APPENDIX A

ALTERNATIVES FOR SECONDARY TREATMENT AT CENTRAL VEHICLE WASH FACILITIES

TABLE OF CONTENTS

ALTERNATIVES FOR SECONDARY TREATMENT AT CENTRAL VEHICLE WASH FACILITIES

List of Tables

List of Figures

ALTERNATIVES FOR SECONDARY TREATMENT AT CENTRAL VEHICLE WASH FACILITIES

1. INTRODUCTION

1.1 Background

Central Vehicle Wash Facilities (CVWFs) are designed and constructed to wash the exterior of tactical vehicles efficiently and in an environmentally safe manner. The current standard design for these facilities provides treatment and recycling of washwater for reuse at the wash points. To produce a washwater suitable for discharge to the environment, or for recycling and safe reuse by troops, secondary treatment is required. Treatment consists of primary removal of suspended and settleable solids, petroleum, oils and lubricants (POL) and some organics followed by secondary treatment as a polishing step to remove excess suspended solids, POL and organics. The standard treatment scheme at CVWFs is primary sedimentation (with floating POL removal) followed by secondary treatment consisting of equalization and intermittent sand filtration (Figure 1). Although this secondary treatment technology has been used successfully at several installations, many designers have expressed concern that guidance found in TM 5-814-9 is too restrictive. This resulted in investigations being done into alternative secondary treatment systems for consideration at CVWFs. The research revealed that intermittent sand filtration, lagoons, and constructed wetlands are acceptable means of secondary treatment. If designed properly, all three alternatives will function with little attention from the operator. Lagoons and wetlands require little maintenance, except that the top surface of sand filters may need period removal.

1.2 Secondary Treatment Washwater Quality

Table 1 gives a comparison between wastewater resulting from washing of Army ground vehicles and typical domestic wastewater. Regardless of which of the above three secondary treatment methods is chosen, the treated effluent should meet the water quality standards presented in Table 2. The system should produce a high quality water for recycle back to the wash facility, protect troop health, and meet discharge requirements.

1.3 Hydraulic Loading

Regardless of the secondary treatment system selected, determine hydraulic loading in cubic meters (gallons) per day based on the total sustained flow of bath monitors (if used) and wash station hoses for an average daily washing period (usually 8 hrs) and for 100 percent utilization of washing fixtures. For standard CVWFs, TM 5-814-9 recommends 5.0 l/s (80 gpm) for each bath monitor and 1.6 l/s (25 gpm) for each wash station hose.

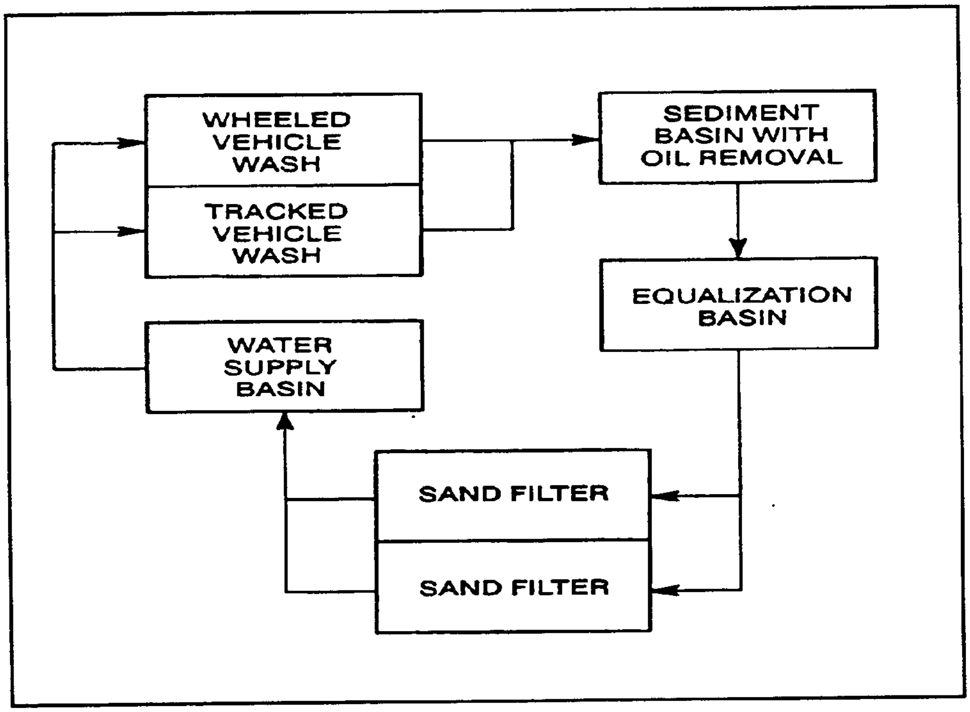


Figure 1. General Schematic of Standard CVWF Recycle System.

Parameter	Domestic Range	Washrack Range
Total suspended solids, ppm	83 - 258	30 -15700
Total oil and grease, ppm	50 - 150	25 - 3096
Biochemical oxygen demand, BOD_5, ppm	75 - 276	8 - 1078
Chemical oxygen demand, COD, ppm	195 - 436	105 - 1620
pH	6.8 - 7.5	7.0 - 8.1

Table 1. Vehicle washwater characteristics compared to domestic wastewater.

Table 2. Effluent quality criteria.

Parameter	Maximum Concentration
Total Suspended Solids (TSS), ppm	60
Total Oil and Grease, ppm	10*
Chemical Oxygen Demand (COD), ppm	100
pH	6.0-9.0
Fecal Coliform, colonies per 100 ml	100

*Effluent shall contain no visible sheen and shall be compatible with and not interfere with the installation domestic wastewater treatment process.

2. INTERMITTENT SAND FILTRATION

2.1 Background

The intermittent sand filter has been the standard secondary treatment unit process used at the majority of CVWFs constructed to date. The filter is an efficient treatment process. The waste washwater from the equalization basin is distributed over the surface of the filter bed by means of flooding, perforated distribution pipes, or distribution troughs. The wastewater solids are filtered or oxidized in passing through 60 to 76 cm (24 to 30 inches) of carefully selected sand. Greater sand depths do not produce significant additional purification. A film containing aerobic and nitrifying organisms may form on the gravel and sand particles of the filter. Suspended solids are removed through physical processes when making contact with sand and gravel grains. The process is also effective in reducing nitrogen compounds and algae populations through a combination of physical and biological processes without the addition of chemicals.

2.2 Description

The intermittent sand filter is an outdoor, gravity, filtration system used for polishing the waste washwater by further reducing, COD and suspended solids. The filter surface is flooded intermittently with water from the equalization basin at intervals which permit the surface to drain between applications. A typical plan and cross-section is shown in Figure 2. It is preferable to have a minimum of four filter cells where good operation and treatment can be accomplished over a 4-day cycle.

2.3 Construction

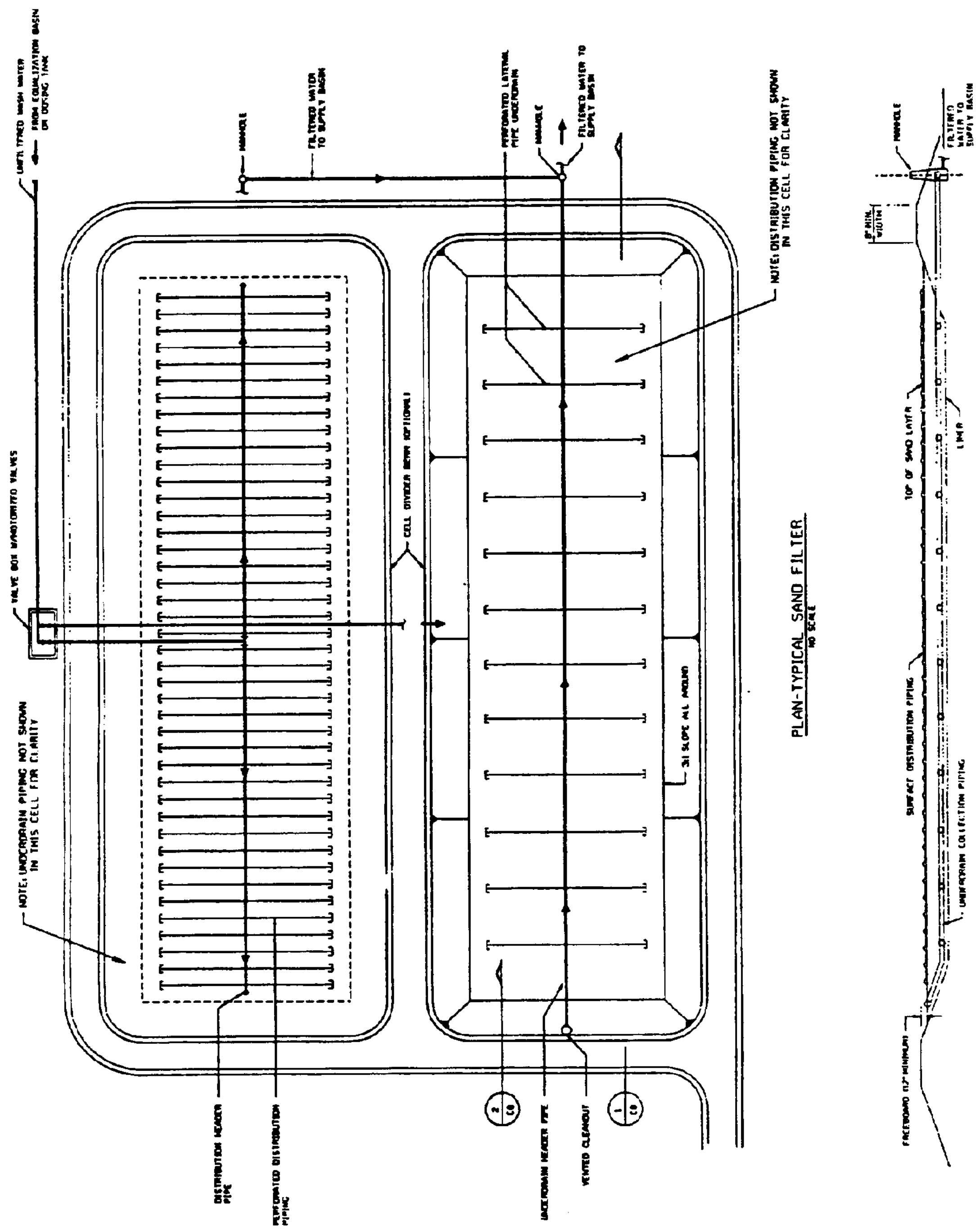


Figure 2. Plan and Section - Intermittent Sand Filter

The filter contains underdrains laid at a depth of three to four feet and surrounded with layers of coarse stone and gravel graded from coarse to fine to keep the overlaying sand out. Since this is a recycle system, the filter must be provided with an impermeable bottom or lining. Influent wastewater is pumped from the equalization basin to the bed through distribution pipes and distributed evenly over the surface.

2.4 Limitations

The two limitations associated with sand filters are the large land areas required and the strict specifications and availability of filter media required. Land area should not be a problem at the installations; however, availability of sands meeting the specifications, which may not be available locally, can drive up the cost significantly if imported from a distance.

2.5 Sand Filter Design

Design sand filters for the average daily flow of washwater generated at the pre-wash (vehicle bath), if used, and final wash stations over the average daily wash period. For a standard CVWF, TM5-814-9 provides flowrates for each bath monitor and for each wash station hose. The normal average wash period is 8 hours, but this can vary between facilities. The percent utilization of wash points needs to be considered for design purposes. Depending on the soiling conditions in the training areas, the application rate should be between 4,600-12,200 m^3/ha/day (490-1,300 kgal/acre/day), which is equivalent to flooding the filter to a depth of 15 to 41 cm (6 to 16 in). Recommended hydraulic loading rates to the filter based on soil type number (S~) (see TM 5-814-9) are given in Table 3 and reflect the range of lowest clay content (S_t=1) to highest clay content (S~=5) of soils in the training areas.

Table 3. Hydraulic loading rates f or intermittent sand filters.

Soil Type Number, S_t	Loading Rate, gpd/acre	Loading Rate, m^3/ha-day
1	1,3000,000	12,200
2	1,000,000	9,400
3	850,000	8,000
4	650,000	6,100
5	490,000	4,600

2.6 Filter Sand

It is important to use selected sands meeting the specifications given in Figure 3. The sand grains should be somewhat uniform in size rather than from fine to coarse to avoid premature clogging of the filter. These are generally described by their *effective size* (e.s.) and *uniformity coefficient (u).* The e.s. is the 10 percentile size, i.e. only 10 percent of the filter sand by weight, is smaller than that size. The uniformity coefficient is the ratio of the 60 percentile size to the 10 percentile size. The sand for single-stage filters should have an e.s. ranging from 0.20 to 0.40 mm and a U of less than 3.5, with less than 1 percent of the sand less than 0.2 mm. In the general case, clean pit-run concrete sand is suitable for use in intermittent sand filters provided the e.s., U and minimum sand size are available. Use local sands and gravels if available. The sand filter media must be carefully constructed and settled by flooding, and distributor and collector pipes laid at exact grade.

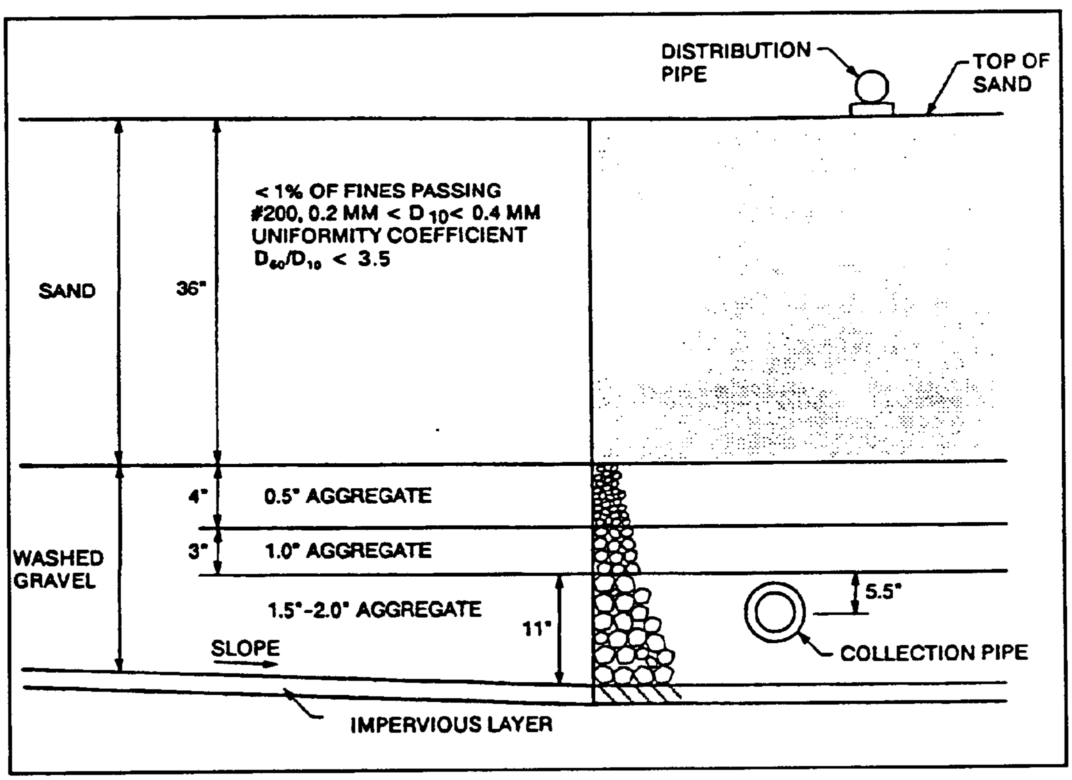


Figure 3. Intermittent Sand Filter Media Cross Section

2.7 Dosing Frequency and Techniques

Each filter cell should be designed to receive three doses per day, one every 8 hours, seven days per week. The dosing sequence using equal dosing per day per filter and delivered by an automatic dosing device or individual pumps for each cell is recommended.

2.8 Dosing Rate

The recommended dosing rate to each filter cell during each of the three dosing intervals should be 360 to 719 1pm (95 to 190 gpm) per 93 m^2 (1000 ft^2) of filter surface area applied for 20 to 40 minutes. Alternating doses between filter cells is accomplished by motor operated valves on electronic timers for pumped systems.

2.9 Typical Construction and Equipment

2.9.1 Construction

The basic construction of sand filters includes piping, graded sand and gravel, excavation and embankment. Excavation and embankment consists of exterior side slopes, impervious liner of clay or synthetic material, and 3 m (10 ft) wide access dike. The ends of filter cells are provided with concrete ramps for access for equipment to remove or replace sand. Each filter cell is separated from adjacent cell with a wooden baffle. There are no provisions for backwashing CVWF sand filters. Initial sand depth must be 0.90 m (36 in) to provide adequate contact surface for treatment. Sand characteristics are well graded with effective size between 0.2 to 0.4 mm.

2.9.2 Equipment

Wastewater is pumped from the equalization basin through a ductile iron pipe to the sand filter. Other piping consists of 15 cm (6 in) lateral underdrains with 3 m (10 ft) spacing and a surface distribution system consisting of UV protected perforated plastic pipes placed on the surface of the sand in a grid pattern. Drilled orifices in the pipes should be no less than 4 mm (0.16 in) to prevent clogging. The distribution system is laid out as a manifold to distribute water as evenly as possible over the filter cell. It is recommended that new designs include cleanouts on the upstream ends of lateral underdrains and collector main to correct any blockages which may occur.

2.10 Expected Filter Performance

Sand filters provide an exceptionally high quality water which can be recycled for reuse at the wash stations. Typical analyses of CVWF wastewaters applied to, and leaving intermittent sand filters and correspondent removal efficiencies are shown in Table 4. A large reduction in turbidity, BOD_5, COD, oils and grease and suspended solids is obtained. Since there is little, if any, bacteria in the filter effluent, no disinfection is necessary or required

Table 4 Typical intermittent sand filter treatment efficiency (from Yakima Firing Range, WA, test results).

Parameter	Influent Concentration	Effluent Concentration	Percent Reduction
Total Suspended Solids, TSS, ppm	122	7	94
Volatile Suspend Solids, VSS, ppm	19	1.9	90
BOD (5-day), ppm	13	5	61
pH	7.6	7.4	NA

* Pre-treated by sedimentation followed by equalization.

2.11 Operational Considerations

Operation of intermittent sand filters requires much more training of the operators than the operation of lagoons or wetlands. Intermittent sand filters operate with little operator attention when automatic dosing systems are fully functional. When automatic dosing systems are malfunctioning, however, responsibility for managing the dosing falls on the operator in the manual mode. This requires knowledge and understanding of the treatment system since improper dosing of the sand filters leads to premature plugging and costly maintenance. To eliminate some of these problems, it is recommended that each filter cell be designed with a separate automatic control for dosing. Although it may add to project costs, a backup dosing tank is also recommended.

2.12 Maintenance Considerations

As waste washwater passes through the filter bed, suspended solids and other organic matter are removed through a combination of physical straining and biological degradation processes. The particle matter collects in the top 5 to 8 cm (2 to 3 in) of the filter bed, and this accumulation eventually clogs the surface and prevents effective infiltration of additional effluent as well as ponding on the surface. When this occurs, the bed is taken out of service, the top layer of clogged sand is raked, tilled or removed, and the unit is put back in service. Removed sand can be washed and reused at a later time or can be discarded. Past experience has shown that sand filters used at CVWFs in training areas with high clay content require more maintenance than those in training areas with sandy soil. Also, it is possible that pondage due to slow drainage could encourage algae growth. A treatment program may be necessary to keep algal growth from plugging the surface. The designer must consider these maintenance aspects and include in the design, measures for access, cleaning equipment, and ease of removal of surface distribution piping. Experience at existing CVWFs is that all motor operated valves throughout the facility are potential maintenance or repair problems, particularly those that are opened and closed often. This has been the case with filter dosing valves. Top quality valves constructed of materials suitable for the product and environment should be specified.

3. LAGOONS

3.1 Description

Lagoons for use at CVWFs are the simplest of the treatment alternatives. They are essentially intermediate depth ponds with depths ranging from 1 to 2.5 m (3 to 8 ft). These lagoons operate as facultative lagoons with wastewater stratified into three zones consisting of an anaerobic bottom layer, an aerobic surface layer, and an intermediate zone. Stratification is the result of solids settling and temperature/water density variations. Oxygen in the upper zone is provided by natural reaeration and photosynthesis while anaerobic processes operate at the bottom layer. Lagoons are customarily operated in series for optimum performance. The usual case is for two or three lagoons to be linked in series. Because of this arrangement, the first lagoon may be used as an equalization basin and located after the sediment basin. A typical flow schematic of a CVWF with lagoon treatment is depicted in Figure 4 (next page).

3.2 Design Criteria

3.2.1 Configuration

Operate at least two to three cells in series. Parallel cells may be used in larger systems.

3.2.2 Sizing

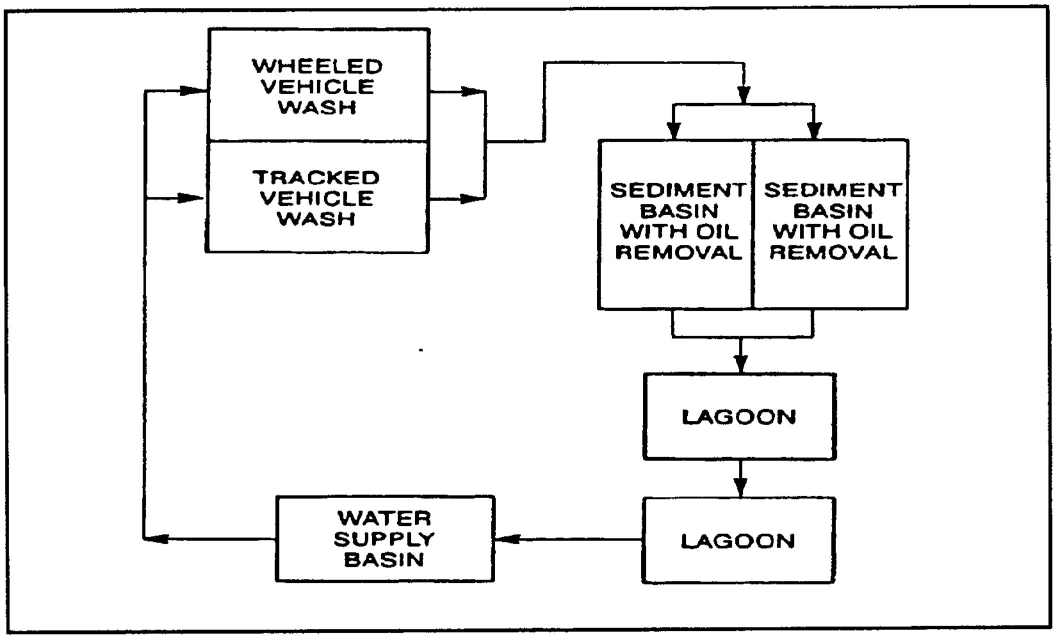


Figure 4. Typical Flow Diagram--Lagoons

Size lagoons according to detention time. The desired total detention time for the entire lagoon treatment is 14 days based on the peak hydraulic loading. Detention time and flow through the lagoon can be controlled through use of strategically placed floating baffles. Sediment accumulation and storage volume over a 20 year period must be estimated and included.

3.2.3 Depth

Lagoon effective water depth should be between 1 to 2.5 m (3 to 8 ft) deep. There is very little practical advantage to constructing lagoons deeper than 2.5 m. It is recommended that effective design depth be set at 2.5 m but allow shallow depths to accommodate topography since a 2.5 m depth would require less land area and less cost to construct than, say a 1 m (3 ft) depth for the same capacity. In sites where, by virtue of the topography, a deeper lagoon, or a lagoon which is deeper in parts may be cheaper to construct, a variable depth should not pose any problems in treatment efficiency. Primary lagoons shallower than 1 m should be avoided since they will be affected by solids deposition, and these as well as the following lagoons would possibly also be affected by vegetation growth, reduced volume and hydraulic capacity. Sediment volume can be computed by adding the expected annual sediment load from all tactical vehicles washed at the rate of 1.4 m^3/yr (50 ft^3/yr) per tracked and 0.4 m^3/yr (15 ft^3/yr) per wheeled and assuming a 20 percent carry-over from the sediment basin for a 20 year period.

3.3 Construction and Equipment

3.3.1 Topography and Siting

Lagoons are commonly contained within earthen dikes. Depending on soil characteristics, lining with various impervious materials such as rubber, plastic or clay may be necessary. The lagoon must be well protected from erosion and the entry of natural runoff. Adapt the lagoon to the surrounding topography where possible, as it is less costly to include existing depressions or valleys rather than to fill them in. Lagoon bottoms may be level or graded to suit topographical features in the best possible way.

3.3.2 Inlet and Outlet Control

The inlet to the primary lagoon may require special features to prevent accumulation of solids at one location. Discharge should be below the water level and near the bottom, but not so low that material will choke the inlet pipe. Outlets withdrawing water only from the surface are not recommended. Submerged or baffled outlets are preferable to reduce the effects of thermal stratification and prevent floating materials and scum from passing out with the effluent. The baffle should reach to about 0.3 to 0.46 m (1 to 1.5 ft) below the normal water surface.

3.3.3 Piping

When succeeding lagoons are at the same level, submerged oversized connecting pipes or overflow weirs should be used to reduce the velocity of the overflow water. The connecting piping should not be so large, however, that peak or surge discharges entering the first lagoon are not balanced out, or else a similar peak outflow from the first lagoon will follow within a very short time. An alternative to using the capacity of the lagoons to balance storage is, of course, to construct an additional storage lagoon or water supply basin for storing effluent from the final lagoon, and to withdraw from this storage at a constant rate.

3.3.4 Construction Features

Slopes of embankments should be dictated by standard engineering practice for small dams. Details at water edge should be designed for preventing growth of vegetation. Capital investment for weed and erosion control may well be repaid by savings in maintenance costs. Provide 3 m (10 ft) wide minimum berms around lagoons, access ramps to the bottom, means of draining, and fencing to keep out animals and unauthorized personnel.

3.3.5 Liners

Groundwater pollution from seepage must be regarded as a possibility for lagoons. Unconfined seepage losses can be high and vary over a wide range depending on the geology of the lagoon bottom and the materials used to construct the walls. If a lagoon is constructed in a high porosity soil (low clay content) or an unusual geological formation, then take steps to seal the bottom by importing and compacting a layer of naturally impervious soil, or otherwise with installing a synthetic liner system. For synthetic liners, assure that the liner will not be ruptured and where it is exposed at the water's edge it should be anchored and covered over to protect it against damage and the weakening effect of UV light. Unfortunately, sealing a lagoon approximately doubles its capital cost. Most states require that lined lagoons be provided with means of monitoring or detecting leakage through them.

3.4 Treatment Performance

Limited experience with the lagoon system at the Ft. Hood, TX, CVWF suggests that lagoons can provide an exceptional water for recycle (Table 5). Chemical Oxygen Demand (COD) reductions of 57 to 73 percent were reported. Effluent suspended solids concentrations of 0 to 19 ppm were achieved. It is not known how CVWF lagoon treatment will respond to occasional input of petroleum products or cleaning compounds as have occurred at these type facilities. As a safeguard, troops must be instructed to cease such practices and a policy enforced to prevent dumping or using these products at CVWFs in order to prevent lagoon treatment upsets.

3.5 Limitations

Lagoons require more land area than do intermittent sand filters. Because of evaporative losses, more makeup water or replacement water will be required with lagoon treatment than with sand filters or constructed wetlands. Also, it is possible that as solids accumulate in the bottom of lagoons, that they may

Table 5. Lagoon water quality data, Fort Hood, TX--lst Cavalry Division.

Parameter	Cell 1		Cell 2
	Influent (Average)	Effluent (Average)	Effluent
Suspended Solids, mg/L	83	12	6
COD, mg/l	30	20	19
Grease and Oil, mg/l	0.2	0	0
pH	6.8	6.7	6.6

become re-suspended by wave action, normal turnover or by aquatic life thereby affecting the quality of the recycled washwater. Washwater quality may also be affected by degradation of feces from aquatic birds and mammals. Lagoons are also subject to algae blooms.

3.6 Reliability, Operability and Maintainability

The service life of a lagoon is estimated to be 15 to 20 yrs. Little operator expertise or knowledge is required to operate a lagoon treatment system. Inlet and outlet structures must be checked periodically for blockages. To check for leakage through a lagoon liner, the total volume of water in the recycle system should be monitored for losses. Unless severe leaks appear, it is unlikely that any significant maintenance or repair actions will be required. Sediment storage within the lagoon must be provided throughout the design life of the lagoon. This is calculated by multiplying the anticipated flow by the anticipated sediment removal efficiency.

4. CONSTRUCTED WETLAND TREATMENT

4.1 Introduction

The capability of wetlands for purification of wastewater is well known, proven, and has been practiced extensively worldwide. Constructed wetland treatment systems (CWTS) are now recommended for use because they are low in cost, low-tech, and can be applied to remote siting situations. This section discusses general design, construction and operational guidelines for design of CWTS at CVWF installations. These guidelines can assist the engineer in designing a CWTS, however, each system is site specific, and all designs should be prepared and reviewed by experts on a site-by-site basis. Designs should be coordinated with installation and State regulatory officials. Since the CWTS is a relatively new technology for CVWFs, these guidelines may undergo future revision as better information is developed and analyzed.

4.2 Applicability

Constructed wetlands are specifically designed for wastewater treatment and are suitable for locations where natural wetlands never existed at the time of construction. Unlike natural wetlands, constructed wetlands are considered to be a unit treatment process and not a "receiving water", and are therefore not subject to applicable laws and regulations for discharge into waters of the U.S. (40 CFR Part 122.2). These two reasons make CWTS directly appropriate for use at CVWFs. Figure 5 shows a typical flow schematic of a CVWF with constructed wetland treatment.

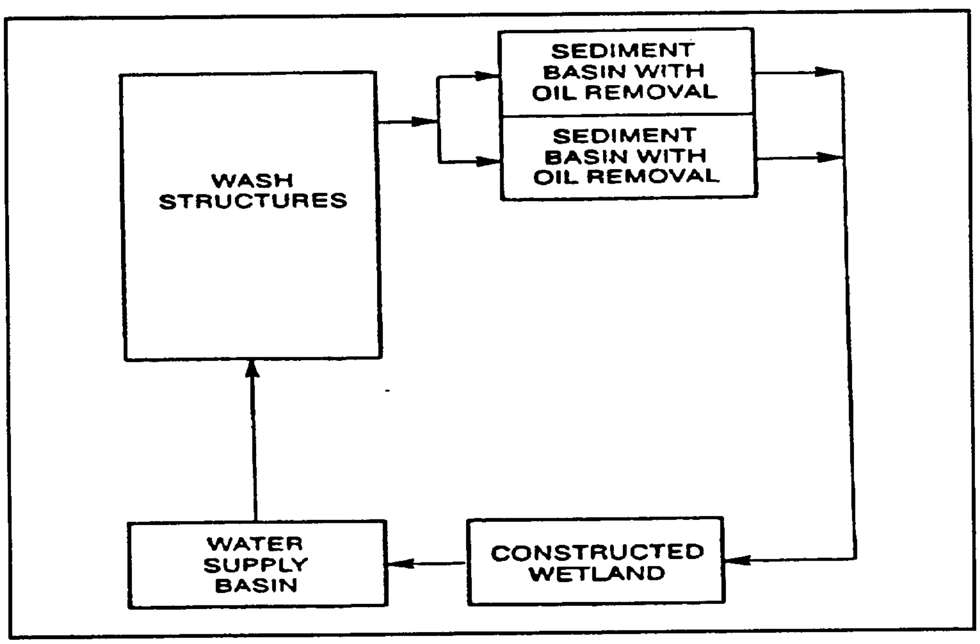


Figure 5. Typical Flow Diagram--Constructed Wetland

4.3 Process Description

Constructed wetlands treat effluent through physical, chemical and biological processes in the same manner as natural wetlands. Proper design, construction and operation of a CWTS optimizes the natural process. The waste washwater either flows over the surface of the wetland bed and is filtered through aquatic plant stems, or through the stratum in which the plants are rooted. Plants are the principal biological means of cleansing wastewaters, but actual removals occur through a combination of physical, chemical and biological exchanges between the plant life, the substrata and the biology which is created. Plants provide a surface for bacterial growth, a filter media for removal of solids, and a means for oxygen transfer to the root system. The root zone provides the aerobic environment for decomposition of organic matter.

4.4 Wetland Type

There are two types of CWTS each characterized by the flow path of water in the system. The first type, called the surface flow (SF) wetland and depicted in Figure 6a (next page), contains emergent aquatic vegetation in a relatively shallow bed or channel. The surface of the water is exposed to the atmosphere as it flows through the bed. The second type (Figure 6b) is called a subsurface flow (SSF) wetland, and contains a foot or more of permeable media, i.e., rock, gravel, sand or soil. The media supports the root system of emergent vegetation, but in this case, the water level in the bed is always maintained below the top of the media so that all flow is below the surface. Surface flow cells are more adaptable and cost effective for handling high levels of suspended pollutants. The SF wetland offers hydraulic resistance to flow through the vegetation, resulting in decreased velocities and increased deposition of suspended solids, the major constituent of concern. For this reason, and to prevent clogging of the inlet zone of the wetland, as well as maintaining low residence times for recycling, the SF wetland is the recommended type for use at CVWFs.

4.5 Performance Expectations

Wetlands reduce many pollutants including Biochemical oxygen Demand (BOD_5), suspended solids (TSS), phosphorus, trace metals and trace organics. This is accomplished by diverse treatment mechanisms, namely sedimentation, filtration, precipitation and absorption, microbial interaction and uptake by vegetation. Table 6 shows a summary of some of these water quality parameters from studies conducted at the Ft. Riley, KS, CVWF constructed wetland.

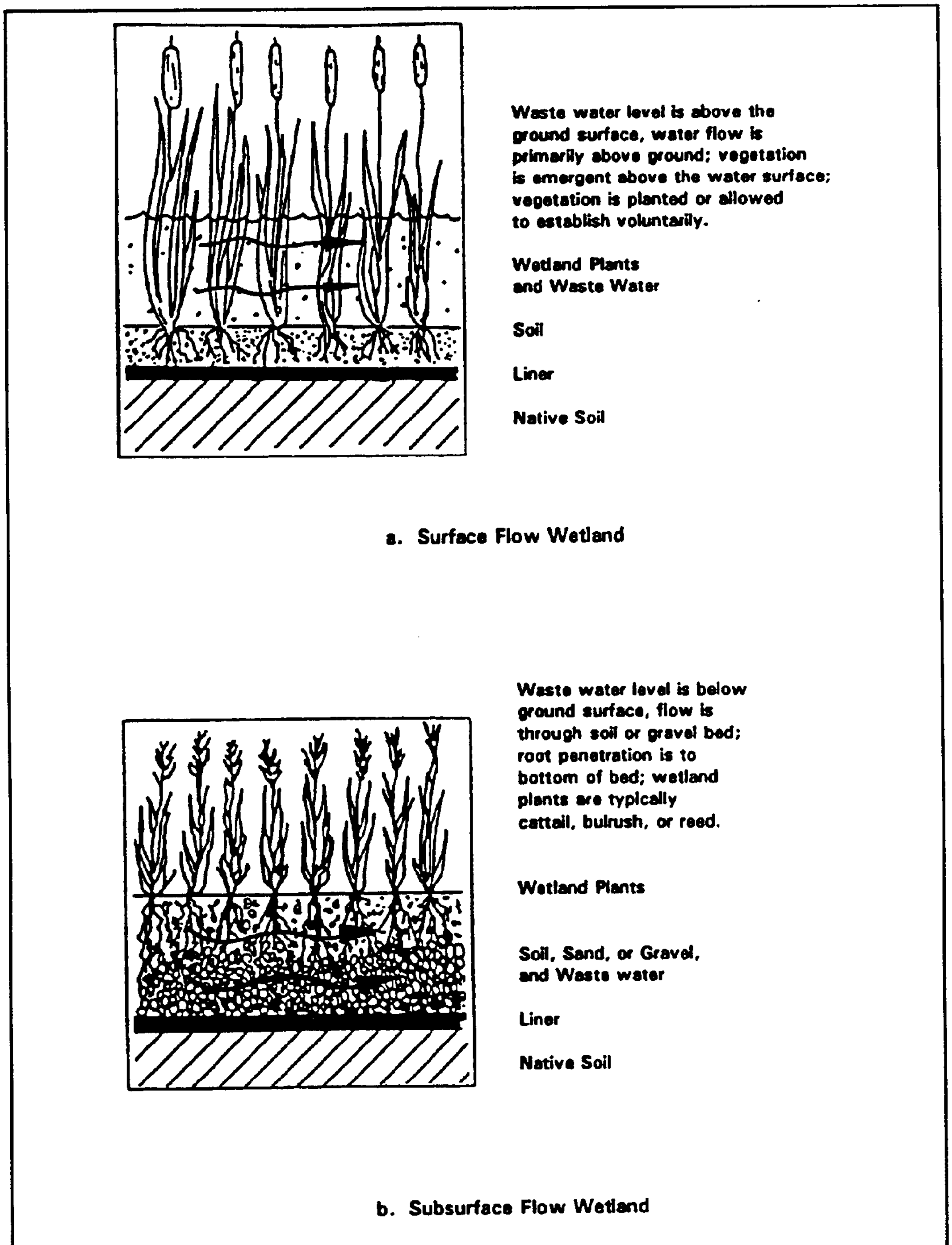


Figure 6. Types of Constructed Wetland Treatment Systems.

Table 6. Constructed wetland treatment water quality data for CVWF at Fort Riley, KS.

Parameter	Influent		Effluent	
	Range	Avg	Range	Avg
Suspended solids, ppm	46 - 1124	259	0 - 75	12
Volatile suspended solids, ppm	6 - 159	37	0 - 73	7
COD, ppm	12 - 130	41	9 - 50	25
BOD_5, ppm	10 - 39	22	8 - 23	13
Oil & Grease, ppm	0 - 23	2	0 - 1	0.09
pH	7.8 - 8.6	8.1	7.3 - 7.9	7.6

4.5.1 BOD_5 Removal

Moderate to high removal efficiencies can be expected for retention times of even less than one day. Since typical retention times are 2 days or more, removal efficiencies can exceed 80 percent for the primary treated CVWF waste washwater when wetland influent concentration is high.

4.5.2 Suspended Solids Removal

The potential for wetlands to assimilate TSS is very similar to BOD_5 removal potential. Removal rate and efficiency are consistently high. Removal of residual inorganic TSS carried over to the wetland from the sediment basin and/or equalization basin occurs rapidly in the inlet zone of the wetland due to filtration and sedimentation. Pretreatment assures high removal efficiencies since the wetland is protected from high inorganic TSS solids blankets which would otherwise build up rapidly causing short circuiting. Remaining solids can be stored for long periods without impacting the operation. The wetland can store biomass produced within the system and can also polish colloidal or fine solids not removed in the primary treatment process. Wetlands for CVWFs should be expected to consistently produce a polished discharge to the washwater supply basin of less than 30 ppm and often less than 20 ppm of suspended solids.

4.6 Wetland Design Considerations

4.6.1 Siting

The primary consideration for siting the CVWF is that it be located near the permanent cantonment area and between the training areas and maintenance shops/motor pools. If constructed wetland treatment is to be used, then secondary considerations such as soil type and topography which affects grading and excavation costs, may influence the actual choice of the site. For example, natural clay soils might provide an impermeable bottom for the constructed wetland or sufficient topsoil (6 to 12 inch layer) may be available to enhance growth of vegetation. The amount of area required for the constructed wetland will vary depending on the loading rate, wastewater volume and quality, and treatment efficiency desired. Location and configuration should take advantage of gravity flow and natural topography to minimize excavation, grading, and pumping costs. The wetland should be located in an upland area where slopes are not excessive (less than 2 to 5 per cent). Construction will be easier with soils of naturally low permeability. Previously drained or altered natural wetland areas, if close to the washrack site may be ideal. Soils must have sufficient stability to support dikes and water control structures.

4.6.2 Pre-Application Treatment

The wash facility will generate waste washwater with high inorganic suspended solids concentration (100-20,000 ppm) as well as oils and greases which may otherwise clog the wetland and render it ineffective in a short time. In order to prevent this, a sediment basin with oil removal, designed in accordance with TM 5-814-9, must be located upstream of the wetland as is done with sand filter and lagoon treatment. Trap efficiencies for this sediment basins have frequently been as high as 85-92 percent depending on the soil types carried in. If this level of efficiency cannot be demonstrated through bench tests, then a flow equalization basin must be added between the sediment basin and the CWTS to attenuate flows and further remove solids carry-over to the above levels. Besides heavy sediment loads, pre-treatment removes other pollutants such as hydrocarbons that can damage the wetland. Pre-treatment also helps attenuate flow volumes and peak rates to maintain the CWTS detention time and prevent or reduce scour and erosion. During construction, erosion and sediment control measures are required to prevent premature sedimentation of the wetland.

4.6.3 Removal Kinetics

Performance of constructed wetlands is based on plug flow kinetics. The basic relationship is $[C_eC_o] = \exp(-K_Jt)$ where C_e = effluent concentration (ppm), C_o = influent concentration (ppm), K_J = temperature-dependent reaction rate constant ($days^{-1}$), and t = hydraulic residence time. A design equation specifically for TSS removal is not generally available. However, it has been noted that the removal kinetics expressed above are similar for organic (BOD_5) and inorganic constituents (TSS) in constructed wetlands. Removal of TSS occurs due to the quiescent conditions, the shallow depth, and the surface resistance by the vegetation in the system. Flocculation and settling account for the high removal of suspended solids.

4.6.4 Sizing

The equation above implies that as hydraulic residence time, ti increases, effluent concentrations of bio-degradable contaminants decrease. Consequently, hydraulic residence time becomes the principal design and operational parameter for optimizing the performance of the wetland. The hydraulic residence time (t) for an unrestricted plug flow system is expressed by

$$t = A_w D n / Q$$

where A_w = area of wetland
= (L)ength x (W)idth
D = water depth
n = porosity, and
Q = average flow rate
= $(flow_{in} + flow_{out})/2$

In an SF wetland, some of the volume is occupied by the vegetation so that the actual detention time is a function of the porosity *(n),* defined as the remaining cross-sectional area available for flow. Porosity is expressed as $n = V_V/V$, where V_V is the volume of voids and V is the total volume. The product of *n* and D is, for all practical purposes, the "equivalent depth" of flow in the system. With known values of Q and estimated values of t and D, a conservative value for L x W can be calculated. Preliminary data from TVA systems indicate the volumes of several common plants are: cattails (Typha)--10 percent, bulrush (Scirpus validus)--14 percent, reeds (Phragmites)--2 percent, wool grass (S. cyperinus)--6 percent, and rushes (Juncus)--5 percent. Corresponding porosity values would range between 86 and 98 percent. For most wetland designs with cattails, a porosity, n, of 0.90 would be representative.

4.6.5 Hydraulic Residence Time (t)

The longer the wastewater is detained in the CWTS, the better the treatment and performance. The flow velocity, and therefore, the hydraulic residence time (HRT) through the wetland is a function of flow, slope, water depth, vegetation, areal extent, and geometric shape (aspect ratio). HRT's of 2 to 7 days should be adequate to allow optimal time for biological assimilation of nutrients and filtering of suspended solids in the wastewater. Figure 7 shows removal data from a SF wetland in Arcata, CA. There appears to be no appreciable additional removal of suspended solids for total detention time beyond 2 days, therefore, the recommended HRT to use in sizing computations is 2 days. Detention times approaching 7 days for suspended solids are ultra-conservative and would increase the area requirements and cost for the wetland. For unusual cases of treating primary effluent at CVWFs, BOD_5 removal should be designed for at least 5 days detention.

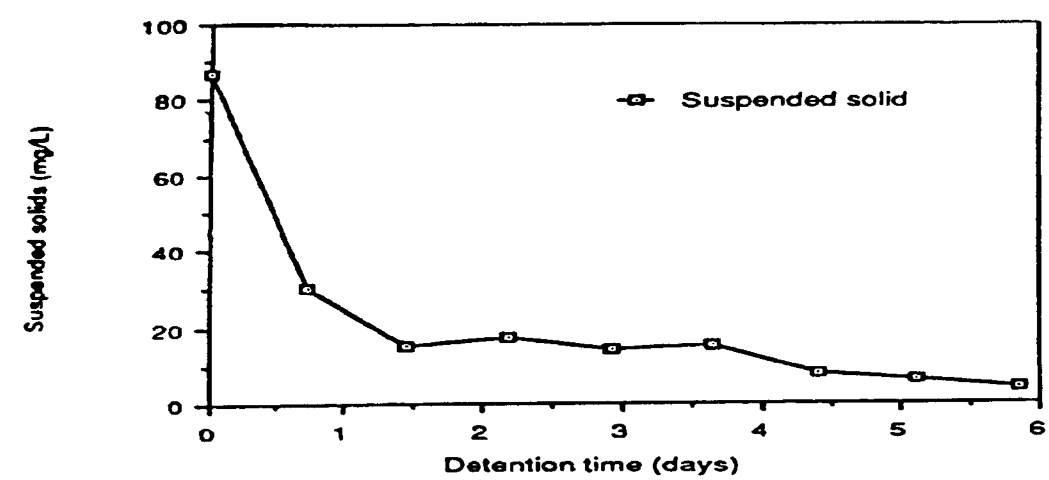


Figure 7. Suspended Solids Removal in a Wetland Cell.

4.6.6 Length and Width

The aspect ratio (length/width) of SF wetlands has been found to be an important factor in improving removal efficiencies for BOD_5 and TSS in wastewater. Dimensions should be established to maximize wastewater contact with the entire surface area of the wetland. In addition, the aspect ratio is an important design factor to ensure plug flow conditions and minimize short circuiting. The optimal wetland configuration is long and narrow with an aspect ratio approaching 10. For SF systems, an aspect ratio of 10 is expected to achieve consistent internal flow distribution and reduce short-circuiting that is likely to occur in shorter rectangular SF cells.

4.6.7 Water Depth

Water depth in an SF system and the time duration of flooding are factors in selection and maintenance of the wetland vegetation. Cattails are adept in submerged soils where standing water depth is up to and over 150 mm (6 in) . Water depths in excess of 30 to 46 cm (12 to 18 in) are inappropriate for cattails. Reeds will grow in water up to 1.5 m (5 ft) deep. Bulrushes can tolerate long periods of soil submergence and can tolerate water depths of 7.5-250 mm (0.3-10 in). Water levels should be kept very shallow in surface flow systems until plants begin rapid growth and spreading. Depths should not exceed the plant stems. Operating depths are typically shallow 15 to 30 cm (6 to 12 in) to increase potential aerobic conditions.

4.6.8 System Configuration

The configuration of a CWTS system influences the removal efficiency for TSS. A good configuration retains wastewater for a minimum of 2 to a maximum of 7 days. The bottom should be evenly graded to prevent short-circuiting and bermed to maintain the distribution of the flow within the wetland. Alternative configurations including single cell, parallel cells, serial cells, serpentine, or combinations of these, can be seen in Figure 8 (next page).

(a) Single Cell. A single cell (Figure 8a) is the simplest design and the least expensive to construct, but operational flexibility is limited, particularly if it needs maintenance during the washing season. A single cell is recommended only for small wash facilities with flows less than 190,000 lpd (50,000 gpd).

(b) Cells in Parallel. At least two parallel cells are recommended for a CWTS to increase operational and maintenance flexibility (Figure 8b). Flow is distributed equally or proportionally between the cells based on loading rates or other reasons. One cell may be drained for maintenance while the other continues operating though treatment effectiveness may decrease. Periodically draining SF cells on a rotating basis enhances mosquito control. Internal divider dikes and flow distribution boxes will increase construction costs. The flow splitter structure and flow distribution system must be flexible and

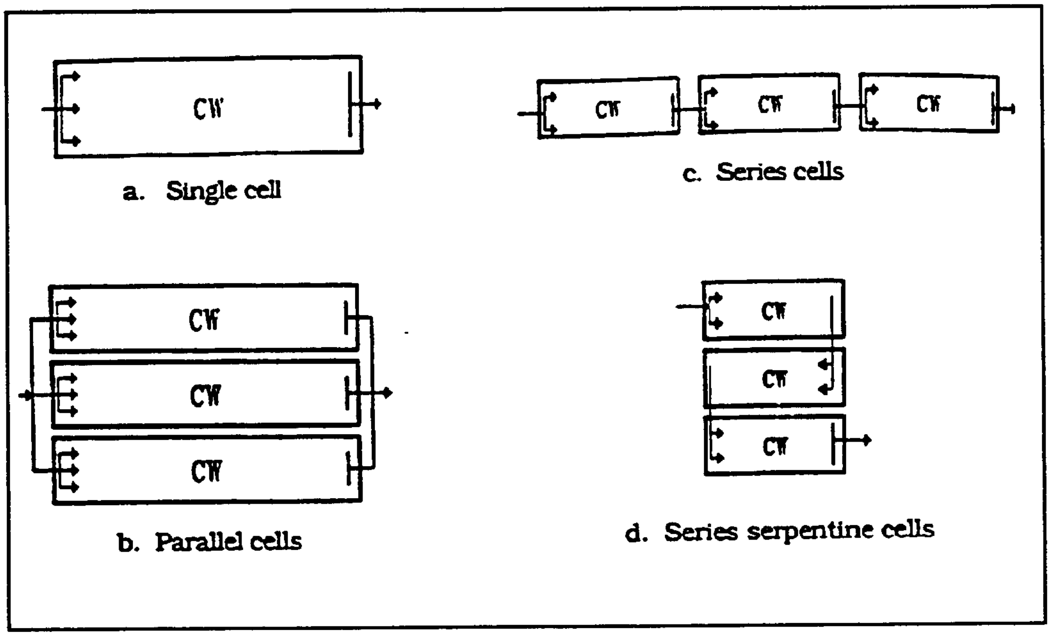


Figure 8. Alternative Configurations for Constructed Wetlands.

accurately constructed to provide even distribution and alternation to the cells at all heads.

(c) Cells in Series. Cells arranged in series can be longitudinal or serpentine (Figure 8d) depending on siting conditions. Both arrangements present the same limited operational and maintenance flexibility as single cell systems unless piping and valves are provided so that individual cells can be by-passed. In a serial cell configuration, most of the suspended solids would be retained in the first cell. By-passing to the second cell would eliminate this problem but the effluent would have to be pumped back to the first cell. This option may not be a good choice for CVWFs.

4.6.9 Slope

To minimize short circuiting, a lateral slope (across the width) of zero and a uniform longitudinal slope (from inlet to outlet) of from 0 to a maximum of up to 1 per cent, as limited by construction tolerances, is recommended for a SF system. Slopes of 0.1 or 0.2 per cent would be better for most sites. Surface flow systems are constructed with a bottom slope in the direction of flow from inlet to outlet end. This allows the effluent to flow horizontally through the established wetland plants to the outlet. In these systems, the water surface is higher than the top of the substrate. Some slope is needed to drain the cell for maintenance and possible vector control.

4.7 Considerations in Wetland Construction

4.7.1 Substrate

Substrates for SF wetland vegetation can be natural soils (clay or topsoil) or soil mixtures. Substrate depth and vegetation type should be compatible. The desirable vegetation should grow densely, spread rapidly and have an extensive vertical/horizontal root system. For SF systems, local soil is used with underlying impermeable soil or liner to protect groundwater.

4.7.2 Vegetation.

(a) Species. The common emergent vegetation includes bulrush (Scirpus validus), reed (Phragmites australis), cattail (Typha latifolia and T. anaustifolia) or soft-stem bulrush (Scirpus validus). These species thrive in many environmental conditions and climates and are easy to propagate. They also are hardy and grow quickly. Other preferred species to consider include: Typhaceae (cattail family), Cyperacea (sedge family), Graminear (grass family) and Junacaea (rush family). Use plant species that grow naturally within the region and select species which have extensive vertical and lateral root growth. Vegetation provides the appropriate surfaces for microbial growth on roots, rhizomes, leaves and stems, filters solids, and transfers oxygen to provide an aerobic/oxidizing environment for decomposition of organic materials. Emergent vegetation can be transplanted locally but this will be time consuming, difficult and costly to accomplish. Maximum bed depths for bulrush, reed and cattail should be 0.76 m (2.5 ft), 0.6 m (2 ft), and 0.3 m (1 ft), respectively.

(b) Sources. Emergent vegetation can be transplanted locally but this will be time consuming, and costly to accomplish. Vegetation can be purchased from reputable plant nurseries who provide stock exclusively for these purposes. A partial list of plant materials suppliers is provided in paragraph 8. Additional sources are listed in reference 5 which is available from USA-WES or NTIS. Only a few commercial nurseries specialize in wetland plants for wetland construction. There are almost none in the central and western U.S. Other sources include state nurseries, commercial nurseries, and seed companies. Regional lists of dealers in plants for conservation planting are available from the Soil Conservation Service, and these lists are invaluable for obtaining wetland adapted species. vegetation should be obtained from regional sources to minimize losses.

(c) Planting. Planting vegetation in the northern U.S. should occur during late spring (May 1-June 30) to early fall (August 15-September 15) to obtain as much growth as possible prior to winter in cold regions, thereby, reducing winter mortality. Prepare the planting area by spreading heavy topsoil to a depth of at least 10 cm (4 in). Plant the vegetation in no less than a 1 m (2 to 3 ft) grid pattern. This spacing should produce a uniform cover in one to two growing seasons. Cattails planted at approximately one meter intervals will produce a dense stand within 3 months. Use plants which, when pruned, have a 6- to 12-in stalk above the roots. Specify planting so that the root portion is in the water and the stalk above. The water level should be adjusted to 2.5 to 5 cm (1 to 2 in) above the top of substrate for SF systems during plant establishment.

4.7.3 Liner

Constructed wetlands typically include some type of barrier to prevent infiltration of groundwater into the cell and seepage and potential groundwater contamination beneath the bed. These range from compacted earth (clay) to membrane liners. If groundwater contamination or water conservation is a concern, an impermeable liner below the substrate layer is required. Possible materials are compacted in-situ soil (permeability less than 10-6 cm/sec), bentonite, asphalt, and ethylene propylene diene monomer (EPDM), synthetic butyl rubber, polyvinyl chloride or polyethylene membranes. The liner must be strong, thick and smooth to prevent root penetration and attachment. Polyethylene liners should be between 0.5 mm to 1.0 mm thick.

4.7.4 Distribution

Cell flow inlet design must minimize short-circuiting and stagnation. For influent distribution use header pipes or troughs to provide uniform wastewater distribution across the width. The distribution piping or trough spreads the flow evenly over the width of the cell to create “sheetflow” conditions. Distribution pipes are provided with swivel tees with elastomeric joints approximately 8 ft (2.5 m) apart and placed on top of a rock bed containing 2 to 4 in (5 to 10 cm) dimension stone. In this case, the stone serves as a pipe support, but it also serves as a means to convert a point discharge into sheet flow, thereby minimizing erosion and maximizing treatment efficiency. The swivel tees allow adjustment of the discharge elevation for more uniform distribution. The pipe should be anchored using concrete pads and straps. Uniformly spaced holes, slots, tees, and serations are other possibilities for pipe distribution systems. Typical inlet distribution design for a surface flow wetland is shown below in Figure 9.

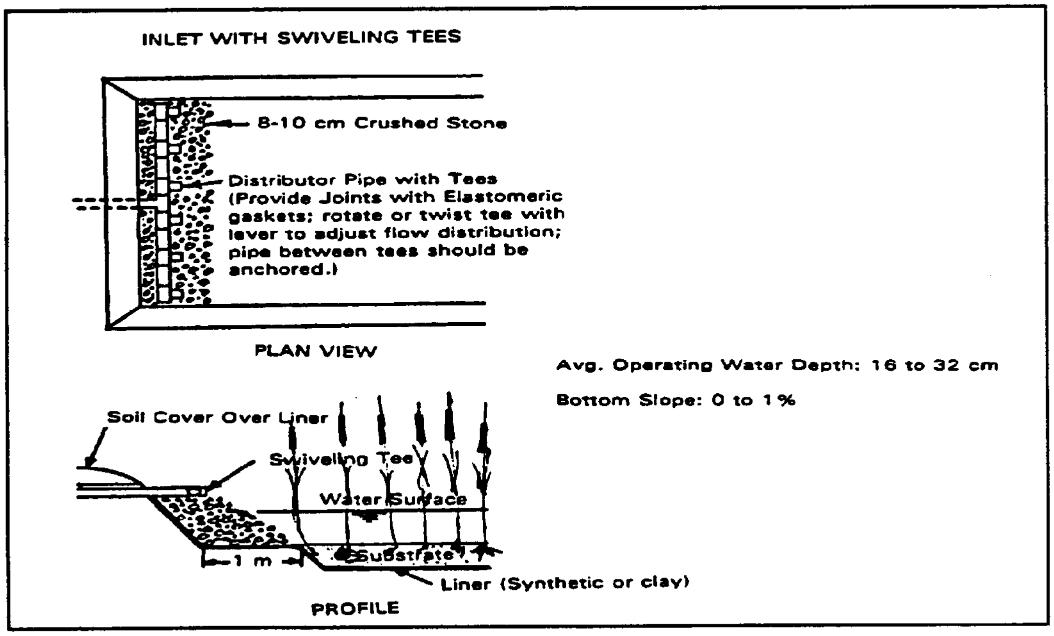


Figure 9. Typical Inlet Control Structure.

4.7.5 Effluent Collection and Water Level Control

The outlet for a SF wetland typically consists of perforated collection pipes buried in coarse gravel across the end of the cell and discharging into an outlet control structure. See Figure 10 on the next page. Water level control and adjustment is critical to the establishment and survival of the CWTS vegetation. One effluent control structure incorporating water level control piping at the end of each cell using either the swivelling standpipe, or a collapsible tubing option is shown in Figure 10. Another method is to provide an adequate length of weir crest per cell using removable stop logs for water surface adjustment. The design of the water level/effluent control structure should allow manipulation of the water level from

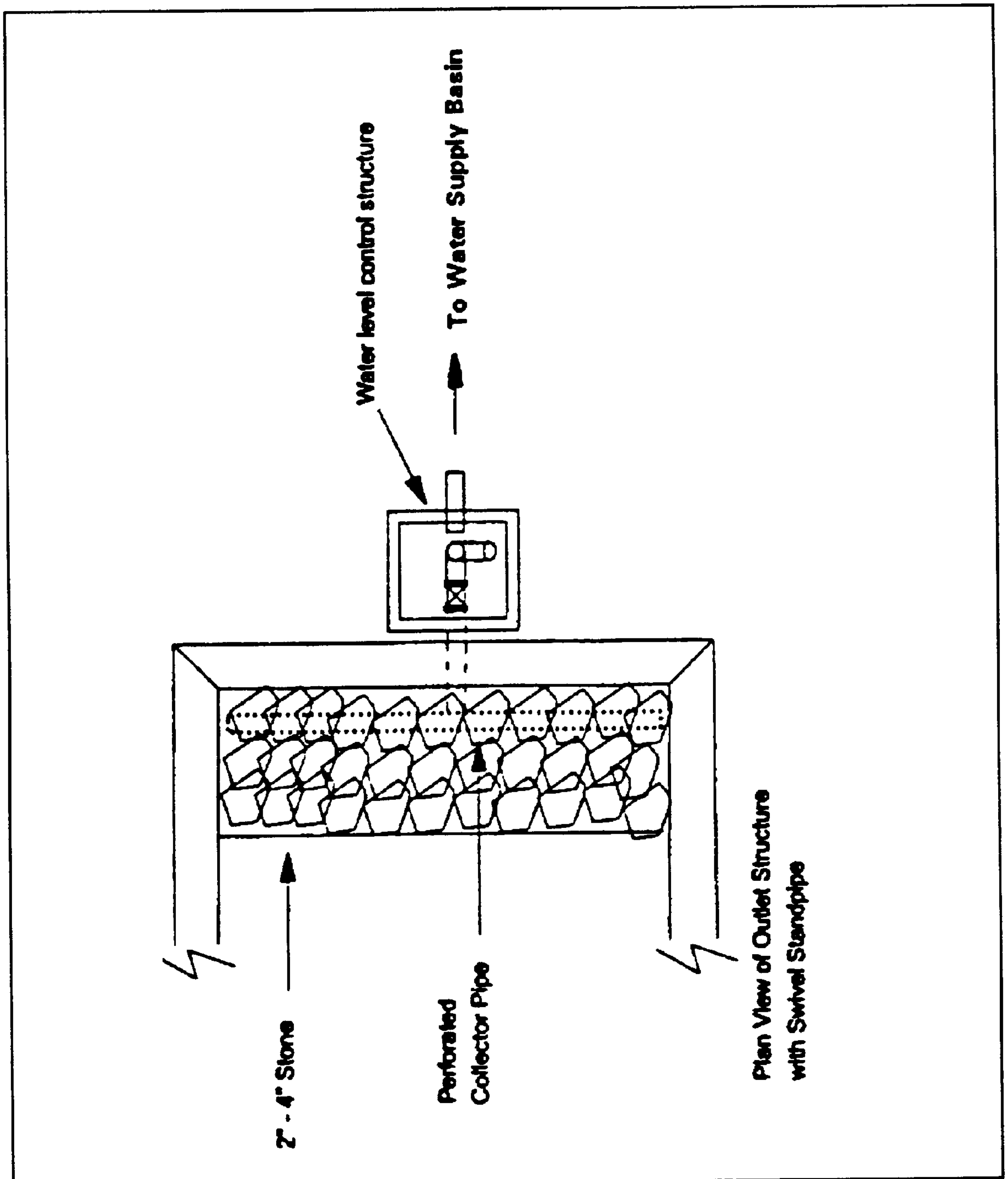


Figure 10a. Typical Plan--Water Level Control Structure.

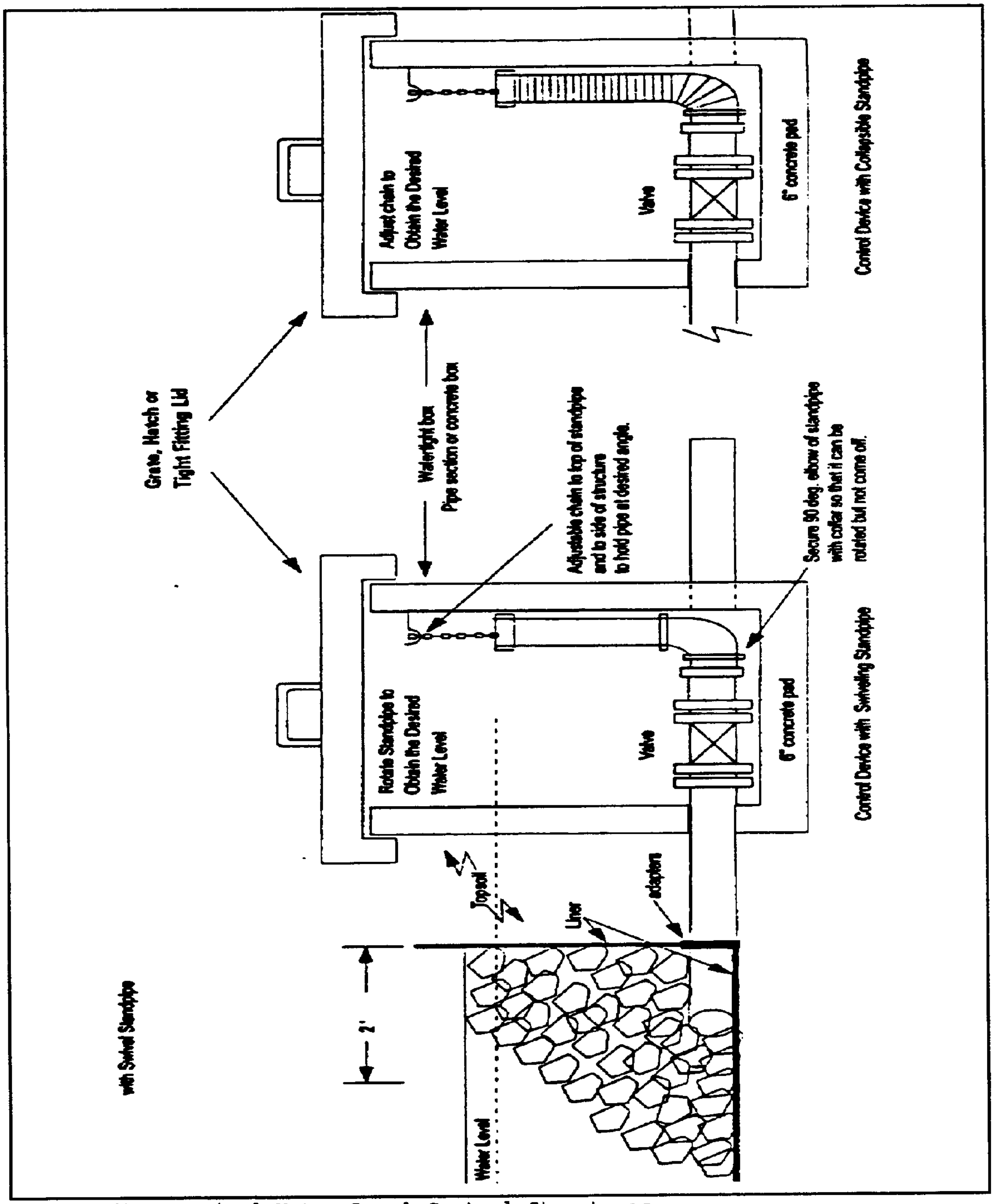


Figure 10b. Typical Water Level Control Structures.

draining the beds to allowing the water to rise to the maximum allowable. The design water surface for the wetland should be variable between 0 and 60 cm (0-24 in). A flow measuring device may also be added to the outlet structure. Flow from the outlet structure is discharged by gravity to the wash water supply basin.

4.7.6 Berms

The CWTS cells should be surrounded with earthen berms or a retaining wall similar to those used in conventional sludge drying beds. The berms confine the wastewater in the treatment system and also prevent potentially contaminated surface runoff from entering the system. The top of the berm or retaining wall should be at least 30 cm (1 ft) above the maximum water level and a minimum of 15 cm (6 in) above the existing ground surface. A depth of from 15 to 30 cm (6 to 12 inches) should be allowed for sediment storage and vegetation debris at the bottom of the wetland. Earthen berms are constructed with compacted clay to prevent seepage and have exterior slopes of 3H:lV. Interior slopes may be 2H:1V or steeper and should be based on characteristics of the existing soil and turf management equipment to be used. If maintenance vehicles are to be used, then the top of the berm should be 3 m (10 ft) wide.

4.7.7 Retaining Walls

Retaining walls are used instead of earthen berms to conserve space or for terraced designs. These can be constructed with concrete blocks, untreated cross ties, landscape timbers or other materials that are strong, durable, and weatherproof. Naturally rot resistant woods such as redwood, cypress, or cedar can be used. Chemically treated wood which could leach harmful chemicals into the CWTS may be used if covered with the liner or otherwise not allowed to make contact with the water being treated. Line, seal or otherwise construct retaining walls to prevent seepage.

4.7.8 Construction Sequence

The sequence of wetland construction is survey control; site preparation; rough grading; installation of structures and pipes in berm; fine grading; installation of liner, baffles (if needed), gravel, and interior pipes; filling the wetland; and planting the vegetation. Site and basin preparation is similar to that of a lined pond. Baffle and media preparation should follow pond liner installation as quickly as possible to minimize the potential for liner damage.

4.7.9 Other

The areas around the CWTS should be sloped or trenched to divert surface water away from the system. Enclose the entire CWTS with a suitable fence, if required, to provide safety, discourage trespassing by humans and animals, and prevent possible sanitary problems.

4.8 Operation and Maintenance.

4.8.1 General.

(a) Constructed wetland treatment systems require minimal operation and maintenance. However, some care is required to maintain an effective and attractive system.

(b) The operator will need to routinely check the effluent structure to ensure that debris is not blocking the flow.

(c) The ability of the wetland system to provide the anticipated levels of treatment will be dependent upon operator ability to control and manage system flows. The operator must prevent adverse effects due to peak washrack usage and extreme bath flushing by (I) storing waste washwater in an equalization basin just ahead of wetland cells, and (ii) gradually drawing the water down.

(d) Another beneficial operational design feature is the ability to isolate individual cells from incoming flows. This allows for draining individual cells, and for oxidizing and compacting the sediment. System operators can then reflood a cell and allow it to stabilize before bringing it back on-line.

(e) Management issues include loading rates, harvesting of vegetation and pest control. Ideal loading rates will vary depending upon the training mission season and weather conditions. In the summer, high evapo-transpiration rates may increase the detention time of the washwater, which could result in a stagnation of the wastewater and unsuitable conditions for aquatic life. Make-up water may have to be added at such times. Heavy rainfall may help dilute the washwater, but it also could decrease the detention time. In such a case, flow would have to be stored upstream in the sediment basin and slowly released to the wetland.

(f) In cold regions during winter months, ice may decrease the volume of the wetland. In this case, water depths may have to be raised before ice forms to increase the volume of the wetland.

(g) At some later point in time it may be necessary to remove areas of decayed or dense vegetation. Thus far there has been no apparent need to remove live or dead vegetation from the wetland at the Ft. Riley, KS, CVWF. Though removal of vegetation is not known to be a requirement, the design should allow for this maintenance to be done efficiently.

(h) Occasionally, pest breeding may need to be controlled. Wetlands provide ideal breeding areas for insects such as mosquitoes and animals such as muskrats. Physical, chemical and biological means of controlling nuisance populations may need to be considered, but must be safe for troops using the recycled washwater.

4.8.2 Start-up

If practical, the CWTS should be constructed first and water discharged to it for at least one growing season. Water should be added to the CWTS to maintain the water level. Liquid fertilizer may be added for live plant growth and to enhance good root development throughout the substrate. The live plant system should be well established even before completion of other components of the CVWF.

4.8.3 Water Level

For SF systems, water level is maintained during normal operation from 0 to a maximum of 0.3 m (1 ft) above the substrate by using the swivel standpipe in the water level control outlet structure or raising and lowering flexible tubing with a notched chain and hook on the wall (Figure 10). A water level gauge can be constructed outside each cell to observe the water level relative to the substrate surface. Water level should be maintained during extended periods of no flows or when weather conditions do not permit washing (e.g. winter months). Without flow, moisture in the cell may evaporate or be transpired by the plants in hot weather, or freeze solid, thereby damaging the roots and tubers during severe freezing conditions. Provisions should be included to add water to the system as needed. Depending on installation location, precipitation falling on the hardstands, sediment basin and CWTS should provide enough moisture during extended non-use and winter periods. Leaks in the water level control structure should be checked and repaired.

4.8.4 Liner

Maintain the cover over the sides of synthetic liners such as polyethylene, PVC, halpalon, neoprene, butyl rubber, etc.

which extend above the substrate and water level to prevent UV degradation of these materials.

4.8.5 Berms

Repair earthen berm erosion when discovered. Repair leaks around the berms or retaining walls by plugging or sealing. Mow earthen berms and around retaining dikes to maintain an attractive side. Exercise care to not erode berms by using light weight maintenance equipment.

4.8.6 Vegetation

(a) Frequently, observe vegetation for signs of disease or other stress frequently. Signs are yellowing or browning, withering, spots, etc. Some vegetation problems occur naturally with changes in temperature and weather conditions. First check water level to assure proper operations. If level is satisfactory, then obtain guidance from plant specialist on post.

(b) Damage from serious insect infestation, which is destroying vegetation, may be controlled or eliminated by chemical agents properly applied after obtaining guidance from a knowledgeable person for proper chemical and application rate.

(c) If vegetation does not appear healthy and water levels are correctly maintained, add a balanced liquid fertilizer three times a growing season to the waste washwater. Normal waste washwater from most CVWF's may not contain all the trace nutrients and elements required by the plants in the substrate.

(d) Replace extremely stressed plants to fill voids.

(e) Weeds, trees, shrubs and other deep rooted plants should be removed from the bed to prevent shading and crowding of the desirable wetland plants.

(f) Do not leave roots exposed to air.

4.8.7 Vector Control

Mosquitoes and other insect pest species are not a problem for subsurface flow wetlands. Surface flow systems, however, provide a potentially ideal breeding environment for insects. It is recommended to design and operate wetlands to minimize mosquito control. This includes avoiding anaerobic conditions and static hydraulic areas. Fortunately, anaerobic conditions are unlikely to occur because of the low organic loads in the washwater influent to the wetland. Operators should be able to remove areas of vegetation that become so thick as to cause potentially static hydraulic or anaerobic conditions. The technology for use of parasitic pathogenic organisms or hormonal substances for the control of mosquito larvae is available. Bacillus sphaericus is a very effective agent which is now approved for marketing.[19] Indications are that muskrat and other burrowing animal trapping may be required to prevent destruction of berms and vegetation.

4.8.8 Health and Safety

The wetland should be fenced, but accessible to operators, to prevent animals and humans from accessing the wetland. Assure that troops do not use any chemicals to clean vehicles. Chemicals can upset the treatment process, damage and kill the wetland vegetation and be potentially harmful to the troops on contact with recycled washwater. Do not apply herbicides and pesticides which can damage vegetation either on or near the system or could couse harm to troops exposed to chemically treated washwater.

5. COSTS

5.1 Design and Construction

Intermittent sand filters will be more costly and more difficult to design and construct than will lagoons and constructed wetlands. Though there is little historical cost data to compare, it is expected that sand filters will be at least 10 percent more costly than lagoons. Surface flow wetlands are expected to be the lowest cost alternatives.

5.2 Typical Costs

Typical costs in 1994 dollars are given in Table 7 (next page). These data illustrate the comparative costs for construction and operation of the three alternatives, but should not be used for estimation purposes on a specific project.

5.2.1 Intermittent Sand Filters

Cost for this treatment process are site specific due to availability of media. Generalized cost curves are not available. Costs items include 60-mu HDPE liner, granular media (sand), gravel, 15-cm (6-in) lateral underdrains with 3-m (10-ft) spacing, D.I.P. distribution piping, surface application piping (UV resistant PVC), concrete thrust blocking and access ramps, redwood baffles between cells, excavation and backfill (slopes 3:1 interior, 2:1 exterior), and 3 m (10 ft) berm. Annual O&M

cost considerations include maintenance, manpower, and energy for pumps.

5.2.2 Lagoons

Construction cost items for lagoons include clearing, excavation, grading, other earthwork required for subgrade preparation, service roads, and inlet/outlet works. Operation and maintenance cost considerations include operating labor, maintenance labor and materials and supplies.

5.2.3 Surface Flow Wetland

Capital cost items include earthwork, inlet distribution structure, effluent collection, water level control structure, vegetation, fertilizing, liming, and effluent collection piping. Annual O&M expenses are for labor only.

Treatment Alternative	Construction Cost $/hectare (acre)	O&M Cost $/m³ treated
Intermittent sand filters	1,090,000 (440,000)	0.10 - 0.20
Lagoons	262,000 (106,000)	0.07 - 0.13
Constructed wetland	98,800 (40,000)	0.03 - 0.09

Table 7. Typical construction and annual O&M costs for secondary treatment alternatives.

6. EXAMPLE PROBLEM

6.1 General Information. The following fictional example, based on the design example in TM5-814-9 illustrates the conceptual design procedures and criteria presented in this ETL. The soil in the training area contains some expansive, cohesive clays. Soil tests revealed a soil type number, S , equal to 4 (Figure 3-3, Th 5-814-9). The maximum washwater volume for the CVWF, V_{max}, has been estimated to be 20,287 m^3 (724,522 ft^3) and the average daily flow is 2160 m^3 (570,042 gal). A major vehicle washing operation takes approximately 2 days (54 hr) but the CVWF will not be fully operational for 7 days after a major exercise. Estimated usage is 665 tracked and 786 wheeled vehicles per month. Computations will be primarily in English units with some metric units given.

6.2 Intermittent Sand Filter

6.2.1 The designer chooses two filters, which will allow flexibility to operate one while the other is allowed to rest. From Table 3 (page A-9) for S_t = 4, a loading rate of 650,000 gpd/ac is selected. The designer selects a filter dose frequency of 8 hr. The total sand filter area required is calculated as follows:

$$A_F = V_{max} / \text{dosing rate}$$

$$= \frac{724.522 \text{ ft}^3 \times 7.28 \text{ gal/ft}^3}{(2 + 7)(650{,}000)}$$

$$= 0.93 \text{ ac } (0.38 \text{ ha})$$

6.2.2 Thus, each filter should have a surface area of 0.47 ac (0.19 ha).

6.2.3 Budget construction cost: 0.93 ac x $440,000/ac = $409,000.

6.3 Lagoon

6.3.1 The volume of water in the lagoon is based on the greater of V_{max} or the average volume, V_{avg} and 7 day assumed wash period and detention time.

$$V_{Lagoon} = 7 \text{ days} \times V_{avg} = 7 \times 570{,}042 \text{ gal} = 3{,}990{,}294 \text{ gal or } 533{,}462 \text{ ft}^3 \text{ or } 14{,}937 \text{ m}^3$$

The designer uses a safety factor of 1.25 times the value of V_{max} or

$$1.25 \times 724{,}522 \text{ ft}^3 = 905{,}653 \text{ ft}^3 \ (25{,}358 \text{ m}^3)$$

Volume of the lagoon is the higher of these values.

6.3.2 Add silt storage volume over a 20 year period, assuming 80 percent sediment basin trap efficiency and an 8 month consecutive washing season using the following formulation:

[No. of tracked washed/month x 2 cf/wash + No. wheeled washed/month x 0.6 cf/wash) x 8 months x 20 yrs x percent carry-over to lagoon.

$$[665 \times 2 + 783 \times 0.6) \times 8 \times 20 \times .20 = 57{,}600 \text{ ft}^3 = 1{,}632 \text{ m}^3$$

6.3.3 Allow at least 2 feet of freeboard and 2 feet of sediment storage.

6.3.4 Select a length to width ratio, side slopes, and maximum water depth and compute the pertinent dimensions for the lagoon.

For length = width, 3H:lV side slopes, 8 ft water depth, 2 ft freeboard, and 2 ft sediment storage, the total surface area occupied by the lagoon is approximately 3.2 ac.

6.3.5 Budget construction cost: 3.2 ac x $110,000/ac = $352,000.

6.4 Constructed Wetland

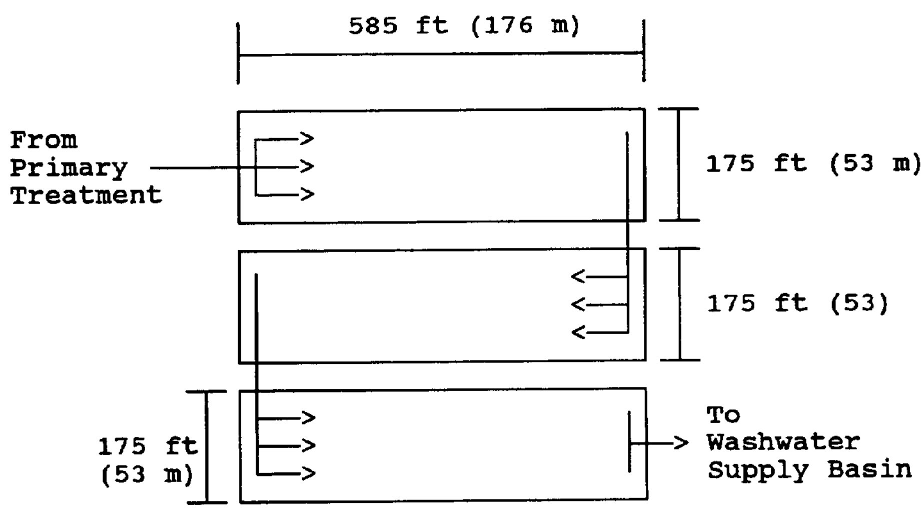
6.4.1 The desired constructed wetland type for the soils encountered at the wash facility is the surface flow (SF) type. The designer selects the following design criteria for sizing the constructed wetland:

Hydraulic residence time, t, = 2 days
Aspect ratio, LIW, = 10
Vegetation: cattails
Design depth, **D**, = 8 in (20 cm)
Porosity, *n,* = 0.75 (cattails)
Equivalent depth, $\mathbf{D_e} = n\mathbf{D}$ = 6 in (15 cm)

6.4.2 Calculate the dimensions of the required wetland to meet the above conditions from : $A_w = Qt/De$:

$A_w = Qt/D_e$=[(570,042 GPD/7.48 gal/ft^3) x 2 days) ÷ (6 in/ 12 in/ft)= 304,835 ft^2 (28,332m^2)
Since L = 10W, then 10W^2 = 304,835 ft^2 (28,332m^2)
Therefore, W = 175 ft (53 m) and L = 10 x 175 = 1750 ft (530 m).

6.4.3 Configuration: Designer selects a series, serpentine cell arrangement with each cell 175 ft x 585 ft (53 m x 176 m), and terraced because of site topography and slope constraints.



6.4.4 Total area occupied by wetland is approximately 7.0 ac. Budget construction cost is 7.0 x $40,000 = $280,000.

6.5 Conversion Factors

Multiply	by	To Get
m^3/d	264	gpd
g/m^2-d	8.92	lb/ac-d
kg/ha-d	0.892	lb/ac-d
kg/m2	0.200	lb/ft^2
m^3/ha-d	106.9	gpd/ac
m	3.28	ft
m^2	10.76	ft^2
ha	2.47	ac
m^3	264	gal