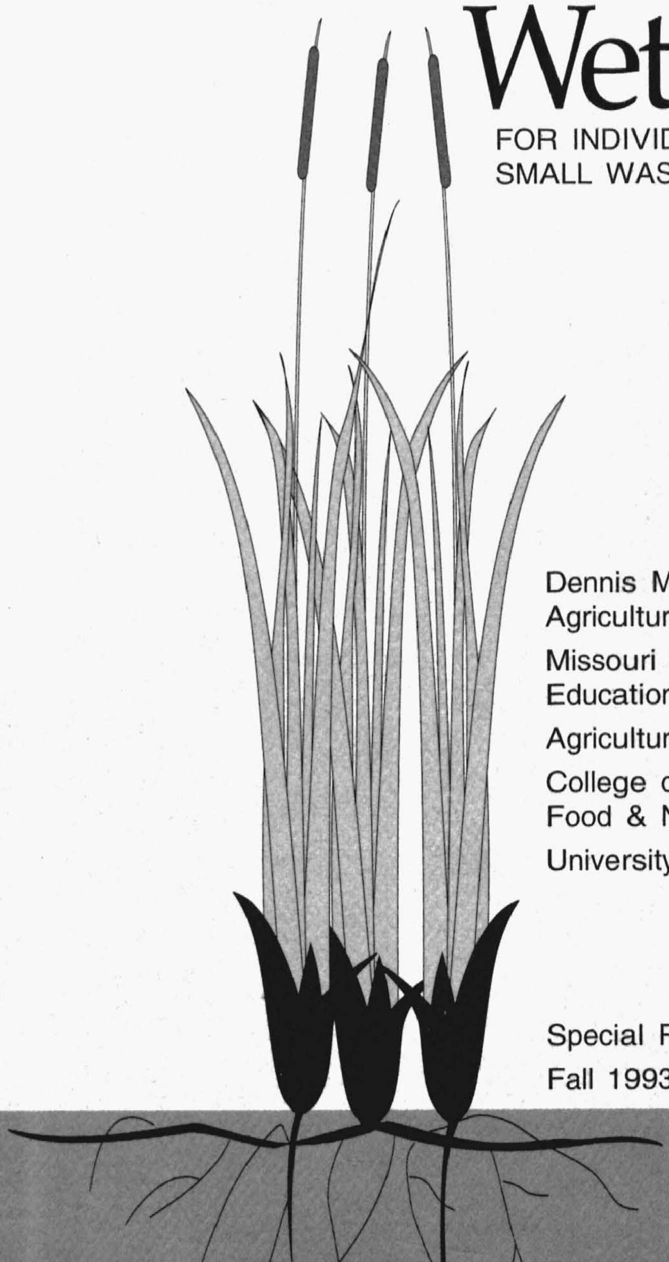
DESIGN OF

Submerged Flow Wetlands

FOR INDIVIDUAL HOMES AND SMALL WASTEWATER FLOWS



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SMALL WASTEWATER FLOWS

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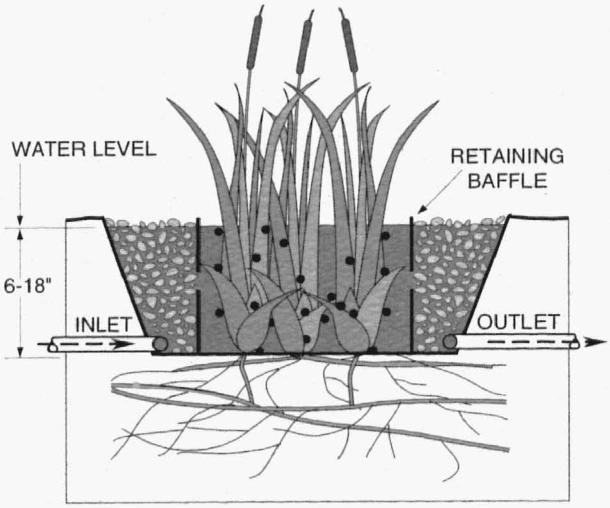

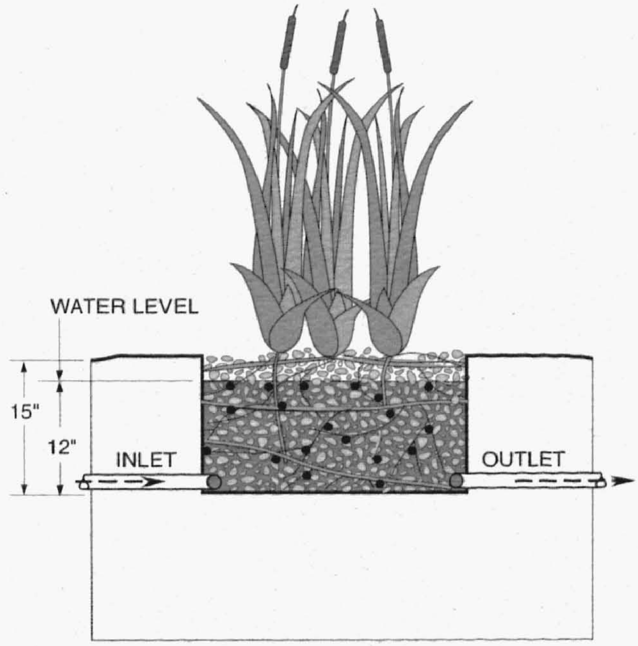

Figure 1. Types of constructed wetlands used for wastewater treatment. (Left) Free Water Surface (FWS). Rock surrounding inlet and outlet pipes protects pipe and helps distribute water. Retaining baffles (i.e. treated 2 x 6s) keep rock in place. (Right) Submerged Flow (SF). Black dots represent attached bacteria.

INTRODUCTION

Constructed wetlands are ecological systems that are created artificially, as opposed to naturally occurring wetlands or restored wetlands, whose purpose is largely to provide wildlife habitat. Constructed wetlands can be defined as engineered systems that use wetland ecology to remove impurities from wastewater flows.

Constructed wetlands provide secondary or tertiary levels of treatment, which means that some form of pre-treatment must be used prior to the wetland (lagoon, septic tank, etc.) Wetlands cannot withstand large influxes of suspended solids. The pre-treatment used must be capable of removing a large fraction of these solids.

Treatment of wastes in constructed wetlands is accomplished by a combination of the following processes: sedimentation of suspended material; physical entrapment by plant roots and rocks; biological oxidation of organics by microorganisms; and ion exchange/adsorption with organic litter and sediments (USEPA, 1988).

Two types of constructed wetlands are being used for wastewater treatment: free water surface (FWS) and submerged flow (SF). Free surface water wetlands are shallow beds or channels (depth less than 24 inches) filled with emergent aquatic plants. The surface of the water is exposed to the atmosphere as the water flows between the plants. Submerged flow wetlands are similar in construction except that they are filled with shallow depths (less than 18 inches) of rock, gravel or sand. The porous media supports the root systems of the emergent aquatic vegetation. The water level is maintained below the top of the porous media (no open water surface). Figure 1 illustrates both types of constructed wetlands being used for wastewater treatment. The black dots represent bacteria growing attached to the plants (left) or plant roots (right).

Submerged Flow Wetlands

This manual describes procedures for designing and constructing SF wetlands as applied to individual homes or other small wastewater flows. The SF wetland was chosen for these applications because it offers some advantages over the FWS wetland. One, it eliminates open water, which is a potential hazard to small children or pets and a breeding area for mosquitoes. Two, the SF wetland can be landscaped into the home area as a very aesthetically pleasing structure. For information on the design and construction of FWS wetlands, consult a qualified engineer.

Missouri state law requires that effluents from on-site sewage treatment systems remain on the land owner's property (no discharge rule). Therefore, the individual homeowner contemplating using an SF wetland will be required to manage the effluent so that it remains on the owner's property. This may involve using a soil absorption field, surface irrigation or an evaporative bed.

If a soil absorption field is used in conjunction with a SF wetland, the area required to dispose of the water may not be less than the area required for a conventional septic tank - soil absorption field system. A soil's ability to transmit water is an inherent physical property and this property may not be enhanced because the wastewater has been treated in a SF wetland. Some enhancement may occur if the soil's original permeability was good. In areas of the state where ground water contamination is a concern and wetland treatment is utilized prior to soil absorption, the soil absorption system should be dosed to allow for unsaturated flow conditions.

For systems other than individual homes, application should be made to the Missouri Department of Natural Resources (MDNR) for appropriate construction and operating permits.

DESIGN AND CONSTRUCTION

Design Flow and Pre-Treatment

For individual homes, pre-treatment will generally consist of a septic tank. For proper sizing, design and construction details, see UM Extension Guide Sheet WQ 401 or consult with a Department of Health representative.

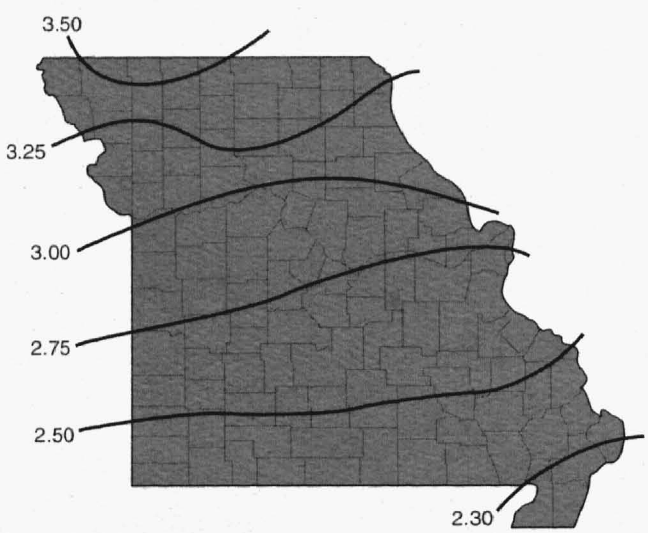

Figure 2. Recommended surface areas (ft²/gallon/day) for SF constructed wetlands in Missouri. Design parameters: C_o=150 mg/L; C_e= 30 mg/L; k_{20}= 1.104; d = 0.25 m; ϕ = 0.30.

Recommended design wastewater flow rates for individual homes is 120 gallons per bedroom per day (MDNR 10 CSR 20-8.021), with the minimum volume of sewage from each single family dwelling being 240 gallons per day. Each additional bedroom above two bedrooms shall increase the volume of sewage by 120 gallons per day. This assumes two persons per bedroom. If the occupancy of the home exceeds two per bedroom, calculate flow on the basis of 60 gallons per person per day.

For individual homes, the recommended organic waste production is 0.17 pounds of biochemical oxygen demand (BOD_5) per person per day (0.2 lbs per day if a garbage disposal is used). A properly operating septic tank will remove 40 percent of the BOD_5. Therefore, the daily organic loading to the wetland will be 0.1 pounds BOD_5 per person. For example, six people in a three-bedroom house would produce a flow of 360 gallons with an organic loading from the septic tank of 0.6 lb/day).

Surface Area of Wetland

The surface area of SF wetlands can be determined by using the following equation (WPCF, 1990):

$$A_s = [Q(\ln C_o - \ln C_e)]/(k_T \times \phi \times d) \quad (1)$$

where:

A_s = wetland surface area, ft²

Q = daily flow rate to wetland, ft³/day([gallons/day] ÷ 7.5)

C_o = influent BOD_5 concentration, mg/L

C_e = effluent BOD_5 concentration, mg/L

k_T = temperature dependent rate constant, per day

d = water depth in wetland, ft

ϕ = void fraction of rock media, decimal.

Design surface areas for the state of Missouri are shown in Figure 2. These design values were calculated using Equation 1 and assuming specific values for each parameter. Mean January monthly temperatures were used. Changing the input parameters can result in substantially different surface areas. Be sure that parameters used to generate Figure 2 are appropriate for your specific design situation.

Once the surface area has been determined, the cross-sectional area (Figure 3) can be calculated and checked against hydraulic and organic loading. For hydraulic loading, the cross-sectional area can be calculated from Darcy's Law (WPCF, 1990):

$$A_h = Q/(K_h \times S) \quad (2)$$

where:

A_h = cross-sectional area (hydraulic loading), ft²

K_h = hydraulic conductivity of rock media, ft/day

S = slope of wetland bottom, decimal.

A value of 800 ft/day can be used for the hydraulic conductivity for rock of 1 inch diameter. Values for slope should range between 0.25 - 1 percent. Wetlands for individual homes need little slope. Some slope in wetlands for larger applications may be desirable, particularly if the wetland needs to be drained occasionally.

The cross-sectional area must now be calculated for organic loading. Excessive organic loading can lead to clogging of the wetland, resulting in ponding and surface flow. A proven value for organic loading which does not lead to clogging does not exist. Based on observations of home systems, Steiner, et al. (1991) recommends that 0.05 lbs BOD/d/ft² be used to prevent the clogging of individual home SF wetlands. The cross-sectional area based on organic loading can be calculated from:

$$A_o = OGL/0.05 \quad (3)$$

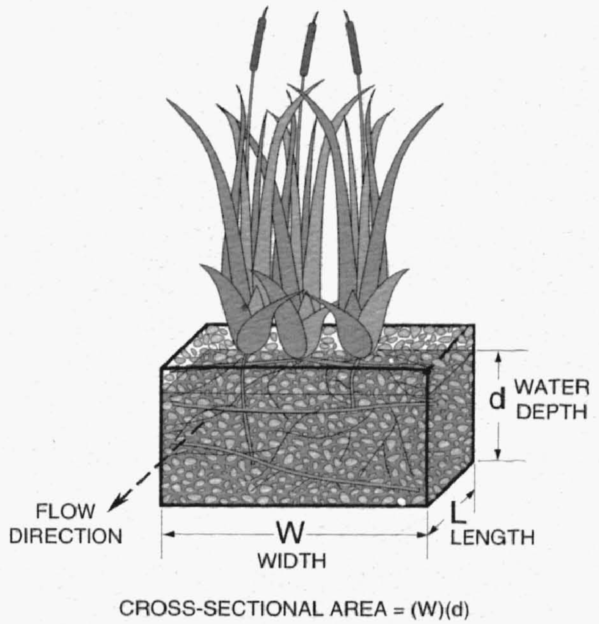

Figure 3. Typical cross-section of an SF constructed wetland.

where:

A_o = cross-sectional area (organic loading), ft²

OGL = organic loading, lbs BOD_5/day

The larger of the two calculated cross-sectional areas, A_h or A_o, should be used to determine the wetland dimensions. The width, W, of the wetland can be calculated by dividing the larger cross-sectional area by the water depth, d, used in Equation 1. The calculated width (W) should not be less than one-third of the length (L) (length: width ratio - 3:1). SF wetlands should not be long and narrow. It has been found that treatment of organics occurs primarily in the upper portion of the wetland and narrow beds may lead to clogging (Reed, 1991). Should it be necessary to construct an SF wetland with a length: width greater than 3:1, step-loading along the length of the wetland should be considered. Surface mounding of water can also be a problem in long, narrow SFs. This problem can be managed if proper water level control devices are used.

The configuration of an SF wetland for an individual home can be a single cell or two cells in series, depending upon the soil properties at the site. Larger systems may consist of multiple cells in parallel or series in order to provide more management options.

Single cells work well for individual homes and this configuration assumes that there will be no percolation of water through the bottom of the wetland. Water movement properties of the soil at the wetland construction site must be determined either by use of properly performed percolation tests or a thorough soil profile analysis performed by a person knowledgeable in soil science. Soils that will allow percolation to occur must be lined with clay or an artificial liner (40 ml or greater). Where influent and effluent pipes enter and exit the cell, the liner should be sealed to prevent leakage using adjustable corrosion resistant bands and plumbers putty to clamp the liner to the pipes.

For soils with reasonably good percolation rates (< 60 minutes per inch), Steiner, et al. (1991) recommend that a two-cell wetland be used for individual homes. The first cell should be lined, allowing no percolation. The second cell would be unlined and filled with sand (not rock) to promote some percolation from the bottom of the wetland. These systems are untried in Missouri. It should be noted that passing the wastewater through the first cell of the wetland will not improve the percolation rate of the soil in the second cell. A soil with a naturally poor percolation rate will continue to have a poor rate even though the wastewater has been treated.

Substrate

The choice of rock substrate for an SF wetland is important, both for hydraulics and plant growth. Large diameter rock (large pores) offers less resistance to flow than smaller diameter rock. However, smaller diameter rock produces better plant growth (McManus, 1992; Steiner, et al. 1991).

All rock will compact with time. Rock with rounded edges will compact less than rock with sharp edges (e.g. crushed limestone). Laboratory studies have shown that loss of porosity due to compaction of sharp-edged rock can be twice that of round-edged rock (McManus, 1992).

Crushed limestone has been used extensively for SF wetlands in the Midwest. Some of these wetlands are experiencing plugging problems. In one study, the plugging of a municipal SF wetland (limestone substrate) was attributed to the formation of a mineral gel (silicon, calcium and aluminum) (Kadlec, 1991). The source of silicon was traced to lagoon algae; calcium to dissolution of the limestone. Wetlands receiving effluent from septic tanks may not have this problem since there are no algae present. However, until studies can prove this, it may be wise to use a rock of different mineral content such as creek gravel. Whatever type of rock is used, it must be thoroughly washed to remove the fine material which may cause plugging.

Recommended rock for substrate is 1-inch diameter, washed river rock or creek gravel (rounded edges). Larger diameter rock (2-4 inches) may be used around inlet and outlet pipes to reduce potential clogging. A 3-4 inch layer of washed pea gravel may be used on top of the 1-inch substrate for decorative purposes.

Piping

All piping can be Standard Schedule 35 Sewer pipe or Schedule 40 polyvinyl chloride (PVC) water supply pipe. Use 4-inch diameter for all piping. Influent should be distributed and effluent collected by header pipes running the width of the wetland. Perforated sewer pipe can be used for the headers. For unperforated pipe, drill 1-1/2-inch diameter holes every 12 inches along the header. Headers should be placed at the bottom of the wetland on a bed of rock and covered with 2-to 4-inch rock. A cleanout should be placed before the influent header.

If effluent from the septic tank flows to the wetland by gravity and there are parallel cells in the wetland, a distribution box should be placed ahead of the wetlands so that flow can be controlled to individual cells. If effluent is pumped from the septic tank, the pumping rate should not exceed 25 gpm and no more than one-third of the daily design flow should be pumped at one time (Steiner, et al. 1991).

Water Level Control

Control of the water level in an SF wetland is essential for proper operation and maintenance. The range of control should be from two inches above the surface of the rock media to the complete draining of the wetland. To conveniently check the water level relative to the gravel surface, place a 4 inch diameter, perforated pipe in the gravel to the bottom of the wetland and observe the water level in the pipe. Control can be obtained by inexpensive structures such as swivel standpipes or collapsible tubing (Figure 4). Maximum water level in the wetland should be a minimum of 12 inches below the outlet of the septic tank so that water does not back up into the septic tank.

Surface runoff should be kept out of the wetland. This may be accomplished by diverting runoff away from the wetland or constructing an earthen berm around the wetland. Berms should be a minimum of 6 inches above the surface of the rock media.

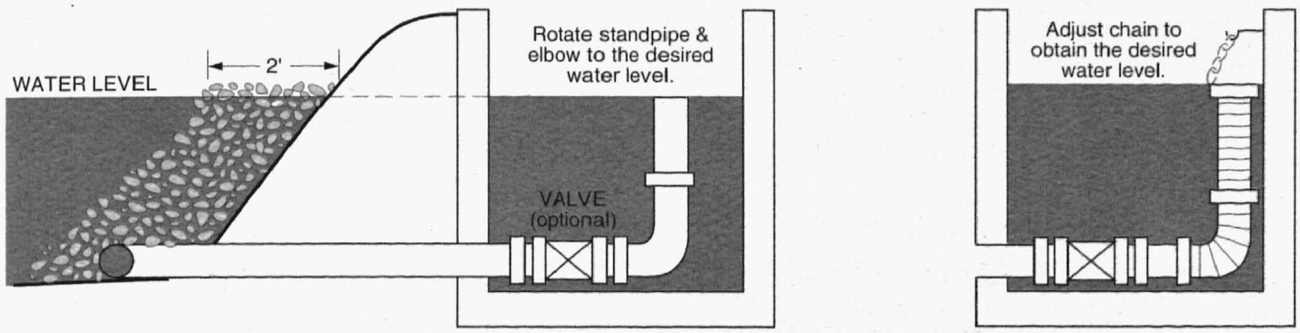

Figure 4. Water level control structures for wetlands. Source: Steiner, et al. 1991.

PLANT SELECTION

Emergent plants are the workhorses of SF wetlands. Their roots provide surface area for attachment of bacteria and supply oxygen to the bacteria; during the growing season, they provide limited nutrient uptake and transpire large amounts of water. In addition, they can provide an aesthetically pleasing landscape feature.

Selection of plants for an SF wetland must be done carefully and will be influenced by

1. The ability of the plant to root and grow in the wastewater - rock environment.
2. The ability to treat wastewater to acceptable levels.
3. The amount of biomass produced (management required).
4. Aesthetics.

Results of growth studies of various emergent aquatics conducted at the University of Missouri are presented in Table 1. All the plants were grown in an SF wetland environment. Bulrush and cattail have been the plants most frequently used in wetlands in the United States and were used here as a comparison to other emergents. Bulrush and cattail produce large amounts of biomass above ground (large top/root ratio), which may require a homeowner to harvest and dispose of large amounts of organic material.

For home wetlands, smaller plants that produce less biomass above ground and more into the roots (e.g. a lower top/root ratio) are often desired. Pickerel Rush, Arrowhead and Horsetail make excellent choices on this basis. Arrowhead and Horsetail will spread rapidly and fill the wetland area. Pickerel Rush grows more bunched with less general spreading (Table 2). All three of these plants have good rooting depths if the total water depth in the wetland is not too deep (less than 12 inches).

Soft Rush had the greatest rooting depth and on that basis should provide the best treatment potential. It does produce more biomass above ground than the three plants previously mentioned, but the growth consists of narrow, hollow stems about 2.5 feet high. This height should not be intrusive in a home wetland and the small amount of biomass is easily harvested.

Water iris is a very pleasing plant for the wetland with its distinctive leaf form and abundant blooms. However, its shallow rooting depth prevents it from contributing much treatment and it is probably best used as a landscaping plant around the edges of the wetland.

Flowering Rush did not grow well in the rock medium. It produced scant biomass above ground and did not bloom. The rock environment is evidently hostile to this plant and it is not recommended for submerged flow wastewater wetlands.

Initial Planting and Start-Up

The best time to plant is early spring (March - April) but planting can also be done in late summer (August). Plants need time to become established and produce root mass before winter freezes occur. Recommended spacings between plants can be found in Table 2. The water level in the wetland should be brought to within 3 inches of the rock surface, a hole dug to the water level, and the plant roots planted so that they contact the water. After the initial month of growth, the water can be slowly lowered (2 inches every two weeks) to the desired operating level. Watch the plants carefully for signs of drying and raise the water level if needed. Some recommendations call for starting plants in clean water that is fertilized before exposing plants to wastewater. There is little data to prove this point one way or the other. Experience at the University of Missouri has shown that Bulrush, Cattail, Arrowhead and Soft Rush that are initially planted in septic tank effluent can grow well. Experiments in which clean water and fertilizer were used produced weaker plants and less growth (Sievers, unpublished data).

Table 1. Plant growth data after one growing season.

Plant Species	Wet Wt. (lbs/ft^2)	Dry Wt. (lbs/ft^2)	Top Dry (lbs/ft^2)	Root Dry (lbs/ft^2)	Top/Root (ratio)	Root Depth (inches)
Softstem Bulrush *(Scirpus validus)*	9.74	4.20	3.20	1.00	3.20	7.0
Horsetail *(Equisetum hyemale)*	1.90	0.55	0.20	0.35	0.57	11.0
Water Iris *(Iris pseudacorus)*	3.28	0.66	0.31	0.35	0.90	8.0
Pickerel Rush *(Pontederia cordata)*	6.24	1.30	0.50	0.80	0.63	15.0
Arrowhead *(Sagittaria latifolia)*	2.25	0.35	0.17	0.18	0.94	10.0
Cattails *(Typha latifolia)*	7.89	3.00	1.90	1.10	1.73	8.0
Soft Rush *(Juncus effusus)*	3.00	1.05	0.65	0.40	1.62	18.0
Flowering Rush *(Butomus umbellatus)*	0.30	0.07	0.01	0.06	0.18	12.0

Table 2. Characteristics of emergent aquatic plants.

Plant Species	Bloom Date	Type of Bloom	Bloom Color	Plant Height (inches)	Growth Pattern	Initial Spacing (feet)
Softstem Bulrush *(Scirpus validus)*	June-July	Oblong Spikelets	Gray	40 - 60	Spreading	3
Horsetail *(Equisetum hyemale)*	July-Aug.	Oblong Spikelets	Brown	30 - 40	Spreading	3
Water Iris *(Iris pseudacorus)*	May-Aug.	Flower	White-Lt. Blue	10 - 18	Bunches	2 - 3
Pickerel Rush *(Pontederia cordata)*	July-Sept.	Flower	Purple	10 - 18	Bunches	2
Arrowhead *(Sagittaria latifolia)*	June-July	Hanging Bulbs	Green-White	6 - 10	Spreading	2 - 3
Cattails *(Typha latifolia)*	May-June	Oblong Spike	Brown	48 - 72	Spreading	3
Soft Rush *(Juncus effusus)*	June-July	Flower	Brown	18 - 30	Bunches	2

OPERATION AND MAINTENANCE

Constructed wetlands require minimum management and maintenance, but that which is required is important and must be performed to ensure good operation. The following is a list of important considerations.

1. The septic tank must be kept functioning properly so that solids are removed in the tank and kept out of the wetland. This will involve scheduled pumping of sludge solids by a reputable operator and periodic checking (every 2 to 4 years) of the baffles to make sure that floating scum solids are not passing from the septic tank.
2. The water level must be maintained at the proper operating level (within 1 to 3 inches of the rock surface). This is especially important during periods of hot, dry summer weather or extreme cold in winter when low water levels could result in damage to the plants due to drying or freezing of the roots and tubers. During vacation periods, make sure that adequate water is supplied to the wetland.
3. Inspect the vegetation for signs of stress (yellowing, excessive dead material, infestations of insects or disease). At the first signs of stress, check the water level to make sure that it is at the proper level. If the water level is satisfactory, consult a professional (i.e. horticulturist) knowledgeable in plant ecology.
4. Remove volunteer vegetation from the wetland. These plants will compete with the aquatics and could crowd them out. Replace dead aquatic vegetation with new plants as soon as possible. Pre-

vent excessive shading of the wetland vegetation by controlling the growth of trees or high shrubs near the wetland cell(s).

5. Remove dormant and brown material during the winter months. For plants that leave a stalk (e.g. cattail or rush), leave at least 12 inches of plant above the rock surface to support new growth in the spring.
6. To minimize objectionable odor, avoid ponding or standing water on the substrate surface. Level any low or high spots on the surface which can create standing pools by raking and/or filling with additional substrate material.
7. By law all wastewater treatment facilities must be fenced sufficiently to restrict entry by children, livestock and unauthorized persons as well as to protect the facility from vandalism. Wastewater treatment wetlands serving single family residences should have some method of preventing access by children, pets or animals to avoid contact with potentially infectious microorganisms.

GLOSSARY

BOD - Biochemical Oxygen Demand. A standard test used to measure the amount of oxygen consumed by bacteria to oxidize biodegradable organic matter under controlled conditions of temperature and time (20½C and 5 days).

Constructed Wetland - Engineered system utilizing aquatic ecology to remove impurities from water and wastewaters.

Emergent Aquatic Vegetation - Aquatic plants such as cattails or rushes which root in the submerged soils of wetlands but have their stems and leaves growing above the water level.

Hydraulic Conductivity - A measure of the ability of water to pass through the void spaces in soil, sand or rock. It has the units of volume per area per time.

Organic Matter - Chemical substances of vegetable or animal origin, basically of carbon structure.

Organic Loading - The amount of biodegradable organic matter applied to a wastewater treatment device, usually expressed as BOD.

Percolation Rate - The time rate of drop of a water surface in a soil test hole. The test is conducted under standard conditions (see 10 CSR 20 - 8.021, MDNR).

Rate Constant - A measure of the rate at which a biological reaction will occur in a given environment. Rate constants are highly dependent upon temperature.

Secondary Treatment - A wastewater treatment process used to convert dissolved or suspended materials into a form more readily separated from the water being treated (i.e. activated sludge).

Suspended Solids - Solids that either float on the surface of, or are suspended in water, sewage or other liquids, and which are largely removable by laboratory filtering.

Tertiary Treatment - Treatment in addition to normal or conventional secondary treatment.

Void Fraction - The fraction of the volume of rock, gravel, sand or soil which consists of open spaces and which may be filled with water or air.

Void Spaces - The open spaces between particles of rock, gravel, sand or soil.

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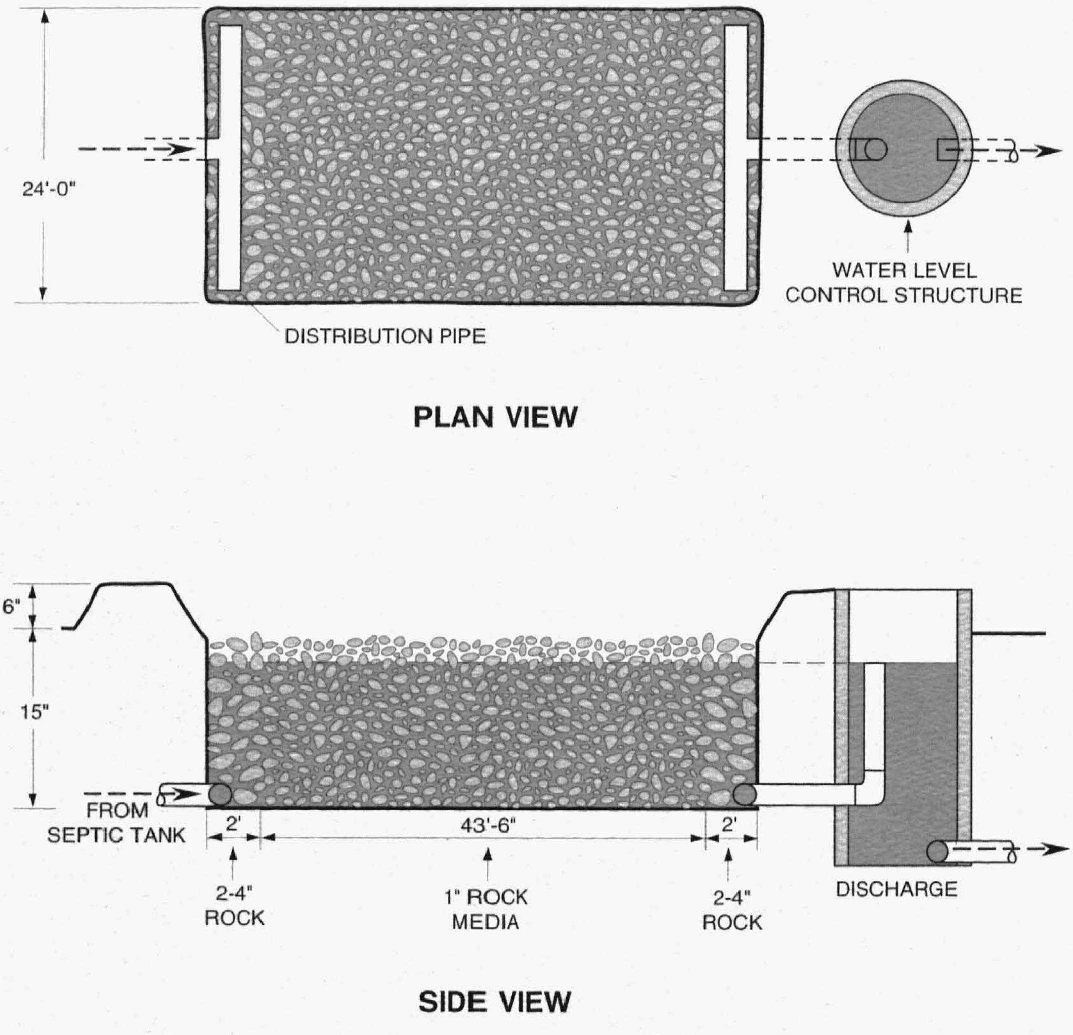

Figure 5. Design layout for a single cell SF wetland .

DESIGN EXAMPLE

Design an SF wetland to treat the wastewater from a private residence (three bedrooms) in Columbia, Missouri. Soils at the site have a percolation rate exceeding 120 minutes/inch. Pre-treatment will consist of a septic tank.

DESIGN I: A Single Cell Wetland

1. **Design Flow**: Q = 3 bedrooms x 120 gpd/bdrm = 360 gpd (48 ft^3).

2. **Organic Load from Septic Tank,** assume 5 people living in home.
   5 persons x 0.1 lb BOD/person = 0.5 lbs BOD/d (OGL).

3. **SF Surface Area** from Figure 2, recommended area = 2.9 ft^2/gpd.
   A_s = 2.9 ft^2/gpd X 360 gpd = 1044 ft2.

4. **Cross-sectional Area, A_h** from Equation 2:
   $A_h = Q/(K_h \times S)$; Assume K_h = 800 ft/d; S = 0.25% (0.0025)
   A_h = 48 ft^3/(800 ft/d X 0.0025) = 24 ft^2.

5. **Cross-sectional Area, A_o** From Equation 3:
   A_o = OGL/0.05 = (0.5 lb BOD/d)/(0.05 lb BOD/ft^2) = 10 ft^2.

6. **Choose larger cross-sectional area**. In this case, 24 ft^2.

7. **Calculate width (W) of wetland.** Assume a 1.0 ft depth of water.
   Width, W = A_h/d = 24 ft^2/1.0 ft = 24 ft.

8. **Calculate length (L) of wetland.** Length, L = A_s/W = 1044 ft^2/24 ft = 43.5 ft.

9. **Check L:W ratio**. Ratio should be less than 3:1. L:W = 43.5/24 = 1.8:1, OK.

10. **Media** will be 1 inch diameter, clean stone. Total stone depth = 15 inches.
    There will be no percolation of water through the soil at the bottom of the wetland in this design. The bottom of the wetland should be compacted with soil high in clay or an artificial liner installed. For individual home systems, effluent from the wetland will have to be managed properly and kept on the owner's property.

11. A plan and side view of this design is presented in Figure 5, opposite.

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