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WILDLIFE HABITAT AND PUBLIC USE BENEFITS OF TREATMENT WETLANDS

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ABSTRACT

Constructed and natural wetlands are being utilized for water quality management of a broad variety of wastewater types worldwide. While water treatment is a primary goal of many of these systems, there is a general recognition that ancillary benefits for public use and wildlife habitat are typical of some of these wetlands. Also, there are growing numbers of constructed wetlands that are primarily focused on providing habitat and/or public use while relying on pretreated wastewater as the principal water supply. Efforts are currently underway to document the normal ranges of human and wildlife use benefits of treatment wetlands, and to provide a reasoned assessment of the potential environmental risks associated with these systems. Information collected from existing surface-flow treatment wetlands indicates consistent net benefits for wildlife habitat and public use. An understanding of the relationship between design and operation of treatment wetlands, and their positive and negative ecological and societal responses, will allow for optimization of new wetland systems. © 1997 IAWQ. Published by Elsevier Science Ltd

KEYWORDS

Ecorisk; habitat; public use; treatment wetlands; wastewater; wetlands; wildlife.

INTRODUCTION

There are currently more than one thousand constructed and natural wetlands worldwide receiving and treating a variety of municipal, industrial, agricultural, and urban runoff wastewaters (Kadlec and Knight, 1996). These systems range in size from less than 200 m^2 to over 4000 ha. The one structural attribute that all treatment wetlands have in common is the presence of emergent wetland plants. Some systems have only a monoculture of a single species such as *Phragmites australis* (common reed), *Typha* spp. (cattail), or *Scirpus* spp. (bulrush), while others have dozens of plant species in relatively natural, diverse assemblages. In addition to emergent wetland plants, most treatment wetlands have an adequate supply of water, either in the subsurface environment or as surface water. These two environmental components, namely abundant water and growing plants, provide the essential basis of an ecological foodweb that results in the presence of wildlife species in all treatment wetlands.

Directly or indirectly as a result of the plants and wildlife present in treatment wetlands, people are attracted to these systems. Plants provide food and fiber in some systems. Wildlife may also provide a food or fur resource or, more commonly, birds attract humans for their aesthetic appeal. Treatment wetlands are increasingly viewed as a visual attraction for humans interested in the environment either for recreation or environmental study.

Since treatment wetlands are inevitably attractive to wildlife species, there is a persistent concern that they may, in some cases, provide an attractive nuisance. For those wastewaters that contain non-degradable hazardous chemicals such as toxic metals and some synthetic organic compounds, there has long been a concern that wildlife attracted to the potentially-contaminated prey base in productive wetlands might receive dangerous levels of toxins and have increased morbidity as a result (Friend, 1985; ESP, 1995).

A steadily-increasing body of information concerning the three issues described above is available to wetland designers (Sather, 1989; Knight, 1992; EPA, 1993; Merritt, 1994). Information on how to optimize wildlife and human use benefits of treatment wetlands while minimizing ecological risk, can be applied in selection of appropriate pretreatment levels; initiation of sufficient plant and physical habitat diversity in wetlands; and incorporation of structures that facilitate human uses. This paper provides a preliminary summary of these important considerations.

TREATMENT WETLANDS AS ECOSYSTEMS

Plant communities

A general tenet of ecology implies that faunal diversity is directly related to plant community diversity. As the number of plant species increases in a given area, the habitat diversity for animal species increases due to multiple structural niches as well as the range of food resources available. Nevertheless, the faunal diversity of near monocultures of wetland plants may be relatively high as evidenced from studies of *Spartina* saltmarshes and *Taxodium distichum* v. *nutans* (cypress) dominated wetlands in North America (McMahan *et al.*, 1972; Ewel and Odum, 1984). Wetland plant communities may have diversity of vertical structure (canopy, subcanopy, and groundcover) and horizontal diversity through plant zones and intermixtures of open water and emergent plants. Both of these types of structural diversity are generally correlated with increased faunal diversity and abundance (Weller, 1978).

Plants also have a very broad diversity of strategies for growth and reproduction, with some species producing fruits or seeds attractive to fauna as part of symbiotic mechanisms of survival, while other plant species may be unattractive as a food resource for the same purpose. Also, wetland plants have variable adaptations to the physical and chemical environments in treatment wetlands such as water depth, dissolved oxygen, salinity, air temperature, and sunlight. Table 1 provides a summary of the growth requirements of a number of plants used in treatment wetlands, as well as information concerning each species potential value to wildlife support. Over 600 plant species have been reported from treatment wetlands in the U.S.

Plant adaptations are highly individualistic and attempts to carefully control wetland plant populations in gnotobiotic patterns following human desires are typically unsuccessful. A more successful strategy for wetland designers and operators is the establishment of the appropriate range of physical environments in a treatment wetland in terms of areas with differing water depths, and inclusion of diversity during plant establishment within the most suitable habitat areas. The individual plant adaptations will respond to the variety of physical conditions to result in a low-management, sustainable plant community compatible with the environmental conditions of the site, including the quality of the wastewater to be treated.

Animal populations

Animal diversity in surface flow treatment wetlands typically incorporates the full range of groups found in natural wetlands including microscopic invertebrates, macroinvertebrates, fish, reptiles, amphibians, birds, and mammals (Feierabend, 1989; Mitsch and Gosselink, 1993). Due to their reduced or non-existent surface water, subsurface flow wetlands may have more of a terrestrial foodchain rather than an aquatic-based foodchain. A diversity of plant structures and food types can also result in a variety of niches available for support of animal species. Plant monocultures of cattail or common reed can result in relatively low animal diversities. However, population density for animals may be quite high, even in a virtual monoculture of plant species. Prevalence of blackbirds in treatment wetlands dominated by cattail or bulrush species is an example of skewed animal abundances in some wetlands. Incorporation of a mixture of open water and emergent marsh areas, and shallow water/deep water area in treatment wetlands result in a variety of animal groups occupying the same wetland (Kroodsma, 1978; Payne, 1992).

Table 1. Aquatic and wetland plants that can be utilized in constructed wetlands

Plant Species	Common Name	Growth Form	Habitat	Shade Tolerance	Wildlife Benefits	Water Regime	Salinity Tolerance
Acer negundo	Box elder	Tree	Forested wetlands	Full sun	Songbirds; waterbirds; small mammals	Irregular to regular inundation or saturation	Fresh water; resistant to salt water
Acorus calamus	Sweet flag	Emergent; herbaceous	Fresh to brackish marshes	Partial shade	Waterfowl; muskrat	Regular to permanent inundation; < 15 cm	Fresh to brackish; < 10 ppt
Alnus serrulata	Smooth alder	Shrub	Fresh marshes and swamps	Full sun	Songbirds; gamebirds; ducks; woodcock; blackbirds; beaver	Seasonal to regular inundation; up to 7 cm	Fresh water; < 0.5 ppt
Carex spp.	Sedges	Emergent; herbaceous	Fresh marshes; swamps; lake edges	Full shade to full sun	Rails; sparrows; snipe; songbirds; ducks; moose	Irregularly to permanently inundated; <015 cm	Fresh water; <0.5 ppt
Ceratophyllum demersum	Coontail	Submerged aquatic	Lakes; Slow Streams		Ducks; coots; geese; grebes; swans; marshbirds; muskrats	Regular to permanent inundation; 0.3 to 1.5 m	Fresh water; <0.05 ppt
Cyperus esculentus	Chufa	Emergent herbaceous	Fresh marshes; wet meadows	Full sun	Waterfowl; songbirds; small mammals	Irregular to regular inundation; <0.3 m	Fresh water; <0.5 ppt
Eichhornia crassipes	Water hyacinth	Non-rooted floating aquatic	Fresh water ponds and sluggish streams	Full sun	Coots; cover for invertebrates and fish	Permanent inundation	Fresh water; < 0.5 ppt
Hydrocotyle umbellata	Water-pennywort	Emergent to floating; herbaceous	Shorelines; shallow marshes	Partial shade	Wildfowl; waterfowl	Regular to permanent inundation;<30 cm	Fresh water; <0.5 ppt
Iris versicolor	Blue flag	Emergent; herbaceous	Marshes; wet meadows; swamps	Partial shade	Muskrat; wildfowl; marsh birds	Regular to permanent inundation; <15 cm	Fresh to moderately brackish
Juncus effusus	Soft rush	Emergent; herbaceous	Marshes; shrub swamps; wet meadows	Full sun	Wildfowl; marshbirds; songbirds; waterfowl	Regular to permanent inundation; <30 cm	Fresh water; <0.5 ppt
Lemna minor	Common duckweed	Non-rooted floating aquatic	Lakes and ponds	Partial shade	Ducks; gallinules; coots; rails; geese; beaver; muskrat; small mammals	Permanent inundation	Fresh water; <0.05 ppt
Nuphar luteum	Spatterdock	Rooted floating to emergent; herbaceous	Marshes; swamps; ponds	Partial shade	Ducks; muskrat; fish	Regular to permanent inundation; up to 1.8 m	Fresh water to infrequent brackish
Nyssa sylvatica	Black gum	Tree	Forested wetlands; swamps	Partial shade	Ducks; woodpeckers; songbirds; aquatic furbearers	Irregular to permanent inundation	Fresh water to infrequent brackish
Phragmites australis	Common reed	Emergent; herbaceous	Fresh to brackish marshes; swamps	Full sun	songbirds; marshbirds; shorebirds; aquatic furbearers	Seasonal to permanent inundation; up to 60 cm	Fresh to brackish; up to 20 ppt
Pontederia cordata	Pickerelweed	Emergent herbaceous	Fresh to brackish marshes; edges of ponds	Partial shade	Ducks; muskrat; fish	Regular to permanent; up to 30 cm	Fresh to moderately brackish; up to 3 ppt
Populus deltoides	Eastern cottonwood	Tree	Forested wetlands	Full sun	Gamebirds; songbirds; waterfowl; aquatic furbearers; browsers	Seasonal inundation or saturation	Fresh water to infrequent brackish
Potamogeton nodosus	Long-leaved pond weed	Rooted submerged aquatic	Streams; lakes; ponds		Waterfowl; marshbirds; shorebirds; aquatic furbearers; moose; fish	Regular to permanent inundation; 0.3 to 1.8 m	Fresh water; <0.05 ppt
Sagittaria latifolia	Duck potato	Emergent; herbaceous	Fresh marshes; swamps; edge of ponds	Partial shade	Ducks; swans; rails; muskrats; beaver	Regular to permanent inundation; up to 60 cm	Fresh water; <0.5 ppt
Salix nigra	Black willow	Tree	Fresh marshes; swamps	Full sun	Gamebirds; ducks; songbirds; woodpeckers; aquatic mammals	Irregular to permanent inundation	Fresh water; < 0.5 ppt
Scirpus americanus	Olney's bulrush	Emergent; herbaceous	Brackish and alkali marshes	Full sun	Ducks; geese; swans; cranes; shorebirds; rails; snipe; muskrats; fish	Regular to permanent inundation; up to 30 cm	Fresh to brackish water; up to 15 ppt
Scirpus validus	Soft stem bulrush	Emergent; herbaceous	Fresh and brackish marshes	Full sun	Ducks; geese; swans; cranes; shorebirds; rails; snipe; muskrats; fish	Regular to permanent inundation; up to 30 cm	Fresh to brackish water; up to 5 ppt
Sparganium eurycarpum	Giant bur-reed	Emergent; herbaceous	Marshes; swamps; pond shorelines	Partial shade	Ducks; swan; geese; beaver; muskrat;	Regular to permanent inundation; up to 30 cm	Fresh water; < 0.5 ppt
Taxodium distichum	Bald cypress	Tree	Fresh water swamps; pond and lake	Partial shade	Perching and nesting site for birds	Irregular to permanent inundation	Fresh water; < 0.5 ppt
Typha latifolia	Broad-leaved cattail	Emergent; herbaceous	Fresh marshes; pond margins	Full sun	Geese; ducks; muskrats; beaver; blackbirds; fish	Irregular to permanent inundation; up to 30 cm	Fresh water; < 0.5 ppt

Source: Adapted with modifications from Thunhorst (1993).

Figure 1 illustrates wetland bird families that are well represented in a large number of North American treatment wetlands. Secretive birds such as rails, sparrow, wrens, and warblers are found in nearly all treatment wetlands during some part of their annual life history. Lower densities of rarer species such as bitterns or gallinules are also present in monocultures of cattails. Wading birds such as herons, egrets, and shorebirds are dependent upon relatively shallow water edges and mudflats at the interface between aquatic and emergent marsh zones. Ducks, grebes, geese, swans, and piscivorous birds are dependent upon aquatic habitat for food. Raptors may be present at the top of the wetland foodchain feeding on the birds, reptiles and amphibians that feed on the animals nearer the base of the wetland foodchain.

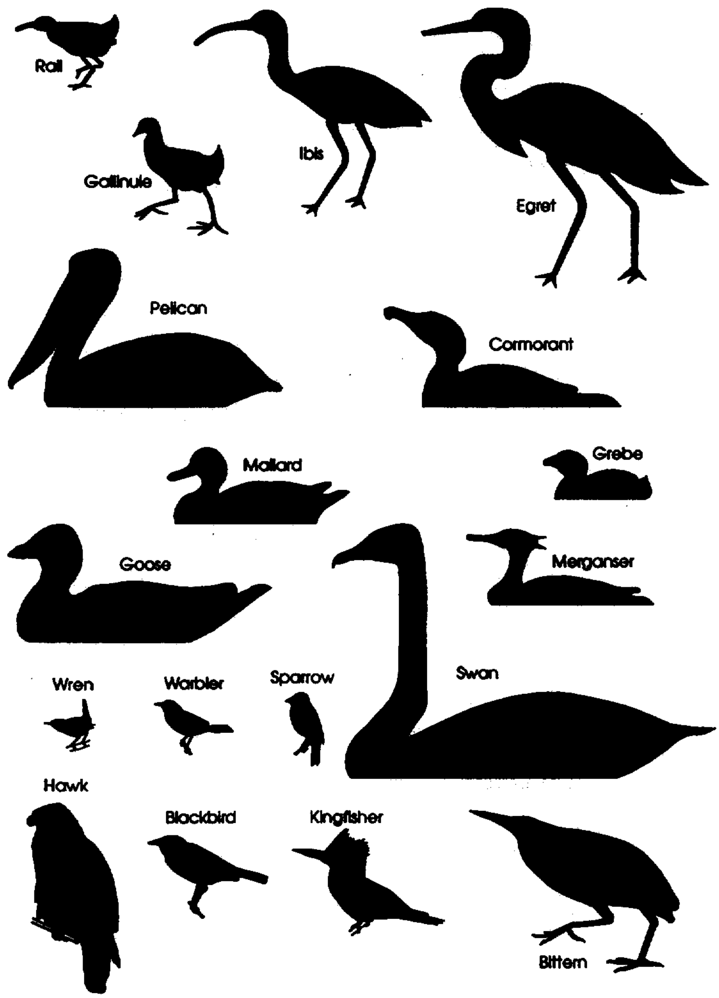

Figure 1. Representative wetland bird family silhouettes (illustrations by Arthur Singer from Birds of North America, Western Publishing Company, Inc).

TREATMENT WETLANDS FOR PUBLIC USE

Production of food, fur and fiber

Treatment wetlands have been utilized for direct human life support by providing a secondary function for aquaculture. Some large constructed and natural treatment wetlands are open for hunting to public or private groups. Examples include Incline Village, Nevada and Iron Bridge, Florida. Some wetlands are harvested for common reed to serve as thatch for roofing, although the quality of reed from treatment wetlands is generally not considered high. Other edible crops such as *Trapa natans* (water chestnuts), finfish such as *Cyprinus carpio* (carp) and *Tilapia* spp. (cichlids), and crayfish (multiple species) can be cultivated in treatment wetlands; however, there are no reported cases where these potential products are harvested on a significant basis. Also, treatment wetlands are an attractive habitat for furbearers such as *Onadatra zibethica* (muskrat), *Myocastor coypus* (nutria), *Castor canadensis* (beaver) and for other commercial species such as *Alligator mississippiensis* (alligators).

Public recreation

The primary human use function for a growing number of treatment wetlands is for passive recreation activities such as hiking, jogging, biking, and wildlife study. Some treatment wetlands, when receiving higher quality wastewater influents, and designed with public use in mind, have been incorporated into park settings that encourage public use. Important examples of such systems include Arcata Wildlife Sanctuary in California, the Cannon Beach Natural Treatment Wetland in Oregon, the Show Low and Pinetop-Lakeside Constructed Wetlands in Arizona, the Orlando Wilderness Park and Greenwood Urban Park in Florida, and the Whangerei Treatment Wetlands in New Zealand. All of these systems incorporate education in the park setting through the use of interpretive signage. Trails, boardwalks, and observation towers facilitate the public's ability to observe the diversity of the wetland habitat and resulting wildlife populations. Birdwatching is an important activity at all of these sites.

Scientific study

Treatment wetlands are in some cases utilized as outdoor laboratories. Because of the interactions between aquatic and upland ecological processes in surface flow wetlands, many of the properties common to a variety of ecosystems can be studied within the boundaries of a treatment wetland. Water quality studies have been the primary focus of much of the research historically conducted in treatment wetlands. This research has looked at the overall transformation rates of elements and chemicals in the aquatic environment of wetlands and has also examined many of the complicated physical, chemical, and biological processes important in those transformations. An increasing amount of research is also being conducted to document plant community distributions and growth rates, populations of invertebrates and vertebrates dependent upon the wetland environment, and the system-level functions including rates of primary productivity, species diversity, peat formation, and trophic interactions.

POTENTIAL FOR ATTRACTIVE NUISANCE

Water quality considerations and pretreatment

Both constructed and natural wetlands are being used at an increasing rate for treatment of wastewaters because of their consistent performance for pollutant removals. Wetlands degrade most forms of organic matter to carbon dioxide and release trace elements in the process. Both particulate and soluble forms of biochemical oxygen demanding compounds are trapped and degraded in wetlands. Potentially toxic metals associated with particulate matter and soluble metals in ionic or complexed form are trapped and retained to varying degrees by the complex biology and chemistry of treatment wetlands. Some organics are only slightly modified and may remain in a treatment wetland in a biologically toxic form for an indefinite time period.

The fate and effect of possibly toxic metals and organics in treatment wetlands is an important concern. A portion of the potentially toxic chemicals that are retained by treatment wetlands will be incorporated into biological tissue. If tissue levels of these chemicals exceed the normal tolerance limits of the wetland biota, problems such as chronic or acute toxic effects may result. Some toxic chemicals are prone to biomagnification in ecological foodchains and, when present in elevated concentrations in wastewaters entering a wetland, they may result in effects at higher trophic levels.

Generally the most effective way to avoid a toxicity problem in a treatment wetland is to prevent it through incorporation of an appropriate level of pretreatment. The goal of pretreatment design is to reduce concentrations of toxic chemicals to levels that will not result in any measurable problems in the treatment wetland. Although heavy metals are commonly found in water samples and in biota, there are action levels below which these concentrations are not a concern. Pretreatment is often the most cost effective method to destroy, or to retain and properly dispose of potentially toxic chemicals without creating an environmental hazard.

The potential for toxicity in treatment wetlands can be controlled but cannot typically be completely eliminated. There are generally highly sensitive species that can be shown to be susceptible to the chronic toxicity of even pre-treated municipal wastewaters. Industrial wastewaters and stormwaters are often even more likely to result in some potential toxicity within a treatment wetland. The complete elimination of toxic substances at toxic amounts, which is the U.S. goal for public surface waters (including natural wetlands), is probably not a realistic goal in constructed treatment wetlands or in any other treatment process. What is realistic is a lesser standard of net environmental benefit within these treatment systems. While the most sensitive species may be diminished in a constructed treatment wetland due to low levels of metals or organics, a suite of other species may be well adapted to tolerate those same concentrations and may provide a high level of primary and secondary productivity of plants and wildlife in the wetland. The net result of such a situation may be the exclusion of sensitive portions of the food web (for example, aquatic fungi and some microscopic invertebrates are very sensitive to some metals), but the existence of viable food chains that still lead to high rates of primary productivity, invertebrate populations, fish, and birds within the same treatment wetland. A constructed treatment wetland may have a reduced diversity of species due to the presence of some toxic chemicals but still result in significant production of healthy wildlife that are important at a regional scale.

Other nuisances to wildlife and humans

Treatment wetlands are potentially hazardous to humans and wildlife through factors other than toxic chemicals in the wastewater. Some of the other possible hazards include pathogens, biting insects, dangerous reptiles, and the potential for drowning. Wastewaters may contain organisms that are pathogenic to humans and wildlife. Examples include viruses, bacteria, fungi, and parasites that can result in the transmission of disease. Where these organisms are potentially a problem, existing technologies are available to prevent disease transmission. Avoidance with direct contact may in some cases be the best prevention.

Mosquitoes and other biting insects may be a nuisance or may be vectors for disease transmission around treatment wetlands. High organic loadings and dense vegetative growth can easily combine to result in high insect production potential in treatment wetlands. Wetlands receiving lower loadings are more likely to have aerated surface waters that can serve as habitat for predaceous organisms (fish and other insects) that naturally control populations of mosquito larvae. Adequate pretreatment, reduced organic loading, and maintenance of aquatic fauna are the best measures to consistently avoid nuisance mosquito populations.

Dangerous reptiles such as poisonous snakes, alligators, and crocodiles are of limited regional significance for treatment wetland design. Where these organisms are a possibility it is important to limit public access to areas where these reptiles can be avoided.

Drowning is a possible problem in treatment wetlands that incorporate deep aquatic zones and the use of the wetland for passive recreation. Boardwalks over deep water should incorporate handrails and deep areas should be bordered by shallow zones along shorelines to avoid accidental drowning.

DESIGN CONSIDERATIONS FOR TREATMENT WETLANDS

Table 2 summarizes many of the design considerations that are important to create wildlife and public use benefits in treatment wetlands. Factors that need to be considered are related to water quality of the wastewater to be treated, design for habitat diversity, and public use considerations. Figure 2 illustrates a treatment wetland with these types of features.

Table 2. Summary of design considerations for treatment wetland habitat and public use

Water Quality Considerations	
Pretreat toxic metals and organics	It is important to protect those wildlife species that range outside the boundaries of the treatment wetland
Pretreat excessive loads of mineral and organic sediments	Mineral and organic sediments can suffocate plant roots
Pretreat excessive organic and ammonia N concentrations	High loadings of oxygen-demanding substances will cause nuisance conditions in wetlands including poor plant growth
Limit total organic loadings	High loadings of oxygen-demanding substances will cause nuisance conditions in wetlands including poor plant growth
Maintain non-zero dissolved oxygen	Anaerobic conditions in the water column will result in negative soil redox potentials and release of hydrogen sulfide and methane
Wildlife Habitat Considerations	
Design flexibility to control water levels	Water level control is the principal tool available to control plant growth and water quality in treatment wetlands
Incorporate deep-water zones without creating hydraulic short circuits	Deep water zones serve multiple purposes including improved hydraulic mixing, increased hydraulic residence time, a sump for solids storage, and perennial habitat for fish and ducks
Utilize a diversity of plant species	Polyculture will provide greater resilience to pests and operational upsets
Utilize plant species with known benefits to wildlife species	Each plant species has benefits to different wildlife species/groups
Incorporate vertical structure by planting herbaceous, shrub, and tree strata	Structural diversity equates to habitat variety for feeding, roosting, and nesting wildlife
Incorporate horizontal structure by incorporating littoral shelves and benches, as well as deep zones	Plant diversity is promoted by varying water regimes that correspond to specific plant preferences
Include structural density by use of irregular shorelines	Irregular shorelines and "fingers" provide visual cover and greater ecotone (edge) length
Include islands in open water areas	Islands provide a refuge for birds and reptiles in wetlands were predation is a potential problem
Install dead snags and nesting platforms	Nesting habitat is frequently limiting in newly-constructed wetlands
Public Use Considerations	
Provide parking and safe access to wetlands	Humans will be attracted to treatment wetlands if they have access and feel safe
Provide boardwalks and observation points	Boardwalks allow the unusual opportunity for non-biologists to get a "feel" for being in a wetland environment
Incorporate interpretive displays	The public is eager to learn more about the natural structure and function of wetlands
Collect public comment and incorporate in design/operation modifications	The public will provide useful suggestions for improvement
Publicize wetlands	The public can be an ally during permitting and funding for treatment wetlands
Enlist volunteer participation	Providing the public with a sense of ownership will help to 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

Water quality considerations focus on maintaining adequate dissolved oxygen and avoiding the presence of toxic substances in excessive concentrations. Pretreatment is commonly necessary to reduce the concentrations of biochemical oxygen demand, suspended solids, ammonia nitrogen, and metals and organics. Pretreatment should attempt to balance the ability of other technologies with the performance of the treatment wetlands to achieve the overall optimum of cost effectiveness and net environmental benefit. For example, elevated concentrations of nutrients such as nitrogen and phosphorus will increase foodchain support for wildlife as long as they do not indirectly lead to anaerobic conditions due to excessive stimulation of algae populations.

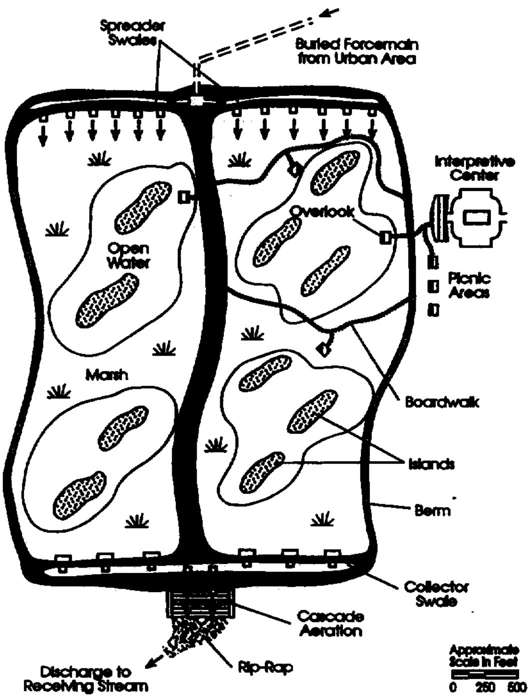

Figure 2. Conceptual plan for treatment wetlands with ancillary benefits.

Wildlife habitat will be created through the mixture of plant and open water zones created in the treatment wetland. Water level control and initial introduction of plant diversity are the two primary influences the designer can manipulate. For the highest diversity, it is necessary to increase the variety of water depths, increase the length of edges between different plant zones, and introduce a variety of native plant species known to be important to desirable wildlife species.

The public will be attracted to treatment wetlands if they are aesthetically pleasing and they are not a nuisance or hazard. The designer should plan to pretreat to levels that preclude odors and mosquito problems; allow convenient public access including public information about the wetland; and design habitat diversity to attract a mix of wildlife species, especially wetland-dependent birds. Given responsible loadings and incorporation of public comment during design, the wetland owner may find a new and valuable ally during planning and permitting of a new treatment wetland.

REFERENCES

Ecological Services for Planning, Ltd (ESP) (1995). *Wildlife Contaminants in Constructed Wetlands and Stormwater Ponds.* Final Report. Prepared for Canadian Wildlife Service Canada Centre for Inland Waters.

Ewel, K. C. and Odum, H. T. (1984). *Cypress Swamps.* University of Florida Press, Gainesville, FL, USA.

Feierabend, J. S. (1989). Wetlands: the lifeblood of wildlife. D.A. Hammer (ed.) *Constructed Wetlands for Wastewater Treatment, Municipal, Industrial, and Agricultural.* Lewis Publishers, Chelsea, MI, USA. Chapter 7, pp. 107-118.

Friend, M. (1985). Wildlife health implications of sewage disposal in wetlands. P.J. Godfrey, E.R. Kaynor, S. Pelczarski, and J. Benforado (eds.), *Ecological Considerations in Wetlands Treatment of Municipal Wastewaters.* Van Nostrand Reinhold, New York, NY, USA. Chapter 17, pp. 262-269

Kadlec, R. H. and Knight, R. L. (1996). *Treatment Wetlands.* Lewis Publishers, Boca Raton, FL, USA. 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.

Kroodsma, D.E. (1978). Habitat Values for Nongame Wetland Birds. P. E. Greeson, J. R. Clark, and J. E. Clark (eds.), *Wetland Functions and Values: The State of Our Understanding*. American Water Resources Association, Minneapolis, MN, USA. pp. 320-326

McMahan, E. A., Knight, R. L. and Camp, A. R. (1972). A comparison of microarthropod populations in sewage-exposed and sewage-free *Spartina* salt marshes. *Environmental Entomology*, 1(2), 244-252.

Merritt, A. (1994). *Wetlands, Industry & Wildlife: A Manual of Principles and Practices.* The Wildfowl Trust, Gloucester, UK. 182 pp.

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

Payne, N. F. (1992). *Techniques for Wildlife Habitat Management of Wetlands.* McGraw-Hill, New York, NY.

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

Thunhorst, G. A. (1993). *Wetland Planting Guide for the Northeastern United States: Plants for Wetland Creation, Restoration, and Enhancement* . Environmental Concern, Inc. St. Michaels, MD, USA. 179 pp.

U.S. Environmental Protection Agency (EPA) (1993). *Constructed Wetlands for Wastewater Treatment and Wildlife Habitat* . EPA 832-R-005.

Weller, M. W. (1978). Management of freshwater marshes for wildlife. R. E. Good, D. F. Whigham,and R. L. Simpson (eds.), *Freshwater Wetlands: Ecological processes and Management Potential.* Academic press, New York, NY, USA. pp. 267-284