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APPLICABILITY OF CONSTRUCTED WETLANDS FOR ARMY INSTALLATIONS

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APPLICABILITY OF CONSTRUCTED WETLANDS FOR ARMY INSTALLATIONS

1. Purpose. This Public Works Technical Bulletin (PWTB) transmits information on the applicability of constructed wetlands for Army installations. A constructed wetland is "a designed and man-made complex of saturated substrates, emergent and submergent vegetation, animal life, and water that simulates natural wetlands for human use and benefits." (Hammer 1989).

2. Applicability. This PWTB applies to all U.S. Army facilities responsible for construction and operation and maintenance (O&M) of wastewater treatment plants and stormwater management.

3. References.

a. Army Regulation (AR) 200-1, "Environmental Protection and Enhancement," 21 February 1997.

b. AR 420-49, "Utility Services," 28 April 1997.

c. *Constructed Wetlands for Wastewater Treatment: Municipal, Industrial and Agricultural*, 1989, D.A. Hammer, ed. Lewis Publishers, Inc. Chelsea, Michigan.

d. See additional references on page A-34.

4. Discussion.

a. Army installations are mandated to meet the requirements of their National Permit Discharge Elimination System (NPDES) permits. These permits have become increasingly stringent as the United States strives to improve the quality of the nation's waters.

b. Constructed wetlands are one method Army installations are using to help cleanse wastewater~~s~~ (which includes stormwater). Constructed wetlands are based on, but different than, natural wetlands. A plot of land is chosen near the wastewater that is to be cleansed. A shallow pond is built and native plants found in natural wetlands within the installation's region such as cattails, reeds, and rushes are planted. The wastewater is then routed through the wetland. Microbial utilization and plant uptake of nutrients, metals and other pollutants results in cleaner water leaving the constructed wetland than when it entered.

c. This PWTB is an overview of constructed wetlands and their applicability to Army installations. Appendix A gives a detailed explanation of this technology.

5. Points of Contact. HQUSACE is the proponent for this document. The POC at HQUSACE is Bob Fenlason, CEMP-RI, 202-761-0206, or e-mail: bob.w.fenlason@usace.army.mil. Questions and/or comments regarding this subject should be directed to the technical POC: U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory, at 1(800) USA-CERL, for Mr. Richard J. Scholze (e-mail: Richard.J.Scholze@erdc.usace.army.mil).

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APPENDIX A

Constructed Wetlands for Wastewater Treatment

1. Background.

a. Constructed wetland use has increased tremendously in application since the 1980s. Applications have been used to treat municipal, domestic, industrial and commercial wastewater, landfill leachates, agricultural wastes, Stormwater runoff, mine drainage, and combined sewer overflows. Constructed wetlands are desirable for these purposes since they are typically inexpensive to build, easy to operate, and capable of very effective treatment. This PWTB focuses on constructed wetlands for the treatment and polishing of wastewater and Stormwater although the reader is reminded that the other applications may also be useful to Army installations.

b. The performance of wetland systems can be evaluated through water quality monitoring, where the operational goal is to produce outflow that meets state and Federal discharge requirements. Because environmental laws differ among different jurisdictions, each wetland system must be designed individually to provide the appropriate hydraulic and biochemical mechanisms. These treatment mechanisms ultimately determine the success or failure of the system.

c. In addition to the primary objective of cleansing inflow, environmental benefits of onsite treatment in a constructed wetland include (1) decreased potential for spills by eliminating the need for offsite transportation, (2) sharp reduction in use of transportation fuel, (3) decreased energy consumption by using natural processes rather than conventional, electrically driven wastewater treatment processes, and (4) the potential creation of new wetlands habitat for living organisms.

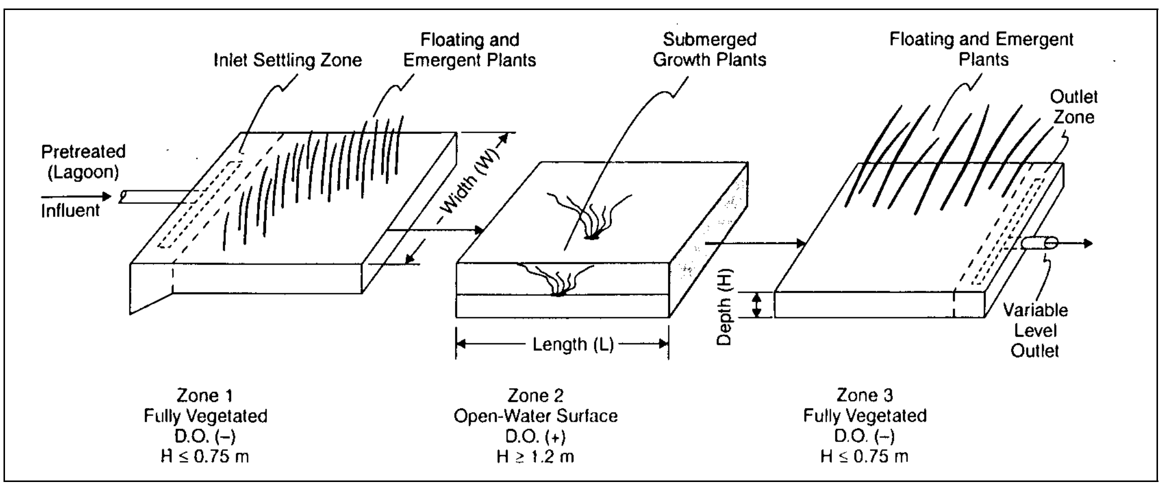
d. Wetlands are defined as land where the water surface is near the ground surface long enough each year to maintain saturated soil conditions along with the related vegetation. Marshes, bogs, and swamps are all examples of naturally occurring wetlands. A “constructed wetland” is a wetland specifically constructed for pollution control and waste management, at a location other than existing natural wetlands. Some recent publications (e.g., USEPA 2000b) have started using the term “constructed treatment wetlands” to more appropriately describe this function. This PWTB will use the term “constructed wetlands.” Most treatment wetlands placed in service over recent years are constructed wetlands. Although constructed wetland technology has gained popularity in the United States, there is limited guidance on design and operation of constructed wetlands.

e. Both natural and constructed wetland systems have been used to treat a variety of wastewaters (which includes stormwater). The use of constructed, rather than natural, wetlands is generally preferred since all natural wetlands are considered part of natural water resources and have to comply with the water quality requirements of regulatory agencies. Other advantages of constructed wetlands include some degree of control of substrate, vegetation types, flow characteristics, flexibility in sizing, and the potential to treat more wastewater via engineering design.

f. The two basic types of constructed wetlands are the free water surface (FWS) wetland and the subsurface flow (SF) wetland. See Figures 1 – 5. Both types use native emergent aquatic vegetation and are similar in appearance to a marsh. A third type of wetland design is presently evolving to allow manipulation of the flow. This type is called a vertical flow subsurface system (VFSS). In VFSS wetlands, water flows vertically through porous media and is collected at the base. VFSS wetlands will not be further discussed in this PWTB. Applications of constructed wetlands in the United States number in the thousands. More than 1,000 of the SF variety have been used for small systems such as individual homes, schools, and smaller applications, while the FWS variety has been used for most of the larger applications.

(1) The FWS wetland typically consists of a basin or channels with some type of barrier to prevent seepage, soil to support the roots of emergent vegetation, and water at a relatively shallow depth flowing through the system. The water surface is exposed to the atmosphere, and the intended flow path through the system is horizontal.

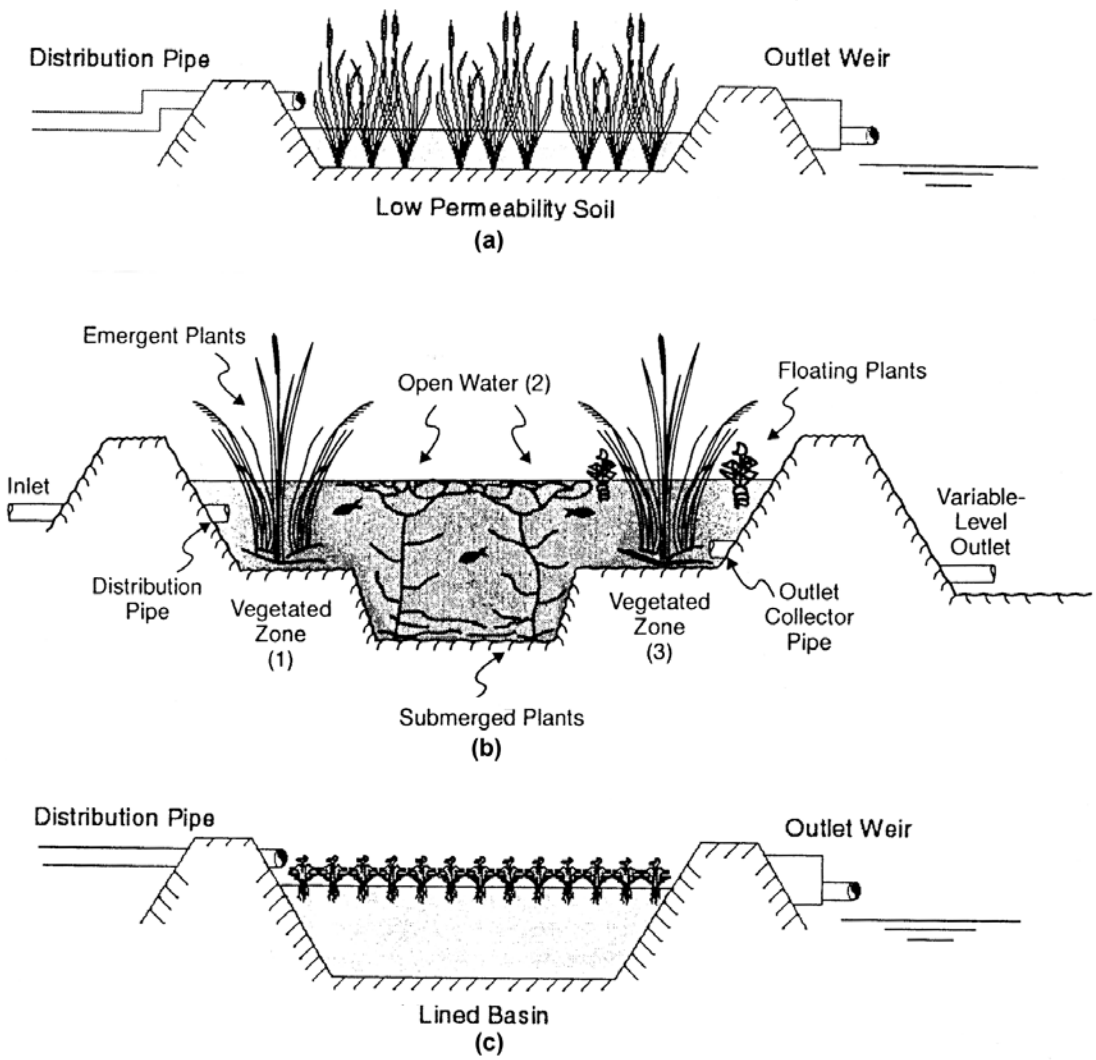
(2) The SF wetland also consists of a basin or channel with a barrier to prevent seepage, but the bed then contains a suitable depth of porous media. Rock or gravel is the most commonly used media type in the United States. The media also supports the root structure of the emergent vegetation. The design of these systems assumes that the water level in the bed will remain below the top of the rock or gravel media. The flow path through the operational systems in the United States is horizontal.



(Source: USEPA 2000a)

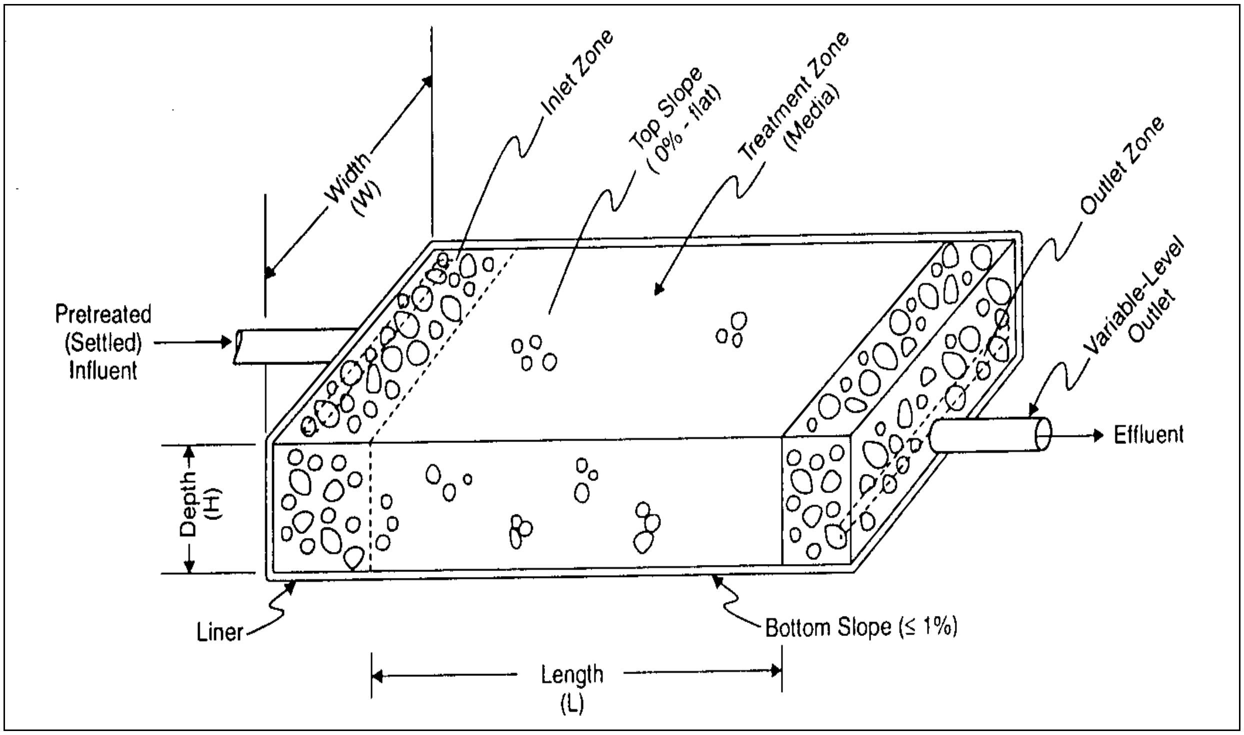
Figure 1. Elements of an FWS constructed wetland.

Definition sketches for constructed wetlands: (a) free water surface constructed wetland with emergent vegetation, (b) free water surface wetland with an open water zone, and (c) constructed floating aquatic plant treatment system (adapted from Kadlec and Knight 1996).



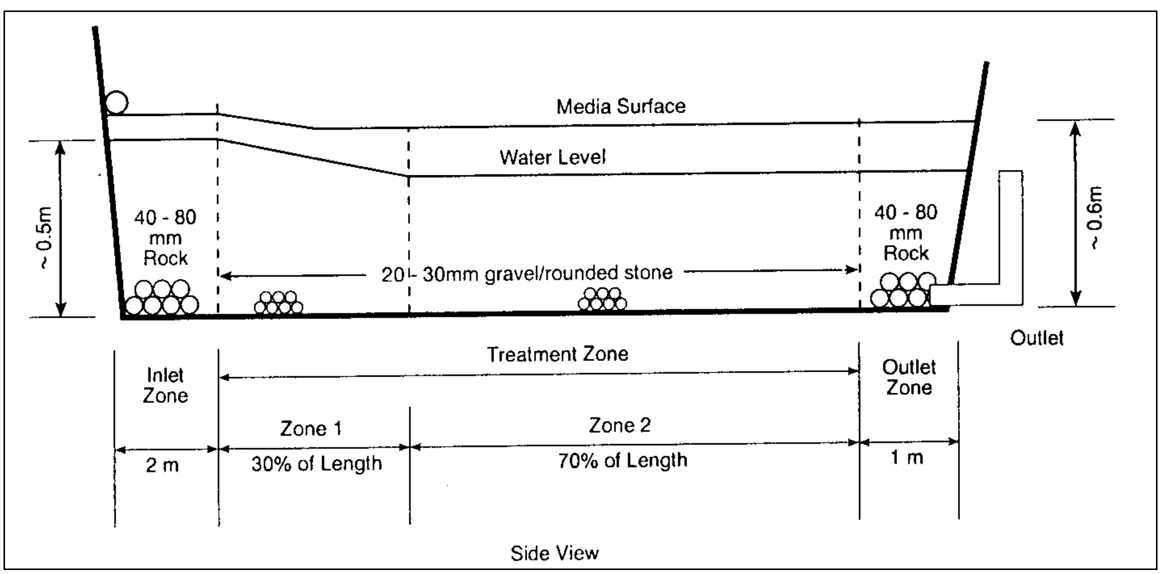
(Source: USEPA 1999.)

Figure 2. Profiles of constructed wetlands.



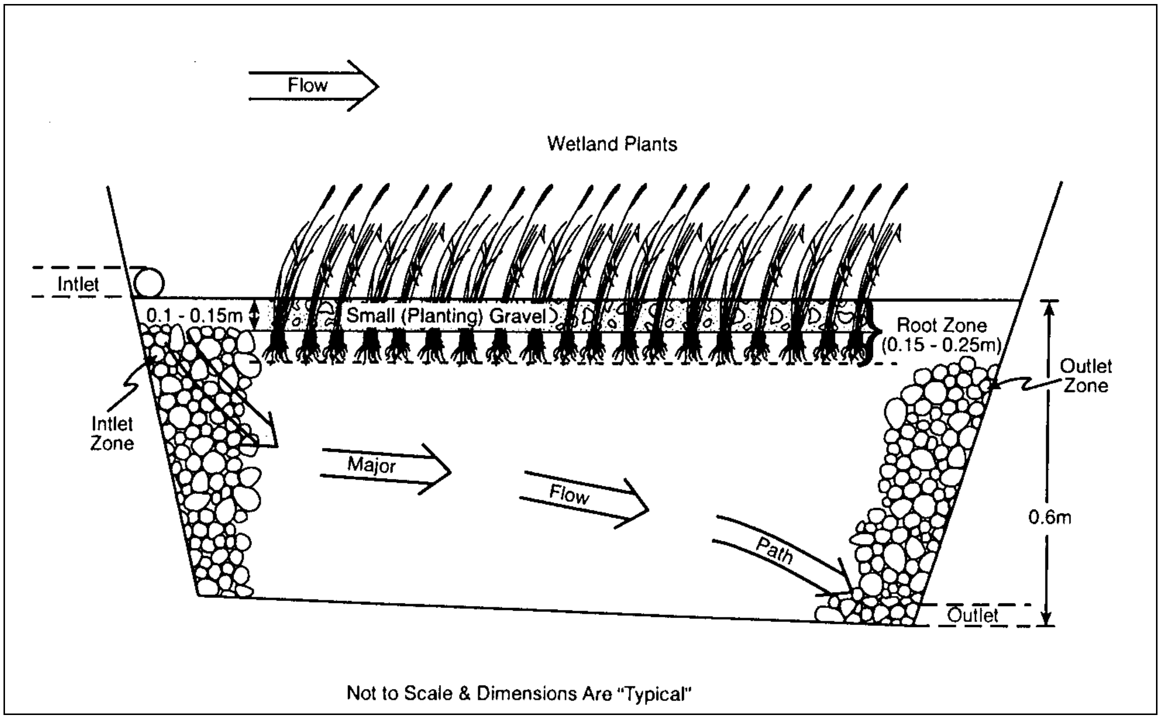
(Source: USEPA 2000a.)

Figure 3. Elements of an SF system.



(Source: USEPA 2000a.)

Figure 4. Proposed zones in an SF system.



(Source: USEPA 2000a.)

Figure 5. Preferential flow in a subsurface flow wetland.

g. The SF wetland has several advantages over the FWS type. If the water surface is maintained below the media surface, there is little risk of odors, public exposure, or mosquitoes. In addition, the media provides greater available surface area for treatment than the FWS concept. As a result, the treatment responses are faster for the SF wetland and it can therefore be smaller in area than an FWS system designed for the same inflow conditions. The subsurface position of the water and accumulated plant debris on the surface of the SF bed offer greater thermal protection in cold climates than surface conditions of the FWS wetland. A variation of the conventional SF wetland using pumping assistance to achieve increased rates of re-oxygenation within the media is referred to as ReCip SF. The SF wetland cell reciprocation is a patented system technology held by Tennessee Valley Authority (TVA) with licensed distributors. It uses the reciprocating cells to alternate the treatment environment back and forth between anaerobic and aerobic conditions. This is a simple, timed process for pumping to drain and fill cells. It has the ability to treat higher strength wastes and reduce the land area from a more conventional SF design due to the higher rate of oxygen resaturation in the subsurface environment. However, it does increase the operations and maintenance (O&M) requirements.

h. These potential advantages of the SF wetland are offset by the significant additional cost for procuring, delivering, and placing the gravel or rock media in the SF bed. The selection of the most appropriate concept will depend on individual site conditions, operational requirements, and the local costs for media and for the land involved. In situations where public access, odors, or vectors are a critical issue, the SF type may be preferred despite cost. When the system can be installed at a remote site where these issues are of lesser concern, the FWS system can typically be constructed for a lower cost. A further advantage of the FWS wetland is improved habitat value as a result of the water surface being exposed and accessible to birds and animals.

i. Some systems in Europe that treat domestic or municipal effluents accept untreated wastewater and typically have an inlet zone dedicated to solids separation. Most U.S. constructed wetlands have some form of preliminary treatment prior to the wetland component. This ranges from septic or Imhoff tanks for small services, to primary treatment, lagoons, and full-scale biological secondary treatments such as activated sludge, trickling filters, oxidation ditches, etc.

2. <u>Functional Components in the Wetland</u>.

a. The biological components in a wetland system that have significant potential for wastewater~~s~~ (which includes stormwater). renovation include vegetation and microbial organisms, either suspended in the water column or attached to the surfaces of the media (in SF systems) or the submerged plant parts (in FWS systems).

b. The vegetation in the wetland may be a major system component, but it is one that plays a minor role in the direct renovation of the inflow. Plant uptake of nutrients and other pollutants does occur, but most of these materials return to the water due to the annual senescence and decomposition of the emergent plant parts. Several studies have shown, for example, that a single harvest of the plants will account for less than 10 percent of the nitrogen removed by the wetland. Multiple harvests might improve permanent removal via the plants, but that activity would then disrupt operations and increase costs. The major role of the vegetation in these systems is simply its physical presence. The dense canopy shades the surface and prevents algae growth in the FWS type, and, in the SF type, the root zone is the source of oxygen for essential aerobic reactions. The roots and the submerged parts of the plants are the substrates for microbial growth.

c. The most active renovative components in the wetland system are believed to be the microbial organisms and, of these, the attached growth types are the most significant contributors. These attached growth organisms occupy the surfaces of the media and the roots in the SF system, and the submerged plant parts and benthic materials in the FWS system. In effect, both types of constructed wetlands function as attached growth reactors with similar reactions and responses to those observed in trickling filters and other conventional treatment methods. The presence of greater available surface area in the SF wetland as compared with FWS is responsible for the higher rates of treatment observed in the case of SF.

d. These natural biological reactions are, in general, allowed to proceed at their natural rates without enhancement or stimulation via aeration, mixing, recirculation, or any sludge management. In effect, these constructed wetland concepts, when compared to traditional treatment systems, trade time and space (i.e., detention time and land area) for energy-intensive operation and maintenance requirements. A treatment occurring in a few hours in an activated sludge process may require several days in a constructed wetland. In locations where suitable land is available at a reasonable cost, the cost will tend to favor the constructed wetland process. These wetlands are also more robust and more forgiving of upsets occurring in the preliminary processes as compared with more finely tuned and intensive mechanical systems such as activated sludge.

e. The major nitrogen (N) removal pathway in these wetlands is microbiological. The pathway includes mineralization of organic N and release of ammonia, nitrification of ammonia, and finally denitrification of the resulting nitrates. In a system where all of the necessary components and support elements are available, nitrogen removal can be very effective. The critical step in the pathway seems to be the nitrification reaction and, in some operating constructed wetlands, this step appears to be limited due to oxygen deficiencies in the system. In the FWS, the major source of oxygen is atmospheric reaeration at the exposed air-water interface. This source is often reduced in a wetland as compared with a pond because the wetland vegetation suppresses wind action, and floating plants such as duckweed can effectively seal the water surface. The lower depths in the FWS wetland are typically anaerobic.

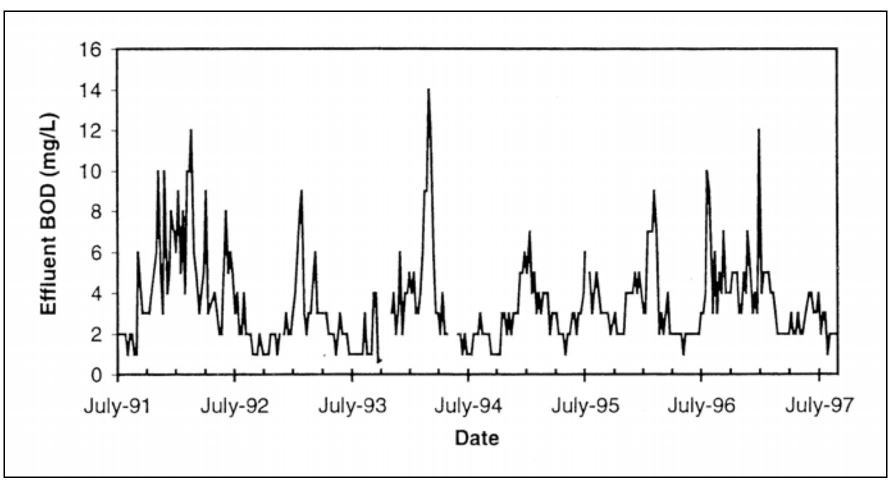
f. The emergent wetland plants used in these systems can transmit air and oxygen to their root systems. This capability has evolved because the plant roots grow in an anoxic environment and would die without some oxygen source. It is believed that the oxygen level responds to the stress level at the roots. This level is limited, however, so very high organic loadings can exceed that capacity causing the plant to die. The oxygen does not diffuse into the soil or the gravel matrix, and converts the surroundings into an effervescent aerobic environment. This oxygen is believed to be available only on the surfaces of the roots. As a result, microsites on these roots are believed capable of supporting aerobic organisms. When the organic loading is low enough, these aerobic microsites may be dominated by nitrifying organisms. When wastewater contacts such a microsite, nitrification can occur followed by denitrification in the largely anoxic environment in the SF bed. Since this oxygen does not diffuse from the roots, it is probably not available to the flowing wastewater in an FWS wetland.

g. Physical and chemical responses also play an important role in constructed wetlands. Sedimentation and filtration account for removal of a large portion of the biological oxygen demand BOD and TSS in the upstream portion of the wetland bed. Volatilization of ammonia and susceptible organics can also occur during the relatively long detention times. Precipitation and complexation reactions effectively remove most metals and similar substances. Many refractory organic compounds can also respond favorably due to the generally anoxic conditions and the longer detention times. Adsorption and ion exchange reactions can also occur, but, unless another mechanism releases or converts the adsorbed substance, these retention sites may be exhausted soon after the system is put into operation.

h. Temperature Impact

(1) Temperature variations also affect the treatment performance of constructed wetlands, although not consistently for all wastewater constituents. Temperature conditions in a wetland affect both the physical and biological activities in the system. Microbial activity varies seasonally in cold regions, with lesser activity in colder months. The biological reactions responsible for biological oxygen demand (BOD) removal, nitrification, and denitrification are temperature dependent. However, in many cases BOD removal performance of existing wetland systems in cold climates has not demonstrated and obvious temperature dependence. This could be due to the long hydraulic residence time provided by these systems, which tends to compensate for the lower reaction rates during the winter months. Treatment performance for some constituents tends to decrease for colder temperatures, but BOD and total suspended solids (TSS) removal through flocculation, sedimentation, and other physical mechanisms is less affected. In colder months, the absence of plant cover allows atmospheric reaeration and solar insolation to occur without the shading and surface covering that plant biomass provides during the growing season. Ice cover is another variable that affects constructed wetlands by altering wetland hydraulics and restricting solar insolation, atmospheric reaeration, and biological activity; however, the insulating layer provided by ice cover would slow down the rate and degree of cooling in the water column but does not affect physical processes such as settling, filtration and flocculation. Plant senescence and decay also decreases under ice cover, with a corresponding decrease in effluent BOD.

(2) Background BOD concentrations are not constant, but have a fluctuating cycle of release that is a function of biogeochemical cycle rates and external (other than wastewater) factors. An example of this cycling can be seen in Figure 6 from the Arcata Wetland. Higher values of BOD occur in the fall while lower values occur in the summer. This variation is attributed to the accelerated decomposition of the vegetative materials and to increased bird activity in the fall. Lower values in the summer are correlated with low decomposition rates (low recent litter production) and decreased bird activity.



(Source: USEPA 1999.)

Figure 6. Variation in effluent BOD at the Arcata Enhancement Marsh.

3. Performance Expectations. Parameters of concern in wastewater treatment systems may include: BOD, TSS, fecal coliforms, nitrogen, phosphorous, metals, petroleum hydrocarbons and trace organics. Actual performance data for each of these are briefly summarized below. Wetland systems can significantly reduce constituents with removal efficiencies in the range of 70 to 90 percent for BOD and TSS, 60 to 86 percent for nitrogen, and between 97 and 99 percent for copper (Cu), zinc (Zn), and cadmium (Cd) being observed. Tables 1, 2, and 3 present information on parameters and removal for FWS, SF, and Stormwater wetlands.

Table 1. 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: Adapted from USEPA 1999.)

Table 2. Summary of performance for 14 SF wetland systems.*

Constituent	Mean Influent (mg/L)	Mean Effluent (mg/L)
BOD_5	28** (5-51)***	8** (1-15)***
TSS	60 (23-118)	10 (3-23)
TKN as N	15 (5-22)	9 (2-18)
NH_3/NH_4 as N	5 (1-10)	5 (2-10)
NO_3 as N	9 (1-18)	3 (0.1-13)
TN	20 (9-48)	9(7-12)
TP	4 (2-6)	2 (0.2-3)
Dissolved P	3	2
Fecal Coliforms (#/100mL)	270,000 (1,200-1,380,000)	57,000 (10-330,000)

* Mean detention time of 3 days (range 1 to 5 days).
** Mean value.
*** Range of values.
(Source: Adapted from USEPA 1993.)

Table 3. Performance of Stormwater wetlands.

Pollutant	Removal Rate(%)
TSS	67
Total Phosphorous	49
Total Nitrogen	28
Organic carbon	34
Petroleum Hydrocarbons	87
Cadmium	36
Copper	41
Lead	62
Zinc	45
Bacteria	77

(Source: Center for Watershed Protection 1997.)

a. BOD Removal

(1) Effluent concentrations of less than 20 mg/L can be achieved in a few days detention time or less, despite input concentrations within the range of 30 to 250 mg/L. Table 4 illustrates this fact with data from a number of application sites.

(2) Both SF and FWS types of wetland systems are unique compared with other forms of wastewater treatment in that BOD is produced within the system due to the decomposition of plant litter and other natural organic materials. As a result, these systems can never achieve complete BOD removal, and a residual of 2 to 7 mg/L is typically present in the final effluent. Seasonal difference may occur in colder climates.

Table 4. Typical BOD and TSS removals observed in FWS constructed wetlands.

	BOD, mg/L		TSS, mg/L	
Location	Influent	Effluent	Influent	Effluent
Arcata, CA	26.0	12.0	30.0	14.0
Benton, KY	25.6	9.7	57.4	10.7
Cannon Beach, OR	26.8	5.4	45.2	8.0
Ft. Deposit, AL	32.8	6.9	91.2	12.6
Gustine, CA	75.0	19.0	102.0	31.0
Iselin, PN	140.0	17.0	380.0	53.0
Listowel, Ontario	56.3	9.6	111.0	8.0
Ouray, CO	63.0	11.0	86.0	14.0
West Jackson Co., MS	25.9	7.4	40.4	14.1
Sacramento Co., CA	23.9	6.5	8.9	12.2

(Source: Crites and Tchobanoglous 1998.)

b. TSS Removal. Removal of TSS is a physical response and should not be related to the plant species used. The inorganic residues from the TSS will accumulate in the wetland bed over the long term. This is more important in the SF concept since the water flows in the void spaces of the media. Based on experience, detrimental clogging of these systems is not expected during the design life of a facility if it is properly operated. Influent suspended solids will accumulate in the upslope areas, near the inlets to the wetland, and can decrease hydraulic detention times. Over time, accumulation of these solids will require removal. SF systems cannot be easily desludged without draining and removing the media, its associated microbial community and plant biomass. Therefore, SF systems should not be considered as stand-alone practices for treating wastewaters with high-suspended solids loads, such as combined sewer overflows and facultative pond effluents, which have high algal concentrations. In these cases, some form of upstream settling basin or forebay, separate from the wetland, should be designed expressly for the removal of the solids. A separate wetland system could then be considered on a case-by-case basis for tandem treatment as a downstream polishing facility in a treatment train application. Most of the heavier solids, found in the upstream portions of SF systems, are removed. Researchers have found that the solids accumulation front will stabilize after a year and not advance. See Table 4 for typical removal efficiencies.

c. Pathogen Removal. Pathogen removal in both FWS and SF wetlands can be very effective. As a general rule, it can be expected that these wetland systems can achieve a one to two log reduction in fecal coliforms with a Hydraulic Retention Time (HRT) of at least 3 days. In some cases, this reduction may not be sufficient where stringent discharge limits prevail and supplementary disinfection may be required.

d. Phosphorous Removal. Phosphorous removal is somewhat limited in constructed wetlands because of the limited contact with the soil and its associated oxides of iron and aluminum. Removal depends on the detention time in the system and generally ranges from 30 to 50 percent. Additional removal will occur in the soil when in-ground disposal is the intended discharge pathway.

e. Metals Removal. Constructed wetland systems can remove metals very effectively. Precipitation and complexation reactions are believed to be the treatment processes.

f. Organic Priority Pollutant Removal. Table 5 lists removal of many organic priority pollutants in constructed wetlands. These data were obtained in pilot-scale studies, but should be achievable in full-scale systems as well. Loss to the atmosphere of the more volatile organics is an obvious pathway during the relatively long HRT in these systems. The generally anoxic environment will also help in the breakdown and removal of the more resistant refractory organics. High concentrations of these materials may be toxic to the plants and organisms in the wetland systems. Neutralization and/or partial removal in preliminary anaerobic reactors will typically be necessary for inflows characterized by very high concentrations of these materials.

g. Nitrogen Removal. The nitrogen entering wetland systems can be a combination of organic nitrogen, ammonia, and nitrate. Nitrogen removal is complex with a number of contributory factors. Further discussion is available in several of the references; see USEPA 2000 or Reed, Crites, and Middlebrooks 1995.

Table 5. Removal of organic priority pollutants in constructed wetlands.

Compound	Initial concentration (mg/L)	Removal in 24 hours (%)
Benzene	721	81
Biphenyl	821	96
Chlorobenzene	531	81
Dimethyl-phthalate	1033	81
Ethylbenzene	430	88
Naphthalene	707	90
p-Nitrotoluene	986	99
Toluene	591	88
p-Xylene	398	82
Bromoform	641	93
Chloroform	838	69
1,2-Dichloroethane	822	49
Tetrachloroethylene	457	75
1,1,1-Trichloroethane	756	68

(Source: Reed, Crites, and Middlebrooks 1995.)

4. Costs for Constructed Wetlands.

a. The total costs for a constructed wetland are determined by the cumulative cost of land, design, earthwork, planting, monitoring, and maintenance. By using the area of the wetland, it is possible to estimate the cost or range of costs for the capital investment and potential monitoring and maintenance cost of the system. In addition, expenditures on structures, liners, and specialty-engineered devices are to be added. In general, economies of scale exist, as smaller systems tend to incur higher costs than larger systems per unit.

b. The major items included in capital costs of constructed wetlands are: land costs, site investigation, clearing and grubbing, excavation and earthwork, liner, media, plants, inlet structures, fencing, miscellaneous piping, pumps, etc., engineering, legal and contingencies, contractor's overhead and profit.

c. Media Costs. Most of these items depend directly on the design area of the system, and the unit costs for almost all are essentially the same for FWS and SF systems. The major difference between the two concepts is the media cost. In the case of an SF wetland, a 60 cm (2 ft) depth of gravel typically fills the bed, whereas the media for a FWS wetland consists of 15 cm (6 in.) or more of topsoil used as growth media for the wetland vegetation.

(1) A variety of liner materials may be used depending upon requirements of the regulatory agencies. Materials include onsite soils, clay, and plastic membranes; sand may be required to protect membrane liners in rocky areas.

(2) Media for an FWS wetland are the soils placed on the prepared bottom of the bed, which serve as the growth medium for the emergent and submerged vegetation in the system. A similar layer of topsoil is also usually applied to the berm slopes to support their ~~re~~vegetation.

(3) The media used in an SF wetland are the gravel or rock placed in the bed. They serve to support the growth of the vegetation and to provide physical filtration, flocculation, sedimentation, and surfaces for attached microbial growth and adsorption to occur. Several different sizes of rock and gravel can be used in these systems. A U.S. Environmental Protection Agency (USEPA) study found medium-sized gravel, 20–25 mm in diameter (0.75–1 in.), was used for treatment. Coarse rock, 40–50 mm in diameter (1.5–2.0 in.), was used to surround the inlet and outlet manifolds, and a layer of pea gravel, 5–10 mm in diameter (1/4–3/8 in.), was sometimes used to cap the gravel in the treatment bed. Coarse stone, 10–15 cm in diameter (4–6 in.), is sometimes used to cover the exposed liner on the side slopes and to reduce the risk of burrowing animals. The unit cost of these materials depends on the size of the material, the volume needed, and the distance from the source to the wetland site. The media is usually the most expensive part of an SF wetland, potentially representing 40 to 55 percent of total construction costs.

d. Plants and Planting Costs. Plant materials sometimes can be obtained locally by cleaning drainage ditches. Care should be exercised to ensure that these materials are exclusively native in origin. Otherwise, they should not be used. It is also possible to develop an onsite nursery at the wetland construction site if advance time is sufficient, or grow native plant sprigs or seedlings and transplant these to the wetland cells. The large and expanding number of nurseries, nationally, can also supply a variety of native plant species for these wetland systems. Ideally, native plants should be obtained from nurseries within a 300-600 mile radius of the proposed site. This proximity will afford them optimal acclimation to the local climate and substantially improve their survival rates. Small systems are typically planted by hand; for large systems, mechanical planters can be used. Costs can run $5,000 per acre.

e. Cost for Inlet and Outlet Structures. The inlet and outlet structures for most small- to moderate-sized wetland systems are typically some variation of a perforated manifold pipe. Large wetland systems typically use multiple drop or weir boxes for both inlets and outlets. Adjustable water level outlet structures should be used to control the water level in the wetland cell. Gate valves, or similar outlet control structures, will provide resource managers maximum flexibility in adaptively managing actual field conditions encountered.

f. Piping, Equipment, and Fencing Costs. These items include the piping to transfer the untreated inflow to the wetland, the piping from the wetland to a discharge point, and any pumps required for either of those purposes. Fencing is typically installed around all municipal wastewater treatment systems, but has not usually been required around the smaller SF wetland beds due to the low risk of public contact and exposure to the untreated inflow.

g. Miscellaneous Costs. These costs include engineering design and legal fees, construction contingencies and overhead and profit for the construction contractor. These are not unique to wetland systems and are typically expressed as a percentage when preparing an estimate. Mobilization and bonding are also typically included. Typical values are:

(1) Mobilization, 5 percent of direct costs.

(2) Bonds, 3 percent of direct costs

(3) Engineering design services, 15 percent of capital costs

(4) Construction services and start-up, 10 percent of capital costs

(5) Contractor's overhead and profit, 15 percent of capital costs

(6) Contingencies, 15 percent of capital costs

h. Tables 6 and 7 present some cost figures for FWS and SF wetlands compared with a conventional wastewater treatment system, a sequencing batch reactor (SBR).

Table 6. Capital and O&M costs for 100,000 gpd wetland.

	Cost ($)*			
	FWS		**SF**	
Item	**Native Soil Liner**	**Plastic Membrane Liner**	**Native Soil Liner**	**Plastic Membrane Liner**
Land Cost	16,900	16,900	16,900	16,900
Site Investigation	3,800	3,800	3,800	3,800
Site Clearing	7,000	7,000	7,000	7,000
Earthwork	34,900	34,900	34,900	34,900
Liner	0	69,800	0	69,800
Soil Planting Media	11,200	11,200	0	0
Gravel Media **	0	0	150,300	150,300
Plants	5,300	5,300	5,300	5,300
Planting	7,000	7,000	7,000	7,000
Inlets/Outlets	17,600	17,600	17,600	17,600
Subtotal	103,700	173,500	242,800	312,600
Engineering, Legal, etc.	60,100	100,600	140,700	181,100
Total Capital Cost	163,800	274,100	383,500	493,800
O&M Costs ($/year)	6,300	6,300	6,300	6,300

* August 2001 Costs, ENR = 6389
** 12,000 cubic yards of 0.75-inch gravel
(Source: Adapted from Water Environment Federation 2000.)

Table 7. Cost comparison for wetland and conventional wastewater treatment.

	Process		
Cost Item	**FWS Wetland**	**SF Wetland**	**SBR**
Capital Cost ($)	274,000	494,000	1,169,000
O&M Cost ($)	6,300	6,300	113,000
Total Present Worth Costs* ($)	341,400	561,000	2,363,000
Cost per 1,000 gal treated ** ($)	0.47	0.77	3.24

* Present worth factor 10.594 based on 20 years at 7 percent interest.
August 2001 costs, ENR CCI = 6389
**Daily flow rate for 365 days/year for 20 years, divided by 1,000 gallons.
(Source: Adapted from Water Environment Federation 2000.)

5. Stormwater Runoff Wetlands.

a. Wetlands used for stormwater treatment can be incidental, natural, or constructed. Incidental wetlands are those created as a result of previous development or human activity. Many experts, regulators, and public interest groups discourage the use of natural wetlands for stormwater treatment. Some states allow wetlands to be used as stormwater Best Management Practices (BMPs), but only in very restricted circumstances and on a case-by-case basis. Studies have indicated SF constructed wetlands, while well-suited for the diurnal pattern of wastewater flow, are not appropriate for the peak flows from stormwater or combined sewer overflows (CSOs), which may be several orders of magnitude higher than the base flow, resulting in a very high cost for the requisite gravel bed. This cost may preclude the use of SF wetlands for stormwater or CSO treatment. Therefore, most stormwater wetlands are of the FWS constructed wetland variety.

b. There are four basic designs of FWS constructed wetlands: shallow marsh, extended detention wetland, pond/wetland system, and pocket wetland. As shown in Figure 7, these wetlands store runoff in a shallow basin vegetated with native wetland plants. Figures 8 through 11 provide more detail on typical types of Stormwater wetlands. The selection of one design over another will depend on various factors, including land availability, level and reliability of pollutant removal, and size of the contributing drainage area.

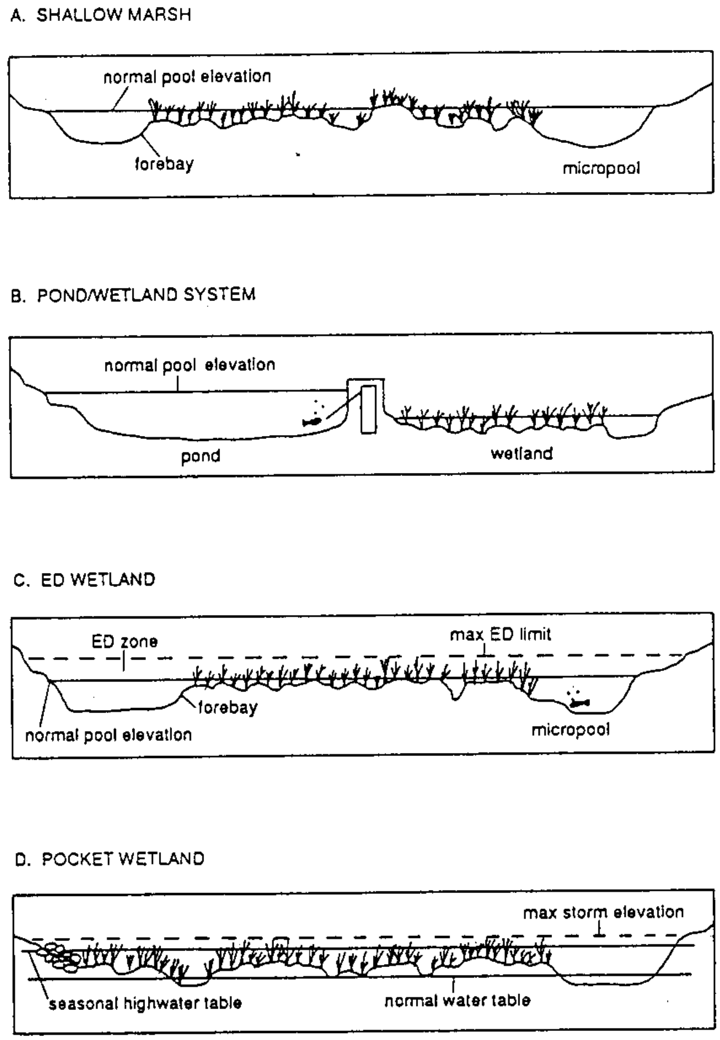
(1) The shallow marsh design requires the most land and a sufficient baseflow to maintain water within the wetlands.

(2) The basic shallow marsh design can be modified to store extra water above the normal pool elevation. This wetland, known as an extended detention wetland, attenuates flows and can relieve some downstream flooding.

(3) The pond/wetland system has two separate cells: an upstream wet pond and a downstream shallow marsh. The wet pond traps sediments and reduces runoff velocities prior to entry into the wetland. Less land is required for a pond/wetland system than for the shallow marsh system.

(4) Still less land is required for a pocket wetland. Pocket wetlands should be designed with contributing drainage areas of 0.4 to 4 hectares (1 to 10 acres) and usually require excavation down to the water table for a reliable water source. Unreliable water sources and fluctuating water levels result in low plant diversity and poor wildlife habitat value.

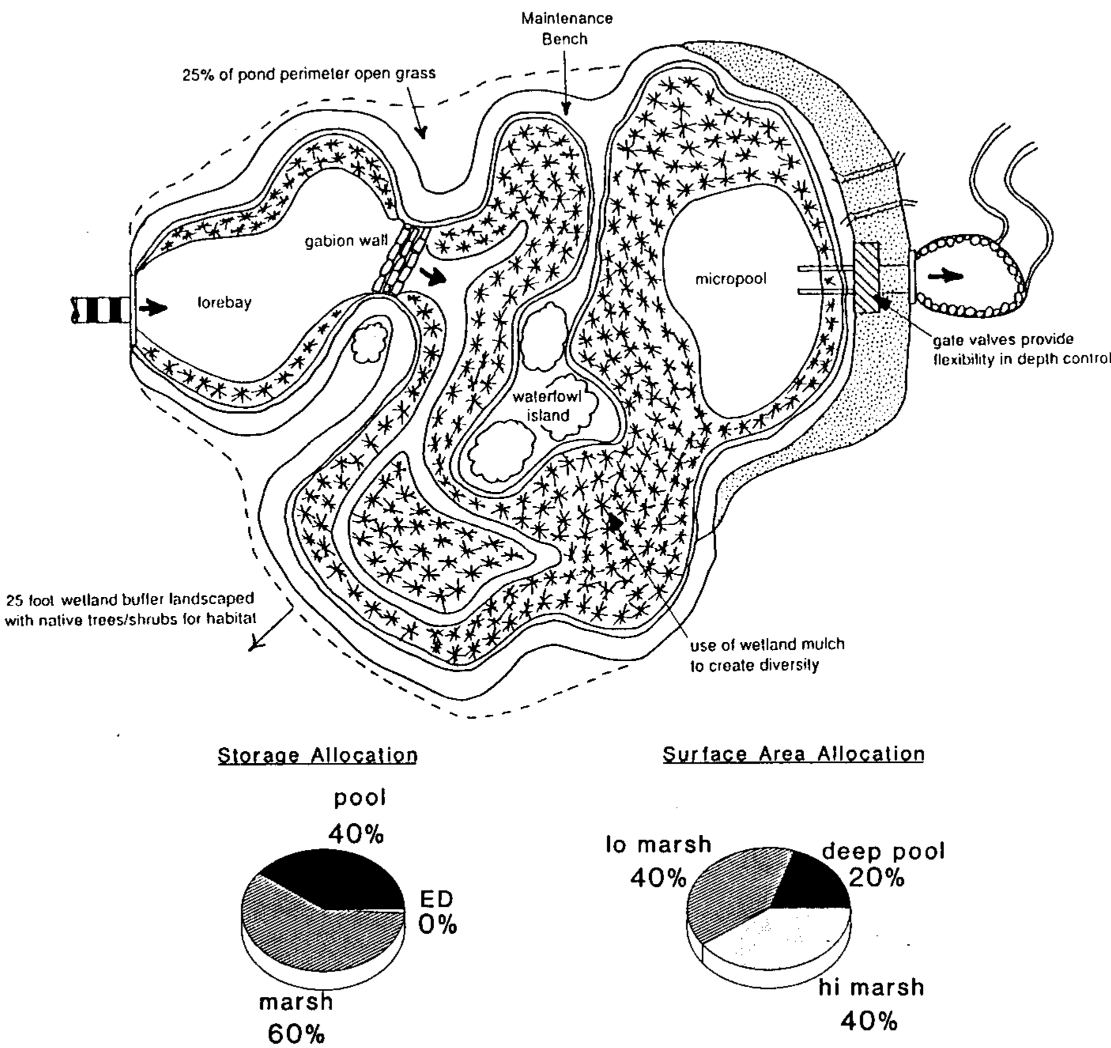
c. Constructed wetlands improve the quality of stormwater runoff and can also control some runoff volume. They are one of the more reliable BMPs for removing pollutants and are adaptable to most locations in the United States.



Cross-sectional profiles of the four stormwater wetlands are not drawn to scale. In Panel A, the majority of the shallow marsh is devoted to shallow depths that support emergent wetland plants. The pond/wetland system (Panel B) is composed of deep and a shallow pool. In ED wetlands (Panel C), the runoff storage of the wetland is augmented by temporary, vertical ED storage. Pocket wetlands (Panel D) are excavated to the groundwater table to provide a more or less constant water elevation.

(Source: MWCOG 1992.)

Figure 7. Comparative profiles of the four Stormwater wetland designs.

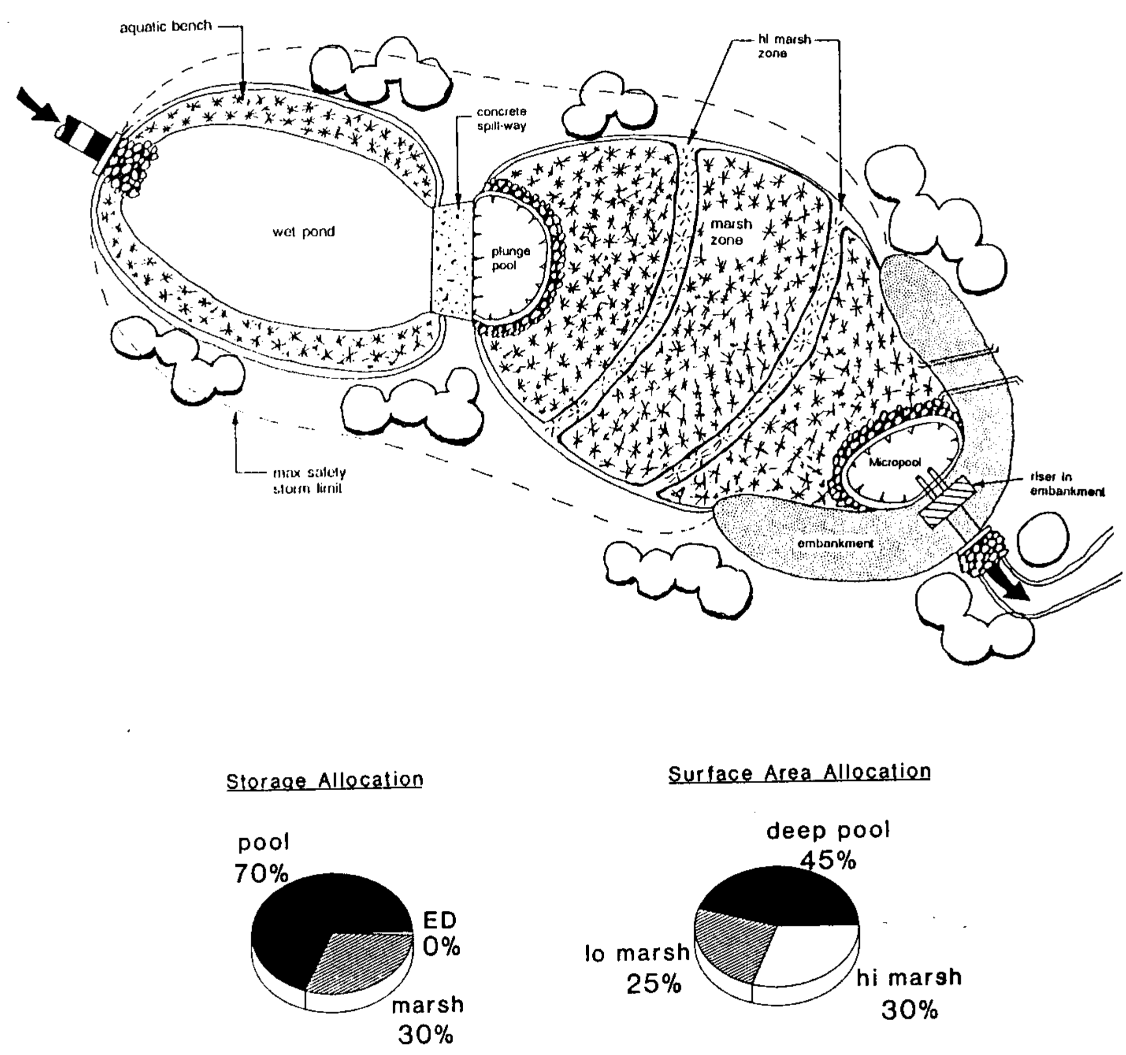


The majority of the shallow marsh system is zero to eighteen inches deep, which creates favorable conditions for the growth of emergent wetland plants. A deeper forebay is located at the major inlet, and a deep micropool is situated near the outlet.

(Source: MWCOG 1992.)

Figure 8. Design No. 1 – the shallow marsh system.

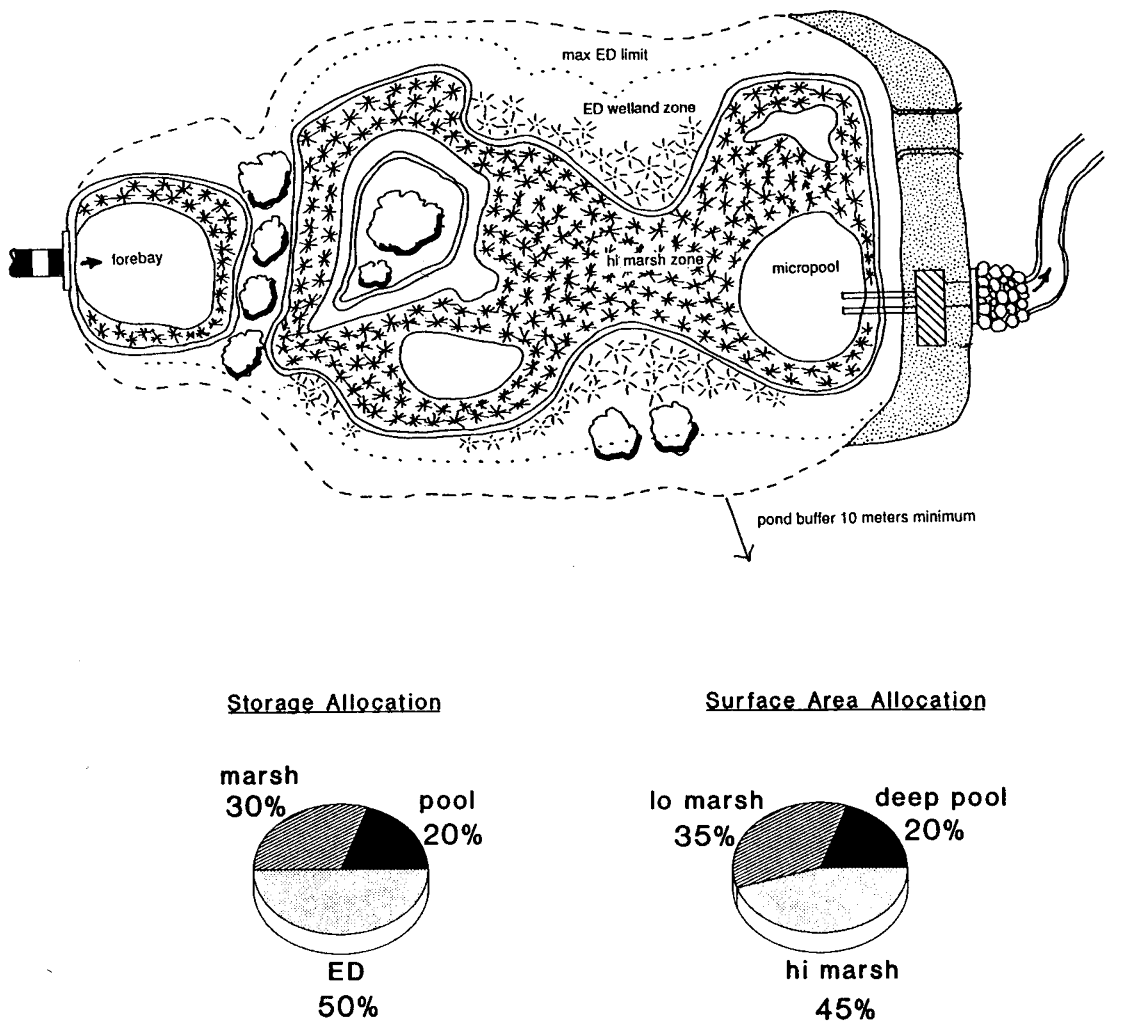
d. Sediment removal, with its associated sorbed suite of pollutants, is typically the major purpose of wetlands designed for treatment of urban Stormwater flow from parking lots, streets, and landscapes. In essence, the wetland is a Stormwater retention basin with vegetation, and the design uses many of the principles of sedimentation basin design. The presence of vegetated fringes, deep and shallow water zones, and marsh segments enhances both the treatment and the habitat functions. These wetlands have been shown to provide beneficial responses for BOD, TSS, pH, nitrogen oxide (NO_3), phosphates, and trace metals.



The pond/wetland system consists of two separate cells - a deep pond leading to a shallow wetland. The pond removes pollutants, and reduces the space required for the system.

(Source: MWCOG 1992.)

Figure 9. Design No. 2 – pond/wetland system.



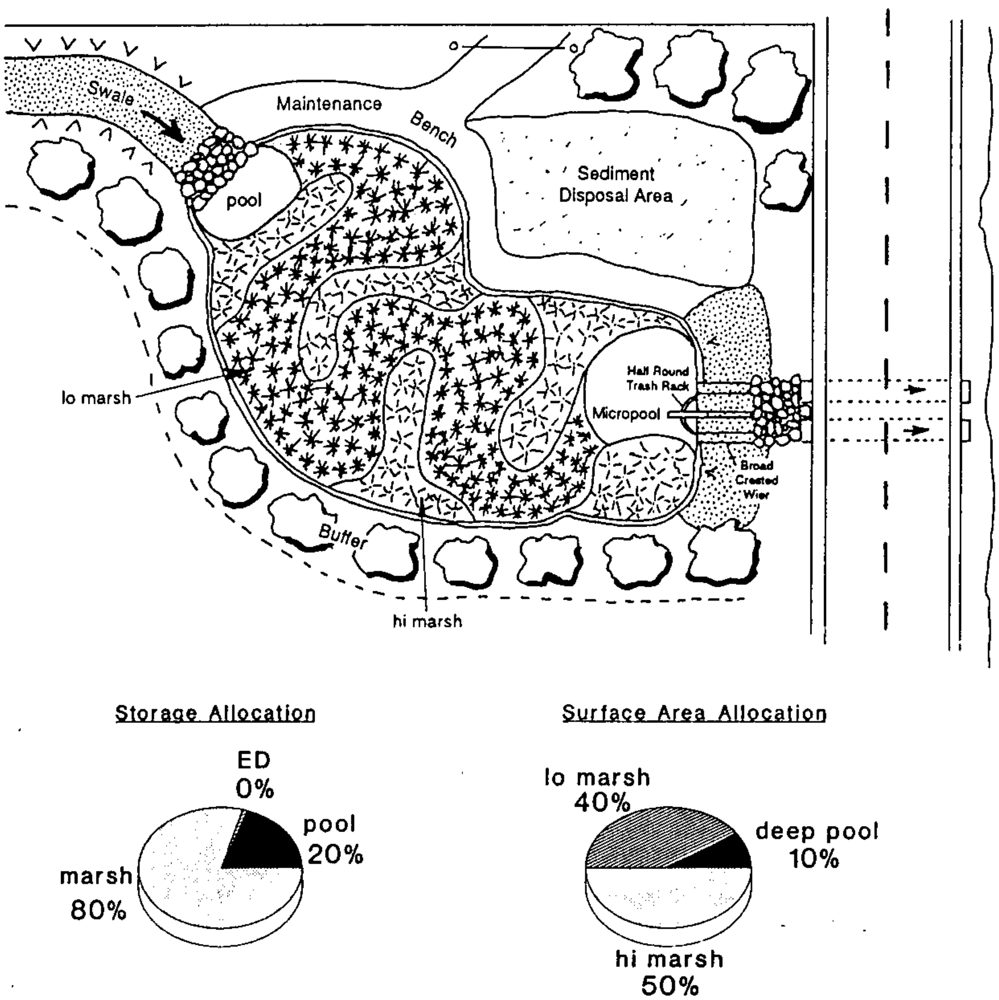
The water level within an ED wetland can increase by as much as three feet after a storm event, and then returns to normal levels within 24 hours. As much as 50% of the total treatment volume can be provided as ED storage, which helps to protect downstream channels from erosion, and reduce the wetland's space requirement.

0(Source: MWCOG 1992.)

Figure 10. Design No. 3 – extended detention wetland.

e. At a minimum, a Stormwater wetland system (SWS) will usually have some combination of deep ponds and shallow marshes. Wet meadows and shrub areas can also be used. Since the flow rate is highly variable and inorganic solids have the potential to accumulate and clog, the SF wetland concept is not practical for this application, so the marsh component in the SWS system will typically be FWS constructed wetlands. Key components include an inlet structure, a ditch or basin for initial sedimentation, a spreader swale or weir to distribute the flow laterally if a wet meadow or marsh is the next component, a deep pond, and some type of outlet device that permits overflow conditions during peak storm events and allows slow discharge to the "datum" water level in the system. The datum water level is usually established to maintain a shallow water depth in the marsh components. Use of drought resistant native plant species in the marsh components would permit complete dewatering for extended periods.

f. Environmental benefits associated with Stormwater runoff wetlands include improvements in downstream water and habitat quality, enhancement of diverse vegetation and wildlife in urban areas, and some flood attenuation. Downstream water quality is improved by partial removal of suspended solids, metals, nutrients, and organics from urban runoff. Habitat quality is also improved as reduced sediment loads are carried downstream and the erosion of stream banks associated with peak Stormwater flows is reduced. Wetlands can support a diverse wildlife population.



Pocket wetlands seldom are more than a tenth of acre in size, and serve development sites of ten acres or less. Due to their size and unreliable water supply, pocket wetlands do not possess all of the benefits of other wetland designs. Most pocket wetlands have no sediment forebay. Despite many drawbacks, pocket wetlands may be an attractive BMP alternative for smaller development situations.

(Source: MWCOG 1992.)

Figure 11. Design No. 4 – pocket Stormwater wetland.

g. A potential negative concern arises ~~is~~ if the wetland acts as a heat sink with the ability to discharge warmer waters to downstream water bodies, affecting sensitive fish and aquatic insects. Another concern may be mosquitoes; proper design and management can minimize these concerns.

6. Constructing Wetlands.

a. Local, state, and Federal permit requirements should be determined prior to wetland design. See the section on permitting later in this appendix.

b. An appropriate site must have an adequate water flow and appropriate underlying soils. The baseflow from the drainage area or groundwater must be sufficient to maintain a shallow pool in the wetland and support the wetlands' vegetation, including species susceptible to damage during dry periods. Some sites may require geotextile liners or a 15 cm (6 in.) layer of clay. After any necessary excavation and grading of the wetland, at least 10 cm (4 in.) of soil should be applied to the site to provide a substrate for the vegetation to become established and to which it can be anchored. Sizing criteria may vary between states. State environmental offices should be contacted to determine appropriate procedures. The Metropolitan Washington Council of Governments (MWCOG) has established criteria appropriate for the Washington, DC and Maryland area. These criteria address water balance, maximum flow path, allocation of treatment volume, minimum surface area, allocation of the surface area, and extended detention. The flow path should be maximized to increase the runoff's contact time with plants and sediments. A recommended minimum length-to-width ratio is 2:1. If a ratio is less than that, the use of baffles, islands, and peninsulas can minimize short-circuiting. The wetland surface area is allocated to four different depth zones: deepwater (0.5 to 2 m, or 1.5 to 6 ft, below normal pool), low marsh (0.17 to 0.5 m, or 0.5 to 1.5 ft, below normal pool), high marsh (up to 0.17 m, or 0.5 ft, below normal pool), and semi-wet areas (above normal pool). The allocation to the various depth zones will create a complex internal topography that will maximize plant diversity and increase pollutant removal.

c. Extending detention within the wetland increases the time for sedimentation and other pollutant removal processes to occur and provides for attenuation of peak flows. To prevent large fluctuations in the water level that could potentially harm vegetation, however, extended detention should be limited to 1 m (3 ft) above the normal pool elevation. The extended detention volume should be detained for 12 to 24 hours. Sediment forebays are recommended to decrease the velocity and sediment loading to the wetland.

d. Flow from the wetland should be conveyed through an outlet structure located within the deeper areas of the wetland. Discharging from the deeper areas using a reverse slope pipe prevents the outlet from becoming clogged. A micropool just before the outlet will also prevent clogging. An adjustable gate valve-controlled drain capable of dewatering the wetland within 24 hours should be located within the micropool to facilitate maintenance.

e. Vegetation can be established by any of five methods: mulching; allowing volunteer vegetation to become established; planting nursery vegetation; planting underground dormant parts of a plant; and seeding.

(1) Donor soils from existing wetlands can be used to establish vegetation within a wetland. This technique, known as mulching, has the advantage of quickly establishing a diverse wetland community. However, the species that grow within the wetland are unpredictable. Non-native species are undesirable and often disallowed by permitting agencies.

(2) Allowing species transmitted by wind and waterfowl to voluntarily become established in the wetland is also unpredictable. Volunteer species are unusually well established within 3 to 5 years. Wetlands established with volunteers are usually characterized by low plant diversity with monotypic stands.

(3) A higher diversity wetland can be established when native nursery plants or dormant rhizomes are introduced. Vegetation for a nursery should be planted during the growing season – not during late summer or fall – to allow vegetation time to store food reserves for their dormant period.

(4) Separate underground parts of vegetation are planted during the plants' dormant season, depending upon the local climate.

(5) The spreading of seeds has not been very successful. It is, therefore, not widely practiced as a principal planting technique.

f. The wetland design should include a buffer to separate the wetland from surrounding land. Buffers may alleviate some potential wetland nuisances, such as accumulated floatables or odors. MWCOG recommends a buffer of 8 m (25 ft) from the maximum water elevation, plus an additional 8 m (25 ft) when wildlife habitat is of concern. Leaving trees undisturbed in the buffer zone will minimize the disruption to wildlife and reduce the chance for invasion of nuisance vegetation such as cattails and primrose willow. If tree removal is necessary, the buffer area should be reforested. This also discourages the settlement of geese, which prefer open areas.

g. The pollutant removal effectiveness of shallow marsh and pond/wetland systems has been fairly well documented, while the amount of removal efficiency data for extended detention wetlands and pocket wetlands is limited. Average long-term pollutant removal rates for constructed wetlands as a whole are presented in Table 3. Excessive pollutant loadings may exceed the wetlands' removal capabilities. The wetlands' effectiveness seems to improve after the first few years of use as the vegetation becomes established and organic matter accumulates.

h. Costs. Costs incurred for Stormwater wetlands include those for permitting, design, construction, and maintenance. Permitting costs vary depending upon state and local regulations. Construction costs for a shallow marsh wetland with a sediment forebay range from $65,000 to $137,500 per hectare ($26,000 to $55,000 per acre) of wetland. This includes costs for clearing and grubbing, erosion and sediment control, excavating, grading, staking, and planting. The cost for constructing the wetland depends largely upon the amount of site excavation required and plant selection. The cost for forested wetlands could be double that of an emergent wetland. Maintenance costs for wetlands are estimated at 2 percent of the construction costs per year.

7. Landfill Leachates and Other Specialty Applications.

a. Both FWS and SF wetlands have been used for the treatment of landfill leachate. In some cases, the leachate is applied directly to the wetland; in others, the leachate flows to an equalization pond from which it is transferred to the wetland unit. Studies of the long-term use of wetlands for leachate treatment have demonstrated significant economic advantages, mainly through lowered construction, transportation, and operation costs.

b. Characterization of the leachate is essential for proper wetland design, since it can contain high concentrations of BOD, ammonia, metals, high or low pH, and possibly priority pollutants of concern. In addition, the nutrient balance in the leachate may not be adequate to support vigorous plant growth in the wetland, and supplemental potassium, phosphorous, and other micronutrients may be necessary. Since leachate composition will depend on the (1) type and quantity of materials placed in the landfill and (2) time, a generic definition of characteristics is not possible and data must be collected for each system design. Table 8 shows examples of leachate water quality with wetland treatment. These data confirm the variability and potentially high concentrations of parameters that may be present.

c. The design of a wetland for leachate treatment will follow the same procedures as that for other constructed wetlands. The reader is encouraged to consult the technical POC for this PWTB or some of the design references for additional information. The removal of metals and priority pollutants is as described earlier. Typically the wetland will be sized to achieve a specific level of ammonia or nitrogen in the final effluent. The atmospheric exposure and relatively long HRT provided will result in very effective removal of the volatile priority pollutants. If the leachate BOD is consistently above 500 mg/L, the use of a preliminary anaerobic pond or cell should be considered. Many of the advantages of the SF wetland concept are not necessary at most landfill locations, so an FWS wetland may be more cost effective, even though more land will be required.

d. Mine drainage and agricultural waste treatment systems also number in the hundreds with wetland treatment being an appropriate, cost-effective technology option. Reed, Crites, and Middlebrooks 1995 and WEF 2000 are suitable references.

Table 8. Landfill leachate treatment in SF wetlands*.

Location and Parameter	Untreated Leachate (mg/L)	Wetland effluent (mg/L)
Tompkins Co., NY:		
BOD	185	124
NH_4	253	136
NO_3	0.5	0.5
Total phosphorous	0.15	0.07
Sulfate	3	1.5
Potassium	235	192
Aluminum	0.2	0.14
Calcium	160	100
Cadmium	<0.01	<0.01
Copper	0.02	0.01
Chromium	0.01	<0.01
Iron	11	5.3
Lead	0.05	<0.01
Magnesium	120	80
Manganese	2.9	1.9
Nickel	0.10	<0.01
Broome Co., NY**		
NH_4	169	19
NO_3	1.8	2.3
Aluminum	0.4	0.1
Calcium	184	54
Magnesium	97	30
Potassium	188	57
Iron	31	0.2
Manganese	1.9	1.0
Zinc	0.2	0.1

* Average values for the entire study periods.
**Two wetland cells, in series, are preceded by an overland flow zone with a permanent pool of water.
(Source: Reed, Crites, and Middlebrooks 1995.)

8. Plants. Different constructed wetland projects have used different types of plants (Guntenspergen, Stearns, and Kadlec 1989 lists 32 different species). The majority of projects in the north temperate zone have used large perennial species such as reed (*Phragmites australis*), reed canary grass (*Phalaris arundinacea*), mannagrass (*Glyceria* sp.) cattail (*Typha* sp.) and various species of sedges such as *Carex* sp. and *Scirpus* sp. These species and others fulfill the most important requirements for use in treatment systems, including ecologic acceptability, tolerance to a range of climates, resistance to disease, and the ability to tolerate a wide range of pollutants. These species are also easy to propagate and generally grow very well. They help to filter leachate and perhaps prevent clogging of the soil. Most species can be harvested during the season without harm so long as water levels do not rise above the cut ends of the plants.

9. Role of Wetlands in the Watershed.

a. The first step in assessing the feasibility of an FWS constructed wetland is to identify the goals and objectives of the wetland within the watershed. Consideration for an SF wetland would be similar. Once a minimum water quality is achieved that protects public health and addresses ecosystem concerns, FWS wetlands can be used to provide considerable benefits beyond water quality improvement. These additional objectives should be integrated into the feasibility and planning process and, ideally, incorporated into an overall master plan addressing the entire watershed and receiving waters.

b. The process used to evaluate the feasibility of FWS constructed wetlands for water quality improvements and to function as landscape units on a watershed requires a sequence of assessments. The procedure described below incorporates evaluation of the possible additional functions of FWS constructed wetlands.

(1) Step 1 – Identify the goals and objectives of the project. In this initial step, the role that the wetland will play in maintaining, restoring, or enhancing the beneficial uses in the receiving stream is established.

(2) Step 2 – Characterize the wastewater(s) entering the proposed FWS constructed wetland. Each type of wastewater or nonpoint water source has its own unique physical, chemical, and biological characteristics. A thorough characterization of the constituents and their concentrations should be conducted combined with identification of pathogen indicators or pathogens. This step should also include a thorough literature review and may require laboratory and mesocosm testing.

(3) Step 3 – Determine the discharge requirements and limitations. The discharge constraints coupled with the constituent properties determined in Step 2 would dictate the required effectiveness of treatment.

(4) Step 4 – Determine the ability for wetland processes to reduce, retain, and transform constituents. Mesocosm and bench-scale treatability studies might be required before proceeding to the next step. Wetland treatability studies usually require more time than most biological treatment systems because of the time it takes to develop the aquatic macrophyte standing crop.

(5) Step 5 – Identify the roles the wetland can fulfill in the watershed given the constituent concentrations and treatment goals imposed upon it. Certain wetland roles may not be appropriate due to factors such as loading variations, types of constituents, and site location. The function and value of wetlands such as ecological (habitat/production), hydrological, biogeochemical, and educational can be important in determining the economic costs or benefits of the system.

(6) Step 6 – Evaluate the site characteristics and constraints. The planning and design of a system is site specific. Once the type of system and the treatment goals have been established, the soil, vegetation, and hydrologic conditions necessary to achieve these goals are identified. The inherent characteristics of the site should be evaluated and compared to these requirements to determine the need for modifications and additions.

(7) Step 7 – Determine the FWS wetland area required to achieve the treatment objectives.

a) A variety of approaches can be used for design purposes following several different models. Extended detail and discussion is available in USEPA 2000a, USEPA 1999, and from practitioners. Models are usually assumed to follow the plug flow reactor approach and are useful as aids. However, none of these equations alone are able to accurately predict the performance of a multi-zone FWS constructed wetland. Even if they could be calibrated to fit a specific set of data, their nondeterministic basis would not give them the ability to fit other circumstances of operation. Given these caveats, a quick estimating approach for Directorate of Public Works (DPW) planners and engineers to design an FWS wetland for municipal wastewater treatment would use areal loading rates, which specify a maximum loading rate per unit area for a given constituent. Areal loading rates can be used to give both planning level and final design sizing estimates for FWS systems from projected pollutant mass loads. For example, knowing the areal BOD loading rate, the expected BOD effluent concentration can be estimated or compared to the long term, average performance data of other well-documented, full-scale operating systems. The USEPA (2000a) has suggested the following areal loadings:

Parameter	Zone 1 Areal Loading	Effluent Concentration
BOD	40 kg/ha-d	30 mg/L
TSS	30 kg/ha-d	30 mg/L

b) If the FWS system were to have significant open areas between fully vegetated zones, a better effluent quality could be attained at areal loadings, based on the entire FWS system area.

Parameter	Areal Loading	Effluent Concentration
BOD	45 kg/ha-d	<20 mg/L
	60 kg/ha-d	30 mg/L
TSS	30 kg/ha-d	<20 mg/L
	50 kg/ha-d	30 mg/L

Typically needed information to develop an initial estimate includes ~~incoming~~ ***in***flow rates and constituent concentration.

c) The following formula can be used for estimating $ALR = Q\ C_o/A_w$

Where:

ALR = areal loading rate
Q_o = incoming flow rate, in m^3/d
C_o = influent concentration, in mg/L
A_w = total area of FWS, in ha

d) Solve for average and monthly flows and design constituents, hydraulic retention times and add an additional area with a factor of 1.25 to 1.4 for buffers and setbacks to get an estimated area.

(8) Step 8 – Evaluate alternate sites. The land capacity in terms of quantity and quality must be compared between alternate sites and technologies based upon constraints and capabilities.

(9) Step 9 – Estimate the total cost of the system. The life-cycle cost is a function of capital cost, and operation/maintenance cost distributed over a predetermined time base. The computed life-cycle cost can be compared with alternative treatment systems or can be used to determine cost effectiveness and for benefit/cost analyses. The value of the additional benefits, such as real estate, habitat, recreation, flood control, and water resource, should be included in the development of a total cost for the system.

(10) Step 10 – Prepare construction and wetland system development plans. Wetland systems have several major differences from the construction of a conventional wastewater treatment plant. The primary difference is that aquatic macrophytes take time to develop into the requisite standing crop to support the treatment processes. Soils that support these plants are also critical to the start-up of the system. Preparing bid documents for the planting and maintenance of aquatic macrophytes should include the skills of a landscape architect and/or botanist with related experience. FWS constructed wetlands must also include flexible hydraulic controls for operational tasks such as isolating and draining cells. Flexibility in hydraulic controls is essential to the support of adaptive management; as water elevations can be critical in the overall viability and maintenance of desired species composition**.** Inlet and outlet location and configuration should be considered at this step, as this can be critical to maximize treatment efficiency.

(11) Step 11 – Plan the system start-up. The start-up of a wetland system might require changes in the hydrodynamics and density of vegetation. The start-up period for an FWS constructed wetland is regionally variable and can take from 18 to 36 months because it takes time for the plants to reach operational density. Discharge permits for a wetland must reflect the lag time necessary to develop the requisite standing crop of vegetation to support treatment processes.

(12) Step 12 – Full-scale operation requires determination of the placement and density of aquatic plants, inlet and outlet control structures, design hydroperiod, and design HRTs. Fine-tuning of hydroperiods and HRT's can be accomplished via careful observation of the performance of a given system and the provision of flexible outlet controls such as gate valves, etc. The full-scale operation should have established background levels of soluble BOD, chemical oxygen demand (COD), ammonia, nitrogen, etc. Full-scale operation could include determining procedures to store and/or draw down the wetland system in anticipation of discharge constraints and/or peak monthly flow conditions. Procedures for control of vectors and nuisance mammals, vegetation management, etc., should also be developed and ready to implement.

(13) Step 13 – Daily monitoring of influent flow and effluent flow should be conducted, and monthly average (weekly samples) BOD, TSS, coliform, and other (ammonia, nitrates, etc.) pollutant concentrations tracked. Vegetation coverage should be monitored annually along with the detrital accumulation (TSS, plant detritus, and floating litter layer). An inspection of the hydraulic integrity of berms, inlet and outlet works, and bottom (if required) should be performed annually. Under certain scenarios, monitoring for mosquito larvae or adults might be required during the mosquito-breeding season. The activities of other potential nuisance organisms such as nutria, beavers, and muskrats need to be monitored monthly as they can have a negative effect on effluent quality and wetland performance, in which case they may require management.

10. Permitting.

a. A number of regulatory influences may apply to constructed wetlands. Required permits and certifications may include Clean Water Act (CWA) Section 401 water quality certifications, Section 402 Stormwater NPDES permits, Section 404 wetland permits, dam safety permits, sediment and erosion control plans, waterway disturbance permits, forest-clearing permits, local grading permits, and land-use approvals.

b. Use of natural marshes is generally avoided. Discharge to a natural marsh or "waters of the U.S." may be possible if discharge standards are met prior to application. Some states also have clauses in their state laws allowing "enhancement" of water quality. Each case must be dealt with on a site-specific basis. Most situations will require site-specific analyses to determine site feasibility and acceptability based on existing natural wetland type, size, condition, and sensitivity. In general, the use of natural wetlands should be avoided when:

(1) The wetlands being considered are pristine wetlands and representative of unique wetland types;

(2) Projected impact to the wetlands would result in changes that would threaten the viability of the system; and/or

(3) Conflicts with other uses such as adjacent land-use activity, availability, and cost of land could not be mitigated adequately.

c. Most natural wetlands are designated as "waters of the U.S." Such wetlands are either adjacent to other water of the U.S. or, upon use, degradation, or destruction, could affect interstate or foreign commerce and, as such, are afforded protection under the CWA. In addition, other wetland protection programs must be considered when evaluating the use of natural wetlands.

d. Under the CWA, programs that can directly or indirectly affect wetland management decisions are:

(1) Water Quality standards (Section 303)

(2) National Pollutant Discharge Elimination System (NPDES) Permits (Section 402)

(3) Discharge of Dredge/Fill Permits (Section 404)

(4) The Construction Grants (Section 201) program will probably not have a bearing on a wholly enclosed installation.

(5) Entities that choose to build constructed treatment wetlands to help meet advanced treatment requirements that are also designed to provide high value wetland habitat for wildlife and public use may find themselves facing CWA Section 404 issues if they locate their system in existing wetlands or waters of the United States. On the other hand, if they seek formal recognition of the habitat values for potential eligibility and use as wetland mitigation areas, they may also create long-term responsibilities to maintain these areas.

(6) FWS constructed wetlands are normally designed to be isolated from underlying aquifers. For site design, the elevation of the seasonal high groundwater table and direction of predominant flow should be determined to ascertain potential problems with interception or berm failure. In the case of unlined FWS constructed wetlands designed to discharge through infiltration, groundwater monitoring will be necessary to measure constituent concentrations and hydraulic effects of the discharge.

(7) Use of non-native plant species is typically prohibited by permitting agencies, and should be avoided.

11. Operations and Maintenance.

a. The O&M of FWS and SF constructed wetlands is much less demanding than for mechanical wastewater treatment technologies such as the activated sludge or tricking filter processes. Routine O&M requirements for wetland systems are similar to those for oxidation pond systems and include hydraulic and water depth control, inlet/outlet structure cleaning, grass mowing of berms, inspections of berm integrity, and wetland vegetation management. Mosquito control may a concern for FWS, but should not be necessary for SF systems. Accumulated solids and litter removal may be required for FWS, but should be minimal for SF systems.

b. Well-designed and maintained wetlands can function as designed for 20 years or longer. Wetland maintenance must actually begin during the construction phase, however. During construction and excavation, many constructed wetlands lose organic matter in the soils. The organic matter provides exchange sites for pollutants, and therefore plays an important role in pollutant removal. Replacing or adding organic matter after construction improves performance. Maintenance requirements for constructed wetlands are important for the first few years while vegetation is becoming established. The design should facilitate these maintenance activities.

c. O&M considerations for FWS constructed wetlands are as important as design issues in meeting regulatory requirements pertaining to effluent quality. The treatment effectiveness of most of the existing FWS constructed wetlands can vary considerably depending on water depth, weir overflow rate, plant density and location, and wildlife activity. Following are some of the more important O&M considerations for FWS constructed wetlands.

(1) Management

a) Many management issues pertaining to FWS constructed wetlands are not mutually exclusive. Typically, one management decision or action influences other management goals.

b) Listed below are considerations that need to be addressed when developing a FWS constructed wetlands management plan:

1) Regulatory requirements

2) Hydroperiod and hydraulic retention time – water depth and flowrate (flexibility of management via adjustable control structures)

3) Hydraulic control – weir overflow rate/inlet-outlet distribution

4) Vegetation control (planting, harvesting, and monitoring)

5) Proximity of airports

6) Wildlife management

7) Vector control (mosquitoes)

8) Structural integrity of berms

9) Nuisance conditions (odors)

10) Inlet/outlet structures

11) Public access

12) Environmental education

c) A set of O&M procedures needs to be developed for each of the goals of the management plan developed above. This management manual should be organized in a manner to assist the operator and owner in effectively operating the wetland system under wide range of environmental conditions. At a minimum, the following categories should be included for each goal of the management plan.

1) Objective and goal for the component

2) Startup condition/monitoring

3) Normal operating condition/monitoring/lead-time

4) Abnormal operating condition/monitoring lead-time

5) Problems

- Indicator
- Cause of abnormal condition
- Course of action to solve problem
- Maintenance requirements
- Sampling/monitoring program

(2) Potential nuisance conditions

a) Because of the very nature of FWS wetlands, they have the potential to create conditions that may be a nuisance to human neighbors or to the wildlife species they harbor. Nuisances that could conceivably occur include mosquito breeding, creation of odors, attraction of dangerous reptiles (snakes and alligators), potential for accidental drowning, and the potential for bioaccumulation or biomagnification of pollutants in wildlife.

b) Wetlands and other stagnant water bodies can provide breeding habitat for mosquitoes. Some species can transmit diseases to humans or livestock. In addition, mosquitoes may be a nuisance because of their large numbers and painful bites. General conclusions are that numbers of breeding mosquitoes in treatment wetlands are not higher than in adjacent natural wetlands.

c) Generally, odors in FWS treatment wetlands are associated with high organic loadings, especially in the inlet region of the wetland. It has been observed that most treatment wetlands have odors similar to the normal range of odors observed in natural wetlands.

d) Dangerous reptiles are attracted to FWS treatment wetlands in some regions of the United States. These same species are generally a natural component of natural wetlands in those same areas, and most citizens are aware of the need to avoid these creatures when they are encountered.

(3) Process Control

a) FWS constructed wetlands have minimal need for active process control. The only two operational controls for FWS wetlands are hydraulic loading and outlet weir level control (if designed to allow varying hydro periods). Further, hydraulic loadings can only be varied if alternative hydraulic pathways exist.

b) Under certain conditions, increasing the outlet weir level for a given period of time will result in no discharge. This would allow for short-term periods of no discharge to a receiving system. This increase in water level will increase the HRT while maintaining the areal loading at a constant value. The maximum depth that can be tolerated by emergent plants in the FWS wetland limits the degree of water level increase.

(4) Monitoring Requirements

a) The most critical monitoring issue during the wetland startup period is vegetation growth and coverage. A wetland that does not develop sufficient emergent and submergent vegetation becomes a shallow oxidation pond that produces algae, BOD, and solids. The planting strategy, combined with hydroperiod control as the plants grow, determines the effectiveness of vegetation growth during the startup period. Other monitoring factors include control of aquatic birds, mammals, and invasive vegetation during the startup period.

b) Once the wetland vegetation has been established, the system can be brought online and the wastewater introduced. After the startup period, routine monitoring requirements will often be necessary. Most important in the operation of a FWS constructed wetland is monitoring hydraulic and organic loadings to, and discharge(s) from, the wetland system (including the monitoring of individual wetland cells). Such tasks require measuring influent and effluent flowrates, and recording water depths in each wetland cell. This information can be used to develop seasonal strategies, based upon hydraulic and organic loadings, hydraulic detention times, and areal loadings.

c) Influent and effluent water quality constituents should also be measured on a weekly or at a minimum, a monthly basis. Parameters such as BOD, TSS, pH, nutrients, temperature, specific conductance, and dissolved oxygen should be monitored as these parameters can be used to assess wetland performance and determine constituent loadings.

(5) Considerations for Minimizing Variability in Effluent Quality. Many items combine to influence the variability of effluent quality from constructed wetlands. The following are important design and operational considerations that can influence and help control variability of effluent water quality and need to be considered throughout the planning and design process, particularly for FWS wetlands:

a) Ability to buffer weekly fluctuations in effluent flow by use of multiple cells.

b) Ability to store water individually in each wetland cell to allow for longer hydraulic detention times for BOD and TN removal, and quiescent conditions for settling processes.

c) Minimize the amount of emergent vegetation necessary to reach treatment goals. The aquatic vegetation contributes to background BOD, ammonia, and dissolved phosphorous levels in the wetland. The lower the influent BOD, TSS, and Total Nitrogen (TN), the greater potential contribution this background source has to the variation in the effluent value.

d) It is important to have 3 to 7 days detention time in the emergent wetland zone immediately upstream of the wetland outlet, if wildlife habitat is one of the goals of the project. This emergent vegetation zone of the wetland has minimal habitat value for migratory and resident birds (source control), and provides a final clarification/vegetative filter zone.

e) Design outlet collection zones, and inlet/outlet structures to minimize open water areas, which can attract wildlife and promote phytoplankton and periphyton production.

f) Minimize the velocity fields at the inlet and outlet zones of the wetland.

g) Design for solids removal, via planned maintenance, at the inlet region of the constructed wetland.

12. Summary.

a. Constructed wetlands are an alternative treatment for a variety of wastewaters (e.g., domestic wastewater, Stormwater runoff, combined sewer overflows, and landfill leachate). They can provide primary, secondary, and tertiary or polishing treatment, depending upon site-specific requirements and whether they are used for wastewater or Stormwater runoff treatment. Constructed wetlands are typically low in capital costs, easy to operate and maintain, and capable of effective treatment and meeting effluent limit goals. Benefits in addition to treatment/storage of wastewater and reductions in energy/chemical costs include providing habitat for fish and wildlife and presenting intrinsic aesthetic appeal. Implementation of this innovative technology on Army installations can be facilitated because the Army has jurisdiction and responsibility throughout its holdings along with a requirement for sound environmental stewardship over its natural resources. Being the sole landlord, the installation is not as constrained as the municipal sector, which must balance the input of numerous landowners, jurisdictions, and special interest groups.

b. The two major categories of constructed wetlands are FWS and SF (free water surface and submerged flow). They each have their appropriate uses for any given situation. FWS constructed wetlands are generally less expensive to construct and provide improved habitat for wildlife, while the SF variety, despite the higher cost, may be preferred where public access, odors, or vectors are critical issues.

c. A number of processes play roles in the effectiveness of constructed wetlands for renovating wastewater (which includes stormwater): microbial reactions, sedimentation, filtration, precipitation and complexation of metals, volatilization, and adsorption. Constructed wetlands can be efficient at reducing concentrations of a number of pollutant constituents, including BOD, COD, metals, organics, fecal coliforms, and nutrients.

d. This PWTB presented a general discussion of the various types and applications of constructed wetlands, benefits and constraints, their effectiveness at removing various parameters, guidance on determining feasibility of their applicability, design and construction advice, operation and maintenance procedures, cost information, the role of wetlands in a watershed, and permitting information. Constructed wetlands can provide all the options mentioned previously in support of the robust Army programs in wildlife management and sustainable installation activities.

13. References.

Center for Watershed Protection, 1997. *National Pollutant Removal Performance Database for Stormwater Best Management Practices.* Prepared for the Chesapeake Research Consortium.

Crites, R.W. and G. Tchobanoglous 1998. *Small and Decentralized Wastewater Management Systems* (McGraw-Hill, Inc.)

Guntenspergen, G.R., F. Stearns, and R.A. Kadlec, 1989. "Wetland vegetation," in Hammer, D.A., ed. *Constructed Wetlands for Wastewater Treatment: Municipal Industrial and Agricultural*, Lewis Publishers, Chelsea, MI.

Hammer, D.A., ed., 1989. *Constructed Wetlands for Wastewater Treatment: Municipal, Industrial and Agricultural*, Proceedings 1st International Conference on Constructed Wetlands for Wastewater Treatment, Chattanooga, TN, Lewis Publishing, Chelsea, MI.

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

Metropolitan Washington Council of Governments (MWCOG), 1992. T.Schueler, *Design of Stormwater Wetland Systems: Guidelines for Creating Diverse and Effective Stormwater Wetland Systems in the MidAtlantic Region*.

Reed, S.C., R.W. Crites, and E.J. Middlebrooks, 1995. *Natural Systems for Waste Management*, McGraw-Hill, Inc.

Water Environment Federation, 2000. *Natural System for Wastewater Treatment,* Manual of Practice (MOP) FD-16, WEF, Alexandria, VA.

Water Pollution Control Federation, 1990. *Natural Systems for Wastewater Treatment*, MOP FD-16, Alexandria, VA.

U.S. Environmental Protection Agency (USEPA), 1993. *Subsurface Flow Constructed Wetlands for Wastewater Treatment: A Technology Assessment*, EPA 832-R-93-008, USEPA Office of Water Management, Washington, DC.

USEPA, 1999. *Free Water Surface Wetlands for Wastewater Treatment: A Technology Assessment*, EPA 832-R-99-002, June 1999.

USEPA, 2000a. *Constructed Wetlands Treatment of Municipal Wastewaters*, EPA 625-R-99-010, September 2000.

USEPA, 2000b. *Guiding Principles for Constructed Treatment Wetlands*, EPA 843-B-00-003, October 2000.