	CON	0.43	AGR
512	David Thompson Farm, NS	CON	0.10	AGR
513	Ken Hunter Farm, NS	CON	0.07	AGR
514	Oregon State University, OR	CON	0.53	AGR
515	Hickok Veal, PA	CON	0.14	AGR
516	Cobb Farm, PA	CON	0.01	AGR
517	Moyer Farm, PA	CON	0.01	AGR
518	Crum Farm, MD	CON	0.11	AGR
519	3M Farm, MD	CON	0.12	AGR
520	Delmarva Farms , MD	CON	0.73	AGR
521	U of Connecticut, CT	CON	0.04	AGR
522	Guy Thompson Farm, PEI	CON	0.15	AGR
523	David Gerrits Farm, WI	CON	0.03	AGR
524	Norwood Farms, IN	CON	0.11	AGR
526	Nowicki Farm, ALB	CON	0.05	AGR
527	Mercer Co., KY	CON	0.14	AGR
528	Piscataquis River, ME	CON	0.04	AGR
529	Tom Brothers Farm, IN	CON	0.19	AGR
530	Purdue University, IN	CON	0.03	AGR
531	Adair Co.#1, KY	CON	0.03	AGR
532	Adair Co.#2, KY	CON	0.04	AGR
533	Casey Co.#1, KY	CON	0.06	AGR
536	Crittenden Co., KY	CON	0.07	AGR
537	Wayne Co.#1, KY	CON	0.03	AGR
538	Wayne Co.#2, KY	CON	0.02	AGR
539	Spencer Co., KY	CON	0.04	AGR
542	Allen Co., KY	CON	3.70	AGR
543	Butler Co.#1, KY	CON	4.90	AGR
544	Hopkins Co., KY	CON	0.93	AGR
545	McLean Co.#1, KY	CON	0.65	AGR
546	McLean Co.#2, KY	CON	0.28	AGR
547	McLean Co.#3, KY	CON	0.12	AGR
548	Union Co., KY	CON	0.12	AGR
549	Butler Co.#2, KY	CON	4.80	AGR
550	Dogwood Ridge, KY	CON	3.80	AGR
600	Hernando, MS	CON	0.08	AGR
601	Pontotoc, MS	CON	0.32	AGR
602	Newton, MS	CON	0.12	AGR
603	Hattiesburg, MS	CON	1.24	AGR
605	Auburn Poultry, AL	CON	0.12	AGR
606	Auburn Swine, AL	CON	0.00	AGR
607	McMichael Dairy, GA	CON	0.29	AGR
608	Tifton, GA	CON	0.22	AGR
610	Louis. St. Univ., LA	CON	0.81	AGR
611	New Mexico State, NM	CON	0.00	AGR
612	Duplin, NC	CON	0.07	AGR
613	Key Dairy, GA	CON	0.35	AGR
615	Crittenden Co., KY	CON	0.34	AGR
616	Union Co., KY	CON	0.10	AGR
617	La Franchi, CA	CON	0.10	AGR

Origin:

CON Constructed
NAT Natural
HYB Hybrid
1 hectare (ha) = 2.47 acres

Source of Waste Water:

AGR Agricultural
IND Industrial
MUN Municipal
OTH Other

Cattails continue to be the workhorse of many treatment wetlands.

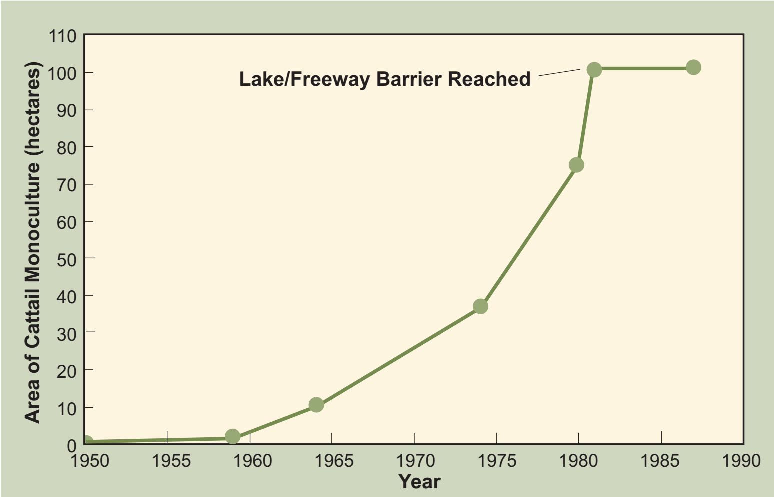
1993). In many cases, wetland plant communities include multiple vertical strata ranging from groundcover species to shrubs and subcanopy trees to canopy tree species. Obligate wetland plant species are defined as those found exclusively in wetland habitats, while facultative species are those that may be found in upland or wetland areas. The U.S. Fish and Wildlife Service (USFWS) has listed more than 6,700 species of obligate and facultative wetland plant species in the United States (Reed, 1988).

Wetland plant diversity is important in determining wildlife diversity because of the creation of niches associated with differing vegetative structure, reproduction strategies, flowering and seeding phenologies, gross productivity, and rates of decomposition. In addition to their diversity of species and growth habitats, wetland plants are important for treatment wetland pollutant removal performance because the physical and chemical structure they provide supports microbial populations.

The ecology of wetland plant communities can be assessed through the use of qualitative and quantitative measures. Lists of plant species provide an overall qualitative inventory of the diversity that is present and the ability of a wetland plant community to adapt to fluctuating environmental conditions. Quantitative measures of dominance (mass or cover per unit area), density (number of individuals per unit area), and frequency (percent occurrence in a number of different samples) of plants species are direct indicators of ecological structure and can be compared between treatment wetlands and control sites to assess differences. Quantitative functional measures of wetland plant populations include primary productivity (gross and various measures of net productivity), litterfall, and decomposition. These measures provide a method to compare the functions of constructed and natural treatment wetlands and to compare treatment wetlands with control wetlands that are not receiving treated effluents.

Plant Communities

Constructed treatment wetlands are typically dominated by emergent marsh, floating aquatic plant, or submerged aquatic plant communities. In some cases these constructed treatment wetlands are dominated by populations of filamentous algae because marsh plant species have had difficulty becoming established. Emergent marsh species are frequently intermingled and codominant with populations of small floating aquatic plants such as duckweed (*Lemna* spp.). Many constructed treatment marshes in the United States are dominated by cattails (*Typha* spp.) or bulrush (*Scirpus* spp.); however, some treatment marshes are dominated by other plant species or by a complex admixture of species that includes cattails and bulrush.



Increasing dominance by cattails (Typha latifolia) at the Kinross, Michigan, natural wetland. The original plant dominants were bog birch (Betula pumila), sedge (Carex flava), and black spruce (Picea mariana). Approximately 1/3 of the entire wetland area (320 ha) was altered by this unplanned treatment project. Water depth changes resulting from beaver activity were implicated in addition to nutrient inputs as an important causative factor for this shift in plant dominance (modified from Kadlec and Bevis, 1990).

Natural wetlands used for water quality treatment may be dominated by emergent marsh plant species, by tree species, or by shrub species. Dominant species in natural wetlands used for water quality treatment vary regionally, depending upon the types of wetlands that are locally available. In the southeastern United States, the dominant forested wetland types that have been used to receive and polish wastewaters include cypress (*Taxodium* spp.), gum (*Nyssa* spp.), bay (*Gordonia lasianthus, Magnolia virginiana,* and/or *Persea* spp.), red maple (*Acer rubrum*), titi (*Cyrilla racemiflora* and *Cliftonia monophylla),* willows (*Salix* spp.), ash (*Fraxinus* spp.), and oaks (*Quercus* spp.). In the northcentral United States, forested wetlands receiving wastewaters are dominated by spruce (*Picea* spp.), willow, and birch (*Betula* spp.). In the northwestern United States, natural shrub forested wetlands that receive treated wastewaters are dominated by alder (*Alnus rubra*) and sitka spruce (*Picea sitchensis*).

In the upper midwest and northeastern United States, natural marshes dominated by cattails, grasses, and sedges have received a variety of wastewater discharges.

Many constructed and natural treatment wetlands undergo plant succession during their operational life. Constructed marshes tend to remain marshes as long as flooding is nearly continuous and water depths exceed about 5 centimeters (cm). At shallower water depths and under conditions that allow germination of woody species (such as at Orange County, Florida, Site No. 5), plant succession moves from herbaceous marsh plant species through shrubs and small trees, to a forested wetland.
Natural treatment systems may undergo succession also. Observed succession in the immediate vicinity of the distribution area at the Bear Bay wetland near Myrtle Beach (Vereen, Site No. 22), South Carolina, and in forested wetlands in north central Michigan (Bellaire, Site No. 201 and Kinross, Site No. 210) was from densely forested to open forest shrub/marsh. The water regime and nutrient quality conditions at these wetlands killed sensitive tree species and promoted growth of herbaceous and woody ground cover and shrubs. Other forested natural treatment wetlands have been observed to continue their normal maturation pattern as indicated by incresing tree basal area over time.

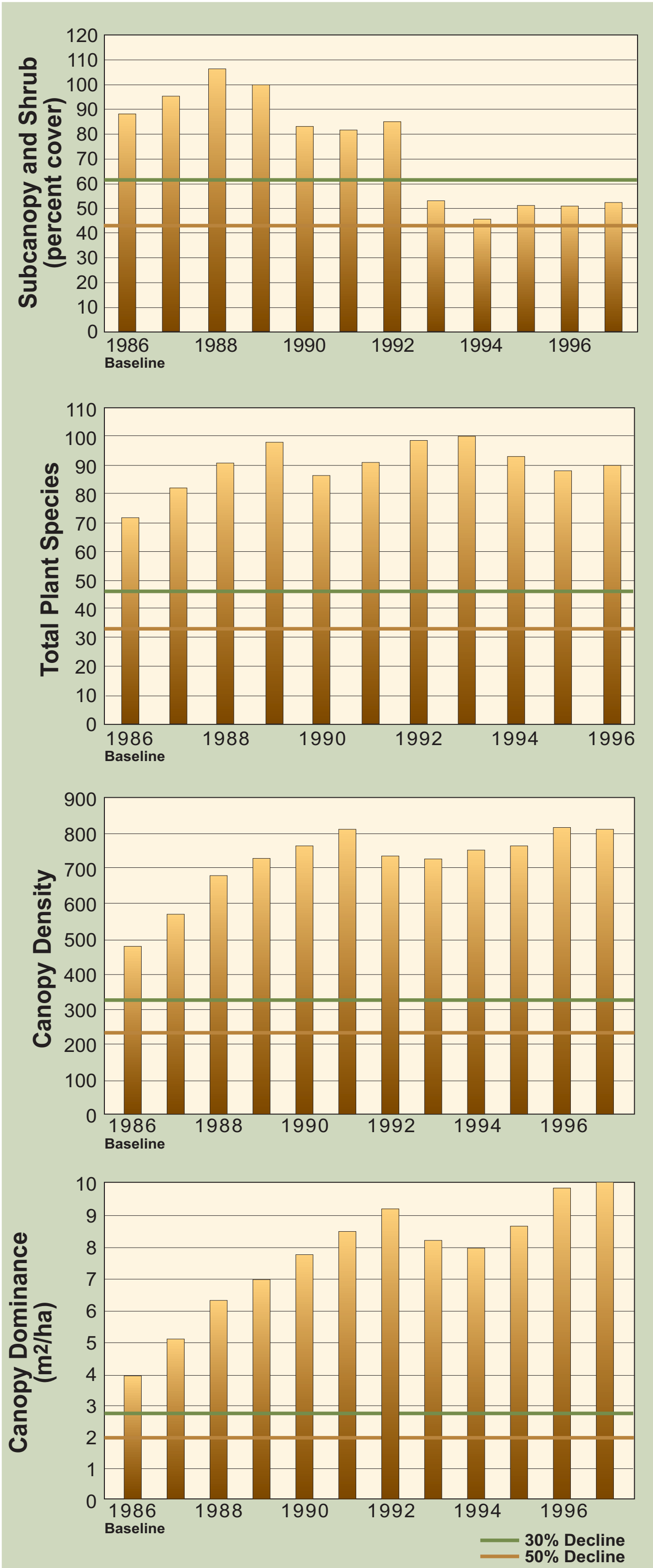
Plant Species Diversity

Of the more than 800 species of macrophytic plants that have been reported in natural and constructed treatment wetlands, 693 species are emergent herbaceous macrophytes, 36 are floating aquatic species, 12 are submerged aquatics, 57 are shrubs, 55 are trees, and 18 are vines. A total of 593 macrophytic plant species has been reported from constructed treatment wetlands, and 427 species from natural treatment wetlands. Emergent herbaceous macrophytes account for 501 species in constructed treatment wetlands and 290 species in natural treatment wetlands. A significant variety of tree and shrub species occur in some constructed wetlands. Tree and shrub species are well represented in natural treatment wetlands with 88 different species recorded.

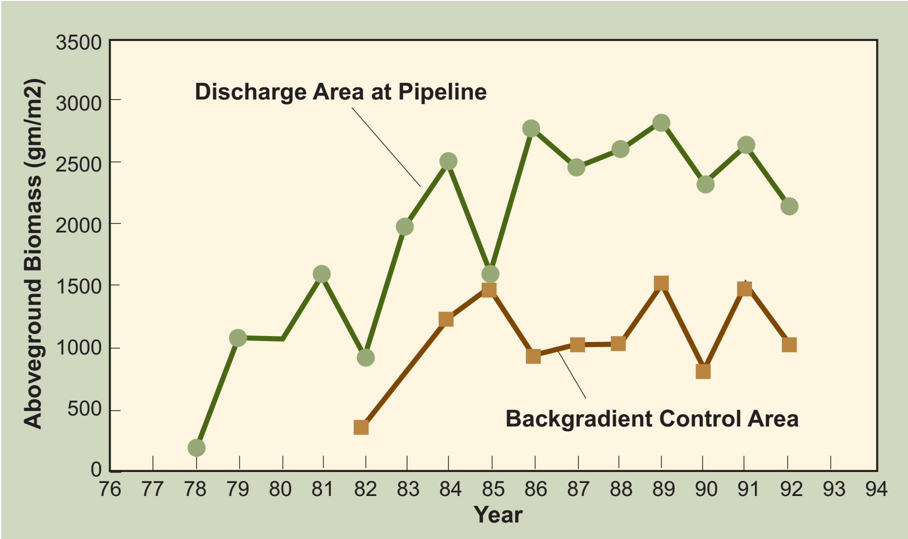
Plant Dominance, Density, and Frequency

Emergent herbaceous plant communities can be quantitatively sampled by use of line-intercept transects or quadrats. These plant ecology techniques provide measures of plant cover by species, plant frequency, and in some cases plant density, height, or biomass. Plant communities in forested wetlands are often quantified through measurements of dominance, density, and frequency. These three quantitative measures can be used to calculate importance value, a relative measure of the contribution of individual tree species in a forest.

Quantitative data from treatment wetlands confirm the common observation that these systems are densely vegetated. Plant biomass values are at the high end of recorded values in non-treatment wetlands. This is the case in both constructed and natural treatment wetlands. Reductions in tree dominance have been observed in a number of natural treatment wetlands while others show no detrimental effect. Effects on wetland trees are species-specific. Some



Biological criteria in the Vereen Natural Treatment Wetland near Myrtle Beach, SC (Site No. 222) include allowable changes for canopy density and dominance, subcanopy and shrub percent cover, and total plant species diversity. While decreases have been observed for one of these criteria (subcanopy and shrub percent cover) the other three criteria have all increased in response to 10 years of treated municipal effluent discharge. Far from becoming a monoculture, the floristic diversity of this wetland has increased by 14 species and overall canopy dominance has increased by 250 percent.



Plant biomass changes in response to addition of treated municipal effluent at Houghton Lake Peatland. Control area experiences hydrologic changes without nutrient increases. Pre-existing peatland vegetation was largely replaced by cattails and duckweed dominants over about one-tenth of the 600 ha area (modified from Kadlec, 1993).

tree species are adapted to the long hydroperiods and low sediment oxygen levels typical of treatment wetlands while other species cannot survive these changes. An understanding of the tolerance limits of individual plant species, careful site selection and project design can maintain high tree dominance in natural treatment wetlands.

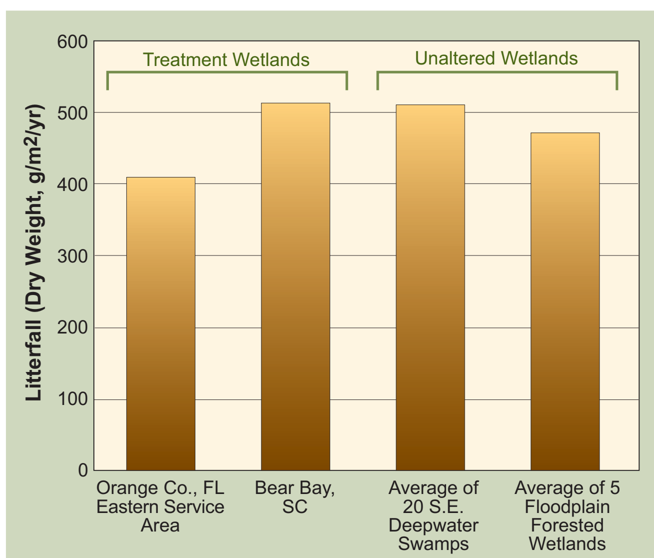
Primary Productivity

Biomass estimates in marsh wetlands provide an index of net plant productivity on a seasonal basis. The biomass estimates in the NADB v. 2.0 indicate that treatment wetland marshes have high net production compared with many non-treatment marshes.

No direct estimates of net primary productivity were recorded in NADB v. 2.0. However, the database includes litterfall rates from two natural forested wetlands (Orange County, Florida, Site No. 5, and Bear Bay, South Carolina, Site No. 22). Litterfall may be used as a measure of net primary production (Mitsch and Gosselink, 1993). The litterfall rates summarized from treatment wetlands are comparable to values from natural forested wetlands and adjacent natural control wetlands.

Plant Decomposition

Litter decomposition rates measure an important component of carbon and nutrient recycling in wetlands. The decomposition rates of individual plant species differ greatly because of their variable cell structure and lignin composition. Litter decomposition rates are available in NADB v. 2.0 from two treatment wetlands, Bear Bay in South Carolina (Site No. 22), and the Orange County Eastern Service Area in Florida. At both sites the presence of shal-



Litterfall rates provide an estimate of net primary productivity in wetlands dominated by woody vegetation. Rates in natural treatment wetlands are comparable to unaltered natural wetlands.

low flooding caused by the discharge of treated effluent increased the decomposition rate of leaves.

Summary and Data Requirements

Treatment wetlands are typically dominated by dense growths of wetland-dependent plant species. These plant communities are similar in ecological structure and function to natural wetland plant communities.

A variety of plant communities occur in treatment wetlands including marshes, shrub swamps, and forested swamps. While most constructed treatment wetlands are marshes, a few constructed treatment systems are developing shrub and swamp characteristics over time, either intentionally or through volunteer plant colonization and succession.

Volunteer plants such as these mud-plantain frequently invade constructed treatment wetlands, adding habitat diversity for wildlife and greater resistance against insect infestations in cattail-dominated marshes.

On the other hand, natural forested wetlands receiving secondary treated municipal wastewaters have been partially converted to marshes in several areas of the United States. Other forested wetlands receiving higher quality municipal wastewaters (advanced secondary with nitrification or tertiary with phosphorus removal) have maintained their canopy dominance over significant periods of time.

More long-term, ecosystem-level studies are needed for both constructed and natural treatment wetlands under a variety of geographical and pollutant loading conditions to fully describe the parameters most predictive of plant community development in treatment wetlands. Also, more studies of the basic quantitative ecology of natural wetlands would be helpful for comparison to treatment wetland structure and function.

Wetland plant diversity is a poorly understood subject, both in unaffected natural wetlands and in treatment wetlands. Non-treatment natural wetlands are frequently dominated by only a few plant species (for example, cypress swamps, cattail, sedge, or sawgrass marshes, etc.) that are best adapted to stressful environmental conditions such as low nutrient levels, low soil oxygen levels, or fluctuating water levels. Other unaffected natural wetlands have higher plant diversity and greater evenness between multiple dominant plant species.

Both constructed and natural treatment wetlands cover the same range of plant dominance and diversity of unaffected natural wetlands. Information collected for NADB v. 2.0 indicates that hundreds of plant species occur in a variety of treatment wetlands. Even when treatment wetlands are dominated by cattails or bulrush, dozens of other herbaceous and woody plant species are typically present.

Data from natural treatment wetlands indicate variable responses to treated effluent discharges: existing diversity may be reduced by the presence of a wastewater discharge (e.g., Houghton Lake, Site No. 209, and Kinross, Site No. 210, Michigan), or diversity may be maintained or increased following the initiation of a discharge to other wetlands (Orange County and Reedy Creek, Florida and Bear Bay, South Carolina).

The effect of treated wastewater discharges on plant diversity in natural wetlands depends on the amount of pre-treatment and the scale of the project. Municipal effluents treated to advanced standards generally have only a water regime effect while those treated to secondary standards may also have a water quality effect. Water quality effects on plant diversity are greatest near the point of inflow, while water regime effects may occur over the entire area of a natural treatment wetland. Over the scale of the entire wetland, plant diversity may be increased by the addition of new plant species associated with the discharge.

Total plant cover and dominance data do not indicate any observable difference between treatment and non-treatment wetlands for these indices. However, biomass data indicate that discharge of secondary municipal wastewater to natural, low-nutrient wetlands will greatly increase plant biomass. This enrichment effect is typical of wetlands receiving treated municipal discharges and is most observable in the immediate area of the discharge.

Very few data have been collected that measure the ecological function of treatment wetland plant communities. High plant growth rates are apparent based on standing crop; however, clip plots, gas metabolism studies, litterfall studies, or other methods for estimating net primary production have been conducted at only a few locations. Litterfall rates in at least two natural forested treatment wetlands are comparable to unaffected natural forested wetlands.

Other ecological functions related to the carbon cycle through wetland plants have been largely ignored in treatment wetland studies. Decomposition rates in treatment wetlands compared with natural wetlands appear to be higher because of greater organic carbon inputs and the continuous presence of water. The proportion of this organic carbon cycling through the wetland plants may be very different between treatment and non-treatment wetlands, and the quantities and forms of carbon being exported across the system's boundaries are likely to be different. More comprehensive studies of the total carbon cycle in treatment wetlands would help quantify the relative importance of these similarities and differences.

Wildlife in Treatment Wetlands

Introduction

Numerous wildlife species of all taxonomic orders depend on wetlands as habitat. Plant productivity and imports of organic carbon from surrounding ecosystems provide the energy basis that supports these wildlife populations. Many wetlands have both

Dragonflies are a common predator found at both constructed and natural treatment wetlands.

aquatic and terrestrial food chains. Plant tissues that fall into the aquatic portion of the wetland are typically degraded by a complex assemblage of microscopic and small aquatic organisms that includes invertebrate animal groups (protozoans, worms, molluscs, arthropods, and others). These organisms, in turn, serve as the basis of the food chain for other invertebrates, and for diverse vertebrate groups such as fish, amphibians, reptiles, birds, and mammals. In addition to their direct support of wildlife food chains, wetlands provide diverse structure for other wildlife habitat needs.

Over 1,400 species of wildlife have been reported for constructed and natural treatment wetlands in the NADB v. 2.0. These include more than 700 species of invertebrates, 78 species of fish, 21 species of amphibians, 31 species of reptiles, 412 species of birds, and 40 species of mammals. Over 800 animal species have been reported in constructed treatment wetlands alone.

Wetland monitoring efforts have charterized all biotic communities in constructed treatment wetlands, including macroinvertebrates.

Because species lists have been determined for only a small fraction of the treatment wetland sites listed in NADB v. 2.0, and because of the widely disparate methods and seasons of measurement, these species totals underestimate the diversity that exists in treatment wetlands in North America. The sections that follow describe findings for each wildlife group individually.

Invertebrates

A total of 709 species of aquatic invertebrates have been recorded from treatment wetlands in NADB v. 2.0. These include 15 species of aschelminthes, 81 species of crustaceans, 12 species of arachnids, 29 species of molluscs, and 589 species of insects. Twenty-three treatment wetland systems listed in NADB v. 2.0 have invertebrate data. In most cases, only species lists are available. A few systems reported quantitative data, although sampling techniques varied. Although a total of 342 species of benthic macroinvertebrates have been reported for constructed treatment wetland sites, the average diversity (H') is low at 1.36 units. The average benthic macroinvertebrate diversity for natural treatment wetlands is 2.29 units with a total of 349 species reported for all sites. These low diversities are typical of unaltered wetland environments due to low ambient dissolved oxygen levels and fluctuating water availability.

Average benthic populations summarized in the NADB v. 2.0 are 6,083 individuals per square meter for constructed treatment wetlands and 2,102 per square meter for natural treatment wetlands. Total populations of mosquito larvae and pupae in treatment wetlands are reported from a few projects. Average densities are 1,144 individuals per cubic meter for constructed treatment wetlands (pilot wetlands in Hemet, Site No. 98, and Sacramento, Site No. 99, California) and 952 per cubic meter in natural treatment wetlands. The range of values around these averages is great and may reflect differences in sampling techniques as much as differences between actual wetland mosquito populations.

No functional measures for invertebrate populations were discovered from treatment wetland studies. Secondary production of invertebrates can be evaluated by using repeated population estimates through time. General anecdotal observations from newly constructed treatment wetlands indicate that invertebrate populations develop quickly when treated wastewaters are added and that these population trends are highly variable when vegetative cover changes during the first few seasons of wetland maturation. Long-term populations of invertebrates appear to be more stable and more characteristic of natural wetland environments.

Snakes such as this water moccasin are an important link in the food webs of treatment wetlands.

Fish

Seventy-eight fish species are reported from 13 treatment wetland sites in NADB v. 2.0 (64 species from constructed treatment wetlands and 24 species from natural treatment wetlands). Mosquitofish (*Gambusia affinis)* were reported from 5 constructed and 4 natural treatment wetlands. This species, found in 69 percent of the treatment wetlands where fish were sampled, is often intentionally introduced into these treatment wetlands; other species are apparently present as a result of volunteer colonization.

Amphibians

Twenty-one amphibian species are reported from 6 constructed and 3 natural treatment wetlands in the NADB v. 2.0. Ten species are reported from constructed treatment wetlands and 14 species from natural treatment wetlands. Amphibian species occurrence was recorded at two natural treatment wetland sites in South Carolina, but populations were not quantitatively sampled. From 4 to 8 amphibian species were observed each year during 7 years of operation of the Vereen natural treatment wetland (Site No. 22). From 4 to 7 amphibian species were observed over 3 years at Central Slough (Site No. 12). The likely amphibian diversity at these two locations is greater than these numbers indicate since sampling was qualitative and conducted over a limited period during the spring of each year. No quantitative data on amphibian populations are included in the database.

Reptiles

Thirty-one reptile species are reported from 5 constructed and 4 natural treatment wetlands in NADB v. 2.0. These species include snakes, alligators, lizards, and turtles. Seven species are reported from constructed treatment wetlands and 28 species from natural sites. The Vereen site in South Carolina (Site No. 22) had between 6 and 9 reptile species while Central Slough (Site No. 12) had between 1 and 6 species. As with the amphibian data above, reptile diversity at these sites is likely greater than what is reflected by these numbers. No quantitative data on reptile populations are included in the database.

Birds

Bird data are reported for 21 constructed treatment wetland sites and 7 natural treatment wetland sites in the NADB v. 2.0. The majority of these data are species lists and population densities. Very few data on breeding success, nesting, brood production, and mortality rates were found for this review.

A total of 412 bird species are reported from these treatment wetlands. Constructed treatment wetlands are represented by 361 bird species and natural treatment wetlands by 170 bird species. Of the bird species listed, 51 are waterfowl, 23 are wading birds, 24 are terns or gulls, 45 are shorebirds, 29 are raptors or scavengers, 7 are fowl-like, and 235 are passerine or non-passerine land birds. Approximately 45 percent of the total of 412 species reported from treatment wetlands are commonly considered to be wetland-dependent for some portion of their life history. This finding indicates that a majority of the bird species recorded at these treatment wetland sites are facultative wetland inhabitants.

Bird species counts and population densities vary between sites, and even at a single treatment wetland site on a seasonal basis.

Bird diversity and density in treatment wetlands is typically high.

Site Name	Number Observed Species	Average Density (#/ha)
Constructed Wetlands		
Lakeland, FL	190	6
West Jackson County, MS	61	10
Arcata, CA	159	61
Hayward, CA	134	114
Show Low, AZ	155	14
Collins, MS	35	7
Tres Rios, AZ	78	2958
Incline Village, NV	53	19
Natural Wetlands		
Gainesville, FL	20	23
Vereen, SC	103	19
Biwabik, MN	46	13

For example, the Hayward marsh (Site No. 51)in California recorded population densities ranging from 34 to 280 birds per hectare during monthly counts. Two demonstration-scale constructed wetlands are being studied at the Tres Rios, Arizona (Site No. 112), constructed treatment wetland. Bird species numbers by month for the Hayfield and Cobble sites reflect this variability, and total species counts for a year are much higher than for any individual month (61 species at the Cobble site and 66 species at the Hayfield site). These two sites are less than 0.5 mile apart and have very similar surface areas and plant communities, but are adjacent to different natural riparian systems. Total bird densities averaged 295 birds per hectare at both sites. These high densities are dominated by yellow-headed blackbirds (*Xanthocephalus xanthocephalus*), with about 1503 birds per hectare. Bird population densities in natural riparian hibitats in the same area are much lower than the average bird densities measured at the Tres Rios Wetlands.

Bird populations were studied at the Des Plaines, Illinois (Site No. 206), constructed treatment wetlands before and after project startup. A total of 22 species were observed during the breeding season in 1985 before construction began, and from 30 to 37 species were observed during breeding season counts in 1990 and 1991. Spring migration waterfowl and wading bird counts were also made at this wetland. Number of waterfowl species observed during the first 7 weeks of migration rose from 3 to 14 (1990) prior to project start-up and 15 (1991) species with the project. Total waterfowl and wading bird densities at this site were between 691 and 929 birds during the spring migration counts and between 363 and 478 birds during the fall migration counts.

Detailed bird population data were collected from natural treatment wetlands at Houghton Lake, Michigan (Site No. 709), and Vereen, South Carolina (Site No. 22). Total number of bird species recorded at the Houghton Lake site (based on three transects combined) were between 34 and 45 from 1978 through 1989 and have declined somewhat more recently. Total number of bird species at Vereen varied from 35 to 45 during the first 5 years of operation, compared with 41 species during the baseline study.

Avian botulism is a paralytic disease of birds caused by ingesting a toxin produced by *Clostridium botulinum*. Insufficient evidence is currently available to identify the specific causes of outbreaks of avian botulism. Avian botulism is a problem in many wildlife refuges and is known to occur in western wetlands that receive agricultural return flows and drain waters. Botulism has also been observed to occur in deep water wetlands and rivers with high oxygen. Although wastewater discharges and treatment wetlands have been implicated with the propagation of this disease (Friend, 1985), specific documented case histories are rare.

Avian cholera is a highly infectious disease caused by the bacterium *Pasteurella multocida* (Friend, 1987). Death can occur in as little as 6 to 12 hours following exposure. Migratory waterfowl concentrated in wetlands are particularly susceptible to this infection, and many other wetland-dependent bird species can also be infected with the disease. Avian cholera has been reported at one treatment wetland, the Hayward Marsh (Site No. 51) on the east shore of San Francisco Bay, south of Oakland, California. Annual episodes of avian cholera have been noted at this site for the past 6 years. Infected birds are collected, counted, and disposed of to reduce spread of the disease. The average number of infected waterfowl collected during a 6 year period was 127 per year (15 to 340 birds per year). This wetland supports very high waterfowl populations during the fall months, with peak numbers above 30,000 birds per day. Also, avian cholera is encountered in nearly all wetlands in and around San Francisco Bay. For these reasons, there appears to be no relationship between the avian cholera observed at this location and the source or quality of the water treated at this system.

The bird watching blind at the Pintail Marsh in Show Low, Arizona, provides educational opportunities for school children.

A parasite that is known to infect wading birds feeding on small fish in Florida wetlands is *Eustrongyloides ignotus* (Spalding, 1990). Only a few studies of the occurrence of eustrongylidosis in wetland wading birds at treatment wetlands have been conducted (Frederick and McGehee, 1994). The most comprehensive study to date was at the Everglades Nutrient Removal project (Site No. 92) in south Florida. Of 12,000 individual fish and 19 species sampled and analyzed during this study, none were infected with the nematode responsible for eustrongylidosis (SFWMD, 1997).

Mammals

Forty mammal species are recorded in NADB v. 2.0. A total of 22 species are reported from 6 constructed treatment wetland sites and 27 species from 4 natural treatment wetland sites. Quantitative data on mammal populations are limited in the database to small mammal surveys at the constructed treatment wetland in Iron Bridge (Site No. 92), Florida (from the downstream Seminole Ranch wetlands that receive the discharge from Iron Bridge) and at the natural treatment marsh in Houghton Lake, Michigan (Site No. 209).

Small mammal densities at Iron Bridge ranged from 2.0 to 37 individuals per hectare with from 1 to 3 species collected on each sample date. Small mammal densities at Houghton Lake ranged from 140 to 213 individuals per hectare with 2 to 7 species per transect in 1979, and 7 to 213 individuals per hectare with 1 to 3 species per transect in 1989. Small mammal monitoring was conducted on three transects at Houghton Lake from 1979 until 1989. These transects were located at 15 m, 250 m, and 500 m downstream of the treated effluent distribution line. Higher small mammal densities and diversities have generally been obtained closer to the distribution pipe in an area of leatherleaf and bog birch mixed with cattails.

Summary and Data Requirements

Qualitative and quantitative studies of animals inhabiting constructed and natural treatment wetlands have revealed that these ecosystems provide attractive and productive habitats. All trophic levels are represented, from microscopic invertebrates to macroinvertebrates, fish, herptiles, birds, and mammals. Numbers of species appear to be generally similar between constructed and natural wetland sites. However, insufficient quantitative faunal data currently exist to correlate population diversity or density with treatment wetland design criteria such as pretreatment water quality, mass loading for key pollutants and nutrients, water depth, vegetation types, etc. Essentially all conclusions concerning relationships between wildlife populations and wetland design must be based on other studies or are currently anecdotal. This lack of information emphasizes the need for well-designed, quantitative studies of wildlife populations conducted in the context of controlled treatment wetland research projects.

Toxic Metals and Trace Organics in Treatment Wetlands

Introduction

A variety of data for metals and trace organic compounds have been collected from 26 wetland treatment wetland sites. Data entered into the NADB v. 2.0 were grouped by the sample matrix: surface water, sediment, or tissue. Tissue samples were further divided into vegetation and wildlife groups. Many data records for metal and trace organic compound concentrations are below detection limits (BDL) in the raw data in the NADB v. 2.0.

Metals

Available data for 25 metals and related elements measured in surface waters, sediments, and biological tissues from treatment wetlands are summarized in the NADB v. 2.0. These data confirm numerous published reports that treatment wetlands reduce surface water concentrations of metals. They also provide a basis for comparing treatment wetland sediment and tissue metals data to published criteria that are considered to be protective of environmental health. Most criteria are based on laboratory tests on highly sensitive species. Comparisons of treatment wetland trace metal concentrations to published criteria should be cautious due to the general lack of research that demonstrates that criteria levels actually create effects in wetland environments.

Trace Organics

Data for more than 120 trace organic compounds are reported for treatment wetland

Comparison of treatment trace metal concentrations to chronic ambient water quality criteria. Mean treatment wetland concentrations are typically close to or less than water quality criteria; however some means and most maximum reported values are above chronic criteria.

	Chronic Ambient	Wetland Effluent Outflow Water Concentration (ug/L)					
	Water Quality	Constructed Treatment			Natural Treatment Wetlands		
Metal	Criteria (ug/L)[a]	Mean	Max	% BDL	Mean	Max	% BDL
Arsenic	190	5.1	25	14	N.D.	N.D.	N.D.
Cadmium	1.0 h	0.5	5.0	69	1.2	5.0	80
Chromium (III)	180 h	4.0	30	41	17	69	50
Copper	11h	7.4	90	32	3.0	15	31
Lead	2.5 h	5.4	40	51	3.2	15	52
Mercury	1.3	0.53	4.9	62	0.24	1.0	86
Nickel	160 h	14.1	210	31	9.3	25	72
Selenium	5.0	1.4	12	69	N.D.	N.D.	N.D.
Silver		0.56	5.0	75	3.9	15	70
Zinc	100h	22	320	35	10	39	42

[a] U.S. EPA 1986a, 1986b, 1987
h = hardness-dependent, assumes 100 mg/l as $CaCO_3$
N.D. = not determined

surface water, sediments, and tissues. Detectable levels for some of these trace organics were found in treatment wetland surface waters, sediments, and biological tissues. A total of 29 trace organic compounds were detected (out of 121 analyzed for) in constructed treatment wetland sediments.

Summary

Wetlands and other aquatic ecosystems can reduce concentrations of metals and trace organics through their complex array of physical, chemical, and biological processes. The efficiency of these pollutant removal processes is of interest as treatment wetlands are being designed for a greater variety of wastewaters with a wide range of concentrations of these trace elements and compounds. On the other hand, sequestration of trace metals and organics in treatment wetlands creates a potential for detrimental biological effects due to the chemically stable forms of these compounds and their biological toxicity. While some trace organics are lost from the wetland environment through biological degradation or atmospheric volatilization, other organics and most metals tend to accumulate in sediments and in biological tissues.

An important issue needing to be scrutinized is the extent to which these potentially toxic chemicals bioaccumulate and whether they are present in amounts that are toxic to the biota that normally inhabit these wetland environments. The data summarized in the NADB v. 2.0 provide a basis from which to begin finding answers to these questions. However, additional data from controlled, realistic-scale treatment wetland research will need to be collected and analyzed to fully evaluate treatment performance and the potential for detrimental effects from each metal or organic compound of interest.

Effects of Treatment Wetlands on Whole-Effluent Toxicity

Introduction

The Clean Water Act requires that discharges to waters of the United States be "free of toxic substances in toxic amounts." While it is widely recognized that low levels of potentially toxic substances exist in nearly all effluents and in most natural surface waters, no significant detrimental effects from those substances is expected unless concentrations exceed critical levels. The definitions of those critical levels are based on a variety of methods that seek to quantify effects to sensitive groups of aquatic organisms. When practical, specific water quality criteria are established by the U.S. EPA to define acceptable maximum levels for specific toxic chemicals, especially heavy metals and trace organics (U.S. EPA, 1986). Permit criteria reflect these critical levels when it is possible to identify specific chemicals in an effluent that may occur in toxic amounts.

The concept of "whole-effluent" toxicity standards has been developed to regulate releases of complex effluents that may contain from several to dozens of potentially toxic chemicals. Standardized toxicity tests have been developed by U.S. EPA to define the concept of whole-effluent toxicity testing (U.S. EPA, 1989). The freshwater test organisms most frequently used are the fathead minnow (*Pimephales promelas*) and water flea (*Ceriodaphnia dubia*). These tests look for "acute" or "chronic" toxicity. *Acute toxicity* is defined as conditions that lead to the relatively rapid death of the test organism. *Chronic toxicity* is a measure of sublethal effects that ultimately result in a decrease of the organism's population size through impaired behavior or reproduction.

The Hayfield Site demonstration Wetland at Tres Rios west of Phoenix, Arizona, includes two cells with variable numbers of deep water zones to test their effect on hydraulic efficiency and wildlife habitat.

End points typically vary from 24 to 96 hours for acute tests and are typically 7 days for chronic tests. Both acute and chronic whole-effluent toxicity test data are included in the NADB v. 2.0.

Two primary issues are related to whole-effluent toxicity tests and treatment wetlands. The first issue is determining how effective wetlands are as a water quality treatment system in reducing concentrations or bioavailability of toxins and thereby reducing whole-effluent toxicity of a wastewater effluent before it is discharged to a receiving water environment. This issue can be characterized as the effect of the wetland on the toxin(s). To examine this first issue, whole-effluent toxicity input/output data collected from wetlands treating wastewaters are summarized in the NADB v. 2.0.

The second issue deals with the potential effects of effluent toxicity to organisms within the treatment wetland. This issue can be characterized as the effect of the toxin(s) on the wetland. The relevancy of acute and chronic whole-effluent toxicity tests to wetland environments has not been examined. These tests are simplistic in that they focus all attention on only one or two animal species that may or may not have sensitivity to toxins similar to the fauna that normally occur in wetlands. Wetland environments are typically dominated by plant and animal species that are hardier and less sensitive to pollutants than more sensitive species that may occur in other surface waters. Quantitative data of direct or indirect toxic effects to wildlife in treatment wetlands are generally lacking.

Acute Toxicity

Acute toxicity test results were available from four treatment wetlands. No significant mortality was observed at three of these sites receiving municipal effluents. One site receiving an industrial effluent did record acute toxicity to minnows and waterfleas (15 to 16 percent mortality in 100 percent effluent) in treatment wetland effluent samples.

Chronic Toxicity

Chronic toxicity results were available from 10 treatment wetland systems. Nine of these systems are constructed and one is a natural treatment wetland. Some chronic toxicity was identified at several sites, but chronic toxicity effects are consistently reduced by passage through treatment wetlands with surface discharges.

Summary

Acute and chronic whole-effluent toxicity test results are available at a limited number of treatment wetland sites in North America. With a few exceptions, any acute or chronic toxicity that may be present in wetland influent is reduced or completely eliminated after the wastewater passes through the wetland. One example exists in an evaporative treatment wetland where toxicity to freshwater test organisms increases with distance from the point of wastewater input due to increasing total dissolved solids.

Whole-effluent toxicity tests do not distinguish the source of toxicity; therefore, mechanisms for toxicity reduction in wetlands are likely to vary greatly and to depend on the form of the toxicant. A variety of metals and trace organics may cause acute or chronic toxicity in wastewater effluents. Additional study with treatment wetlands is necessary to understand the effects of toxicants on the wetland biota as well as the effects of the wetland on the toxicant.

Human Use of Treatment Wetlands

The primary goal of most treatment wetlands is water quality improvement. Increasingly, however, treatment wetlands have multiple purposes, and it cannot always be assumed that their water treatment goal is more important than their other roles, such as creating wildlife habitat or human recreation areas. The majority of this Executive Summary focuses on the habitat functions of treatment wetlands. This project also summarized what is known about their human uses other than water quality improvement.

Recognized human uses of treatment wetlands in addition to water purification can be lumped into five general categories:

- Nature study
- Exercise activities
- Recreational harvest
- Education
- Commercial harvest

Activities in Treatment Wetlands

Summaries of human use data exist for only a few treatment wetland systems. The

A wooden tower provides a panoramic view of the Boggy Gut Wetland on Hilton Head Island, South Carolina.

Arcata, California (Site No. 25), constructed wetland is used by an estimated 100,000 visitors per year (Benjamin, 1993). This level of activity is sustained because the system is located in a progressive, coastal California community near a trail system and park-like setting. Data from Arcata summarized in the NADB v. 2.0 indicate that from 27,000 to 64,000 human use-days per year (HUD/y) are devoted to general picnicing and relaxing. These data may also be expressed on a unit area basis as a total of about 1,600 HUD per hectare per year (HUD/ha/y) for the entire Arcata Marsh and Wildlife Sanctuary. At the Show Low, Arizona (Site No. 76), constructed treatment wetland, human use data are lumped for all categories and averaged about 370 HUD/yr or about 7 HUD/ha/yr. The Iron Bridge, Florida (Site No. 13), constructed wetland has an overall estimated human use of about 4,800 HUD/y or about 10 HUD/ha/y.

Nature Study

Nature study includes a variety of activities that may be associated with treatment wetland projects:

- Bird study
- Plant observation and identification
- Observation and identification of other wildlife groups
- Plant and wildlife photography
- Plant and wildlife art

Few data are available that specifically describe any of these activities. Arcata, California, has reported data indicating about 10,000 HUD/yr or 165 HUD/ha/yr for bird watching. Photography and art account for about 360 to 900 HUD/yr at Arcata. Anecdotal information is available that indicates that bird-watching groups regularly use treatment wetlands at West Jackson County, Mississippi (Site No. 18); Hillsboro, Oregon; Show Low, Arizona (Site No. 76); Pinetop-Lakeside, Arizona; Lakeland, Florida (Site No. 1); and Iron Bridge, Florida (Site No. 13). Some of these sites are visited by organized groups on a regular basis (once a week or month), while others are visited by individuals or groups on a less regular schedule.

Exercise Activities

When treatment wetlands are open to the public, they are frequently used for activities that provide exercise. Forms of exercise known to occur in treatment wetlands include hiking, jogging, and off-road bicycling.

Treatment wetland sites that are open to the general public for these activities include Show Low, Arizona; Pinetop-Lakeside, Arizona; Tres Rios, Arizona; Arcata, California; Sea Pines, South Carolina; Iron Bridge, Florida; Cannon Beach, Oregon (Site No. 204); Hillsboro, Oregon; and Mountain View, California (Site No. 312).

Bird counts have shown that constructed treatment wetlands have bird diversity and population numbers as high or higher than many natural wetlands.

Hiking and jogging at the Arcata, California, constructed wetland is estimated as about 18,000 HUD/yr. One specific component of this use that was identified includes about 900 HUD/yr just for walks led by the Redwood Region Audubon Society.

No other quantitative data specifically recording exercise activities in treatment wetlands were available for this review.

Recreational Harvest

A small number of treatment wetlands are open to the public or to private individuals for hunting and/or fishing.

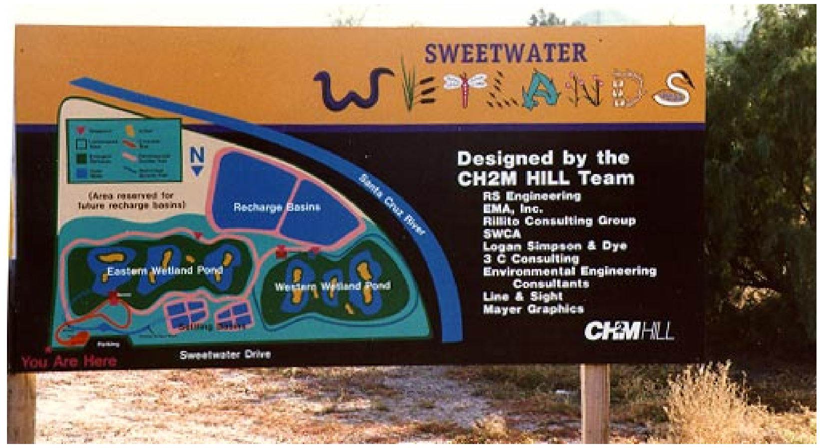
A borrow pit at the Arcata Marsh and Wildlife Sanctuary in California is open for fishing, but use is reported to be light and seasonal.

At Incline Village, Nevada (Site No. 310), duck blinds are available on a lottery basis. Typical hunter use days are about 877 HUD/yr or 5.6 HUD/ha/yr. About 817 ducks and 60 geese are harvested per year at this constructed wetland.

The Iron Bridge, Florida (Site No. 13), constructed wetland is closed to the public from September through March of each year and is available to former land owners for waterfowl hunting and fishing during this period. The Houghton Lake, Michigan natural treatment wetland (Site No. 209); the Show Low, Arizona (Site No. 76), constructed wetland; and the area downstream of the Columbia, Missouri, constructed wetland are open to hunters as state-controlled wildlife management areas. About 836 HUD/yr or 1.6 HUD/ha/yr are available for duck hunting at the Columbia, Missouri, site.

Education

Treatment wetlands have been used for a variety of educational opportunities. Some sites are open for controlled access of grade school and high school students and for various college classes and individual undergraduate and graduate research. The only two sites that were quantified are Arcata, California, with an estimated 1,500 HUD/yr and Vereen, South Carolina with an estimated 234 educational and research HUD/yr.



The City of Tucson, Arizona, has made its Sweetwater Wetlands a community affair.

Commercial Harvest

The potential to use treatment wetlands for commercial production of food and fiber has been discussed (Wengrzynek and Terrell, 1990; Knight, 1992; Kadlec and Knight, 1996). Types of potential commercial uses include:

- Plant harvesting for food (such as water chestnuts) or fiber (such as common reed, pulp wood, saw timber)
- Trapping of mammals for furs (nutria, muskrat, beaver)
- Aquaculture (baitfish, food fish, crayfish, frog legs, etc.)

No data concerning any of these uses were obtained for this project.

Miscellaneous Activities

Treatment wetlands may provide human-use benefits other than those described above. It is not possible at this time to anticipate all of the possible uses that will be derived from these green machines. Types of miscellaneous activities that have been observed include:

- School projects to name constructed wetlands
- Community service outings to help plant new constructed wetlands, clear trash, and install bird and bat houses
- Boy Scout projects to build public use facilities
- Citizen groups and government officials meeting to review wastewater management options

These activities are known to exist but have been difficult to quantify.

Summary

Treatment wetlands often provide human use benefits in addition to their primary role for water quality treatment. These uses vary greatly and have been quantified in only a few cases. Additional data on human use in treatment wetlands are needed to determine the significance of these activities and to provide information to designers on how to provide the best opportunities for cost-effective use.

Permitting-related work at the Pintail Marsh in Show Low, Arizona (Site No. 76), included an assessment of the net ecological benefits of these effluent-dependent waters.

Treatment Wetland Design for Wildlife Habitat and Human Use

Introduction

The need for information related to the potential effects of treatment wetlands on natural biota and humans has been recognized for years (Godfrey et al., 1985 and Feierabend, 1989). The ETI Treatment Wetland Habitat Project is the first attempt to provide a comprehensive summary of the state of our knowledge concerning the relationship between treatment wetlands and their interaction with wildlife and human use. While this summary indicates significant areas of incomplete understanding, it also provides a clearer view of those areas where conclusions are warranted.

The information summarized in this Executive Summary and the companion report indicates that treatment wetlands typically have the following properties:

- Their biological structure is substantial and is dominated by relatively diverse assemblages of wetland plant species, typically including a few dominants and many less common species that have specific adaptations to grow in saturated soils
- All major animal groups and trophic levels that occur in natural wetlands are represented in treatment wetlands; population size and diversity in treatment wetlands are generally as high or higher as in other wetlands; no documented occurrences of detrimental effects to wildlife caused by the pollutant-cleansing function of treatment wetlands were noted

- Contaminant data from treatment wetlands for heavy metals and trace organics are available for sediments and biological tissues; treatment wetlands are effective at reducing concentrations of these pollutants; these data do not generally indicate a threat to flora and fauna based on the existing range of contaminant loadings
- Treatment wetlands are generally effective at reducing levels of whole-effluent toxicity
- Humans are using treatment wetlands for a variety of purposes in addition to water quality enhancement

As data concerning each of these items continue to become more available, the next step is to apply this information to the design and operation of new and existing treatment wetlands. Brief discussions of important areas for additional research and how resulting knowledge might be applied in the future are provided below. New projects that have benefited from this expanding information base have been designed and implemented during the lifetime of the ETI Treatment Wetland Project. Examples of these new systems include municipal effluent treatment wetland projects at Beaufort, South Carolina (Great Swamp Natural Effluent Management System), Tucson, Arizona (Sweetwater Wetlands), and Palm Beach County, Florida (Wakodahatchee Wetlands).

Water Quality Considerations

The effects of wetlands on water quality have been described in detail elsewhere (e.g., Kadlec and Knight, 1996; U.S. EPA, 1999). The ETI Treatment Wetland Habitat Project is intended to provide information to researchers who may wish to examine the flip-side of this question—namely, the effect of the water quality on the wetland environment.

Contaminants in wastewaters are known to affect the wetland environment. These effects are highly variable depending on the specific constituents and the biological components of the wetland in question. Research efforts should be designed to correlate these water quality conditions with treatment wetland environmental conditions. The most basic comparisons have not been made between treatment wetlands with varying dissolved oxygen and nutrient conditions and their ability to support diverse plant and animal populations. Although pH requirements for some individual plant and animal species are known, there are no studies of the effect of varying pH in treatment wetlands. Although the toxicity of many trace metals and organics are known in laboratory studies with one or a few plant or animal species, there is very little information on the ecosystem-level effects of these substances in treatment wetlands. The information collected for this ETI Habitat Project only provides a starting point for the studies needed to develop empirically based treatment/habitat wetland design criteria.

Biological Considerations

During the review of new and existing discharge permits to treatment wetlands, environmental agency staff are frequently faced with the difficulty of assessing the potential for harmful environmental effects. The potential receptors of most interest are typically the vertebrate inhabitants of the wetlands including fish, amphibians, reptiles, birds, and to a lesser extent, mammals. These organisms tend to be more highly visible to people than the invertebrates, and concern for their fate is highest in the public’s priorities. While it is recognized that the invertebrates are also of importance, their protection is generally justified based on their place in the food chain supporting the vertebrate forms.

Summary of design considerations for treatment wetland habitat and public use benefits.

Design Criteria	Explanation
Water Quality Considerations	
Pre-treat toxic trace metals and organics	It is important to protect those wildlife species that range outside the boundaries of the treatment wetland
Pre-treat excessive loads of mineral and organic sediments	High sediment loads can suffocate wetland emergent plant roots
Pre-treat excessive organic and ammonia nitrogen concentrations	High loadings of oxygen-demanding substances will cause nuisance conditions in treatment wetlands, including poor plant growth
Wildlife Habitat Considerations	
Design flexibility to control water levels	Water level control is the principal tool available to control plant growth and water quality improvement
Incorporate deep-water zones without creating hydraulic short circuits	Deep water zones serve multiple purposes, including improved hydraulic mixing and residence time, a sump for solids storage, and perrenial habitat for fish and waterfowl
Utilize a diversity of plant species	Polyculture will provide greater habitat diversity and greater resistence to pests and operational upsets
Utilize plant species with known benefits to wildlife species	Each plant species provides differing benefits to different wildlife species/groups
Incorporate vertical structure by planting aquatic, emergent, shrub, and canopy strata, and by installing snags and nesting platforms	Structural diversity equates to habitat variety for feeding, roosting, and nesting wildlife
Incorporate horizontal structure by providing littoral shelves, islands, and the use of irregular shorelines	Plant diversity is promoted by varying water depths, islands provide a refuge for birds and other wildlife, and irregular shorelines provide visual cover and greater ecotone length
Public Use Considerations	
Provide parking and safe access to wetlands	Humans will be attracted if they have access and feel safe
Provide boardwalks and observation points	Boardwalks allow the public to get a "feel" for being in the wetland environment
Incorporate interpretive displays	The public is eager to learn more about the structure and function of wetlands
Collect public comment and incorporate in design/ operation modifications	The public will provide useful suggestions for improvement
Publicize the wetlands	The public can be an ally during permitting and funding for treatment wetlands
Inlist volunteer participation	Providing the public with a sense of ownership will help enlist support
Establish accessible monitoring points	Treatment wetlands provide excellent classrooms for environmental study
Provide blinds for wildlife study	Observing wildlife without disturbing it will optimize both habitat and public uses
Maintain adequate monitoring records	The public has a right to know about any hazards or benefits being created by a treatment wetland

While the use of wetlands to improve the quality of wastewaters is considered an important goal, it is also important to balance the benefits of meeting that goal with the avoidance of harm to those organisms that will ultimately reside in the living treatment system.

The information gathered for this report indicates that biological changes can occur in response to discharges of treated effluents. These changes cover the spectrum from obvious to subtle. Many of the changes that have been noted favor one group of species over another. The most

Alligators are a common predator in constructed treatment wetlands throughout the southeastern United States.

common changes result in an increase of wetland structure and function at an ecosystem level. Assigning value judgments to these types of changes becomes a matter of perspective.

There is currently no evidence that treated wastewater effluents cause increased risks for vertebrates in treatment wetlands. This lack of evidence does not prove that there are no effects, but it indicates that most treatment wetland projects can be permitted without special requirements other than reasonable caution. Greater caution should be exercised when project wastewaters are known or suspected to contain unusually elevated concentrations of heavy metals, trace organics, un-ionized ammonia, or other chemicals that are likely to be acutely or chronically toxic to aquatic and wetland biota. These potentially toxic chemicals are only of special interest when they are at concentrations above the range typical of normal wastewaters from the same general source. This greater level of caution during project design and review is most relevant to those wastewaters, leachates, and stormwaters that have received minimum levels of pretreatment.

Human Use

Very little information is available about how to best integrate human use with treatment wetlands. Benjamin (1993) presents a highly useful summary of the issues related to public perception and use of the most-visited treatment wetland in the United States, the Arcata Marsh and Wildlife Sanctuary in California. That study concluded that the Arcata Marsh is a great success in its role as a community open space and as a recreational, ecological, and educational resource. Interviews identified birds and wildlife viewing as the most popular public uses of the marsh. The second most common response to questions about the benefits of the marsh focused on its aesthetic qualities, including scenery, beauty, and open space. The most common response to the survey question concerning what the public disliked about the Arcata Marsh was “nothing.” These obvious benefits are being accomplished even as the Arcata Marsh meets its primary goal of water quality protection.

Anecdotal information indicates that similar responses might be obtained at several other treatment wetland sites open to the public. Studies similar to the one conducted by Benjamin (1993) should be conducted at a number of treatment wetlands that are open to the public to develop wider guidance for how humans interact with wetlands.

Summary

The ETI Treatment Wetland Habitat Project demonstrates that both natural and constructed treatment wetlands have substantial plant communities and wildlife populations. The concern that treatment wetlands are botanical monocultures is not supported by the data. Diverse and abundant populations of wildlife use the variety of niches provided by the complex plant communities that develop in many treatment wetlands.

This project has documented the presence of potentially harmful substances in the water, sediments, and biological tissues of treatment wetlands. While it is highly likely that some or all of these substances at high concentrations could create harmful conditions for the biota attracted to treatment wetlands, contaminant concentrations are generally below published action levels and there is apparently no documentation that harm has occurred in any wetland intentionally designed for water quality improvement. While this lack of evidence does not prove that harm does not occur somewhere in a treatment wetland, current evidence indicates that treatment wetlands support complex ecosystems that are as productive as, or more productive than, unaltered natural wetlands.

The Cobble Site Demonstration Treatment Wetland for the City of Phoenix tests the feasibility of recreating habitat in the dry channel of the Salt River.

This project represents a first step at collecting and summarizing the information on habitat and wildlife use of treatment wetlands. The number of new treatment wetland projects gathering and reporting these types of data is increasing yearly. While substantial data about the diversity of plants and animals inhabiting treatment wetlands are available, it is hoped that these new and ongoing studies will shed greater light on the ecological functions of these systems and their full potential for environmental benefit or harm.

References

Bastian, R.K. and D.A. Hammer. 1993. The Use of Constructed Wetlands for Wastewater Treatment and Recycling. Chapter 5, pp. 59-68 in G.A. Moshiri (ed.), *Constructed Wetlands for Water Quality Improvement*. Lewis Publishers, Boca Raton, Florida.

Bastian, R.K., P.E. Shanaghan, and B.P. Thompson. 1989. Use of Wetlands for Municipal Wastewater Treatment and Disposal-Regulatory Issues and EPA Policies. Chapter 22, pp. 265-278. In D.A. Hammer (ed.), *Constructed Wetlands for Wastewater Treatment: Municipal, Industrial, and Agricultural*. Lewis Publishers, Chelsea, Michigan.

Benjamin, T.S. 1993. *Alternative Wastewater Treatment Methods as Community Resources: The Arcata Marsh and Beyond.* Master of Landscape Architecture Thesis, University of California at Berkeley.

CH2M HILL, 1997. *Treatment Wetland Habitat and Wildlife Use Assessment Project.* Prepared for the U.S. Environmental Protection Agency, U.S. Bureau of Reclamation, and the City of Phoenix with funding from the Environmental Technology Initiative Program.

CH2M HILL and Payne Engineering. 1997. *Constructed Wetlands for Livestock Wastewater Management. Literature Review, Database, and Research Synthesis.* Report Prepared for the Gulf of Mexico Program, Nutrient Enrichment Committee, Stennis Space Center, MS.

Frederick, P.C. and S.M. McGehee. 1994. "Wading Bird Use of Wastewater Treatment Wetlands in Central Florida, USA. " *Colonial Waterbirds* 17(1):50-59.

Freierabend, J.S. 1989. Wetlands: The Lifeblood of Wildlife Chapter 7, pp. 107-118. In D.A. Hammer (ed.), *Constructed Wetlands for Wastewater Treatment: Municipal, Industrial, and Agricultural.* Chelsea, Michigan: Lewis Publishers. 1989.

Friend, M. 1987. (ed.) *Field Guide to Wildlife Diseases. Volume 1. General Field Procedures and Diseases of Migratory birds*. U.S. Department of the Interior, Fish and Wildlife Service. National Wildlife Health Center, Madison, Wisconsin.

Friend, M. 1985. Wildlife Health Implications of Sewage Disposal in Wetlands. Chapter 17, pp. 262-269 in: P.J. Godfrey, E.R. Kaynor, S. Pelczanski, and J. Benforado (eds.). *Ecological Considerations in Wetlands Treatment of Municipal Wastewaters*. Van Nostrand Reinhold, New York.

Godfrey, P.J., E.R. Kaynor, S. Pelczarski, and J. Benforado. 1985. (eds.) *Ecological Considerations in Wetlands Treatment of Municipal Wastewaters.* Van Nostrand Reinhold, New York, 473 pp.

Guntenspergen, G.R. and F. Stearns. 1985. Ecological Perspectives on Wetland Systems. Chapter 5, pp. 69-97 in: P.J. Godfrey, E.R. Kaynor, S. Pelczanski, and J. Benforado (eds.). *Ecological Considerations in Wetlands Treatment of Municipal Wastewaters*. Van Nostrand Reinhold, New York.

Kadlec, R.H. and R.L. Knight. 1996. *Treatment Wetlands.* Lewis Publishers, Boca Raton, FL, 893 pp.

Knight, R.L. 1992. Ancillary Benefits and Potential Problems With the Use of Wetlands for Nonpoint Source Pollution Control. *Ecological Engineering* 1:97-113.

Knight, R.L., R.W. Ruble, R.H. Kadlec, and S. Reed. 1993. Wetlands for Wastewater Treatment: Performance Database. Chapter 4, pp. 35-58 in: G.A. Moshiri (ed.). *Constructed Wetlands for Water Quality Improvement.* Lewis Publishers, Boca Raton, FL.

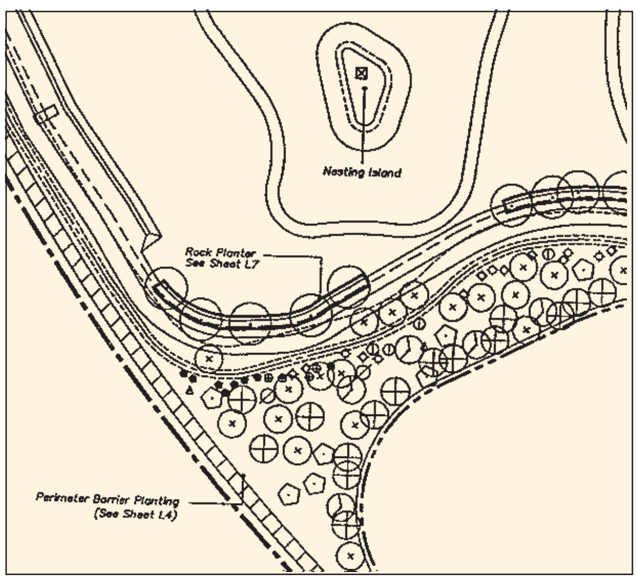
Knight, R.L. 1997. Wildlife Habitat and Public Use Benefits of Treatment Wetlands. *Water Science & Technology* 35(5): 35-43.

McAllister, L.S. 1992. *Habitat Quality Assessment of Two Wetland Treatment Systems in Mississippi: A Pilot Study.* U.S. Environmental Protection Agency. Environmental Research Laboratory, Corvallis, Oregon. November 1992. EPA/600/R-92/229.

McAllister,L.S. 1993a. *Habitat Quality Assessment of Two Wetland Treatment Systems in the Arid West: A Pilot Study.* U.S. Environmental Protection Agency. Environmental Research Laboratory, Corvallis, Oregon. July 1993. EPA/600/R-93/117.

McAllister,L.S. 1993b. *Habitat Quality Assessment of Two Wetland Treatment Systems in Florida: A Pilot Study.* U.S. Environmental Protection Agency. Environmental Research Laboratory, Corvallis, Oregon. November 1993. EPA/600/R-93/222.

Mitsch, W.J. and J.G. Gosselink. 1993. *Wetlands*. Second Edition. Van Nostrand Reinhold, New York. 722 pp.



Many constructed treatment wetland designs include diverse plantings of native wetland species to provide wildlife habitat as well as project aesthetics.

Pries, J.H. 1994. *Wastewater and Stormwater Applications of Wetlands in Canada.* North American Wetlands Conservation Council (Canada). Issues Paper, No. 1994-1, Ottawa, Canada.

Reed, Jr., P.B. 1988. *National List of Plant Species that Occur in Wetlands: National Summary*. U.S. Fish and Wildlife Service. Biol. Rep. 88(24) 244 pp.

Sather, J.H. 1989. Ancillary Benefits of Wetlands Constructed Primarily for Wastewater Treatment. Chapter 28a, pp. 353-358 in: D.A. Hammer (ed.) *Constructed Wetlands for Wastewater Treatment, Municipal, Industrial, and Agricultural.* Lewis Publishers, Chelsea, MI.

South Florida Water Management District (SFWMD). 1997. Everglades Nutrient Removal Project. Year 2 Synopsis. West Palm Beach, Florida.

Spalding, M.G. 1990. Antemortem Diagnosis of Eustrongylidosis in Wading Birds (Ciconiiformes). *Colonial Waterbirds* 13(1): 75-77.

U.S. Environmental Protection Agency (U.S. EPA) 1993. *Constructed Wetlands for Wastewater Treatment and Wildlife Habitat – 17 Case Studies*. EPA832-R-93-005, 174 pp.

U.S. EPA. 1999. *Free Water Source Constructed Wetlands: Technology Assessment.* EPA 823- -99- . __ pp.

U.S. EPA. 1986. *Quality Criteria for Water.* EPA-44015-86-001.

U.S. EPA. 1989. *Short-Term Methods for Estimating the Chronic Toxicity of Effluents and Receiving Waters to Freshwater Organisms.* EPA/600/4-89/001.

Wengrzynek, R.J. and C.R. Terrell. 1990. Using Constructed Wetlands to Control Agricultural Nonpoint Source Pollution. In: P.F. Cooper and B.C. Findlater (eds.). Proceedings of the International Conference on Use of Constructed Wetlands in Water Pollution Control. Cambridge, United Kingdom. Pergamon Press, Oxford, UK.

Wilhelm, M., S.R. Lawry, and D.D. Hardy. 1989. Creation and Management of Wetlands Using Municipal Wastewater in Northern Arizona: A Status Report. Chapter 13a, pp. 179-185 in D.A. Hammer (ed.), *Constructed Wetlands for Wastewater Treatment: Municipal, Industrial, and Agricultural*. Lewis Publishers, Chelsea, MI.

Wren, C.D., C.A. Bishop, D.L. Stewart, and G.C. Barrett. 1997. *Wildlife and Contaminants in Constructed Wetlands and Stormwater Ponds: Current State of Knowledge and Protocols for Monitoring Contaminant Levels and Effects in Wildlife.* Canadian Wildlife Service Ontario Region, Technical Report Series Number 269.

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