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Subsurface Flow Constructed Wetlands For WasteWater Treatment

A Technology Assessment

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EXECUTIVE SUMMARY

Interest in, and the utilization of, constructed wetlands for treatment of a variety of wastewaters has grown rapidly since the mid 1980s. However, a lack of consensus has resulted in the use of different, and often conflicting, criteria and guidance for the design of these systems. Therefore a better understanding of the internal renovative processes in these systems was essential for the future application 'of this promising technology, and to ensure reliable and cost-effective design procedures. A consensus on the report contents was reached via several review cycles by an internationally recognized panel of experts and via discussions at a two-day workshop in September 1992.

Two types of constructed wetlands are in common use: the first type, the free water surface (FWS) wetland, exposes the water surface in the system to the atmosphere. The second type, the subsurface flow (SF) wetland, maintains the water level below the surface of gravel or other media placed in the wetland bed. This report is concerned with the SF wetland type.

This report verifies that SF constructed wetlands can be a reliable and cost-effective treatment method for a variety of wastewaters. These have included. domestic, municipal, and industrial wastewaters as well as landfill leachates. Applications range from single family dwellings, parks, schools, and other public facilities to municipalities and industries. It can be a low-cost, low-energy process requiring minimal operational attention. As such the concept is particularly well suited for small to moderate sized facilities where suitable land may be available at a reasonable cost. Significant advantages include lack of odors, lack of mosquitoes and other insect vectors, and minimal risk of public exposure and contact with the water in the system.

The process can remove BOD_5 and suspended solids to very low concentrations and produce the equivalent of tertiary effluent. Interim design guidelines for BOD_5 removal are provided in the report. Nitrogen removal to very low levels is possible if sufficient detention time and oxygen to support the necessary nitrification reactions are present. Many of the early systems were deficient in both respects. Corrective action is possible, and the report presents tentative methods for appropriate design. A limited data base supports the capability of the SF wetland process for effective removal of metals and other priority pollutants. However, the process has limited capacity for removal of phosphorus as presently conceived, and supplemental treatment may be necessary. A one- or two-log reduction in fecal coliforms can be

reliably achieved with this process, lower levels may require post disinfection.

In addition to design guidelines, the report provides an assessment of concept applicability and the research needs for a better understanding of the process.

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CHAPTER 4

DESIGN CONSIDERATIONS

The major concerns in the design of SF constructed wetlands include:

- Hydraulic and hydrological conditions,
- BOD_5 and TSS removal mechanisms,
- Nitrogen removal efficiency,
- Vegetation selection and management,
- Construction details, and
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HYDRAULICS & HYDROLOGY

A basic intent of the SF wetland treatment concept is the maintenance of flow-beneath the surface of the media in the bed. However, a significant number of operating SF constructed wetlands are exhibiting varying degrees of surface flow on top of the media bed. Since these systems were designed for complete subsurface flow, this condition represents a potential design deficiency. It has been suggested that this surface flow is due to clogging of the void spaces in the bed either by the vegetative roots and associated plant materials or by the accumulation of suspended solids separated from the wastewater stream. However, most of these systems have been in operation for less than five years and surface flow was observed at many soon after flow commenced.

BED CLOGGING

A preliminary, unpublished 1990 investigation by Reed suggested a relationship between the organic loading on the cross section of the bed at the entry zone and observed surface flow on the SF wetland bed. The assumption was that clogging at the entry zone was causing the surface flow. A cross sectional loading of < 0.5 kg

$BOD_5/m^2/d$ (0.1 lb $BOD_5/ft^2/d$) was associated with no observed surface flow. Systems with observed surface flow had higher organic loadings, > 0.5 $kg/m^2/d$. Unfortunately, this apparent relationship has now been published in a number of sources and has become part of some design guidelines (17). Subsequent investigations at the original sites have indicated that the observed surface flow at most of the systems can be explained by inadequate hydraulic design and inattention to the requirements of Darcy's Law (described below). The organic loading approach may have some merit in that a reduced organic loading on the cross section should certainly reduce the potential for clogging. There are, however, no data available at present to support the selection of a specific cross sectional organic loading. The net affect of this approach is to increase the cross sectional area of the bed and thereby reduce the aspect (L:W) ratio. That same result can be achieved, in a more rational manner, by proper application of Darcy's Law.

Pits have been excavated in six of these SF systems (two in Kentucky, four in Louisiana) to observe any clogging substances, and to determine their characteristics (26,27,28). At only one Kentucky site, by June 1990, a persistent gelatinous substance had almost completely clogged the void spaces in the first 25 percent of the bed. Laboratory tests indicated that this material was about 80 percent inorganic, with that fraction composed of silica, clay minerals', and limestone dust. The clogging at this site occurred rapidly during the first year of operation and did not significantly expand in area in subsequent years. Pits excavated at the same locations in 1992 showed no evidence of gelatinous substances anywhere in the bed. It is likely that this isolated case of severe clogging may have been due to the overloaded condition of the bed during its first year of operation.

At the four sites in Louisiana, and the second site in Kentucky, the suspended matter in the rock voids was not gelatinous in character and washed easily from the rock surfaces (27,281. It was similar in appearance to a mixed liquor sample, with a slight odor in some cases. At three of the four sites in Louisiana, the solids present occupied less than two percent of the void space available for flow of water; in the worst case the solids present occupied about six percent of the available void spaces at a location close to the inlet pipe. In all cases, these solids were at least 80 percent inorganic material. Plant roots and related detritus were not encountered below depths of about 0.3 m (1 ft) in any of these systems (27,281. As a result, at these five sites it does not appear that accumulation of TSS or plant detritus were responsible for clogging or for any surface flow which may have occurred.

At all six of the sites investigated, the rock media were delivered by truck over unpaved roads, in all kinds of weather, and, as described by the operators, the trucks tended to follow the same pathway entering and leaving the wetland bed. It is quite possible that a large portion of the inorganic solids observed in the void spaces of the media was due to soil from the truck tires, and soil, rock dust and fines from the rock media transported in the truck. At the formerly partially clogged Kentucky site, these inorganic materials may have then trapped algal solids entering the bed, resulting in formation of the gelatinous material creating the clogging. The fact that the clogged zone never expanded beyond the first 25 percent of the bed, and that the gelatinous material has now disappeared, suggests that construction activity may have been the primary cause of the clogging instead of a continuing biochemical reaction.

HYDRAULIC DESIGN

When subsurface flow conditions are expected in the SF wetland bed it is common practice to use Darcy's Law, which describes the flow regime in a porous media. Darcy's Law is typically defined with equation (2).

$$Q = k_s A S \qquad (2)$$

Where:
- Q = flow per unit time, m^3/d (ft^3/d), or (gal/d), etc.
- k_s = hydraulic conductivity of a unit area of the medium perpendicular to the flow direction, $m^3/m^2/d$ ($ft^3/ft^2/d$), or (gal/d), etc.
- A = total cross-sectional area, perpendicular to flow, m^2 (ft^2).
- S = hydraulic gradient of the water surface in the flow system dh/dL, m/m, (ft/ft).
  (All units must be consistent)

Darcy's Law is not strictly applicable to subsurface flow wetlands because of physical limitations in the actual system. It assumes laminar flow conditions, which may not be the case when large rock or very coarse gravel are used as the media. Turbulent flow will occur in these coarse media when the hydraulic design is based on a high hydraulic gradient. Darcy's Law also assumes that the flow (Q) in the system is constant and uniform, but in the actual case in a SF wetland the input versus output Q may vary due to precipitation, evaporation, and seepage; and short circuiting of flow may occur due to unequal porosity or poor construction. **Ail of these factors limit the theoretical applicability of Darcy's Law, but it remains as the only reasonably accessible model for design of these SF systems.** If small to moderate sized gravel (< 4 cm) is used as the media, if the system is properly constructed to minimize short circuiting, if the system is designed to depend on a minimal hydraulic gradient, and **if the Q in equation (2) is considered to be the "average" flow ([Q_{in} + Q_{out}l/2) in the system to account for any gains or losses due to precipitation, evaporation or seepage,** then Darcy's Law can provide a reasonable approximation of the hydraulic conditions in these SF beds.

Some of the constraints on Darcy's-Law can be reduced by conducting predesign tests with the actual media to be used to determine the "effective" hydraulic conductivity under various flow and hydraulic gradient conditions, and to ensure that laminar flow conditions prevail. These tests are recommended for large-scale projects and/or for repetitive use of the same media on a number of small-scale projects. The test can use a flume or trough of reasonable length (< 6 m) and reasonable cross sectional area (depends on size of media to be tested, but generally < 0.2 m^2). The inlet end of the trough is capable of being raised above the datum to produce the desired test slope. The gravel is contained within perforated plates in the trough, and manometers are installed at appropriate locations to measure the head differential (dh) for calculation of the hydraulic gradient (dh/dL). Clean water is used in the test, and the inflow adjusted so that the gravel is saturated at the head of the flume but with no surface flow. During' the test the outflow (Q) is measured with a stop watch and a conveniently sized container, and the depth of the wetted zone (A) at the perforated outflow plate is measured. It is possible with these data to then calculate the "effective" hydraulic conductivity for design of the system, and to calculate the Reynolds number to ensure laminar flow conditions.

It is believed that the surface flow observed on many of the operational SF systems in the U.S. is the result of an inadequate hydraulic gradient provided by the system's design and selected configuration (13). Many of the problem systems in the U.S. have been constructed with a very high aspect ratio (L:W), and without any bottom slope or water level controls at the outlet works. In some cases, the outlet ports in the effluent manifold were at or near the top of the bed, thereby negating the development of any significant hydraulic gradient in the bed and ensuring the occurrence of surface flow from the beginning of operations. Systems in the U.S. and. Europe with successful hydraulic performance (i.e.,: maintenance of subsurface flow) do so with either **a** sloping bottom and/or adjustable outlet works which allow the water level to be lowered at the end of the bed. A sloped bottom or lowering the water level at the end of the bed then produces the pressure head required to overcome resistance to flow through the media and the maintenance of subsurface flow conditions. **An adjustable outlet provides greater flexibility and control and is the recommended approach.**

Aspect Ratio

The aspect ratio (L:W) of the wetland bed is a very important consideration in the hydraulic design of SF wetland systems, since the maximum potential hydraulic gradient is related to the available depth of the bed divided by the length of the flow path. Many of the early systems designed with an aspect ratio of 10:1 or more and a total depth of 0.6 m (2 ft) have an inadequate hydraulic gradient and surface flow is inevitable. The hydraulic gradient (S factor in equation 2) defines the total head available-in the system to overcome the resistance to horizontal flow in the porous. media.

For example, in a SF bed 200 m long and 0.6 m deep, if the water level is at the surface of the media at the influent end and near the bottom of the bed at the effluent end (water depth = 0.2 m), the available hydraulic gradient would be 0.4m/200m or 0.002. If this wetland bed were 100 m wide (L:W = 2:1) and used **a** gravel media with a hydraulic conductivity (k_s) of 10,000 $m^3/m^2/d$, the maximum subsurface flow, based on equation (2), would be 800 m^3/d (0.21 mgd). Using the same volume of gravel in a bed 450 m long results in a bed width of about 45 m (L:W = 10:1) and a hydraulic gradient of 0.0009; the maximum subsurface flow in this case would be 162 m^3/d (0.04 mgd), which is 20 percent of the flow allowed by the shorter bed. If the design flow were actually 800 m^3/d in the second case, then surface flow on top of the bed would be unavoidable, even though the bed contains exactly the same volume of media.

Bed Slope

SF systems in Europe (29) have been constructed with up to 8 percent slope on the bottom of the bed to maintain an acceptable hydraulic gradient. However, it is not practical and probably not possible with SF systems to precisely design and construct the bed for a specific hydraulic gradient due to variabilities in the media used and in construction techniques, and the potential for longer term partial clogging. In addition, the construction of a bed with a sloping bottom provides no flexibility for 'future adjustments. Greater flexibility and control is possible with an adjustable outlet' which permits control of the water level over the entire design depth of the bed. In this case, the bottom of the bed could be flat or with a very slight slope to ensure drainage, when required. However, because of the hydraulic gradient requirements, the aspect ratio (L:W) will have to be relatively low (in the range of 0.4:1 to 3:I) to provide the flexibility and the reserve capacity for future operational adjustments.

Media Types

Table 4 presents a summary of typical characteristics for the types of media which have been used in SF constructed wetlands. Essentially all of the operational SF constructed wetlands in the U.S. have used media ranging from medium gravel to coarse rock. The values in Table 4 are intended as preliminary information only. **Following selection of a media type and size; the hydraulic conductivity and porosity of the material should be determined in the field or laboratory, prior to system design,**

The recent. trend in the Gulf States toward the use of larger sizes of rock is believed due to the impression created by the surface flow conditions on many of the early systems. It was apparently thought that the surface flow was caused by clogging and that the use of a coarser rock with larger void spaces and a higher hydraulic conductivity would overcome the problem. In most cases the problem has not been overcome since the hydraulic gradient provided is too small. The use of smaller rock sizes has a number of advantages in that there is more surface area available on the media for treatment, and the smaller void spaces are more compatible with development of the roots and rhizomes of the vegetation, and the flow conditions should be closer to laminar. When turbulent flow occurs in the coarser media listed in Table 5, the “effective” hydraulic conductivity will be less than the values listed in the table.

Table 5. Typical Media Characteristics for SF Wetlands

Type	Effective Size D_{10} mm	n^a Porosity %	k_s^b Hydraulic Conductivity $m^3/m^2/d$
Coarse Sand	2	32	1,000
Gravelly Sand	8	35	5,000
Fine Gravel	16	38	7,500
Medium Gravel	32	40	10,000
Coarse Rock	128	45	100,000

a. The porosity is used to determine the actual flow velocity in the void spaces, and in equations (3) and (5) to determine the size of the SF bed. Porosity is equal to Void Volume/Total Volume, and is expressed as a percent.

b. Assuming non-turbulent, near laminar flow conditions, with clean. water. $m^3/m^2/d \times 24.6 = gpd/ft^2$.

The hydraulic conductivity (k_s) values in Table 5 assume that the media and the water flowing through it are clean so that clogging is not a factor. As discussed in a previous section, some clogging can occur in these systems, especially near the inlet zone where most of the suspended solids will be removed. As noted previously, the observed clogging represented less than 6 percent of the void spaces in the systems investigated. The majority of the material (>80%) was inorganic and believed to be the residue from construction activities, and should not, therefore, have a cumulative impact on hydraulic conductivity. It is, however, necessary to provide a large safety factor against these contingencies and adoption of an approach similar to that used in the design of land treatment systems (30) is proposed. **It is therefore recommended that a value < 113 of the "effective" hydraulic conductivity (k_s) be used for design. The initial design, for the same reasons, should not utilize more than 70 percent of the potential hydraulic gradient available in the proposed bed. These two limits, combined with an adjustable outlet for the bed discharge should ensure a more than adequate safety factor in the hydraulic design of the system.** These two limits will also have the practical effect of limiting the aspect ratio of the bed to < 3:1 for 0.6 m (2 ft) deep beds and to about 0.75:1 for 0.3 m (1 ft) deep beds. Using such a low value for hydraulic gradient will help maintain near laminar flow in the bed and further validate the use of Darcy's Law for design of these systems. Since this approach ensures a relatively wide entry zone, it will also result in a low organic loading on the cross sectional area and thereby reduce concerns over clogging.

In addition to the internal hydraulic concerns discussed above, it is necessary to have adequate inlet and outlet structures for the bed to assure proper distribution and collection of flow and maximum utilization of the media provided in the bed.

Inlet Structures

The inlet devices at operational systems include surface and subsurface manifolds, an open trench perpendicular to the flow direction, and simple, single point weir boxes. The manifold designs include a variety of features. In some cases perforated pipe is used for both surface and subsurface installations. In one case the subsurface- manifold utilized two to three valved outlets in the cell. A surface manifold developed by TVA uses multiple, adjustable outlet ports (31,32). This allows the operator to make adjustments for differential settlement of the pipe and to maintain uniform distribution of the wastewater. The proponents of subsurface inlet manifolds claim they are necessary to avoid the build-up of algal slimes on the rock surfaces and resulting clogging adjacent to a surface manifold. The disadvantages of a subsurface manifold are the inability for future adjustment and the limited access for maintenance. In one case, a buried manifold became clogged with turtles (entered the piping system from the preliminary treatment lagoon) and had to be removed.

A surface manifold, with adjustable outlets, seems to provide the maximum flexibility for future adjustments and maintenance and is recommended. Use of a coarse rock (8 to 15 cm [3 - 6”]) in this entry zone, coupled with an adequate hydraulic gradient for the bed, should ensure rapid infiltration and prevent ponding and algae development. In continuously warm and sunny climates, shading of this entry zone with either vegetation or a structure may also be necessary. In cold winter climates, some thermal protection for an above-surface manifold will probably be necessary.

Outlet Structures

Outlet structures in use at operational SF wetland systems include subsurface manifolds, and weir boxes or similar gated structures. The perforated subsurface manifold is the most commonly used device; however, the location of that manifold in the bed has varied considerably. In a few cases it has been located in a shallow trench, below the bottom of the bed, permitting complete drainage of the bed and development of the maximum hydraulic gradient for the system. In many cases, the manifold and/or the outlet ports have been located above the bottom of the bed, and in some cases the outlet ports have been iocated near the top of the bed. As indicated previously, this latter practice results in surface flow on the bed.

In most cases, the subsurface outlet manifold connects directly to the final discharge pipe, and/or to a concrete channel used for final disinfection. Some system designs in Europe and those in the U.S. derived from that practice (31,32), connect the subsurface manifold to an adjustable outlet for water level control. Flow then proceeds to either discharge or disinfection.

The use of an adjustable outlet was previously recommended to maintain an adequate hydraulic gradient in the bed. This device can also have significant, operational and maintenance benefits. The surface of the bed can be flooded to encourage, development of newly planted vegetation and to suppress undesirable weeds, and the water level can be lowered in anticipation of major storm events and to provide additional thermal protection against freezing during winter operations in cold climates.

The use **of a perforated subsurface manifold connected-to an adjustable outlet would seem to offer the maximum flexibility and reliability as the outlet device for SF** wetland systems. Since the manifold is buried and inaccessible following construction, careful grading and subbase compaction would be required during construction and clean-out risers should be provided in the line.

BOD_5 REMOVAL

When process kinetics were given any consideration, most of the existing systems in the U.S. and. Europe were designed as an attached growth biological reactor using a first order plug flow model, shown previously as equation (1):

$$\frac{C_e}{C_o} = e^{(-K_T t)} \tag{1}$$

The effluent BOD_5 (C,) in equation 1 is, as previously discussed, influenced by the production of residual BOD_5 within the wetland from decomposition of plant detritus and other naturally occurring organics. This residual BOD_5 is typically in the range of 2 to 7 mg/L. **As a result, equation (1) should not be used for designs for a final $BOD_5 < 5$ mg/L.**

It has been argued that plug flow kinetics do not apply to SF constructed wetland systems because the dye and tracer studies which have been performed do not exhibit the ideal plug flow response. Figure 13 presents the results of a tracer study, using lithium chloride (an inorganic, conservative tracer), conducted in 1980 at the operational SF wetland system at Carville, LA (27). Essentially 100 percent of the tracer was accounted for in the effluent, so this can be considered a valid study. It clearly did not exhibit ideal plug flow responses, but the curve is much closer to plug flow conditions than to the complete mix alternative. The centroid of the curve indicates an HRT of 48 hours, which is identical to the theoretical detention time calculated with the actual flow, measured porosity, and wetland cell dimensions. There was no surface flow during this test. Data from similar tests at other sites show an even closer resemblance to plug flow.

The shape of the curve on Figure 13 is similar to those observed with facultative ponds and similar wastewater treatment concepts where plug flow conditions are also assumed as the basis for design (33). Models are available for these systems which attempt to define conditions between plug flow and complete mix, but the difficulty in defining the necessary parameters has resulted in minimal use of these alternatives.

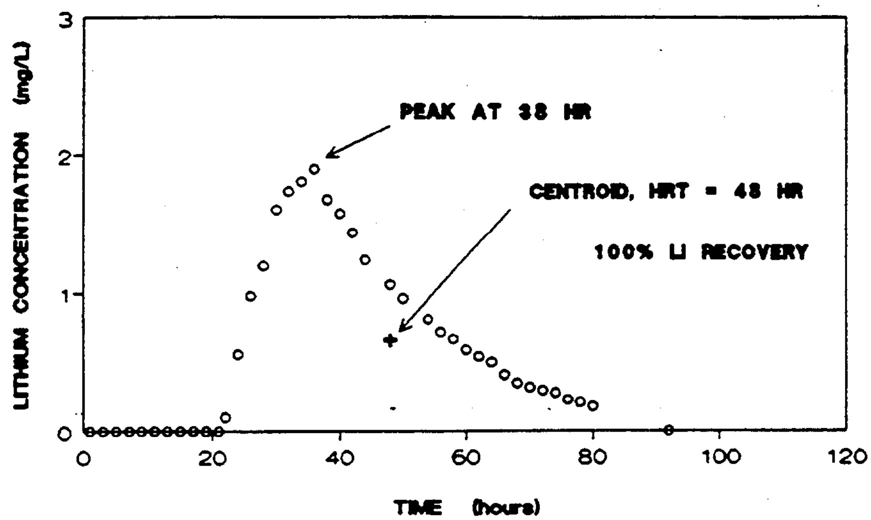

Figure 13. Lithium Tracer Study, Carville; LA.

The plug flow model is presently in general use. and it seems to provide a reasonable approximation of performance in these SF constructed wetlands. However, more sophisticated models have also been proposed for SF wetlands. One model includes a plug flow segment followed by three continuously stirred (complete mix) reactors in series (43). When sufficient data are available to validate these alternative models, they may replace the current approach. **In the interim, the use of the plug flow model is recommended for design.**

The "t" or hydraulic residence time (HRT) factor in equation (1) can be defined as:

$$t = \frac{nLWd}{Q} \qquad (3)$$

Where:
- n = effective porosity of media (see Table 5) % as a decimal
- L = length of bed, m (ft)
- W = width of bed, m (ft)
- d = average depth of liquid in bed, m (ft)
- Q = average flow through the bed, m^3/d (ft^3/d)

The Q value in equation (3) is the average flow in the bed to account for precipitation, seepage, evapotranspiration and other gains and losses of water during transit of the bed. This is the same value used in Darcy's Law for hydraulic design. Published values are usually available for an estimate of precipitation and ET losses at a particular site.

The d value in equation (3) is the average depth of liquid in the bed. If, as recommended previously, the design hydraulic gradient is limited to 10 percent of the potential available, -then the average depth of water in the bed will be. equal to 95 percent of the total depth of the treatment media in the bed.

The temperature dependence of the rate constant in equation (1) is defined as:

$$K_T = K_{20} (\Theta)^{(T-20^\circ)} \tag{4}$$

Where:
- K_T = rate constant at temperature T, d^{-1}
- K_{20} = rate constant at 20°C, d^{-1} = 1.104
- Θ = 1.06

Combining equations (1), (3), and (4) produces:

$$\frac{C_e}{C_o} = e^{(-K_T L W d n)/Q} \tag{5}$$

Since the term LW in equation (5) is equal to the surface area of the bed, rearrangement of terms in equation (5) permits the calculation of the surface area (A,) required to achieve the necessary level of BOD_5 removal:

$$A_s = (L)(W) = \frac{Q[\ln(C_o/C_e)]}{K_T dn} \tag{6}$$

Where: A_s = bed surface area, m^2 (ft^2)

Other terms defined previously

The depth of media selected will depend on the design intentions for the system. If the vegetation is intended as a major oxygen source for nitrification in the system, then the depth of the bed should not exceed the potential root penetration depth for the plant species to be used. This will ensure availability of some oxygen throughout the bed profile, but may require management practices which assure root penetration to these depths. Table 6 presents results from the pilot system in Santee, CA (4) showing the relationship between root penetration and performance. The root depths shown in Table 6 are considered to be near the maximum practical limit to be expected. The design approach in Europe has also assumed a maximum depth of 0.6 m for *Phragmites* (15).

Table 6. Performance of Vegetated and Unvegetated SF Wetland Beds (4)

Bed Type	Root Depth, m	Final Effluent Quality, mg/L[a]		
		BOD_5	TSS	NH_3
Bulrush, *Scirpus*	0.8	5	4	2
Reeds, *Phragmites*	0.6	22	8	5
Cattails, *Typha*	0.3	30	6	18
No Vegetation	0.0	36	6	22

a. Primary effluent input (BOD_5 = 118 mg/L, SS = 57 mg/L, NH3 = 25 mg/L)

There is one operational system in the U.S. (Monterey, VA) with a media depth of 0.9 m (3 ft); the most commonly used depth is 0.6 m (2 ft). One system (Bear

Creek, AL) using *Typha* in fine gravel is obtaining excellent performance with a depth of 0.3 m, which matches the root penetration listed in Table 6 for that plant.

The final design and sizing of the SF bed for BOD_5 removal is an iterative process:

1. **Determine the media type, vegetation, and depth of bed to be used.**

2. **Determine by field or laboratory testing the porosity (n) and "effective" hydraulic conductivity (ks) of the media to be used.**

3. **Determine the required surface area of the bed, for the desired level of BOD_5 removal, with equation 6.**

4. **Depending on site topography, select a preliminary aspect ratio (L:W); 0.4:1 up to 3: 1 are generally acceptable.**

5. **Determine bed length (L) and width (W) from the previously assumed aspect ratio, and results of step 2.**

6. **Using Darcy's Law (equation 2) with the previously recommended limits (ks < 1/3 "effective" value, hydraulic gradient S < 10% of maximum potential), determine the flow (Q) which can pass through the bed in a subsurface mode. If this Q is less than the actual design flow, then surface flow is possible. In that case it is necessary to adjust the L and W values until the Darcy's Q is equal to the design flow.**

7. **It is not valid to use equation 5 with effluent BOD_5 (Ce) values below 5 mg/l. As previously discussed, these wetland systems export a BOD_5 residual due to decomposition of the natural organic detritus in the system.**

8. **In cold climates it is necessary to assume a design temperature for BOD_5 to first determine the required surface area. Thermal calculations are then necessary to determine the winter heat losses and bed temperature conditions during the design HRT. Further iterations of this procedure are necessary until the assumed temperature and the temperature determined by the heat loss calculations converge.**