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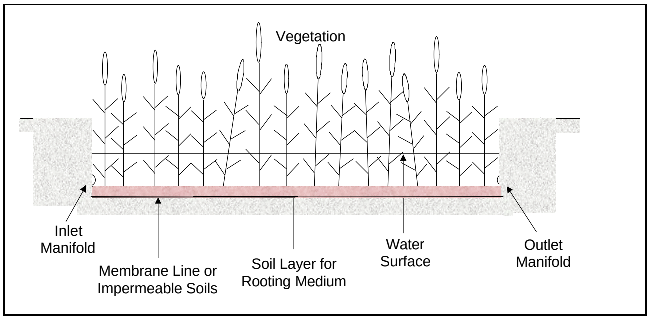
Wastewater Technology Fact Sheet

Free Water Surface Wetlands

DESCRIPTION

Free water surface (FWS) wetlands are defined as wetland systems where the water surface is exposed to the atmosphere. Most natural wetlands are FWS systems, including bogs (primary vegetation mosses), swamps (primary vegetation trees), and marshes (primary vegetation grasses and emergent macrophytes.) The observation of water quality improvements in these natural wetlands for many years led to the development of constructed wetlands in an effort to replicate the water quality and habitat benefits of natural wetlands in a constructed ecosystem. The majority of FWS constructed wetlands designed for wastewater treatment are marshes, but a few operating examples of bogs and swamps exist. In FWS treatment wetlands, water flows over a vegetated soil surface from an inlet point to an outlet point. In some cases, water is completely lost to evapotranspiration and seepage within the wetland. A diagram of FWS wetland is shown in Figure 1.



Source: Adapted from drawing by S.C. Reed, 2000.

FIGURE 1 FREE WATER SURFACE WETLAND

There are relatively few examples of the use of natural wetlands for wastewater treatment in the United States. Because any discharge to a natural wetland must satisfy National Pollutant Discharge Elimination System (NPDES) limits, these wetlands are typically used for advanced wastewater treatment (AWT) or tertiary polishing. The design goals for constructed wetlands range from an exclusive commitment for basic treatment functions to systems which provide advanced treatment and/or combine with enhanced wildlife habitat and public recreational opportunities. The size of the FWS wetland systems ranges from small on-site units designed to treat septic tank effluents to large units with more than 16,188 hectares (40,000 acres). A large system is being used to treat phosphorus from agricultural storm water drainage in south Florida. Operational FWS wetlands designed for municipal wastewater treatment in the United States range from less than 3785 liters per day (1,000 gallons per day) to more than 75,708 m^3/day (20 million gallons per day).

Constructed FWS wetlands typically consist of one or more shallow basins or channels with a barrier to prevent seepage to sensitive ground waters and a submerged soil layer to support the roots of the selected emergent macrophyte vegetation. Each system has appropriate inlet and outlet structures to ensure uniform distribution and collection of the applied wastewater. The most commonly used emergent vegetations in constructed FWS wetlands include cattail (*Typha* spp.), bulrush (*Scirpus* spp.), and reeds (*Phragmites* spp.). In systems designed primarily for treatment, it is common to select only one or two species for planting. The plant canopy formed by the emergent vegetation shades the water surface, preventing growth and persistence of algae, and reduces wind-induced turbulence in the water flowing through the system. Perhaps most important are the submerged portions of the living plants, the standing dead plants, and the litter accumulated from previous growth. These submerged surfaces provide the physical substrate for the periphytic-attached growth organisms responsible for much of the biological treatment in the system. The water depth in the vegetated portions of these systems ranges from a few inches to two feet or more.

The influent to these wetlands spreads over a large area of shallow water and emergent vegetation. The subsequent low velocity and essentially laminar flow provides for very effective particulate removal in the front part of the system. This particulate material, characterized as total suspended solids (TSS), contains Biochemical Oxygen Demand (BOD) components, fixed forms of total nitrogen (TN) and total phosphorus (TP), and trace levels of metals and more complex organics. The oxidation or reduction of these particulates releases soluble forms of BOD, TN, and TP to the wetland environment, which are available for adsorption by the soils and removal by the active microbial and plant populations throughout the wetland. Oxygen is available at the water surface, microsites on living plant surfaces, and on root and rhizome surfaces, allowing some aerobic activity the wetland. It is, however, prudent to assume that the bulk of the liquid in the FWS wetland is anoxic or anaerobic. The lack of oxygen can limit the biological removal of ammonia nitrogen (NH_3/NH_4 - N) via nitrification, but the FWS wetland is still effective for removal of BOD, TSS, trace metals, and some complex organics because the treatment of these occurs under both aerobic and anoxic conditions.

If nitrogen removal and/or enhancement of wildlife habitat is a project goal, consideration should be given to alternating shallow water emergent vegetated zones with deeper (greater than 1.83 meters or six feet) water zones containing selected submerged vegetation. Deeper water zones provide a completely exposed water surface for atmospheric re-aeration and submerged vegetation provides an additional source of oxygen for nitrification. The deeper water zones will also attract and retain a large variety of wildlife, particularly ducks and other water birds. This concept, in use at Arcata, California, and Minot, North Dakota, can provide excellent treatment on a year-round basis in warm climates and on a seasonal basis in colder climates where low temperatures and ice formation occur. The hydraulic residence time (HRT) in each of the open water zones should be limited to about three days at design flow to prevent the re-emergence of algae. Such systems should always start and end with shallow emergent vegetation zones to ensure retention and treatment of particulate matter and to minimize wildlife toxicity in the open water zones. The use of FWS constructed wetlands has increased significantly since the late 1980's. The systems are widely distributed in the United States and are found in about 32 states.

Common Modifications

In the United States, it is routine to provide some preliminary treatment prior to a FWS wetland. The minimal acceptable level is the equivalent of primary treatment which can be achieved with septic tanks, with Imhoff tanks for smaller systems, or with deep ponds with a short HRT. About 45 percent of operational FWS wetland systems use facultative lagoons for preliminary treatment, but these systems have also been used behind other treatment systems. For example, some of the largest FWS systems, in Florida and Nevada, were designed for tertiary effluent polishing and receive effluent from mechanical AWT plants.

Non-discharging, total retention FWS systems have been used in arid parts of the United States where the water is completely lost through a combination of seepage and evapotranspiration. These systems require that attention be paid to the long term accumulation of salts and other substances which might become toxic to wildlife or plants in the system. While it is impossible to exclude wildlife from FWS wetlands, it is prudent to minimize their presence until the water quality approaches secondary levels of treatment. This can be accomplished by limiting open water zones to the latter part of the system and using dense stands of emergent vegetation in the front part of the wetland. Selecting vegetation with little food value for animals or birds may also help. In colder climates or where large land areas are not available for wetland removal of nitrogen, a smaller wetland system can be designed for BOD/TSS removal. Nitrogen removal can be achieved with a separate process. Wetland systems in Kentucky and Louisiana successfully use an integrated gravel trickling filter for nitrification of wastewater ammonia. Seasonally operated FWS wetlands are also used in very cold climates, in which the wastewater is retained in a lagoon during the winter months and discharged to the wetland at a controlled rate during the warm summer months.

APPLICABILITY

FWS wetlands require a relatively large land area, especially if nitrogen or phosphorus removal is required. The treatment is effective and requires little in the way of mechanical equipment, energy, and skilled operator attention. Wetland systems can be a most cost effective treatment alternative where suitable land is available at reasonable cost. They also provide enhanced habitat and recreational values. Land requirements and costs tend to favor application of FWS technology in rural areas.

FWS wetland systems reliably remove BOD, Chemical Oxygen Demand (COD), and TSS. With a sufficiently long HRT, they can also produce low levels of nitrogen and phosphorus. Metals are also removed and a reduction in fecal coliforms of about a one log can be expected. In addition to municipal wastewaters, FWS systems are used to treat mine drainage, urban storm water, combined sewer overflows, agricultural runoff, livestock and poultry wastes, landfill leachates, and for mitigation purposes. Because the water is exposed and accessible to humans and animals, the FWS concept of receiving partially treated wastewater may not be suited for use in individual homes, parks, playgrounds, or similar public facilities. A gravel bed subsurface flow (SF) wetland is a choice for these applications.

ADVANTAGES AND DISADVANTAGES

Some advantages and disadvantages of FWS wetlands are listed below:

Advantages

- FWS wetlands offer effective treatment in a passive manner, minimizing mechanical equipment, energy, and skilled operator requirements.

- FWS wetlands may be less expensive to construct, and are less costly to operate and maintain than conventional mechanical treatment systems.

- Year-round operation for secondary treatment is possible in all but the coldest climates. Year-round operation for advanced or tertiary treatment is possible in warm to moderately temperate climates.

- Wetland systems provide a valuable addition to the “green space” in a community, and include the incorporation of wildlife habitat and public recreational opportunities.

- Wetland systems produce no residual biosolids or sludges requiring subsequent treatment and disposal.

- The removal of BOD, TSS, COD, metals, and persistent organics in municipal wastewaters can be very effective with a reasonable detention time. The removal of nitrogen and phosphorus can also be effective with a significantly longer detention time.

Disadvantages

- The land area required for FWS wetlands can be large, especially if nitrogen or phosphorus removal are required.

- The removal of BOD, COD, and nitrogen are biological processes and essentially continuously renewable. The phosphorus, metals, and some persistent organics removed by the system are bound in the wetland sediments and accumulate over time.

- In cold climates low winter temperatures reduce the rate of removal for BOD and the biological reactions responsible for nitrification and denitrification. An increased detention time can compensate for this, but the increased wetland size required in extremely cold climates may not be cost effective or technically feasible.

- The bulk water in most constructed FWS wetland systems is essentially anoxic, limiting the potential for rapid biological nitrification of ammonia. Increasing the wetland size and, therefore, the detention time, may compensate for this, but may not be cost effective. Alternate methods for nitrification in combination with a FWS wetland have performed successfully.

- Mosquitoes and other insect vectors can be a problem.

- The bird population in a FWS wetland can have adverse impacts if an airport is nearby.

- FWS constructed wetlands can remove fecal coliforms by at least one log from typical municipal wastewaters. This may not be sufficient to meet discharge limits in all locations and supplemental disinfection may be required. The situation is further complicated because birds and other wildlife in the wetland produce fecal coliforms.

DESIGN CRITERIA

Published models for the pollutant removal design of FWS wetland systems have been available since the late 1980's. More recent efforts have produced three textbooks containing design models for FWS wetlands (Reed, et al., 1995; Kadlec & Knight, 1996; Crites & Tchobanoglous, 1998) All three models are based on first order plug flow kinetics but provide different results based on the use of different databases. The Water Environment Federation (WEF) presents a comparison of the three approaches in the Manual of Practice on Natural Systems (WEF, 2000.) Another comparison is found in the U.S. EPA design manual on wetland systems (U.S. EPA, 2000.) This manual also includes design models developed by Gearheart and Finney. The designer of a FWS wetland system should consult these references and select the method best suited for the project under consideration. A preliminary estimate of the land area required for an FWS wetland can be obtained from Table 1 of typical areal loading rates presented below. These values can also be used to check the results from other references.

The pollutant requiring the largest land area for removal determines the necessary treatment area for the wetland, which is the bottom surface area of the wetland cells. The wastewater flow must be uniformly distributed over the entire surface for that area to be 100 percent effective. This is possible with constructed wetlands by careful grading of the bottom surface and the use of appropriate inlet and outlet structures. Uniform distribution of wastewater is more difficult when natural wetlands are used for treatment or polishing. The existing configuration and topography are typically retained in these natural wetlands, which can result in significant short circuiting of flow. Dye tracer studies in such wetlands have shown that the effective treatment area can be as little as 10 percent of the total wetland area. The total treatment area should be divided into at least two cells for all but the smallest systems. Larger systems should have at

TABLE 1 TYPICAL AREAL LOADING RATES

Constituent	Typical Influent Conc. (mg/L)	Target Effluent Conc. (mg/L)	Mass Loading Rate (lb/ac/d)*
Hydraulic Load (in/d)	0.4 - 4**		
BOD	5 - 100	5 - 30	9 - 89
TSS	5 - 100	5 - 30	9 - 100
NH_3/NH_4 as N	2 - 20	1 - 10	1 - 4
NO_3 as N	2 - 10	1 - 10	2 - 9
TN	2 - 20	1 - 10	2 - 9
TP	1 - 10	0.5 - 3	1 - 4

least two parallel trains of cells to provide flexibility for management and maintenance.

Wetland systems are living ecosystems. The life and death cycles of the biota produce residuals which can be measured as BOD, TSS, nitrogen, phosphorus, and fecal coliforms. As a result, regardless of the size of the wetland or the characteristics of the influent, there will always be a residual background concentration of these materials in wetland systems. Table 2 summarizes these background concentrations.

Because removal of BOD and various nitrogen forms is temperature dependent, the temperature of the wetland must be known for proper design. The water temperature in large systems with a long HRT (greater than 10 days) will approach the average air temperature except during subfreezing weather in the winter. Methods to estimate the water temperature for wetlands with a shorter HRT (less than 10 days) can be found in the references cited.

TABLE 2 "BACKGROUND" FWS WETLAND CONCENTRATIONS

Constituent	Concentration Range
BOD_5 (mg/L)	1 - 10
TSS (mg/L)	1 - 6
TN (mg/L)	1 - 3
NH_3/NH_4 as N (mg/L)	< 0.1
NO_3 as N (mg/L)	< 0.1
TP (mg/L)	< 0.2
Fecal Coliforms (MPN/100mL)	50 - 500

Because living plants and litter provide significant frictional resistance to flow through the wetland , it is necessary to consider the hydraulic aspects of system design. Manning's equation is generally accepted as the model for the flow of water through FWS wetlands. Descriptive information is found in the references cited. Flow resistance impacts the configuration selected for the wetland cell: the longer the flow path, the higher the resistance. To avoid hydraulic problems, an aspect ratio (L:W) of 4:1 or less is recommended.

PERFORMANCE

A lightly loaded FWS wetland can achieve the "background" effluent levels shown in Table 2. In general, an FWS constructed wetland is designed to produce a specified effluent quality. Table 1 can be used to estimate the size of the wetland necessary to produce the desired effluent quality. The design models in the referenced publications provide a more precise estimate of required treatment area. Table 3 summarizes actual performance data for 27 FWS systems from a recent Technology Assessment (U.S. EPA, 2000).

In theory, the performance of a wetland system can be influenced by hydrological factors. High evapotranspiration (ET) rates may increase effluent concentrations, but may also increase the HRT in the wetland. High precipitation rates dilute the pollutant concentrations but also shorten the HRT in the wetland. In most temperate areas with a moderate climate, these influences are not critical for performance. Hydrological aspects only need to

TABLE 3 SUMMARY OF PERFORMANCE FOR 27 FWS WETLAND SYSTEMS

Constituent	Mean Influent (mg/L)	Mean Effluent (mg/L)
BOD_5	70	15
TSS	69	15
TKN as N	18	11
NH_3/NH_4 as N	9	7
NO_3 as N	3	1
TN	12	4
TP	4	2
Dissolved P	3	2
Fecal Coliforms (#/100mL)	73,000	1320

Source: U.S. EPA, 2000.

be considered for extreme values of ET and precipitation.

OPERATION AND MAINTENANCE

The routine operation and maintenance (O&M) requirements for FWS wetlands are similar to those for facultative lagoons. They include hydraulic and water depth control, inlet/outlet structure cleaning, grass mowing on berms, inspection of berm integrity, wetland vegetation management, mosquito and vector control (if necessary), and routine monitoring.

The water depth in the wetland may need adjustment on a seasonal basis or in response to increased resistance from the accumulating plant litter in the wetland channel. Mosquitoes may require control, depending on local conditions and requirements. The mosquito population in the treatment wetland should be no greater than in adjacent natural wetlands.

Vegetation management in FWS wetlands does not include the routine harvest and removal of the harvested material. Plant uptake of pollutants represents a relatively minor pathway, so harvest and removal on a routine basis does not provide a significant treatment benefit. Removal of accumulated litter may become necessary if there are severe restrictions to flow. Generally, this will only occur if the wetland channels have been constructed with very high aspect ratios (L:W > 10:1). Vegetation management may also include wildlife management, depending on the type of vegetation selected for the system. Animals such as nutria and muskrats have been known to consume all emergent vegetation in FWS constructed wetlands.

Routine water quality monitoring is required for all FWS systems with an NPDES permit. The permit specifies the monitoring requirements and frequency of monitoring. Sampling for NPDES monitoring is usually limited to untreated wastewater and the final system effluent. Since the wetland component is usually preceded by some form of preliminary treatment, the routine monitoring program does not document wetland influent characteristics. Periodic samples of the wetland influent should be obtained and tested for all but the smallest systems to provide the operator with an understanding of wetland performance and a basis for adjustments, if necessary.

COSTS

The major items included in the capital costs for FWS wetlands are similar to those for lagoon systems, including land, site investigation, site clearing, earthwork, liner, rooting media, plants, inlet and outlet structures, fencing, miscellaneous piping, engineering, legal, contingencies, and contractor's overhead and profit. The liner can be the most expensive item. For example, a plastic membrane liner can approach 40 percent of construction costs. In many cases, compaction of the in-situ native soils provides a sufficient barrier for groundwater contamination. Table 4

TABLE 4 CAPITAL AND O&M COSTS FOR 100,000 GAL/D FWS WETLAND

Item	Cost ($)*	
	Native Soil Liner	Plastic Membrane Liner
Land Cost	16,000	16,000
Site Investigation	3,600	3,600
Site Cleaning	6,600	6,600
Earthwork	33,000	33,000
Liner	0	66,000
Soil Planting Media	10,600	10,600
Plants	5,000	5,000
Planting	6,600	6,600
Inlets/Outlets	16,600	16,600
Subtotal	98,000	164,000
Engineering, legal, etc.	56,800	95,100
Total Capital Cost	154,800	259,100
O&M Costs ($/year)	6,000	6,000

* June 1999 Costs, ENR CCI = 6039

Source: Water Environment Federation, 2000.

summarizes capital and O&M costs for a hypothetical 378,500 liters per day (100,000 gallon per day) FWS constructed wetland, required to achieve a 2 mg/L ammonia concentration in the effluent. Other calculation assumptions include the following: influent NH_3 = 25 mg/L; water temperature = 20°C (68°F); water depth = 0.46 meters (1.5 ft); porosity = 0.75; treatment area = 1.3 hectares (3.2 ac); and land cost = $12,355/hectare ($5,000/ac).

Table 5 compares the life cycle costs for this wetland to the cost of a conventional sequencing batch reactor (SBR) treatment system designed for the same flow and effluent water quality.

TABLE 5 COST COMPARISON FOR FWS WETLAND AND CONVENTIONAL WASTEWATER TREATMENT

Cost Item	Process	
	Wetland	SBR
Capital Cost ($)	259,000	1,104,500
O&M Cost ($)	6,000/yr	106,600/yr
Total Present Worth Costs* ($)	322,700	2,233,400
Cost per 1000 gal treated ** ($)	0.44	3.06

*Present worth factor 10.594 based on 20 years at 7 percent interest

**Daily flow rate for 365 d/yr for 20 yr, divided by 1000 gal.

Source: Water Environment Federation, 2000.

REFERENCES

Other Related Fact Sheets

Wetlands: Subsurface Flow
EPA 832-F-00-023
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Other EPA Fact Sheets can be found at the following web address:
http://www.epa.gov/owmitnet/mtbfact.htm

1. Crites, R.W. and G. Tchobanoglous, 1998, *Small and Decentralized Wastewater Management Systems,* McGraw Hill Co., New York, NY.

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

3. Reed, S.C.; R.W. Crites; and E.J. Middlebrooks, 1995, *Natural Systems for Waste Management and Treatment - Second Edition,* McGraw Hill Co, New York, NY.

4. U.S. EPA, 2000, *Free Water Surface Wetlands for Wastewater Treatment: A Technology Assessment,* U.S. EPA, OWM, Washington, D.C.

5. U.S. EPA, 2000, *Design Manual Constructed Wetlands for Municipal Wastewater Treatment,* U.S. EPA, CERI, Cincinnati, OH.

6. Water Environment Federation, 2000, *Natural Systems for Wastewater Treatment,* MOP FD-16, WEF, Alexandria, VA.

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