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SMALL SCALE WASTE MANAGEMENT PROJECT

Subsurface Constructed Wetlands for On-Site Waste Water Treatment Design summary

by

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January 1999

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SUBSURFACE CONSTRUCTED WETLANDS FOR ON-SITE WASTE WATER TREATMENT

DESIGN SUMMARY[1]

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A constructed wetland wastewater treatment system (CW) can be defined as "a man-made, engineered, marsh-like area which is designed, constructed and operated to treat wastewater by attempting to optimize physical, chemical and biological processes of natural ecosystems" (Steiner and Watson, 1993). Wetlands are a nutrient/sediment sink and deposition of contaminants. They need to be managed and over time can release contaminants when the "sink" becomes full.

Constructed wetlands can be either free water surface wetlands or subsurface flow wetlands (EPA, 1993. Free water wetlands consist of a shallow basin or channels where water is exposed to the atmosphere and flows horizontally. The subsurface wetland consists of a shallow basin or channel with a bed of suitable porous media of rock or gravel with the water level remaining beneath the surface and the water flows horizontally. Today, there are variations such as vertical flow subsurface wetlands. Each unit supports aquatic plant life. This presentation will concentrate on the subsurface flow unit.

The objective of this paper is to provide the reader with some basic knowledge about the concepts and design of a constructed wetland. It should be thoroughly understood that there is much more involved in the design, construction and management of the constructed wetland than conveyed in this paper and additional information should be sought. Most of this material came directly from Steiner and Watson (1993) and EPA, (1993).

Figure 1 provides a cross section of a typical subsurface constructed wetland. The system consists of a septic tank, a lined first stage cell and an unlined second stage cell. The second cell may be replaced with a soil dispersal unit such as a in-ground trench, at-grade or mound

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[1] This is a design summary. The material was summarized from two primary sources which are by Steiner and Watson, 1993 and EPA, 1993 (See reference list). Much of the material was taken verbatim from these materials.

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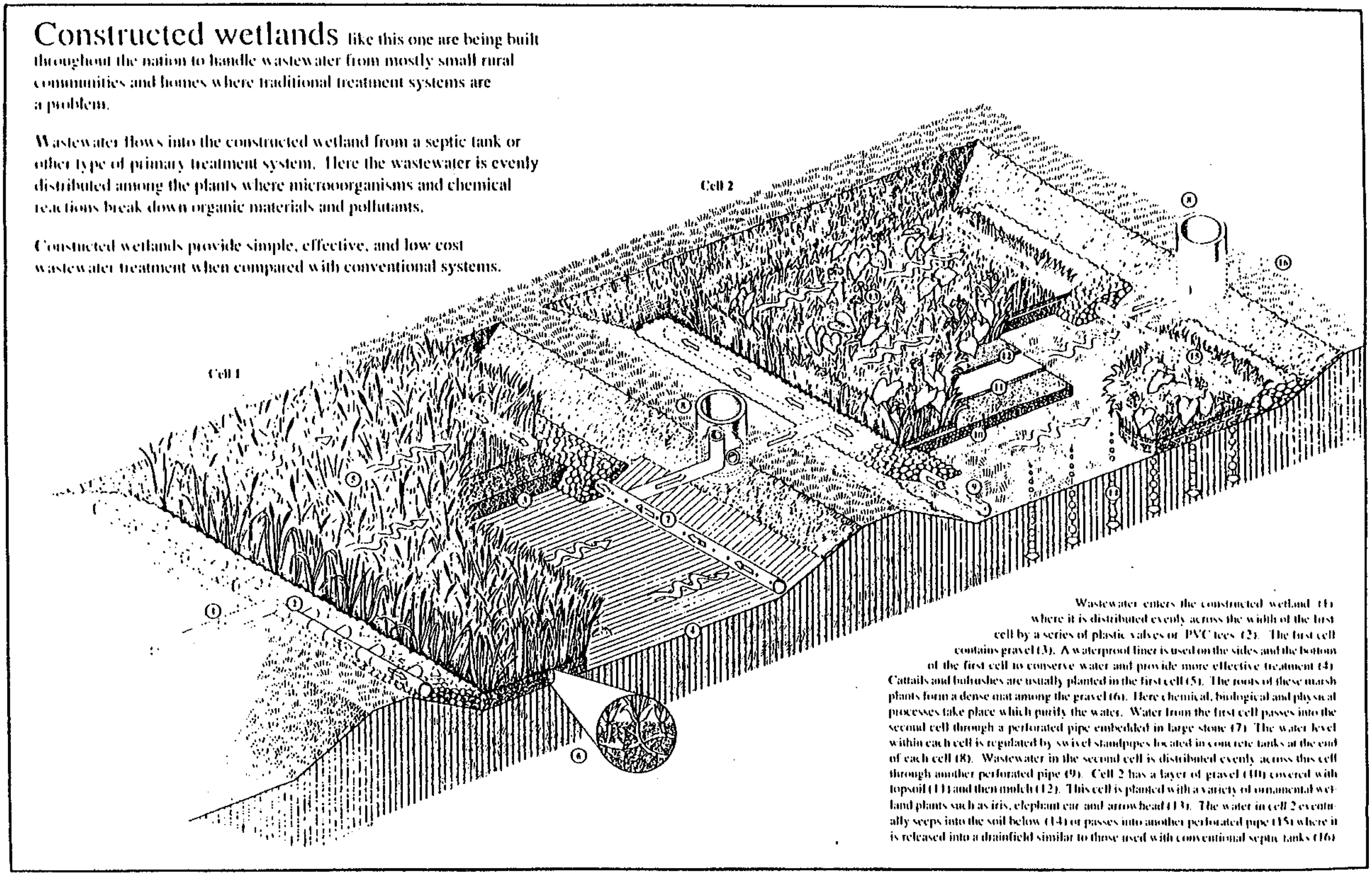

Fig. 1. Cut-a-way prespective of a 2-cell constructed wetland system. (Steiner and Watson, 1993).

depending on the soil/site conditions. Converse and Tyler (1997) discuss various options for subsurface discharge depending on effluent quality and soil and site conditions. A pump chamber may be installed between the septic tank and the first stage cell if the effluent needs to be pumped uphill and/or if timed dosing to the cell is desired.

Constructed wetlands can be discharge to receiving waters or discharge via subsurface or through evaporation. In Wisconsin discharge is via subsurface with some evaporation/transpiration.

Performance:

Most of the constructed wetland research and experience has been in the southern part of the U.S. In recent years, a number of systems have been installed in the northern climates with data becoming available. Data reported here is based primarily on warmer climates and limited to systems discharging relatively small flows (e.g. individual homes, small business and schools). However, small is relative with the literature reporting performance on systems up to 20,000 gallons (EPA, 1993).

BOD Removal: BOD removal occurs through settling and entrapment of particular matter. Soluble BOD is removed by microbial growth on the media surface and attached to the plant roots. BOD inputs range from 140-150 mg/L and exit < 10 mg/L.

Total Suspended Solids: Suspended solids removal efficiencies range from 60-90% with effluent TSS < 20 mg/L.

Nitrogen Removal: The removal of the non-ionized ammonia (NH_3) is a major concern for systems directly discharging to streams because of ammonia toxicity to fish and other aquatic animals. Organic nitrogen entering the wetland and that associated with plants in the wetland is converted through decomposition and mineralization process to ammonia. Biological nitrification followed by denitrification is believed to be the major pathways for ammonia removal (EPA, 1993). Nitrogen removal to less than 10 mg/L will require a hydraulic retention time (HRT) of 6 days during warm weather and about 10 days for cold climates (EPA, 1993). If the effluent is discharged to the soil, the ammonia should be converted to nitrates in the soil profile as is the case for septic tank effluent discharged to the soil.

Phosphorus Removal: Phosphorus removal by wetlands in not always effective. The wetland may serve as a sink but the wetland will discharge P as there are a limited number of cationic sites available (EPA, 1993).

Fecal Coliform Removal: Submerged wetlands are capability of one to two logs reduction in fecal coliforms (EPA, 1993). With septic tank effluent entering at 10^5 col./100 mL, a 2 log reduction to 10^3 col/100 mL is not sufficient to satisfy surface discharge which is in the range discharged by aerobic units and recirculating sand filters. Discharge to the soil may be more appropriate.

DESIGN

The following is a **summary** of the design concepts put forth by Steiner and Watson (1993) and EPA (1993) for individual residences. If a system is to be designed and installed, the designer should obtain these two publications for more details on design, construction and operation before attempting the design. This is a relatively new technology and the latest design technology should be sought. All local and state codes must be complied with prior to design and installation. **There are companies that specialize in wetland construction for treating of domestic wastewater. It might be appropriate to enlist their assistance. They are listed at the end of this publication.** There are new design concepts being incorporated to improve system performance.

1. Pretreatment:

The influent entering the constructed wetland must be pretreated to at least typical septic tank effluent quality. Effluent filters on the outlet end of the septic tank is recommended. Heavy BOD and TSS loading to the wetland will reduce wetland performance. Timed dosing may be desired to even out the flow to the constructed wetland but there is very little performance data available to support time dosing. Converse, 1999, provides information on filters, time dosing and combination tanks for septic tanks/pump chambers.

2. Hydraulic and Organic Loading:

a. Hydraulic loading:

Determine the hydraulic loading in gallons per day. In Wisconsin it is 150 gpd/bedroom.

b. Organic loading:

Method 1: Determine the organic loading rate to the wetland. Assume an average organic loading rate of 0.17 pounds BOD_5 per day. Assume that 50% of the BOD is removed in the septic tank and there are 2 people per bedroom. Thus, the organic loading rate is 0.17 pounds BOD_5 per day/bedroom. This value is high as most people don't generate 0.17 and on average there are not 2 people per bedroom. However, it will give a conservative number.

Method 2: If the septic tank effluent BOD (mg/L) and the flow rate in gpd are know, then the organic loading rate in pounds BOD_5 per day can be determined by:

$$\text{Organic loading rate} = BOD_5 * 8.34 \times 10^{-6} * \text{flow rate}$$

For an effluent with a BOD of 150 mg/L and flow of 200 gpd

Organic loading rate = 150 mg/L*8.34x10^{-6} *200gpd

= 0.25 pounds/day

3. **Design Considerations:**

a. Site Factors:

Site factors to consider are soil depth, and permeability, seasonal water levels, surface topography, lot size and shape, shading by trees and owner preference and attitudes.

b. System Type:

The system will be a submerged construction wetland meaning that the effluent will remain beneath the surface.

c. System Configuration:

The system may consist of a single cell, two cells in series or multiple cells in parallel. For home size systems consider a single cell or two cells in series.

1. Single cell units should be used for sites where a) wastewater will not percolate because of high water table, shallow soil over impermeable rock or very impermeable clay, b) topography is relatively flat and c) drainfields following constructed wetlands are required by code.

2. Two cell units are used on sites with soil which will allow infiltration of treated wastewater. The first cell is lined and the second cell is unlined to allow infiltration. If infiltration is too rapid the cell may be to dry for proper vegetation growth.

d. System Sizing:

1. Surface area for constructed wetland

   Use a surface area hydraulic loading criterion of 1.3 ft^2/gpd (unrestricted areas or cold climates or 0.87 ft^2/gpd (restricted areas).

   For unrestricted areas or cold climates:

   S.A. = 1.3 ft^2/gpd * hydraulic loading rate (gpd)

2. Cross Sectional Area:

Calculate the cross-sectional area based on hydraulic loading and organic loading rate. Select the larger value.

a. Hydraulic Loading:

Use Darcy's Law

$$A_c = Q/k_sS$$

where:

A_c = cross sectional area of bed (ft^2)
Q= design flow (ft^3/d)
k_s = hydraulic conductivity

- 850 $ft^3/d/ft^2$ for gravel

S = hydraulic gradient

- 0.005 for flat bottom
- 0.01 - 0.02 for 1 and 2% bottom slope

The goal is to design the system so that effluent remains beneath the surface. Surfacing will occur if the influent enters the cell at a rate faster than it can move away through the gravel. So very narrow cells have a greater potential for surfacing than wider cells. However wider cells have greater potential of short-circuiting. Thus a balance is needed.

b. Organic Loading:

Calculate area based on the organic loading criterion of 1 ft^2/ 0.05 lb BOD/d.

3. Substrate Depth:

Select inlet end substrate depth of 12" for unrestricted areas or 18" for restricted areas. In cold climates a deeper cell should be sued to allow for greater waste depths during extreme cold weather to prevent freezing. Use 18" depth with the surface hydraulic loading criteria of at least 1.3 ft^2/gpd.

For flat bed (0% slope), determine the outlet end depth based on the calculated depth and assumed low hydraulic slope (typically 0.5%). Make the depth for the entire cell length equal to the outlet end depth, which will simplify bed construction for small systems.

4. Width:

The effective width (bottom if sloping sides are used) is calculated by dividing the cross-sectional area by depth.

W = cross-sectional area/depth

Limit cell width to 14 ft to minimize short-circuiting potential. If wider cells are required, consider splitting the inflow into two inlet distributors.

5. Length:

To calculate the effective system length (bottom of cell), divide surface area by width.

L= surface area (ft^2) / width (ft)

For single-cell systems with flat bottoms, the length will be L.

For two-cell systems with flat bottoms, each cell length is equal or L/2.

On sloping sites of 1%, limit each cell length to 100 ft as elevation differences between inlet and outlet will exceed 12".

6. Aspect Ratio:

The aspect ratio is the length to width ratio. The smaller the aspect ratio the greater the short-circuiting potential. Cells should be as narrow as possible while considering all other factors affecting the final aspect ratio. In practice, trade-offs must be carefully considered and balanced within the recommended limits set forth in these guidelines. For example, higher hydraulic gradients decrease cell width (positive factor), but increase cell length and depth (negative factor). Multiple cells should be used to stay within recommended limits. For larger systems (EPA, 1993), recommends ratios of 2:1. If the system is too long, there will not be sufficient gradient and surface flow will result. Using a flat bottom with a hydraulic gradient of 0.005 is conservative and should not be a problem for home size systems. It is essential that the system have an adjustable outlet device so gradient can be adjusted.

7. Berms/Retaining Walls:

a. An earthen berm or a retaining wall should be placed around the constructed wetland cells to prevent surface runoff from entering the cells or allowing effluent to exit the unit. The top should be at least 6" above the ground surface.

b. If berms are used, slope the exterior surface to 3H:1V or flatter with interior slopes at 2H:1V. Figure 2 shows how plywood can be used to shape the interior wall.

c. Concrete blocks, cross ties, landscape timbers can be used to build the retaining walls. Line and seal walls to prevent seepage.

8. Liner:

a. Install the impermeable liner inside the berm/retaining wall on the bottom and sidewalls of the cell. The liner prevents exfiltration of wastewater from the cell and infiltration of groundwater into the cell. The second cell, (2 cell unit), is not lined to allow infiltration.

b. Liner materials consist of 30-45 mil membrane such as ethylene propylene diene monomer (EPDM) rubber, polyvinyl chloride or polyethylene or compacted clay. Use UV resistant material.

c. Remove all rocks, roots and debris that might puncture the liner. A 1-2" layer of sand between the bed bottom and liner will provide additional protection.

d. Provide leak proof seal such as boots between the liner and piping which enters/exits the cell such as the inlets and outlets.

9. Substrate:

a. The most common substrate is sized washed pea gravel with rounded surfaces to minimize compaction and puncture the liner. Crushed lime stone is not recommended.

b. For the main substrate use gravel with average size of 1/8 to 1/4 diameter (A.H.D of 8 or 9.) as the preferred aggregate but 3/8 to ½" diameter (A.H.D of 6 or 7) is an alternative. The larger size should be used if the septic tank effluent is pumped to the wetland. The substrate should be washed to remove fines which may clog the substrate and cause surface flow.

c. The first and last two feet of the cell(s) should have 2 to 4" zone around the influent distributor and the effluent collector pipes to reduce influent and effluent clogging potential.

d. The substrate surface should be flat to facilitate water level control, vegetation planting and growth and prevent stagnation pools with allowable tolerances of 0.5" or less.

e. Surface mulches should be applied to help control potential odors, prevent reflective sun scalding of vegetation and for visual aesthetics. Mulches, approximately 3" thick, may include bark, pine straw, tree chips, composted leaves etc.

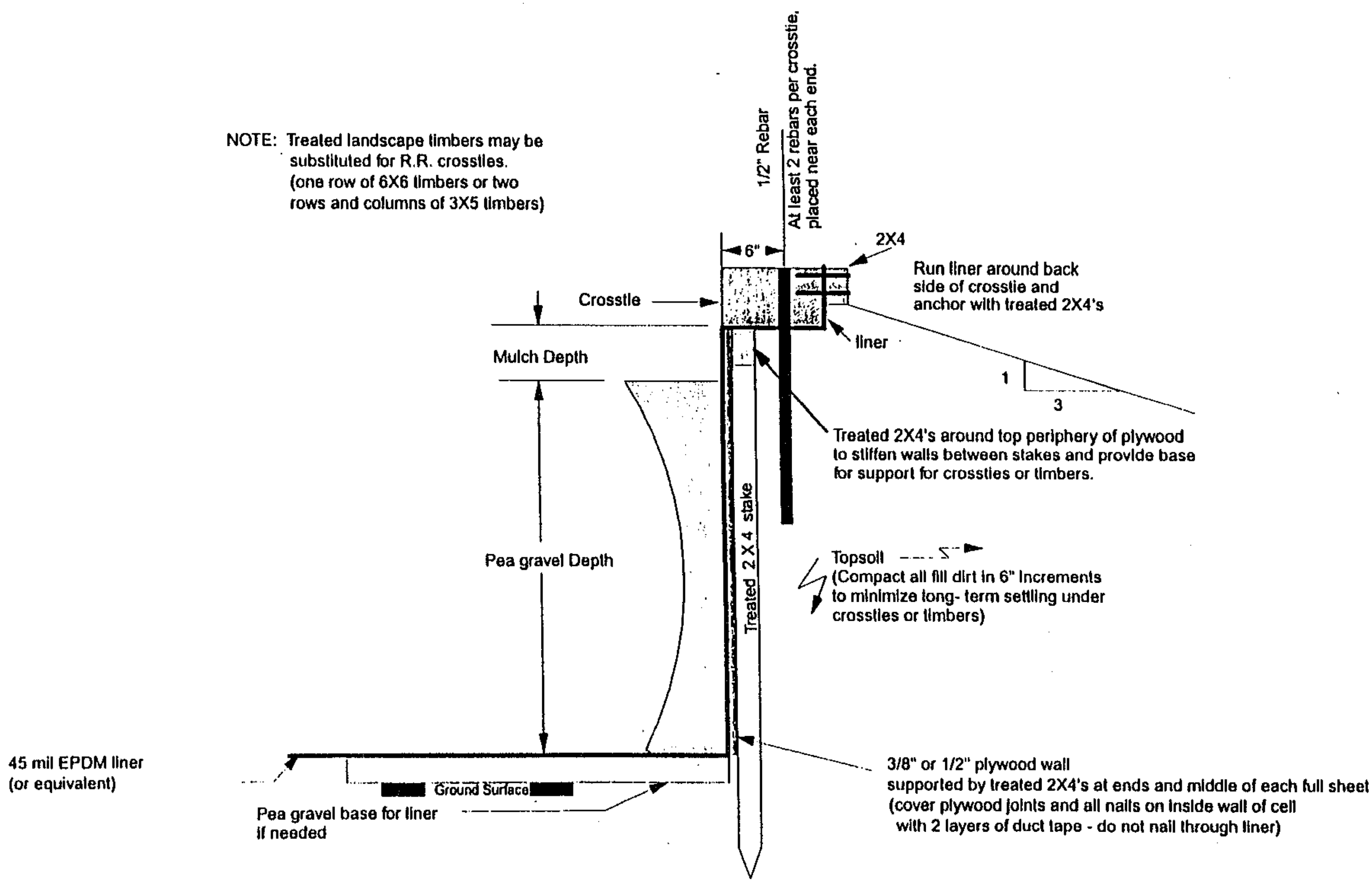

Fig. 2 Method for vertical wasll construction (Steiner and Watson, 1993).

10. Piping

a. Use a header pipe to provide uniform wastewater distribution. Use a 2" diameter pipe for up to 3 bedrooms and 3" diameter pipe for up to 4 bedrooms. Drill 5/8" dia. Holes spaced 6" apart on top, bottom and each side (4 rows). Place the inlet distributor at mid-depth in 2-4" stone. In cold climates, it may be appropriate to place the distributor above the water line so that it drains. Place rock and mulch over the pipe.

b. If the septic tank effluent is pumped to the system, make the 2-4" stone depth about 3" deeper; place the pipe (sized to maintain a flow velocity of 2 ft/sec or higher) on top of the stone (above the water level); drill orifice holes 1/8" dia. spaced 6"' apart in series of 3 holes facing up and 1 hole facing down (allows pipe to drain); place orifice shields made of 3" PVC caps over each 1/8" orifice facing up; and cover the distributor assembly with material such as filter fabric, fiberglass screen or liner followed by mulch.

c. Use a header pope to provide uniform wastewater collection. For up to 4 bedrooms homes, use 2" diameter or larger pipe with 5/8" dia. holes spaced 6" apart on top, bottom and each side of pipe (4 rows). Place pipe on the cell bottom in 2-4" stone.

d. Place a capped clean out on each end of the inlet distributor and outlet collector. Extend the clean out at least 12" above the mulch.

11. Water Level Control:

a. Water level control and adjustment is critical to the establishment and survival of the plants.

b. Figure 3 shows an adjustable water level control device using either a swivelling standpipe or collapsible tubing. For home systems the structure may consist of an 18" PVC pipe section embedded vertically in a 6" concrete floor pad. Place a tight fitting lid over the control structure. Place a valve as shown in Fig. 3 so the effluent flow can be stopped if the standpipe needs servicing.

12. Pumping:

a. Gravity flow systems are desired but there are situations where pumping is required. Always include a septic tank filter such as Zabell, Orenco, Zoeller or equivalent to minimize solids being carried over. Time dosing may enhance performance as it is feeding effluent in more uniformly throughout the day. If time dosing is used, the septic tank/pump chamber must be enlarged to provide for surge storage. Converse, 1999 provides information relative to septic tank/pump chamber combinations.

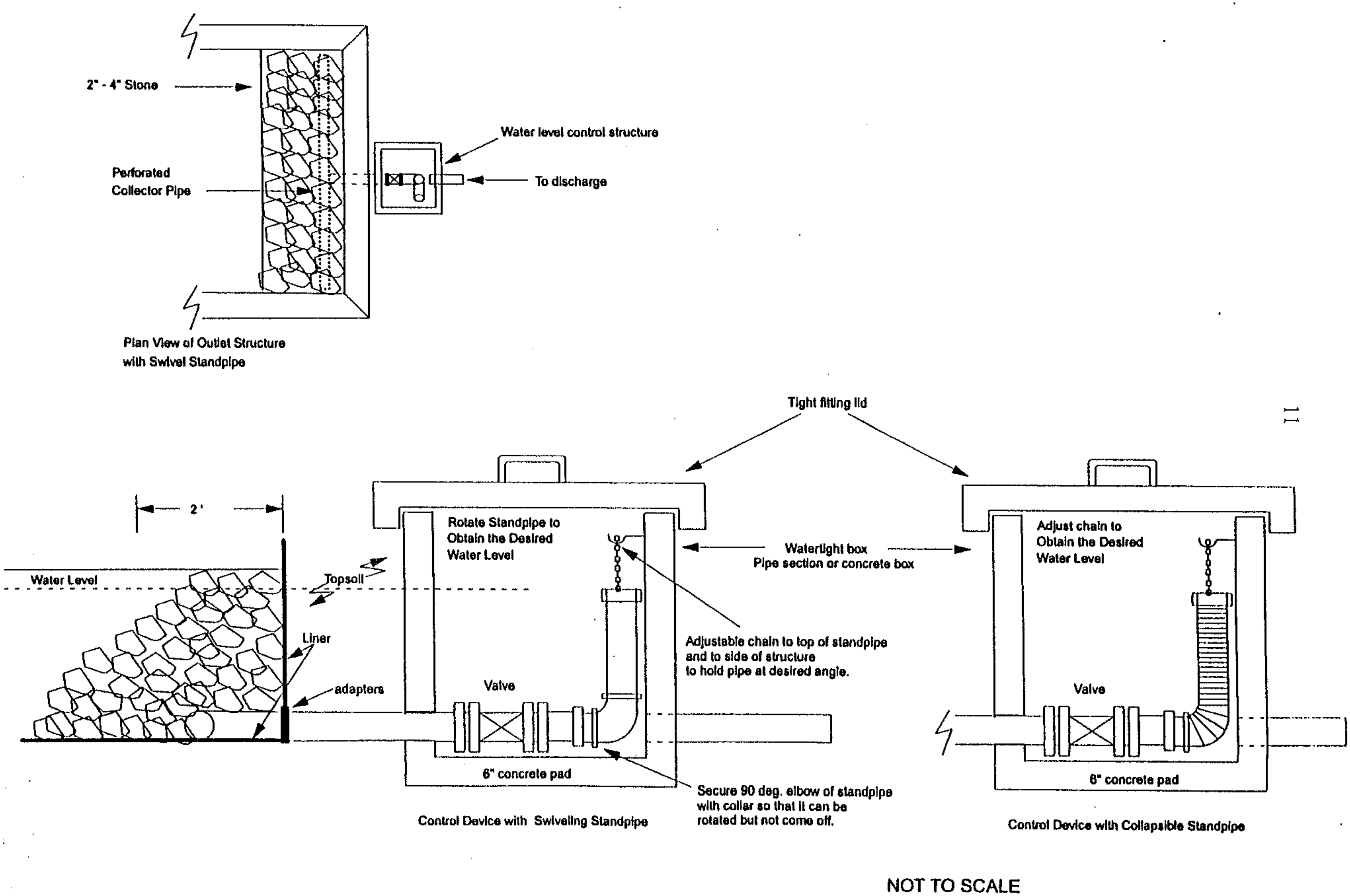

Fig. 3. Outlet water level control structures (Steiner and Watson, 1993).

b. Restrict the pumping rate by a valve or prevent and minimize surface flow in the constructed wetland. Set the dosing volume so that it does not exceed one forth the daily design flow. Additional valve adjustments may be needed later. Again, time dosing may be appropriate or smaller doses used for demand dosing.

13. Safety:

The constructed wetland should be enclose with a suitable fence to prevent possible sanitary problems. Water level control boxes should be secured.

14. Effluent Disposal:

If surface discharge with disinfection is not an option, then subsurface discharge must be incorporated into the design. This can be done either by:

a. Designing a two-cell unit with the second cell unlined which will allow the effluent to infiltrate into the soil. In this case the soil must have suitable infiltration characteristics and the separation distance from the bottom of the cell to limiting condition must meet code.

b. Designing a subsurface soil absorption unit following constructed wetland. Converse and Tyler(1997) provide alternative units depending on soil/site conditions. The system must meet code requirements but sized using the same criteria as for sand filters or aerobic units as effluent quality is similar.

15. Plantings:

a. Initially, planting should be done during spring and early summer to maximize growth before winter.

b. Use species suitable for the area. Common plants are cattails, sedge, rush, soft stem bulrush and reeds. Decorative, flowering plants may be used around the edges.

c. Plant species on no less than a one foot center grid pattern. Use plants with 6-12" stalk above the roots. Plant through much so that root portion is in the water and stalk is above the water.

OPERATION AND MAINTENANCE:

1. Maintenance:

Constructed wetlands require minimal operation and maintenance. However, some care is required by the owner to maintain an effective and attractive system. Periodic observations are needed to preclude problems or minimize identified problems. Winter-kill must be addressed with possible replanting in spring.

2. **Start-up:**

Preferably, plants should grow for one growing season before continuously sending wastewater to the system. This will enhance good root development throughout the substrate. Although most systems are typically placed n service as soon as they are completed, plan and conduct an extended start-up period under reduced loading conditions, if possible. Add waster or wastewater to the system to maintain the water level and liquid fertilizer for good plant growth during the first year if wastewater is not being added.

Make adjustments to the liquid level by adjusting the water control device. Set the overflow elevation to maintain waster level about 1" above the gravel substrate surface until the plants have about 1-2' of new growth.

3. **Septic tank:**

It is essential to maintain the septic tank with periodic pumping to minimize solids care over-over. Filters will protect the downstream components from solids.

4. **Water Level:**

Under normal operations, maintain water leveling the first cell about 1" below the gravel substrate surface at the inlet end. During extended periods when influent is not entering the wetland, add waster to the cells to maintain liquid levels.

5. **Inlet Distributor:**

Periodically check the water level in the clean outs on each end of the inlet distributor. If water level is higher in the cleanouts than in the cell, check for orifice clogging. Clean distributors and collectors once a year.

6. **Liner Leaks:**

Periodically check liner for leaks. Maintain cover over sides of liners t prevent UV degradation.

7. **Vegetation:**

a. Check vegetation for signs of disease or other stress (yellowing or browning, withering, spots etc.) Some symptoms may occur naturally as the plants mature, especially after seeds have matured. Seek professional help. A balanced fertilizer may need to be added.

b. Replace dead plants. Pull out "volunteer" weeds, trees and shrubs.

c. Prevent excessive shading of wetland vegetation. Most wetland plants need 6 hrs/day of sun.

d. Encourage deep root growth by lowering the water level over several weeks during the dormant vegetation period (see details in Steiner and Watson, 1993)

DESIGN EXAMPLE

Design a constructed wetland treatment system for a 3 bedroom residence. The site has a 3% slope with 150 ft along the contour and 60 ft along the slope. The soil profile consists of 1) 6" of silt loam, 2) 10" of silty clay loam with mottling at 12" beneath the surface and 3) clay loam with soil evaluation to 72". The system is being designed for cold climates.

1. Hydraulic Loading Rate (Q):

$Q = 3$ bedrooms @ 150 gpd/br = 450 gpd or 60.2 ft^3

2. Organic Loading Rate (OLR):

Assume 6 people in house at 0.17 lbs. BOD/person/day and assuming 50% removal in septic tank. (Realistically this is high which will make the design conservative).

OLR = 0.17 lb/person/d x 6 persons x 0.5 = 0.51 lbs BOD/day

3. Hydraulic and Organic Loading Criteria:

$Q = 1.3\ ft^2$ / gpd

OLR = 1.0 ft^2 / 0.05 lbs BOD/d

4. Wetland Surface Area (A_s):

A_s = 450 gpd x 1,3 ft^2 / gpd = 585 ft^2

5. Flat or Sloping Bottom:

This site is relatively flat (3%) with 150 ft along the contour.

The designer has a choice of a flat bottom or sloping bottom. Select a flat bottom. Assume a hydraulic gradient, S= 0.5% or 0.005, and hydraulic conductivity, K_s = 850 ft/d (Conservative rate based on long-term clogging of gravel) .

6. Cross-Sectional Area (A_x):

Based on hydraulic load (Q) and Darcy's Law

$$A_x = Q/(K_s \times S)$$

$$= 60.2 \text{ ft}^3 / (850 \text{ ft/d} \times 0.005) = 14.17 \text{ ft}^2$$

Based on organic load

$$A_x = 1.0 \text{ ft}^2 / 0.05 \text{ lbs BOD/d} \times 0.51 \text{ lbs/BOD/d} = 10.2 \text{ ft}^2$$

7. Depth at Front of Cell (D_f): (For calculations purposes)

Since space is not limited, use a depth of 1.0 ft. If space were limited use 1.5 ft depth with hydraulic loading criterion of 0.87 ft^2 /gpd. For cold climates use depth of 1.5 ft and hydraulic criterion of 1.3 ft^2 /gpd. Since this unit is sized for cold climate:

$$D_f = 1.5 \text{ ft.}$$

8. Cell Width (W):

Use cross-sectional area of 14.17 ft^2 based on hydraulics as it is larger.

$$W = A_x / D_f$$
$$= 14.17 \text{ ft}^2 / 1.5 \text{ ft} = 9.45 \text{ ft}$$

9. System Cell Length (L):

$$L = A_s / W$$

$$= 585 \text{ ft}^2 / 9.45 \text{ ft} = 61.9 \text{ ft.}$$

Rounding off results in cell dimensions of 62 ft long by 10 ft wide.

11. Substrate Depth (D_s):

Using one cell system

Cell inlet: 1.5 ft

Cell outlet: 1.5 ft + (0.005 x 62) = 1.81 ft or 21.7 in.

Using two cell system

Cell inlet: 1.5 ft

Cell outlet: 1.5 ft + (0.005 x 62/2 = 1.81 ft or 21.7 in.

Use 22" substrate depth for one cell of 62 ft by 10 ft and 20 " depth for 2 cells each 31 ft by 10 ft.

12. Configuration:

Refer to Fig. 4 for one cell design and Fig. 5 for 2 cell design.

13. Inlet Distribution Piping:

Site will allow gravity flow. Use a 2 in. dia. PVC pipe 9 ft long with 5/8" holes spaced 6" on center on top, bottom and sides (4 rows). Place pipe as shown in Fig. 4.

14. Outlet/Control Structure:

Figure 3 shows the control structure to control liquid depth in the cell. The collection pipe should be 2" dia. PVC pipe with 5/8" dia. holes spaced 6" apart on top, bottom and sides.

15. Walls:

Install vertical walls as shown in Fig. 2. Earthen berm walls can be used.

DESIGN COMMENTS

EPA, 1993 has several concerns about this design which are:

It does not take into account the temperature influence on performance when applied in cold climates. However, the extra depth will help to minimize freezing.

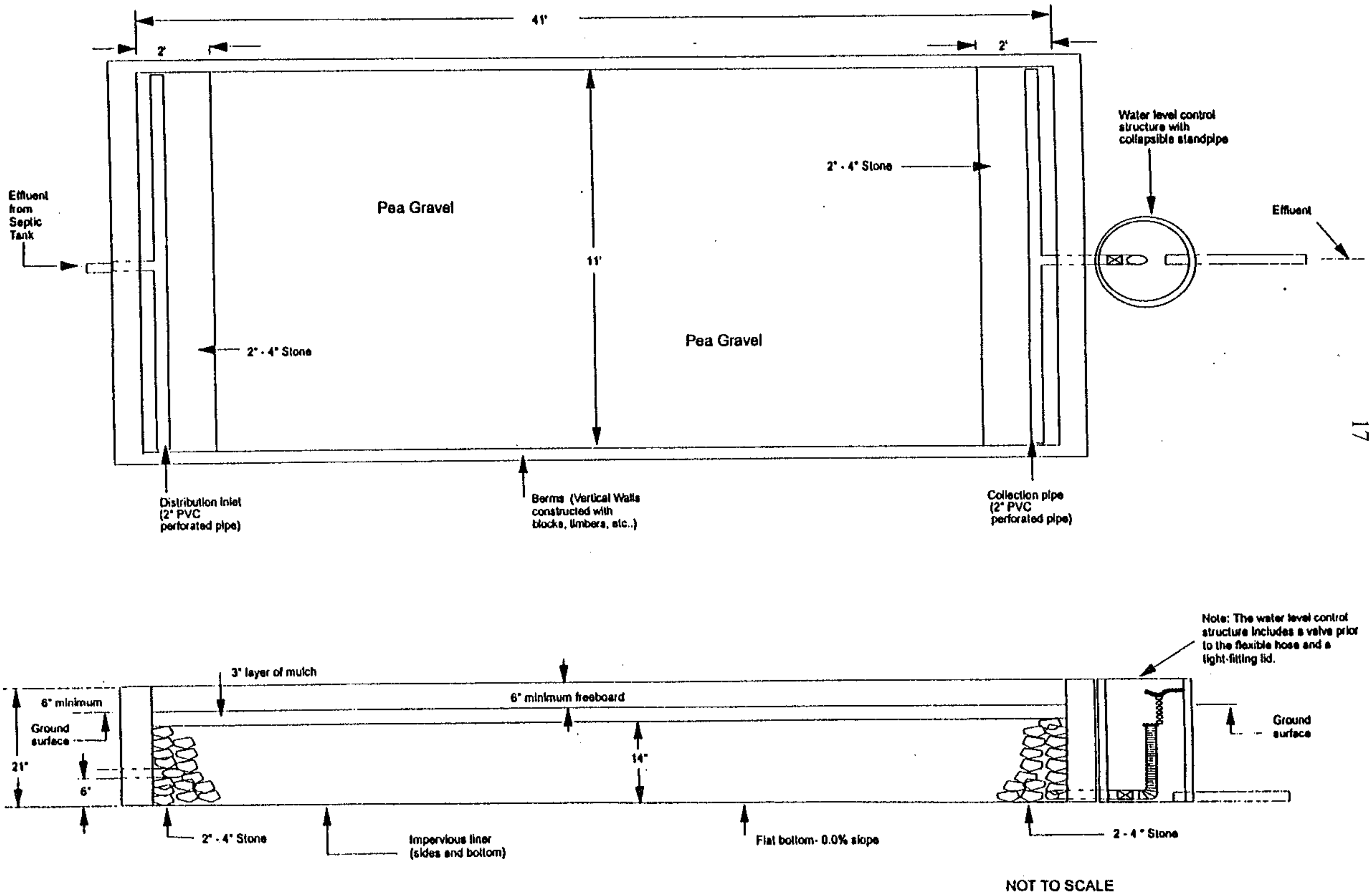

Fig. 4. Single cell constructed wetland for a 3 bedroom house (Steiner and Watson, 1993). The dimensions don't necessarily match the design example.

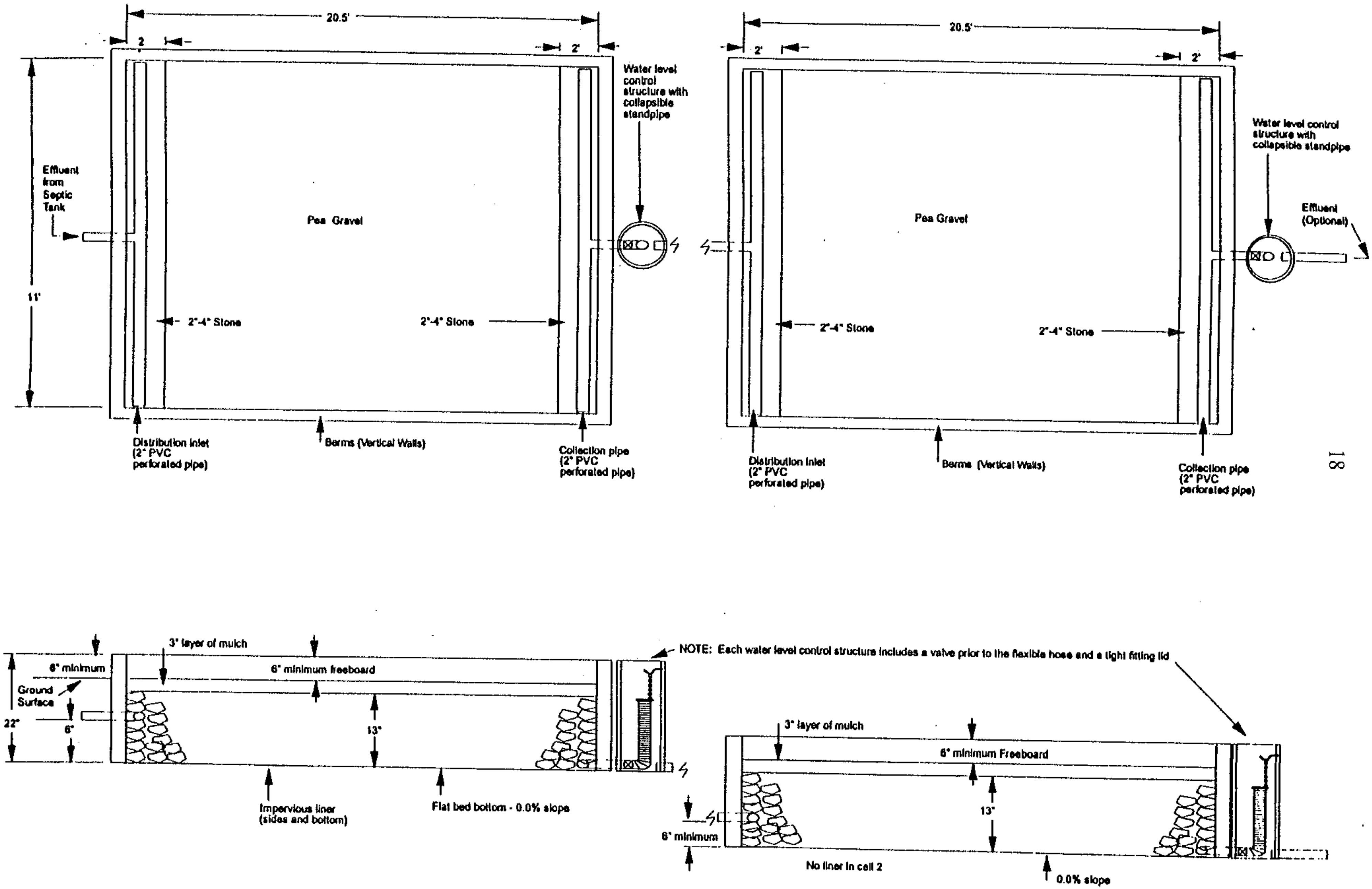

Fig. 5. Two cell constructed wetland for a 3 bedroom house (Steiner and Watson, 1993).
The dimensions don't necessarily match the design example.

It does not provide a method for estimating nitrogen removal in the systems for locations where ammonia or nitrogen control is required. The hydraulic retention time (HRT) for these systems will probably range from 3-4 days at design flow, which may not be sufficient to deal with ammonia levels leaving the septic tanks. The above approach may not be sufficiently conservative for design of systems with a surface discharge in locations with cold climates and it should be used with caution in these areas.

As indicated earlier, up to 10 day HRT may be required to reduce the nitrogen level to below 10 mg/L. However, there is very little experience at this time.

THIS DESIGN SUMMARY IS AN ATTEMPT TO PRESENT DESIGN CONCEPTS WITH SOME DETAIL. MANY DETAILS ARE NOT INCLUDED. IF YOU WANT TO DESIGN A SYSTEM, YOU MUST OBTAIN THE FOLLOWING TWO REFERENCES IN ORDER TO OBTAIN AS MANY DETAILS AS POSSIBLE.

REFERENCES

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DESIGNERS/INSTALLERS

The following firms are designing and installing constructed wetlands in the upper Midwest. There may be others unknown to the author. This listing does not mean endorsement, explicitly or implicitly. You should ask for references and visit some of there sites.

J.F. New and Associate, Inc. 708 Roosevelt Road, Walkerton, Indiana 46547. (219-586-3400) and Fax (219-586-3446).

North American Wetland Engineering, P.A.. 29920 Keewahtin Ave. N., Forest Lakes, MN 55025. (651-433-2115) and Fax (651-433-4280).