Tennessee Valley Authority
Resource Group
Water Management

GENERAL DESIGN, CONSTRUCTION, AND OPERATION GUIDELINES

CONSTRUCTED WETLANDS WASTEWATER TREATMENT SYSTEMS FOR SMALL USERS INCLUDING INDIVIDUAL RESIDENCES

SECOND EDITION

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BACKGROUND

The Tennessee Valley Authority (TVA) is a federal regional resource development agency. One of TVA's major goals is cleanup and protection of the waters of the Tennessee River system. Although great strides have been made, point source and nonpoint source pollution still affect the surface water and groundwater quality in the Tennessee Valley and nationally.

Pollution impairs water uses, causes public health problems, creates regulatory enforcement headaches, and hinders community and economic development. Causes of this pollution are poorly operating wastewater treatment systems or the lack of them. Also, a common local problem faced by homeowners and others in rural and non-sewered areas is poor site conditions which do not allow installation and satisfactory performance of conventional on-site systems such as septic tank-drain fields. Practical solutions are needed, and there is great interest and desire to abate water pollution with effective, simple, reliable and affordable wastewater treatment processes.

In recognition of this need, TVA began demonstration of the constructed wetlands technology in 1986 as an alternative to conventional, mechanical processes, especially for small communities. As the process is investigated, its potential to treat various types and volumes of wastewaters continues to be realized.

Constructed wetlands can be downsized from municipal systems to small systems, such as for schools, camps and even individual homes. The systems are effective, simple, affordable, aesthetically pleasing, and educational. Constructed wetlands "let nature do the dirty work."

These guidelines have been developed by TVA to provide state-of-the-art and simple instructions for designing, constructing and operating constructed wetlands for small wastewater flows. They have been field-tested and shown to be effective; however, they should be considered as only "guidelines," not standards. Flexibility should always be allowed so that innovators can test potentially improved concepts. Feedback is encouraged on both positive and negative experiences so that TVA can share the information.

The information contained in this document represents the views of the authors and does not necessarily reflect TVA's official perspective.

PURPOSE OF SECOND EDITION

"General Design, Construction, and Operation Guidelines: Constructed Wetlands Wastewater Treatment Systems for Small Users Including Individual Residences," TVA/WR/WQ--91/2, was published in March 1991. Subsequently, there have been numerous presentations at conferences and meetings, articles published in "Small Flows" by the National Small Flows Clearinghouse and in other magazines and journals, and local and national television and press coverage about small systems and the guidelines.

In response to telephone and written requests though April 1993, TVA distributed approximately 1800 copies of the March 1991 guideline. Approximately another 1000 copies were distributed by TVA at conferences and meetings. Additional copies have been distributed through the National Small Flows Clearinghouse. The authors believe that this large public response indicates the desire and need for alternative treatment systems that can provide affordable solutions to environmental and regulatory compliance problems.

In the introduction to the March 1991 guideline, it was stated that the guidelines may undergo future revisions based on improved information. Therefore, the purpose of this second edition is to significantly revise, improve, and expand information in the first edition based on accumulated TVA experience. Also, an attempt has been made to present some design information in a more "user friendly" format.

GENERAL DESIGN, CONSTRUCTION, AND OPERATION GUIDELINES

CONSTRUCTED WETLANDS WASTEWATER TREATMENT SYSTEMS
FOR SMALL USERS
INCLUDING INDIVIDUAL RESIDENCES

I. GENERAL

A. Constructed Wetlands Definition

A constructed wetlands wastewater treatment system (CW) may 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." Figure 1 is a cut-a-way perspective of one optional CW configuration. It summarizes the components of and processes occurring in a CW. A CW can be effective, reliable, simple, and relatively inexpensive as compared to conventional systems. A CW can be built for wide flow ranges, including sources having relatively small flows (e.g., individual homes, small businesses and schools).

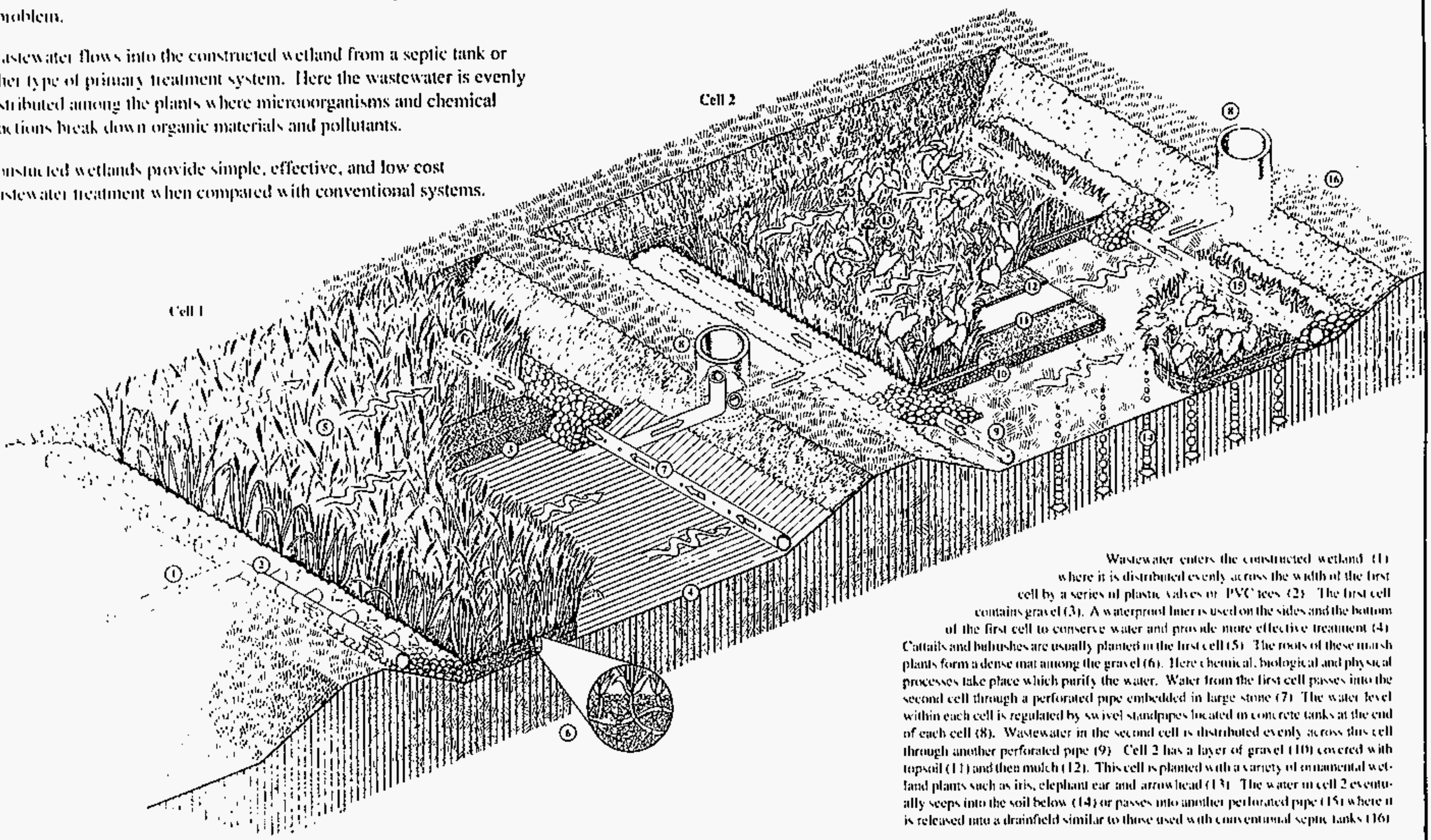
B. Discharge and Non-Discharge Systems

A CW can be a discharge system (i.e., discharges to a receiving "waters of the U.S.") or a non-discharge system (discharges to a stream are eliminated by evaporation, transpiration, and/or percolation). A non-discharge system is used where conventional on-site methods are ineffective due to poor site conditions (e.g., low soil percolation, shallow soils, high groundwater table, Karst topography). A non-discharge system is classified as "on-site" if it is located within the property boundaries of the owners producing wastewater.

Constructed wetlands like this one are being built throughout the nation to handle wastewater from mostly small rural communities and homes where traditional treatment systems are a problem.

Wastewater flows into the constructed wetland from a septic tank or other type of primary treatment system. Here the wastewater is evenly distributed among the plants where microoorganisms and chemical reactions break down organic materials and pollutants.

Constucted wetlands provide simple, effective, and low cost wastewater treatment when compared with conventional systems.



Wastewater enters the constructed wetland (1) where it is distributed evenly across the width of the first cell by a series of plastic valves or PVC tees (2). The first cell contains gravel (3). A waterproof liner is used on the sides and the bottom of the first cell to conserve water and provide more effective treatment (4). Cattails and bulrushes are usually planted in the first cell (5). The roots of these marsh plants form a dense mat among the gravel (6). Here chemical, biological and physical processes take place which purify the water. Water from the first cell passes into the second cell through a perforated pipe embedded in large stone (7). The water level within each cell is regulated by swivel standpipes located in concrete tanks at the end of each cell (8). Wastewater in the second cell is distributed evenly across this cell through another perforated pipe (9). Cell 2 has a layer of gravel (10) covered with topsoil (11) and then mulch (12). This cell is planted with a variety of ornamental wetland plants such as iris, elephant ear and arrowhead (13). The water in cell 2 eventually seeps into the soil below (14) or passes into another perforated pipe (15) where it is released into a drainfield similar to those used with conventional septic tanks (16).

Figure 1. Cut-A-Way Perspective of a Constructed Wetlands System

C. Size of CW

This guideline is generally for "small" CW systems, but "small" is not strictly defined. The smallest system designed by TVA has been for 83 gpd, a one bedroom house with limited wastewater. "Small" may be considered as systems treating flows of 20,000 gpd or less. However, a system designed to treat 100,000 gallons per day for a rural town would also be "small" compared to a system for one million gallons per day. The design features of larger systems will follow many of the guideline criteria. The guideline identifies some differences for "larger" systems.

D. Regulatory Considerations

1. Coordinate planning of all designs with local and state officials and obtain required approvals.
2. "Small" discharge systems can be reliably designed to meet "secondary" level permit limits. Large systems also can be designed to meet secondary limits but additional information is needed to optimize designs and minimize costs. To meet "advanced" level permit limits for nutrients, such as for phosphorous and ammonia-nitrogen, loading rates need to be relatively small and the CW system should utilize multiple cells in series or stages with each stage designed for specific treatment objectives. Additional research and demonstration are needed on the reduction of nutrients by a CW before designs can be developed which will consistently meet advanced level permit limitations and also be affordable.
3. On-site, non-discharge systems can be reliably designed, constructed and operated for "small" wastewater flows, depending on wastewater characteristics and siting conditions. Their best use will be to replace failed adsorption fields or as an alternative to conventional systems where percolation rates are low. The technology may also be an alternative to low pressure mound systems by constructing the CW system on top of bedrock, impermeable clay, or high groundwater.

E. "Cookbook" Designs

"Cookbook" designing of CW systems is strongly discouraged. The cost-effectiveness of CW's is very site specific. Prepare and review all designs on a site-by-site basis, and use the technology only where it has a reasonable chance of performing acceptably.

F. An Alternative Technology

Constructed wetlands for an on-site, non-discharge system (such as for homes) is still considered to be an "alternative" technology to a conventional septic system. Most applications will be for home owners whose septic systems have failed or for those building in a location unsuitable for conventional systems. Consequently, a CW can cost more than a conventional system. Also, its use normally will require accepting some degree of risk (as with other alternative technologies). The CW option should be compared to other available alternatives so that the most cost-effective selection is made.

G. Developing Technology

CW is a relatively new technology. These guidelines may again be revised as information improves. For example, research may find that the design hydraulic conductivity can be increased. This could decrease the required width for larger systems, which typically would be advantageous.

II. PRE-TREATMENT

A. Water Conservation

1. Water conservation is strongly encouraged. It is considered a "pre-treatment" method since it can significantly reduce waste characteristics. Low-flow plumbing fixtures will help minimize wastewater flow to the CW system. For example, efficient ultra-low flush toilets using only 1.6 gallons and less per

flush versus the common 5 to 6 gallon flush are available. These fixtures will pay back their cost from water bill savings and can decrease sewage flow by about one-third or more.

2. Existing Facilities - Consider replacing standard flush toilets with ultra-low flush toilets. Modify other plumbing fixtures (e.g., showers, faucets) with water saving devices. Repair any leaky fixtures as soon as they are noticed.
3. New Facilities - Require water conserving plumbing fixtures such as ultra-low flush toilets and flow restricting shower heads and faucets.

B. Septic Tank

1. To reduce suspended solids by removing coarse and heavy solids prior to the CW, install a septic tank(s) of appropriate size and design configuration. Refer to state design criteria for design, construction, and installation requirements.
2. Use at least one two-cell septic tank. Two tanks in series may be used if a two-cell tank is not available. Other design features such as baffling and flow constriction may be used as an option to a two cell septic tank, if locally available and approved by regulatory agencies. If minimization of solids and organic load to the CW is a design objective, or if proper maintenance of the tank is questionable, include a septic tank effluent filter (section II.C).
3. Obtain septic tanks from a manufacturer whose septic tank series is approved by the appropriate state/county health department. Tanks must be free of any defects. Field repairs are discouraged and generally should not be acceptable.
4. Tank failures can be minimized by providing a solid foundation beneath the entire tank. This is best done by excavating about 2 inches below the final elevation of the tank and backfilling with small gravel (1/2 inch or less) or sand. The gravel or sand can be quickly leveled, precluding humps that can cause stress failure when the tank is filled with water.

5. Set the septic tank(s) in place at the location specified by the plans, backfilling around the sides but leaving the top exposed. Fill the tank(s) to overflow and observe for 24 hours to ensure watertightness. The local health department may adjust this time so as not to hinder the installation of the constructed wetlands system. Leave the water in the tank after the testing period. Properly close the tank after testing.

C. Septic Tank Effluent Filter

1. A filter (with associated vault, access riser and cover, and other standard accessories) may be installed in the effluent side of the septic tank. Options include the Zabel Model A100, Orenco Models F1248 or F1260, or equivalent. A filter will further reduce solids and organic load to the CW system and assure long-term protection of the CW against septic tank upsets and poor maintenance. The filters are typically cost-effective and low maintenance.
2. If the septic tank effluent must be pumped to the CW, a combined filter and pump system may be used.

D. Other Pre-Treatment

Pre-treatment to reduce suspended solids may differ from septic tanks, especially for larger systems. For example, one alternative may be a stabilization pond. Also, a CW may be used to "polish" the effluent of an existing treatment facility such as a mechanical package plant or a pond. These "pre-treatment" facilities must be operated and maintained to be efficient. Excess suspended solids from a poorly operated and maintained facility can quickly lead to serious problems in CW cells (such as surface flow, short-circuiting, odors, and poor effluent quality).

III. HYDRAULIC AND ORGANIC LOADING

A. Hydraulic Loading

1. Determine hydraulic loading to the CW in gallons per day (gpd), based on the required flow per bedroom for home systems and flow per person or per fixture for other small systems. These rates are established by each state. (Typical rates are 120 and 150 gallons per day per bedroom; therefore, a three bedroom house at 120 gpd per bedroom would have a 360 gpd design flow.)
2. Reduced or increased hydraulic loadings may be approved by the appropriate regulatory agency based on actual usage.

B. Organic Loading

1. Home Systems - Determine the organic loading to the CW in pounds BOD_5 per day (lb/d). When assuming 0.17 pounds BOD_5 average daily organic loading per person and 50 percent BOD removal in the septic tank, use 0.085 lb BOD_5 per day per person.
2. Other Small Users - Use accepted unit loadings approved by the state.
3. Additional organic load reductions can be taken if a septic tank effluent filter or two tanks in series are used, possibly a total of 70 percent or greater. Determine the acceptable reduction through the appropriate regulatory agency.

IV. BASIS OF CW DESIGN AND CONSTRUCTION

A. General

1. Do not "cookbook" designs. A specific design should be developed for each system based on site characteristics and hydraulic and organic loadings. Site factors to consider are soil depth and permeability, seasonal water levels, surface topography, lot size and shape, shading by trees, and owner preferences and attitudes.

2. Design Examples - Refer to the Appendix for calculations of surface area, cross-sectional width, depth, and length for four typical systems with different site conditions. Engineering schematics are included for two options.
3. General Guideline for Dimensions - The Appendix includes a table which lists, as a general guideline, various design dimensions for two, three, and four bedroom houses and larger small systems for typical state hydraulic loading criteria.
4. Elevation Differences between System Components - System components should have elevation differences to provide for the most effective operation. Suggested relative differences are provided in the Appendix.

B. <u>CW Type</u>

1. There are two basic types of CWs - subsurface flow and surface flow (or free water surface).
2. Subsurface Flow - These systems contain porous substrate and are designed and operated to prevent visible standing water. For residential use, a subsurface flow system is recommended to minimize potential odor, vector, and public health problems.
3. Surface flow (or free water surface) - These systems have visible standing water. Their design is not covered by this guideline. They have the potential to be more cost-effective for larger systems and increase wildlife benefits, but there are also disadvantages such as potential mosquito problems. A surface flow CW could be used in whole or part to enhance a "water garden" concept for a small system, but potential problems must be considered and managed.

C. <u>Configuration</u>

1. A small CW configuration may consist of a single cell, two cells in series, or multiple cells in parallel and/or series.
2. Single Cell System - A single cell typically should be used for sites where (a) wastewater will not percolate (i.e., high groundwater table, shallow soil above impermeable rock, or very impermeable clay), (b) topography is relatively flat (preferred

elevation differences between major system components cannot be readily obtained), and (c) drainfields following the CW are required by state or local health department.

3. Two-Cell System - Two cells in series may be used at sites with soil which will marginally percolate treated wastewater. The first cell is lined to assure sufficient water for maintenance of healthy wetland plants. The second cell is unlined to allow percolation of the treated wastewater and preclude or minimize surface discharges. If percolation rates are high, the second cell may be too dry to maintain healthy vegetation. (This is not negative since it indicates that the system is functioning well.) A layer of decorative mulch may be maintained on the substrate in the second cell if vegetation cannot be sustained.
4. Multicell System - Use parallel and/or series cells to provide design and operational flexibility for larger systems. Some specific advantages of modular cells include design simplification (to limit the dimensions of gravel cells to less than 200 feet wide, 100 feet long, and 2-1/2 feet deep), addition of cells as system load increases with time, optimization of treatment processes (BOD removal in first stage cells and nutrient removal in subsequent cells), adaptation to site shape or topography (allow cells to be terraced in parallel or series to reduce and balance cut and fill), and flexibility to temporarily remove individual cells from service or load differently.

D. <u>Dimensions</u>

1. Surface Area

a. To determine CW surface area, multiply surface hydraulic loading criterion in square feet of total surface area per gallon per day (ft^2/gpd) by the hydraulic load (section III.A) in gallons per day (gpd).

b. Unrestricted Area - Use a surface hydraulic loading criterion of 1.3 ft^2/gpd.

c. Restricted Small Area - Use a surface hydraulic loading criterion of 0.87 ft^2/gpd.

d. Cold Climates - Use a surface hydraulic loading criterion of at least 1.3 ft^2/gpd.

2. Cross-section Area

a. Calculate the cross-section area based on hydraulic loading and organic loading rates. Select the larger value.

b. Hydraulic Loading - Calculate area based on the hydraulic loading (section III.A) and Darcy's Law (Appendix). Use a relatively low hydraulic gradient (assume equal to bed slope) up to 1 percent and a conservative long-term hydraulic conductivity (850 feet per day). For a flat bottom (0% slope), assume a low hydraulic gradient for the calculation (typically 0.5 percent). For sloping lots, bed slopes of 2 percent or higher can be used to minimize cut and fill. For cells receiving secondary or higher quality wastewater, a higher hydraulic conductivity may be used (up to a 10-fold increase, i.e., 8500 ft/day). This will normally be advantageous for larger systems to reduce the total inlet width needed. (NOTE - The design values for hydraulic conductivity are still considered conservative. As more experience and data are acquired, the design values may be increased, resulting in improved dimensional flexibility for larger flows. The actual hydraulic gradient is expected to vary with distance down the cell due to the partial but differential filling of substrate pore spaces with time. It may be greater than design value in the inlet area and less than design value in the outlet area. Darcy's Law is used to design the cross-section area to assure that the flow is subsurface, and also is considered to be a conservative approach. Darcy's Law applies to laminar flow regimes. Flow in clean gravel can range from laminar to turbulent, depending on flow rates and gravel sizes. Use of low, long-term hydraulic conductivities and small gravel sizes assures flow regimes that are either laminar or in the transitional region, thus assuring practical applicability of Darcy's Law.)

c. Organic Loading - Calculate area based on the organic loading (section III.B) and an organic loading criterion of 1 ft^2 per 0.05 lb BOD per day. For larger systems or steep sloping lots where a reduced inlet width is advantageous, an organic loading criterion of 1 ft^2 per 0.10 lb BOD per day may be used with a risk of occasional surface flow in inlet area over long term.

3. Substrate Depth

a. For calculation, select inlet end substrate depth of 12 inches or 18 inches.

b. Unrestricted Area - Use a 12 inch depth to provide the best treatment by assuring flow is through the most effective portion of the plant root zone. Aerobic microorganisms that degrade waste organics obtain oxygen from the plant roots. Most root biomass will be in the top 12 inches of the cells.

c. Restricted Small Area - Use 18 inch depth if available surface area is limited by the lot size or shape.

d. Cold climates - A deeper cell should be used to allow for greater water depths during extreme cold weather to prevent freezing. Use 18 inch depth with the surface hydraulic loading criteria of at least 1.3 ft^2/gpd.

e. Flat beds (0% slope) - Determine the outlet end depth based on the calculated depth and an 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.

f. Sloped beds - A sloped bed and a flat surface will result in a deeper effluent end than influent end. The difference between the influent and effluent substrate depths should be less than 6 inches preferably and no greater than 12 inches. (NOTE - For a relatively long cell, the gravel in the outlet area could be dry for a depth equal to the difference between the inlet and outlet depths. This is due to the actual hydraulic slope, and could make maintenance of healthy vegetation in this area more difficult. An option for a long cell is to slope both the bed bottom and top of substrate according to the hydraulic gradient; however, the risk of surface flow would increase since the hydraulic gradient will vary with time and distance down the cell.)

4. Width

a. To calculate effective width (width of cell bottom if side slopes are used), divide cross-sectional area (section IV.D.2) by depth (section IV.D.3).

b. It is suggested that the width of cells with buried inlet distributors be restricted to a maximum of about 14 feet to reduce short-circuiting potential. As an alternative, wider cell widths can be used with flow splitters and corresponding segmented buried inlet distributors.

c. For larger flows, a practical upper limit on the width of each cell using surface distributors is about 200 feet.

5. Length

a. To calculate the effective system length (bottom of cell), divide surface area (section IV.D.1) by width (section IV.D.4).

b. Single Cell System - The length of a cell (bottom) in a single-cell system is the effective system length (section IV.D.5.a). The actual cell length will be restricted by criterion for sloped beds in section IV.D.3.f in combination with the design hydraulic gradient. For example, for a hydraulic gradient of 1.0%, the length of a cell should not exceed 100 feet since the difference between inlet and outlet substrate depths would exceed 12 inches. This may become important for larger systems, requiring series cells to provide the total effective cell length.

c. Two-Cell System - If the in-situ soil type will provide an estimated percolation rate of 120 minutes/inch or better, a two-cell system may be used to achieve either zero or minimal discharge due to water loss through percolation and evapotranspiration from the system. The surface area of the system is divided equally between each cell, and the second cell is unlined (section IV.F). The length of each cell is one-half the system length (section IV.D.5.a).

6. Balancing Aspect (Length to Width) Ratios - Generally, design should minimize short-circuiting potential which increases with smaller aspect ratios. It is believed that 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. Optionally, less conservative design values for long-term hydraulic conductivity and/or unit organic loading can be used, but the corresponding risk of at least intermittent surface flow in the inlet area must be accepted. As more operational experience and performance information become available, risk can be better assessed and design criteria can be upgraded to reduce conservatism.

E. <u>Berms/Retaining Walls</u>

1. Surround the CW cells with earthen berms or a retaining wall to retain wastewater in the treatment system and prevent surface runoff from entering the system.
2. The top of the berm/retaining wall should be a minimum of 6 inches above the CW bed surface (top of mulch) and a minimum of 6 inches above the existing ground surface.
3. Earthen Berms -

a. Exterior slopes should be 3H:1V or flatter.

b. Interior slopes may be vertical or sloped up to 2H:1V, determined based on existing soil characteristics, construction techniques to be used, and landscaping objectives. Plywood can be used to shape interior vertical walls (Figure 2).

4. Retaining walls -

a. Use instead of earthen berms to conserve space or for terracing needs. Build with concrete blocks, crossties, landscaping timbers, or other materials that are strong and durable (e.g., Plia-Dike, or equivalent).

NOTE: Treated landscape timbers may be substituted for R.R. crossties. (one row of 6X6 timbers or two rows and columns of 3X5 timbers)

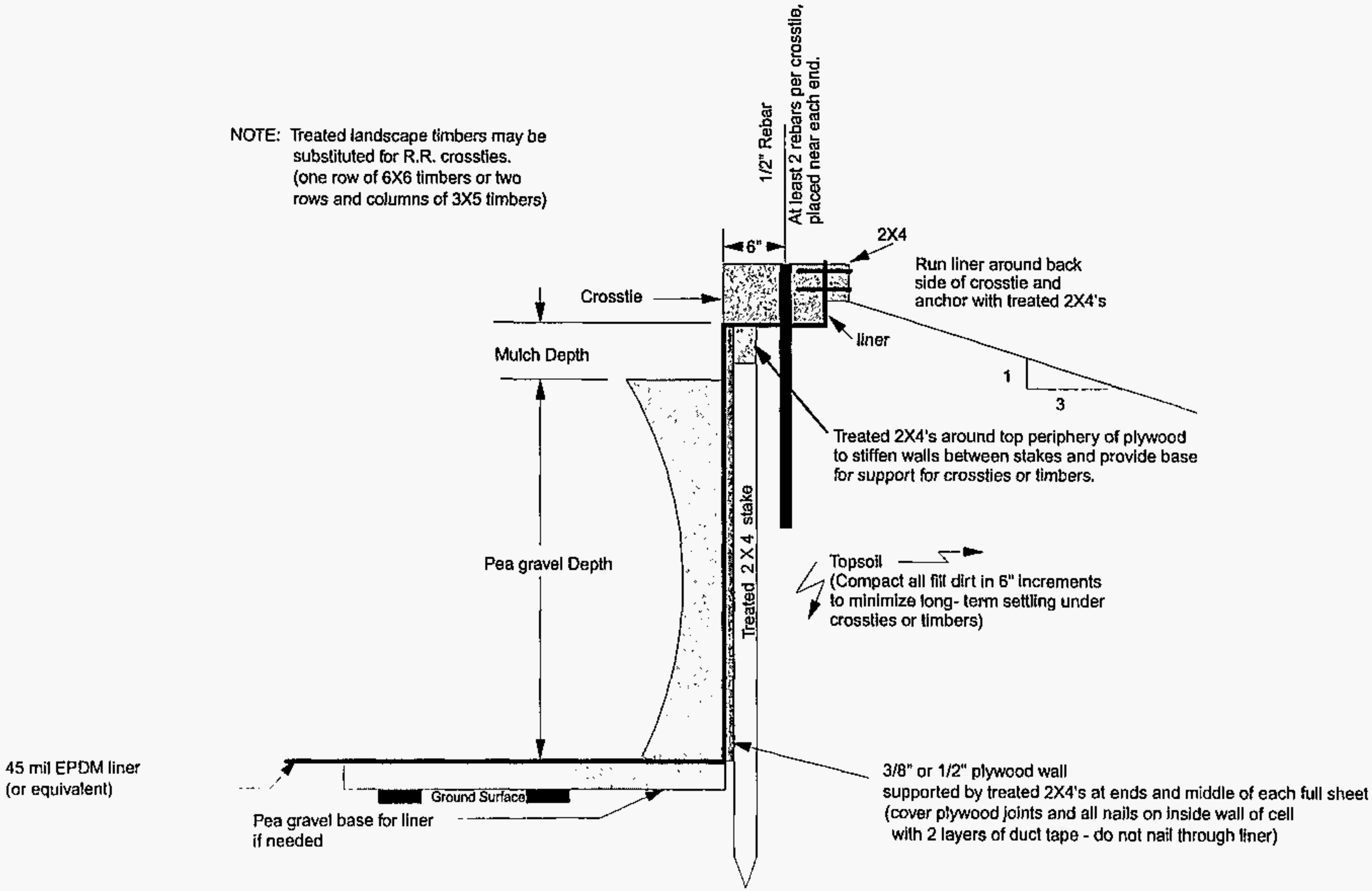


Figure 2. Optional Method for Vertical Wall Construction

b. Line or seal retaining walls to prevent seepage (section IV.F).

5. Cap - For small (home) systems, the top of the berms or retaining walls may be capped with 6" X 6" landscape timbers or railroad crossties to secure the liner, prevent surface runoff from entering the cell, and improve the appearance of the cell. For larger systems with an earthen berm, a minimum top width of three feet would facilitate grass cutting.

F. Liner

1. Install an impermeable liner inside berm/retaining wall on the bottom and side walls of cell. The primary purpose of the liner is to prevent exfiltration of wastewater from the cell and infiltration of groundwater into the cell. With exfiltration, a sufficient water level could not be assured for maintenance of wetland vegetation. With infiltration, retention time needed for wastewater treatment would be reduced.

2. Type

a. Materials - Use a type of heavy duty synthetic 30-45 mil membrane, such as ethylene propylene diene monomer (EPDM) rubber, polyvinyl chloride, or polyethylene, or compacted clay. Use UV resistant materials.

b. With a synthetic liner, remove all rocks, roots and debris that might puncture the liner. A 1 to 2 inch layer of sand or round pea gravel between the bed bottom and the liner would provide additional protection and should be required for all installations where bedrock must be excavated.

3. Single Cell System - Install an impermeable liner on the bottom and sides of the cell. In areas having a high groundwater table or bedrock near the ground surface, the CW may be built on the ground surface with impermeable liner and appropriate provisions for effluent disposal.

4. Two-Cell System

a. Cell 1 - Line as in a single cell system.

b. Cell 2 - Do not line typically. However, if installed on sloping terrain, downhill sides of the second cell may need to be lined to prevent water seepage at the interface between the fill material and the original ground surface. If this is the case, dig through the fill material and extend the sidewall liner at least 6 inches into the original soil below the fill material in the cell bottom.

5. Provide leakproof seal between the liner and piping which enters and exits the cell for inlet and outlet distributors. For example, use Tank Adaptors or equivalent.

G. <u>Substrate</u>

1. Type and Size

a. Type - The most common substrate is sized, washed gravel. A preferred substrate to reduce compaction is a gravel with rounded surfaces such as river pea gravel. Do not use crushed limestone unless it is the only available alternative; it can compact more due to its angular shape and has a greater potential to puncture a liner.

b. Size - For the main substrate, use A.H.D. sizes 8 through 9 (average diameter 1/4 inch and 1/8 inch, respectively). Larger sizes (e.g., A.H.D. sizes 6, 67, or 7 - 1/2 to 3/8 inch) may be used if more readily available in certain locations, but the smaller size is preferred. Also, the larger size should be used if the septic tank effluent is pumped to the CW.

c. Influent distribution and effluent collection - In the first and last two feet of the cell(s), use 2 to 4 inch stone around the influent distributor and effluent collector pipes to reduce influent and effluent clogging potential. One foot instead of two feet may be used for very small systems (e.g., one bedroom house) with a short cell length.

2. Cleanliness - The substrate should be washed to minimize fines which will plug the pore spaces of the substrate and possibly cause surface flowing.

3. Depth - The effective substrate depth is that selected in section IV.D.3.

4. Substrate Surface - The substrate bed surface should be flat to facilitate water level control, vegetation planting and growth, and prevent stagnant pools. Allowable tolerances should be 0.04 feet (0.5 inch) or less at any point on the surface for small systems (1/4 acre or less), and 0.08 feet (1.0 inch) for larger systems (greater than 1/4 acre).

5. Surface Mulch - For small systems, apply a 3-inch layer of mulch on top of substrate to help control potential odors, prevent reflective sun scalding of vegetation and for visual aesthetics. Mulches may include bark, pine straw, tree chips, composted leaves, etc. (Mulch is generally not used on larger systems where water levels can be temporarily raised above the gravel surface for planting and special maintenance operations.)

H. Piping

1. Complete necessary replumbing on house sanitary plumbing to connect all household wastewater to the septic tank.

2. Use approved plumbing standards (e.g., The Southern Plumbing Code), to determine house replumbing needs, type of pipe, and location and spacing of cleanouts between the house and septic tank.

3. Influent Distribution

a. Use a header pipe to provide uniform wastewater distribution. Distribution can either be on or below the surface of the substrate. Use a buried or covered distributor for smaller systems where accessibility to the wastewater needs to be controlled, such as for an individual home where children can be present. Use a surface distributor for larger flows (above about 2,000 gpd).

b. Buried Distributor - This method is used for smaller gravity flow systems to limit access to the wastewater. Use 2-inch diameter pipe for homes with up to three bedrooms with typical water use. Use 3-inch diameter pipe for a four bedroom house. Place inlet distributors at mid-depth in 2 to 4 inch stone. Drill holes 5/8 inch diameter, spaced 6 inches apart on top, bottom, and each side of pipe (4 rows).

c. Small Systems With Pump - Make the 2 to 4 inch stone depth about 3 inches deeper; place the pipe (sized to maintain a flow velocity of 2 ft/sec or higher) on top of the stone (above water level); drill orifice holes 1/8 inch diameter, spaced 6 inches apart, in series of 3 holes facing up and 1 hole facing down (to allow the pipe to drain between pump cycles); place orifice shields made of 3 inch PVC caps over each 1/8 inch orifice facing up; and cover the distributor assembly with a material such as a piece of filter fabric, fiberglass screen, or liner, and then followed by mulch.

d. Surface Distributor - This method is preferred for larger systems, both gravity flow and pumping from the pre-treatment unit. Use a 3 inch minimum (sized for flow) header pipe having tees which can be swivelled to distribute the flow evenly from each tee. Tees will have lubricated slip fittings. Preferred tee spacing on the header is 4-6 foot centers for headers less than 100 feet long and 5-8 foot centers for headers between 100 feet and 200 feet long. At the end of each header will be a plug or cap which can be removed for flushing accumulated solids. The pipe needs to be firmly anchored between tees to prevent movement during adjustment of tees.

4. Effluent Collection

a. Use a header pipe to provide uniform wastewater collection.

b. Use 2 inch diameter, or larger, pipe, sized for flow. A 2-inch diameter pipe is adequate for homes with up to four bedrooms with typical water use. Drill holes 5/8 inch inch diameter, spaced 6 inches apart on top, bottom, and each side of pipe (4 rows).

c. Place pipe on the cell bottom in the 2 to 4 inch stone.

5. Cleanouts - Install a capped cleanout on each end of the inlet distributor and outlet collector. Locate cleanouts at the inside edge of each cell and extend above the top of the mulch. Extend the inlet distributor cleanouts at least 12 inches above the mulch to allow observation/monitoring of increase in head due to partial pipe/gravel clogging with time.

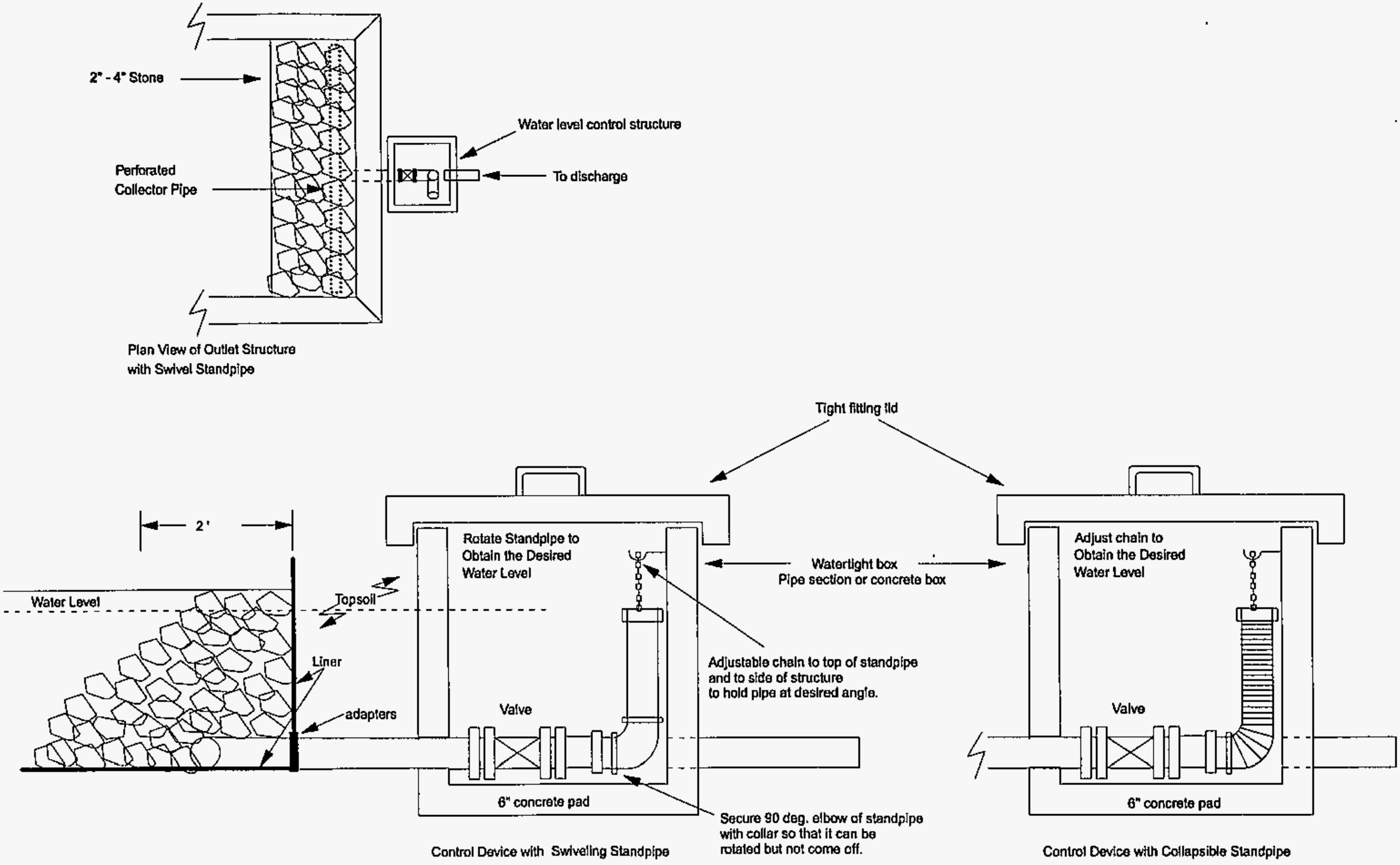
I. Pumping

1. Ideally, a gravity flow system is desired. However, if wastewater cannot gravity flow from house plumbing to the septic tank and CW, the septic tank effluent must be pumped.
2. Select the required pump based on flow and total head, working with the pump manufacturer.
3. Always include either a septic tank filter (Orenco, Zabel, or equivalent) or a second septic tank to minimize solids pumped to the CW (sections II.B and II.C).
4. Restrict the pumping rate by a valve to prevent or minimize surface flow in the CW. Set the dosing volume so that it does not exceed one-fourth the daily design flow. Also, adjustments (increases) may be needed in the influent cross-sectional area based on instantaneous pumping rates.
5. Surface surging which may eventually occur during pumping may be mitigated by reducing dosing volume, flow rates, and/or lowering cell water depth to provide additional surge capacity.
6. Additional information is needed to better identify minimum appropriate pumping rates, dosing volumes, and cell design. This will be developed through experience.

J. Water Level Control

1. Water level control and adjustment is critical to establishment and survival of the plants. Roots of emergent plants must be kept wet and the plants will not survive if they are completely covered with water for extended periods. Also, if water is allowed to stand in or above the mulch, surface odor may occur.
2. Install a suitable discharge structure incorporating an adjustable water level control device at the effluent end of the cell(s) using either the swivelling standpipe or collapsible tubing options as shown in Figure 3.

a. For a home system, the structure may consist of an 18 inch PVC pipe section, embedded vertically in a 6 inch concrete floor pad. For larger systems to accommodate larger piping, the structure may consist of a larger PVC pipe section or a concrete block box.



Plan View of Outlet Structure with Swivel Standpipe

Control Device with Swiveling Standpipe

Control Device with Collapsible Standpipe

NOT TO SCALE

Figure 3. Water Level Control Structures

b. The discharge pipe from the effluent collection header will enter the control structure.

c. Place a valve on the discharge pipe from the cell into the water level control structure immediately in front of the water level control device. The valve will allow flow to be stopped if the standpipe ever needs servicing.

d. Connect the adjustable water level control device after the valve. For smaller systems, the water level control device may be a length of flexible/collapsible tubing such as super heavy duty sewer hose used for travel trailers. For larger systems, a swivelling standpipe is suggested. Refer to Figure 3.

e. The standpipe/tubing should allow manipulation of the water level from draining the beds to 2 inches over the surface of the gravel substrate.

f. Provide a tight fitting lid for the water level control structure to prevent escape of possible odors, keep out leaves and other objects, discourage vandalism of the valve and piping, and preclude possible safety considerations.

K. Miscellaneous

1. Rainfall Runoff - Slope or trench the area around the CW to divert surface water away from the system.
2. Safety - The entire CW area may be enclosed with a suitable fence. This is especially encouraged with larger systems where the substrate is flooded for planting and operational measures. Fences will also discourage trespassing and prevent possible sanitary problems. Also, water level control box lids may be secured and locked.

L. Effluent Disposal

1. No discharge from CW cells - For sites with good to marginal soil percolation, a small system (e.g., individual home) utilizing an unlined second cell typically has no discharge due to water loss by evaporation, transpiration, and percolation of treated water from the unlined cell.

2. Discharge from CW cells

a. When all water cannot be eliminated in the CW cells or local health department policy requires drainfields as a precautionary measure, route excess water to a drainfield of gravel-less leach bed tubing (or equivalent) installed according to manufacturer instructions. The size of the drainfield is typically much smaller than that required following septic tanks because of the improved long-term percolation rates of the higher quality CW effluent. One successful sizing criterion is 50 feet of 8 inch gravel-less pipe per bedroom. The bottom of the gravel-less pipe typically should be at least 12 inches above bedrock, impermeable clay, or seasonally high groundwater level. If necessary, use a "mound" design incorporating permeable top soil for the drainfield.

b. Land application or drip irrigation - The highly treated discharge could be land applied to an area planted with landscaping plants or with wetlands or water tolerant grasses. Consult with the local health department or regulatory agency for applicable design criteria.

c. Nonpoint source discharge - A discharge for the highly treated wastewater could be designed as a nonpoint source discharge to an appropriate approved area.

d. Point source discharge - Larger systems requiring point source effluent disposal to a receiving stream must be approved by the appropriate state agency and designed to meet all limitations.

V. Vegetation

A. Species

1. Use plant species that grow naturally within the region.
2. Select species which have extensive vertical and lateral root growth. Preferred species include, but are not limited to: Typhaceae (cattail family), Cyperacaea (sedge family), Graminear (grass family), and Junacaea (rush family). Scirpus

validus (softstem bulrush) has been used successfully at several municipal systems. Phragmites australis (giant reed) is a very good species for wastewater treatment, but is considered a "noxious" plant in some areas due to its aggressive growth.

2. Sunlight - Full sunlight for most of the day during the growing season is needed for most species. For shady locations, select shade tolerant species such as ferns.
3. Ornamental species - Flowering and other types of ornamental species can also be used for aesthetic attractiveness, especially around the perimeter of the cell(s). Several species include, but are not limited to: canna lily (Canna flaccida), elephant ear (Colocasia esculenta, calla lily (Zantedeschia aethiopica), various water iris (Iris pseudacorus), arrowhead (Sagittaria latifolia), arrow arum (Peltandra virginica), pickerelweed (Pontederia cordata), and sweet flag (Acorus sp.).

B. Planting

1. Ideally, plant vegetation during spring to early summer to obtain as much growth as possible prior to winter. This reduces winter mortality. Do not plant vegetation after 2 weeks prior to early frost date.
2. Adjust the water level in a single cell system or the first cell in a two-cell system to the top of the gravel substrate.
3. Space plants on no less than a one foot centers grid pattern for small systems (less than 1/4 acre) and two foot centers for larger systems (greater than 1/4 acre). This planting density should provide a uniform vegetation cover in one to two growing seasons.
4. Use plants with a 6 to 12 inch stalk above the roots; prune if necessary.
5. Plant through the mulch so that root portion is in the water and the stalk above water.
6. In the second cell of two-cell systems, use sprinkler to water plants until they have at least 1 foot of new growth.

C. Miscellaneous

1. At the completion of construction activities, dress the site. Rake any ruts and bare areas made during construction to equivalent original condition.
2. Minimize erosion on earthen berms by sowing a suitable cover crop (e.g., Kentucky 31 Fesque) and cover with a straw mulch.
3. If wet conditions occur at the CW discharge point, plant reed canary grass or other water tolerant species as a cover crop.

VI. OPERATION AND MAINTENANCE

A. General

1. Constructed wetland treatment systems for small wastewater flows require minimal operation and maintenance. However, some care by the owner is required to maintain an effective and attractive system. Casual observations are needed to preclude problems or minimize identified problems.
2. The length and detail of these guidelines should not alarm the user. Potential problems are addressed that are not expected to occur unless the system is abused.

B. Start-Up

1. Delayed Organic Loading - 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 in service as soon as they are completed, plan and conduct an extended start-up period under reduced loading conditions, if possible. Add water or wastewater to the system to maintain the water level and liquid fertilizer for good plant growth.
2. Flow Distribution - For surface distribution, adjust each swivel tee on the distribution pipes to obtain equal flow from each tee. This is accomplished by trial and error. Insert a lever (short section of like size pipe) into the tee and then gently rotate the tee to the proper elevation. Set the

overflow elevations from the tees so that the distributor pipes will be about half full of water.

3. Water Level - Maintain water level about 1 inch above the gravel substrate surface until the plants have about 1 to 2 feet of new growth (may not be possible in an unlined cell).
4. Grass Mowing - Do not mow the newly planted grass until it is at least 4 inches high. Do not cut it any lower than 3 inches until it is fully established (for at least the first two growing months after planting). Do not blow grass clipping into the wetland cells to reduce the need for weeding the cells.
5. Sprinkler Use - For systems with a second wetland cell, check the water level in the second cell at least once a week. If the water level is more than two inches below the top of the gravel (or deeper than the root depth of the plants), water the cell with the sprinkler at least weekly during dry periods of the growing season for at least 2 hours, or more frequently if the plants are not growing good.

C. Septic Tank

1. Do not allow septic tank to fill with solids so that solids carry over into the CW. Solids can plug the distributor pipes and the gravel in the CW. If this does occur, sewage can back up into the plumbing and surface in the CW. Also, odor and aesthetic problems can result. These can become costly and time-consuming problems to mitigate.
2. Check the depth of accumulated solids in the septic tank after the first 5 years of operation, and every two to four years thereafter. When the sum of the depths of the bottom sludge and floating scum is one-third of the distance from the tank bottom to the outlet pipe, a professional septic tank pumper should clean the tank and dispose of the septage as approved by the local health department.
3. Tanks with filters (Zabel, Orenco, or equivalent)

a. Clean filters whenever the tank is pumped. This should be done by the professional septic tank pumper. Clean filter by spraying with clean water according to the manufacturer's instructions. Direct the wash water back to the septic tank.

b. If the house plumbing becomes clogged to the extent that none of the plumbing fixtures are draining properly, the filter is one likely source of the drainage problem. It should be inspected and cleaned as necessary. If this occurs, it indicates an upset of the septic tank caused by excessive flow or disposal of harmful chemicals that should be preventable.

D. Water Level

1. Normal Operation - Maintain water level in the first cell about one inch below the gravel substrate surface at the inlet end. Adjust water level using the pipe/tubing in the water level control structure. For a swivel standpipe, gradually rotate it down to lower the level and up to raise the level. For the flexible tubing, lower or raise the top of the tubing with the notched chain and hook on the wall. To conveniently check the water level relative to the gravel surface, remove the caps of the observation standpipes at each end of the inlet distributor, or remove a small area of mulch and dig a shallow hole in the gravel (fill hole after checking). Water levels will temporarily increase with flow surges.
2. Extended No Flow Periods (e.g., long vacations) - Maintain water level in the bed. Without flow, water in the cell will evaporate in hot weather and freeze during severe cold weather conditions. Both extremes will damage roots and tubers over a prolonged period. Plan to have water added to the system as needed.
3. Pump Systems - Adjust the pump floats, pump outlet valve, and the water level so that the pump cycle does not result in wastewater surging above the mulch layer. Periodic adjustments may be needed as the system matures to keep the surges below the mulch or gravel.

4. Leaking Joints - Check adjustable standpipe or hose in the water level control structure for leaks from joints. Repair to stop any leaks. First, shut off flow using valve located in front of adjustable standpipe or hose. Open valve as soon as repair is completed.

5. Surface Ponding

a. If surface ponding in a wetland cell can not be controlled by water level adjustment, it may be caused by either excessive flows above the design basis or clogging of the substrate by excessive solids from the septic tank or by microbe growth due to excessive organic loads.

b. Determine if solids are collecting in inlet distributor by cleaning with a homemade cleaning gig constructed with a wire and sponge. Snake the wire from one end of the distributor pipe through the other end. Wrap one end of the wire around a sponge or other material that is large enough to be compressed when pulled through the pipe. Clean the pipe by pulling sponge through the pipe several times. A large amount of solids in the pipe indicates plugging of the wetland by excessive solids discharging from the septic tank.

c. Draining and drying the cell for a week or more may temporarily help the problem, but correction will probably require replacement of the gravel from the inlet to the point where flow reenters the gravel.

d. Identify and implement actions to prevent the problem from recurring, such as pumping the septic tank more frequently, installing a septic tank filter or another septic tank in series, and eliminating the use of any toxic chemicals that have the potential to "upset" the septic tank.

e. If cleaning of the inlet distributor reveals little or no solids buildup in the pipe, ponding is probably caused by excessive water flow which exceeds the hydraulic capacity of the substrate. Corrective actions include use of water conserving fixtures or installation of another parallel wetlands cell.

f. Water levels may temporarily increase with flow surges. Do not make major corrections unless the water level remains above the gravel or mulch surface for an extended period.

E. Inlet Distributor

1. Buried Distributor - Periodically check the water level in the cleanouts on each end of the inlet distributor. If the water level in the cleanouts is obviously higher than the top of the gravel, holes in the distributor pipe or the large stone around the pipe are clogging. Clean the pipe using a homemade cleaning gig described above. If pipe cleaning doesn't correct the problem, the large stone can be cleaned by carefully pouring oxidizing chemical such as bleach or hydrogen peroxide into the distributor pipe cleanouts. Replace any wetland plants that may be killed in the inlet area.
2. Small Systems With Pump - Clean the distributor pipe once per season (spring, summer, fall, and winter) by removing the end caps and running the homemade gig described above through the pipe several times.
3. Surface Distributor - Check and maintain the distributor tees so that the flows are about equal. A tee may become partially blocked by solids, algae, or other articles. Flush solids out of the distributor pipe by temporarily removing an end cap/plug or turning an end tee down one at a time. The flow of water should flush most solids. Use a garden hose to remove remaining solids. Remove any articles such as paper, sticks, or rags that may block a tee. Periodically brush each tee to remove accumulated algal growth.

F. Liner

1. Maintain cover over the sides of synthetic liners (e.g., EPDM, polyethylene, PVC, hypalon, neoprene, butyl rubber, etc.) which extend above the substrate and water level to prevent UV degradation.

2. Periodically check for liner leaks. Dyes should be used to verify suspected leaks. Drain cell, remove gravel in the suspected leak area, locate leak, and patch the liner following manufacturer's instructions. Leaks around the inlet and outlet pipes may be caused by caulking pulling away from the liner. If so, recaulk as necessary. Draining and repairing leaks should be accomplished within one day to reduce risk of killing the wetlands vegetation.

G. Berms/Retaining Walls

1. Repair any earthen berm erosion as soon as it is noted.
2. Repair leaks around berms/retaining walls as soon as noted by plugging, sealing, etc.
3. Mow earthen berms or around retaining dikes to maintain an attractive site.

H. Pumps

If a pump is part of the system, maintain the pump and any alarm system according to manufacturer's specifications.

I. Vegetation

1. Check the vegetation for signs of disease or other stress (yellowing or browning, withering, spots, etc.). Some of these symptoms may occur naturally as the plants mature, especially after seeds have matured. If the water level is satisfactory, obtain guidance from a local agricultural extension agent, or knowledgable garden center.
2. Manually pick large insects (e.g., caterpillars, slugs) causing damage to the wetland vegetation. For serious insect infestation which is destroying the vegetation, a chemical agent may be applied after obtaining guidance from a knowledgable person (e.g. agricultural extension agent, or good garden center) for proper chemical and application rate.
3. If vegetation does not appear healthy and water levels are correctly maintained, add a balanced liquid fertilizer

periodically (three times a growing season) to the wastewater by flushing down a toilet. "Normal" domestic sewage may not contain all the trace nutrients and elements required by the vegetation in a gravel substrate.

4. Replace dead plants as necessary to fill voids.
5. Pull up "volunteer" weeds, trees and shrubs from the wetlands. These species will shade and crowd the desirable wetland plants.
6. Prevent excessive shading of wetland vegetation by controlling growth of trees or high shrubs near the wetland cells. Most wetland plants need at least six hours of sunshine each day.
7. Remove mature wetland vegetation after the plants have browned in the fall if desired for visual aesthetics. However, only cut approximately two-thirds of the height of the plants. The removed material may be laid on the bed surface as a mulch.
8. Deep root growth

a. Encourage deep root growth by lowering the water level over several weeks during the dormant vegetation period. Do not drop the water level too low, too quickly and leave the roots without water.

b. Suggested procedure - After frost has killed the top of the plants, drop the water level below the gravel surface to one-third the gravel depth (e.g., 4 inches for a 12 inch depth) for a week; raise the level back to 1 inch below the surface for a week; drop the level two-thirds the depth (e.g., 8 inches for a 12 inch depth) for a week; again raise the level to 1 inch below the surface for a week; drop the level to 1 inch above the cell bottom (11 inches for a 12 inch depth) for a week; raise the level to 1 inch. Repeat this cycle once more.

9. Divide and replant decorative flowering species (e.g., iris) to enhance the system attractiveness.

J. Odor Control

1. Standing water on the substrate surface is the probable cause of objectionable odor. Level any low and high spots on the substrate surface which create small standing pools by raking

and/or filling with additional substrate. If a too high water level is causing standing water on most of the substrate surface, lower the level using the water level control device so that it is about one inch below the substrate surface.

2. Odors will also occur from water standing or flowing within the water level control structure and open observation standpipes. Odors from these structures should be noticeable only when the caps or covers are removed or loose. Secure the caps and lids in place to prevent these odors from escaping.

K. Drain Field

1. Mow to keep the area attractive.
2. Fill in any low areas where surface water ponding occurs.
3. If wastewater surfaces above the drainfield for extended periods, check risers to ensure that all extensions are receiving water. If any section is not receiving water, a pipe may be separated or crushed. Repair as necessary.
4. Installation of water conserving plumbing fixtures or additional drain field area may be necessary.

L. Health and Safety

1. Prevent children from playing in the system to avoid contact with potentially infectious microorganisms.
2. The tight fitting lid on the water level control structure may be secured with a latch and lock if a potential safety problem is a strong consideration.

M. Miscellaneous

1. Leaky Plumbing Fixtures - Repair faulty plumbing fixtures as soon as they are noticed. Leaky or stuck commode flaps can particularly reduce treatment effectiveness of a small CW due to the large quantity of water that can be lost in a short time period.
2. Household Chemicals - Do not empty strong chemicals (e.g., some drain cleaners, floor cleaners, bleach) into the sanitary

system. Chemicals can upset the septic tank causing excessive solids to wash out of the septic tank and possibly plug the substrate. Also, chemicals can damage and kill the vegetation.

3. Pipe Clogging - Prevent or minimize pipe clogging by restricting flushing of grease, food particles, and tampons and other personal hygiene products. Use cleanouts installed before the septic tank and the wetland cells to unclog pipes.
4. Herbicides/Pesticides - Do not apply herbicides and pesticides which can damage vegetation either on or near the system.
5. Mulch - Maintain a three-inch mulch layer on top of the substrate, either with litter from the wetland vegetation, pine straw or bark, or other suitable material.
6. Surface Drainage - Reroute any surface draihange entering the CW around or away from the cell(s).
7. Animals - Prevent animals from digging in CW, destroying vegetation and making holes in the substrate and mulch.
8. Unusual Problems - Contact your local county health department for guidance if any unusual problem is noted.

VII. ADDITIONAL INFORMATION

Questions about the guidelines may be directed to the authors, Tennessee Valley Authority, Water Management, Haney Building 2C, 1101 Market Street, Chattanooga, Tennessee 37402-2801, or telephone 615/751-3164.

APPENDIX

Design Examples for Four Optional Residential Constructed Wetlands Systems

Table of Design Dimensions for Selected Systems

Table of Relative Elevation Differences Between System Components for Constructed Wetlands Wastewater Treatment Systems

Design Examples

Residential/Small Constructed Wetlands Systems With Septic Tank (ST) Primary Treatment

Note: Calculations are not rounded. Dimensions are rounded (usually to the nearest whole number) after all calculations are completed.

Assume 3 bedroom house occupied by 4 people.

Hydraulic Load, Q = 120 gpd per bedroom * 3 rooms = 360 gpd (48.132 ft^3/d)

Organic Load = 0.17 lb/d/person * 4 people * 50% ST carryover = 0.34 lb/d

Hydraulic Loading Criteria = 1.3 ft^2/gpd

Organic Loading Criteria = 1.0 ft^2/0.05 lb BOD/d

Determine CW cell surface area, A_s:

A_s = 360 gpd * 1.3 ft^2/gpd = 468 ft^2

Option 1:

Site condition - Yard is relatively flat and area is not constrained. The in-situ soil percolation rate is between 90 and 120 min/in.

Use flat bed. Assume hydraulic gradient, S = 0.5%, or 0.005, and hydraulic conductivity, K_s = 850 ft/d (conservative rate based on long-term clogging of the gravel).

Determine cell cross-section area, A_x, based on hydraulic load, Q, and Darcy's Law:

$A_x = Q/(K_s * S)$, where
K_s = substrate hydraulic conductivity (long term)
S = hydraulic gradient (assume equivalent to bed slope)

A_x = 48.132/(850 * .005)
= 11.325 ft^2

Determine cell cross-section area, A_x, based on organic load:

A_x = 1.0 ft^2/0.05 lb BOD/d * 0.34 lb BOD/d = 6.8 ft^2

A_x is larger by hydraulic loading; therefore, use 11.325 ft^2.

Use 1.0 ft for cell depth, D (front of cell)

Determine cell width:
$W = A_x/D$
= 11.325/1.0
= 11.325 ft

System cell length, $L = A_s/W$
$= 468/11.325$
$= 41.325$ ft

Rounding to the nearest whole number results in cell dimensions of 11 ft wide and 41 ft long. Since the soil percolation rate is 120 min/in or faster, the wetlands system may be divided into two equally sized cells (each cell 11 ft wide and 20.5 ft long with the second cell unlined) if the local health department does not require a subsequent drain field. If a drain field is required, one lined cell (11 ft wide and 41 ft long) will be more cost effective.

Substrate depth:
one cell system:
cell inlet: 1.0 ft
cell outlet: 1.0 ft + (0.005 * 41.325) = 1.2066 ft = 14.479 in

two cell system:
cell inlet: 1.0 ft
cell outlet: 1.0 ft + (0.005 * 68.824/2) = 1.1033 ft = 13.240 in

Use a flat cell bottom (to simplify construction) and a cell depth of 14 in for a one cell system and 13 in for a two cell system.

Refer to Figure A1 for the two cell system and Figure A2 for the single cell system options.

Option 2:

Site condition - Yard is relatively flat; however, the homeowner desires a more narrow system which fits into the landscaping along one side of the yard as much as possible. The in-situ soil percolation rate is between 90 and 120 min/in.

Assume bed slope, S = 1.0%, or 0.01.

$A_x = Q/(K_s * S)$
$= 48.132/(850 * .01)$
$= 5.6626 \text{ ft}^2$

Since organic load width (same as Option 1) is larger, use 6.8 ft^2.

The equivalent bed slope is:
S = 48.132/(850 * 6.8) = 0.0083273 or 0.833%

Use 1.0 ft for cell depth, D (front of cell)

Determine cell width:
$W = A_x/D$
$= 6.8/1.0$
$= 6.8$ ft

System cell length, $L = A_s/W$
$= 468/6.8$
$= 68.824$ ft

Rounding to the nearest whole number results in cell dimensions of 7 ft wide and 69 ft long. Since the soil percolation rate is 120 min/in or faster, the wetlands system may be divided into two equally sized cells (each cell 7 ft wide and 34.5 ft long with the second cell unlined) if the local health department does not require a subsequent drain field. If a drain field is required, one lined cell (7 ft wide and 69 ft long) will be more cost effective.

Substrate depth:
one cell system:
cell inlet: 1.0 ft
cell outlet: 1.0 ft + (0.0083273 * 68.824) = 1.5731 ft = 18.877 in

two cell system:
cell inlet: 1.0 ft
cell outlet: 1.0 ft + (0.0083273 * 68.824/2) = 1.2866 ft = 15.439 in

Use a flat cell bottom (to simplify construction) and a cell depth of 19 in for a one cell system and 15 in for a two cell system.

For Options 1 and 2, if practical, construct the second cell at a lower elevation than the first cell to allow independent water level control in each cell. Ideally, the top of the second cell should be at or below the bottom of the first cell. If this is not practical, lowering the water level in the first cell may be restricted by the water level in the second cell.

<u>Option 3</u>:

Site condition - Site has shallow soil, averaging only 3 inches deep, above a silty sandstone bedrock with low permeability.

Since there will be no percolation, the option of two cells is eliminated. Use a flat bed and one cell.

Use Option 1 dimensions for one cell (11 ft wide and 41 ft long).

Refer to Figure A2.

<u>Option 4</u>:

Site condition - Available site has 25% slope; therefore, a relatively wide bed would require costly cut and fill for berms. Also, fractured rock will require a system liner.

Use a multicell system with parallel beds which are flat. Terrace the parallel cells on the slope. Use a flow splitter to divide the flow equally between two parallel beds.

Since the design objective is to minimize cell width, follow the procedure used in option 2. Organic loading requires an inlet area of at least 6.8 ft^2, which corresponds to a bed slope of 0.833%. Divide the single cell obtained in option 2 into two parallel cells that are 3 ft wide, 69 ft long, and 19 in deep. Dimensions could be reduced further using a design depth of 18 in and a hydraulic loading criterion of 0.87 ft^2/gpd. For a one cell system the dimensions would be 5 ft wide, 69 ft long, and 25 in deep.

(W = 6.8/1.5 = 4.5333 ft)
(L = 313.2/4.5333 = 69.089 ft)
(D = 1.5 + [0.00833 * 69.089] = 2.0755 ft = 24.906 in)

If needed, two parallel cells could be used that were each 2.5 ft wide, 69 ft long, and 25 in deep.

Cell walls need to be designed to assure long-term stability on the steep slope.

Design a mounded drainfield below the wetland cell.

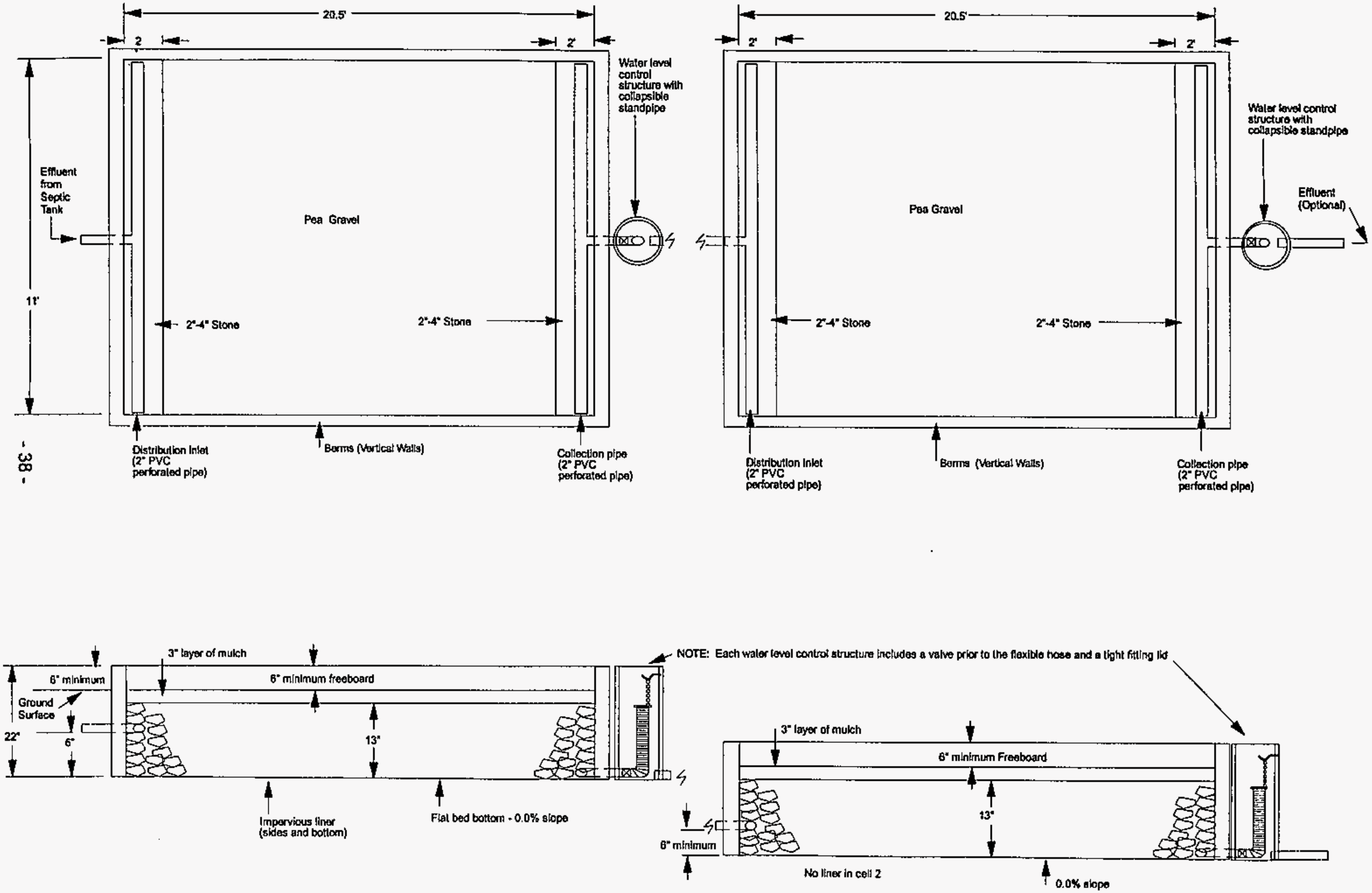
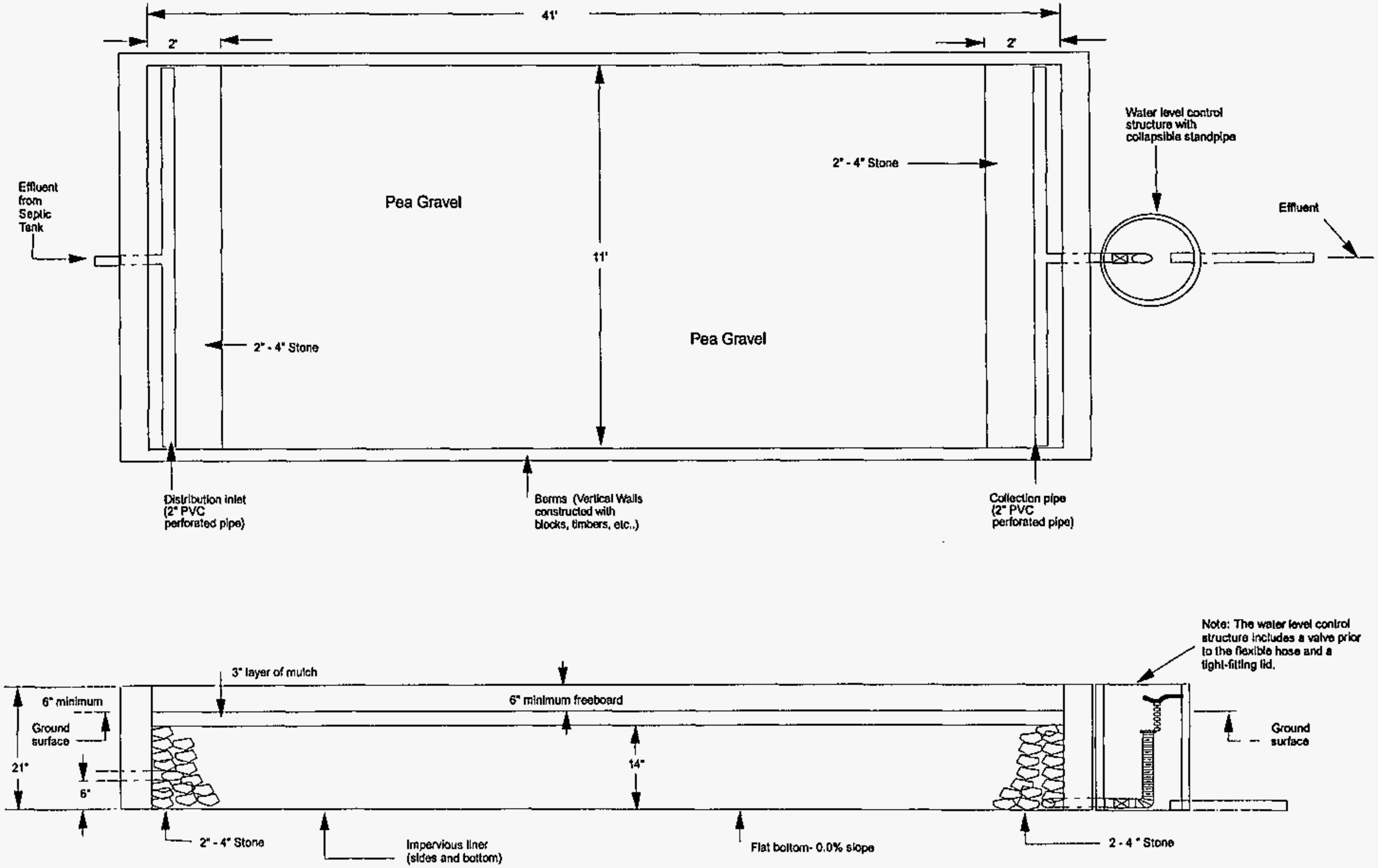


FIGURE A1. Two Cell Constructed Wetlands for a three Bedroom House (Option 1)



NOT TO SCALE

FIGURE A2. Single Cell Constructed Wetlands for a Three Bedroom House (Options 1 and 3)

DIMENSIONS GUIDELINE - RESIDENTIAL SYSTEMS
BASED ON HYDRAULIC AND ORGANIC LOADINGS[1]

			One Cell System			Two Series Cells		
Hydraulic Loading gpd	Hydraulic[2] Slope, %	Cell Area ft2	Substrate Depth[3] Inlet/Outlet,in	Width ft	Length ft	Substrate Depth[3] Inlet/Outlet,in	Width ft	Length ft
TWO BEDROOM HOUSE - 3 PEOPLE:								
240	0.50	312	12/14	8	41	12/13	8	20.5
240	0.50	209	18/20	5	41	18/19	5	20.5
240	0.726	312	12/17	5	60	12/15	5	30
240	0.726	209	18/23	3	60	18/21	3	30
300	0.50	390	12/14	9	41	12/13	9	20.5
300	0.50	261	18/20	6	41	18/19	6	20.5
300	0.907	390	12/20	5	75	12/16	5	37.5
300	0.907	261	18/26	3	75	18/22	3	37.5
THREE BEDROOM HOUSE - 4 PEOPLE:								
360	0.50	468	12/14	11	41	12/13	11	20.5
360	0.50	313	18/20	8	41	18/19	8	20.5
360	0.833	468	12/19	7	69	12/15	7	34.5
360	0.833	313	18/25	5	69	18/21	5	34.5
450	0.50	585	12/14	14	41	12/13	14	20.5
450	0.50	392	18/20	9	41	18/19	9	20.5
450	1.04	585	12/23	7	86	12/17	7	43
450	1.04	392	18/30	5	86	18/24	5	43
FOUR BEDROOM HOUSE - 5 PEOPLE:								
480	0.50	624	12/14	15[4]	41	12/13	15[4]	20.5
480	0.50	418	18/20	10	41	18/19	10	20.5
480	0.888	624	12/20	9	73	12/16	9	36.5
480	0.888	418	18/26	6	73	18/22	6	36.5
600	0.50	780	12/14	19[4]	41	12/13	19[4]	20.5
600	0.50	522	18/20	13	41	18/19	13	20.5
600	1.11	780	12/24	9	92	12/18	9	46
600	1.11	522	18/30	6	92	18/24	6	46

1/ Dimensions are rounded to the nearest whole number based on unrounded calculations. Slightly different dimensions may be obtained for other methods of rounding.

2/ Hydraulic Slopes - Larger values for each hydraulic loading scenario provide the minimum cross-section area, which is equal to the cross-section area controlled by the organic load.

3/ Inlet/Outlet Substrate Depth - Cell bed(s) can be sloped from inlet to outlet, or the bed(s) can be made flat and use the deeper outlet depth.

4/ Not recommended for a buried distributor without splitting flow equally to a segmented distributor.

DIMENSIONS GUIDELINE - 2,000 TO 10,000 GPD SYSTEMS
BASED ON HYDRAULIC LOADING[1]

			One Cell System			Two Series Cells		
Hydraulic Loading gpd	Hydraulic Slope, %	Cell Area ft2	Substrate Depth[2] Inlet/Outlet,in	Width ft	Length ft	Substrate Depth[2] Inlet/Outlet,in	Width ft	Length ft
2,000	0.50	2,600	12/14	63	41	12/13	63	20.5
2,000	0.50	1,740	18/20	42	41	18/19	42	20.5
2,000	1.0	2,600	12/22	31	83	12/17	31	41.5
2,000	1.0	1,740	18/28	21	83	18/23	21	41.5
5,000	0.50	6,500	12/14	157	41	12/13	157	20.5
5,000	0.50	4,350	18/20	105	41	18/19	105	20.5
5,000	1.0	6,500	12/22	79	83	12/17	79	41.5
5,000	1.0	4,350	18/28	52	83	18/23	52	41.5
10,000	0.50	13,000	12/14	315[3]	41	12/13	315[3]	20.5
10,000	0.50	8,700	18/21	210[3]	41	18/19	210[3]	20.5
10,000	1.0	13,000	12/22	157	83	12/17	157	41.5
10,000	1.0	8,700	18/28	105	83	18/23	106	41.5

1/ DIMENSIONS BASED ON ORGANIC LOAD MUST ALSO BE CHECKED AND USED IF CONTROLLING. Dimensions are rounded to the nearest whole number based on unrounded calculations. Slightly different dimensions may be obtained for other methods of rounding. All inlet distributors should be above ground.

2/ Inlet/Outlet Substrate Depth - Cell bed(s) can be sloped from inlet to outlet, or the bed(s) can be made flat and use the deeper outlet depth.

3/ Not recommended without splitting equally between two parallel cells.

Relative Elevation Differences Between System Components for Constructed Wetlands (CW) Wastewater Treatment Systems*

	Relative Elevation Difference		
Components	Preferred	Acceptable	Comments
House drains to septic tank (ST) inlet	> 1% slope	1% slope	All pipes and the septic tank need at least 6" of topsoil cover; perferably 12". Mounding may be used if necessary.
ST outlet to top of CW gravel	12" or larger	6" (with filter or 2 ST's)	6" difference increases potential for flooding ST if clogging of CW inlet area occurs. This potential is considered to be low.
Top of CW gravel to natural ground surface on high side of slope	0"	up to 6" higher/lower	Having the top of the gravel level with the uphill slope assures that the cell is neither too high nor low for the terrain. Runoff is easily diverted. Cut and fill is generally balanced on moderate slopes while excess fill results on small slopes (which is generally not a problem). The acceptable range (6" higher or lower) provides flexibility to adjust cut and fill for actual site conditions so long as the preceding criterion concerning the elevation difference between the ST outlet and top of gravel is met. The cell should be oriented so that the cell length parallels the site's natural contour.
Bottom of gravel (1st CW cell) and top of gravel (2nd CW cell) between two CW cells in series (if applicable)	0" or larger	less than 0" (up to same elevation for top of gravel for both cells)	Partial flooding of the water level control structure for the first cell may occur under the "acceptable" criterion when water enters the second cell at a rate greater than its percolation rate.
Bottom of CW cell to bottom of 8" gravelless drain	12" or greater	3"	Any difference less than 8" will result in partial flooding of the CW water level control structure if the drain pipe fills with water. Although this condition should be avoided if practicable, it's primary effect would be to limit water level adjustments in the CW cell. The minimum acceptable difference of 3" will allow water to infiltrate into the soil and not flood the water level control structure until the flow rate exceeds the percolation capacity of the system at a head of about 1" above the drain holes in the gravelless drain pipe.

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* The suggested relative elevation differences assume that the various components are located close to one another. Friction losses may need to be considered (added to the suggested values) if components are separated by large distances. The grade for all piping between components should be at least 1%.

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