CHAPTER 6

OVERLAND FLOW PROCESS DESIGN

6.1 Introduction

The design procedure for overland flow (OF) is presented in Figure 6-1. Application rate and hydraulic loading rate determinations are the most important design steps because these values plus the storage requirement fix the land area requirements. Preapplication treatment can be increased if inadequate land area is available.

6.1.1 Site Characteristics and Evaluation

Overland flow is best suited for use at sites having surface soils that are slowly permeable or have a restrictive layer such as a claypan at depths of 0.3 to 0.6 m (1 to 2 ft). Overland flow can also be used on moderately permeable soils using higher loading rates than would be possible with an SR system. It is possible to design an OF system on very permeable soils by constructing an artificial barrier to prevent downward water movement through the soil, although the capital costs of such construction may be prohibitive for all but the smallest systems.

Overland flow may be used at sites with gently sloping terrain with grades in the range of 1 to 12%. Slopes can be constructed on nearly level terrain and terraced construction can be used when the natural slope grade exceeds about 10%. Topographic maps of proposed sites with 0.3 m (1 ft) contour intervals should be used in detailed site evaluation.

6.1.2 Water Quality Requirements

Most of the treated water leaving an OF site occurs as surface runoff, and discharge requirements to receiving waters must be met. Protection of ground water quality at OF sites is generally ensured by the fact that little water (usually less than 20%) percolates and the heavy clay soils remove most of the pollutants. Based on limited experience with OF on moderately permeable soils, a long-term decrease in the percolation rate can be expected due to clogging of soil pores and a relatively small percentage of the applied wastewater will percolate. If OF is considered for use on moderately permeable soils, however, it is recommended that consideration be given to ground water impacts as discussed for SR systems in Chapters 4 and 9.

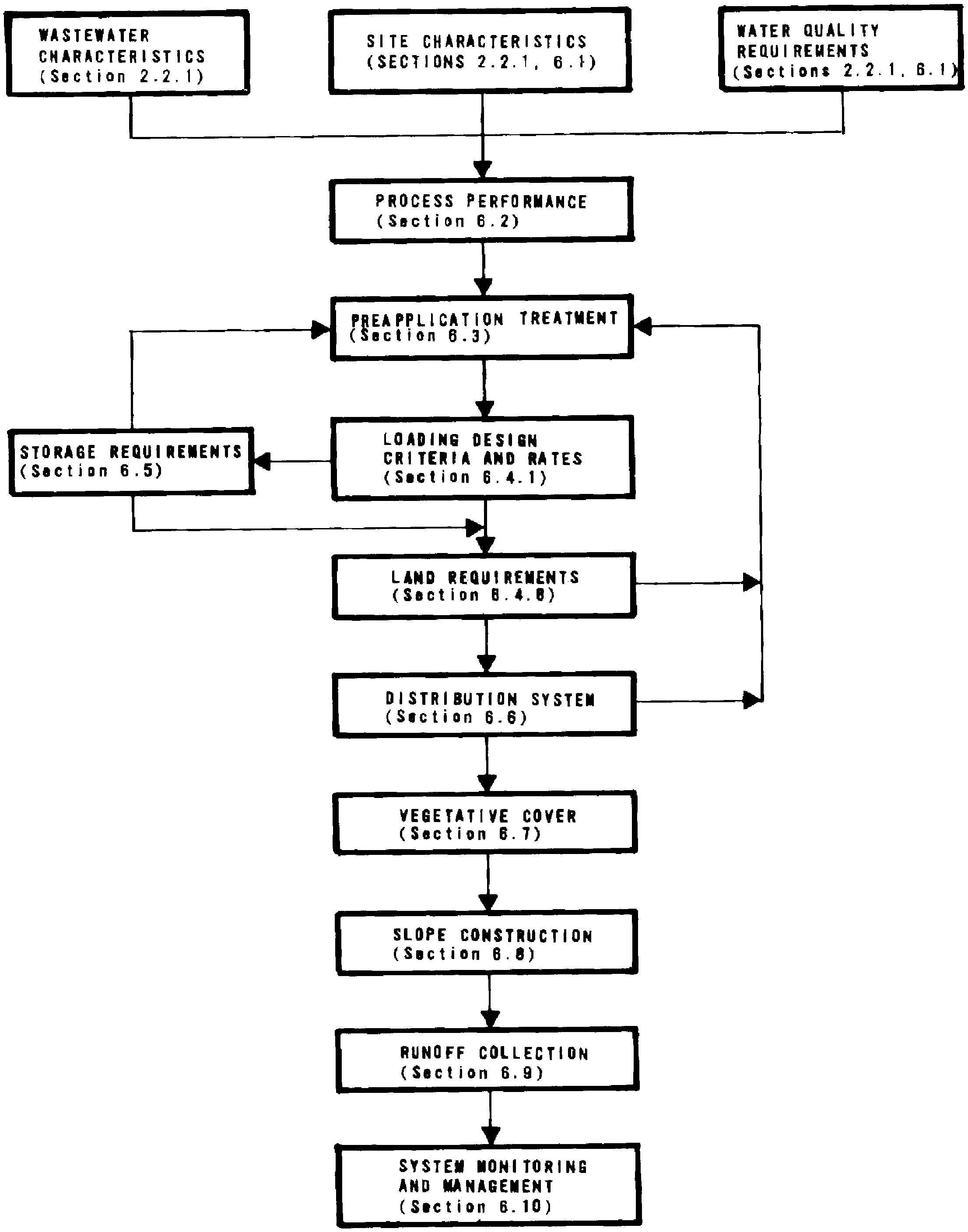

FIGURE 6-1
OVERLAND FLOW DESIGN PROCEDURE

6.1.3 Design and Operating Parameters

The basic design and operating parameters are defined in Table 6-1.

TABLE 6-1
OF DESIGN AND OPERATING PARAMETERS

Parameter	Definition	Range of values in practice
Hydraulic loading rate	Average flowrate divided by the wetted slope area	0.6-6.7 cm/d 6.3-40 cm/wk
Application rate	Flowrate applied to the slope per unit width of slope	0.03-0.24 $m^3/m \cdot h$
Application period	Length of time per day of wastewater application	5-24 h/d
Application frequency	Number of days per week that wastewater is applied to the slope	5-7 d/wk

Note: See Appendix G for metric conversions.

6.2 Process Performance

Knowledge of the relationship of process performance and design criteria for OF systems is necessary before the design can be accomplished. The removal mechanisms discussed in this section relate to operating parameters, slope lengths, and levels of preapplication treatment. A summary of design and operating characteristics for existing municipal OF systems is presented in Tables 6-2 and 6-3. Health and environmental effects of trace elements and trace organics are discussed in Chapter 9.

6.2.1 BOD Removal

Biological oxidation is the principal mechanism responsible for the removal of soluble organic materials in the wastewater. The diverse microbial populations in the soil and the surface organic layer sorb and subsequently oxidize these substances into stable end products much like the biological shines on trickling filter media. Suspended and colloidal organic materials, which contribute about 50% of the BOD load in raw domestic sewage, are removed by sedimentation and filtration through the surface grass and organic layers. Subsequent breakdown of the degradable settled particulate materials is also achieved by the micro-organisms on the slope. Typical removals of BOD are presented in Table 6-2.

TABLE 6-2
SUMMARY OF PROCESS OPERATING PARAMETERS, BOD AND SS PERFORMANCE AT OF SYSTEMS[a]

Wastewater applied	Location	Slope length, m	Application rate, $m^3/m \cdot h$	Hydraulic loading rate, cm/d	Application Period, h/d	Application Frequency, d/wk	BOD, mg/L Influent	BOD, mg/L Effluent	SS, Mg/L Influent	SS, Mg/L Effluent	Reference
Raw wastewater	Ada, Oklahoma	36	0.075	1.63	8	6	150	8	160	8	[1]
			0.098	3.3	12	6	132	10	185	16	[1]
	Pauls Valley, Oklahoma	46	0.041	0.73	8	7	117	14.8	105	5.2	[2]
	Easley, South Carolina	55	0.22	2.36	6	5	200	23	186	8	[3]
Primary effluent	Ada, Oklahoma	36	0.065	2.5	12	6	70	8	56	7	[1]
			0.098	3.3	12	6	70	8	56	7	
	Hanover, New Hampshire	30.5	0.075	1.25	5	5	72	9	74	10	[4]
			0.127	2.8	7	5	72	9	59	7	[5]
	Melbourne, Australia	250	0.24	2.3	24	7	507	12	233	19	[6]
Secondary effluent	Ada, Oklahoma	36	0.12	4.2	12	6	18	6	12	5	[1]
			0.20	6.7	12	6	18	5	12	5	[1]
	Hanover, New Hampshire	30.5	0.075	1.25	5	5	45	5	47	3	[4]
Stabilization pond effluent	Pauls Valley, Oklahoma	46	0.06	1.66	12	7	27.7	20.5	114	72.8	[2]
	Utica, Mississippi	46	0.032	1.27	18	5	22	3.5	30	5.5	[7]
			0.065	2.54	18	5	22	4.0	30	8.0	[7]
			0.049	2.54	24	7	22	5.5	30	13.0	[7]
			0.13	5.08	18	5	22	7.5	30	13.0	[7]
			0.10	1.27	6	5	22	8.6	30	6.4	[7]
	Easley, South Carolina	46	0.23	3.58	7	5	28	15	60	40	[3]

a. Performance during warm season

TABLE 6-3
SUMMARY OF NITROGEN AND PHOSPHORUS PERFORMANCE AT OF SYSTEMS[a]

Wastewater applied	Location	Hydraulic loading rate, cm/d	Total N, mg/L		Ammonia-N, mg/L		Nitrate-N, mg/L		Total P, mg/L		Reference
			Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent	
Raw wastewater	Ada, Oklahoma	1.63	23.6	2.1	17.0	0.6	0.8	0.4	10.0	4.3	[1]
		3.3	34.0	7	23.0	2	<1	2	8	4.5	[1]
	Pauls Valley, Oklahoma	0.73	24.2	9.8	16.7	5.3	<0.1	0.4	8.3	8.7	[2]
	Easley, South Carolina	2.36	30.5	7.7	16.0	3.3	1.4	0.3	8.9	4.0	[3]
Primary effluent	Ada, Oklahoma	2.5	19	5	14.0	1.5	1	3	7	4.7	[1]
		3.3	19	5	14.0	1.5	1	3	7	5.2	
	Hanover, New Hampshire	1.25	45	9.4	37.6	5.8	0.9	1.6	5.7	1.1	[4]
		2.8	36	11.3	24.0	4.5	<0.1	3.5	6.6	4.4	[5]
	Melbourne, Australia	2.3	55.6	39.7	31	31	<0.1	0.3	9.0	8.4	[6]
Secondary effluent	Ada, Oklahoma	4.2	16	8.5	6	0.5	8	5.5	7	5.0	[1]
		6.7	16	8.5	6	0.5	8	7.5	7	5.9	[1]
	Hanover, New Hampshire	1.25	31.3	13.7	21.7	4	7.1	6.2	6.0	3.6	[4]
Stabilization pond effluent	Pauls Valley, Oklahoma	1.66	15.5	11.4	1.7	0.4	<0.1	0.2	6.3	5.1	[2]
	Utica, Mississippi	1.27	20.5	4.3	15.6	0.1	<1.0	1.0	10.3	4.9	[7]
		2.54	20.5	7.5	15.6	0.8	<1.0	2.6	10.3	6.1	[7]
		2.54	20.5	7.3	15.6	0.7	<1.0	3.1	10.3	5.9	[7]
		5.08	20.5	10.0	15.6	1.1	<1.0	4.8	10.3	8.2	[7]
		1.27	20.5	7.0	15.6	0.8	<1.0	3.2	10.3	7.1	[7]
	Easley, South Carolina	3.58	6.7	2.1	1.0	0.4	2.4	1.1	3.8	2.2	[3]

a. Performance during warm season.

The performance of OF systems treating primary and secondary effluent in cold regions was evaluated in Hanover, New Hampshire [4]. For primary effluent, it was found that runoff BOD concentration was not substantially affected by temperature until the soil temperature dropped to about 10 °C (50 °F). Below 10 °C, effluent BOD levels increased with decreasing temperatures. At soil temperatures below 4 °C (39 °F) effluent BOD levels exceeded 30 mg/L. For secondary effluent, OF effluent BOD values remained below 15 mg/L at soil temperatures of 4 °C. Storage may be required during cold weather to meet stringent BOD discharge requirements.

Relationships between BOD removal and the process operating parameters are not well defined. However, results of recent studies conducted to develop rational design methods for OF indicate that, for primary effluent, BOD removal is largely a function of application rate and slope length and is independent of hydraulic loading rate within the ranges used at existing systems [5, 8] (see Section 6.11).

6.2.2 Suspended Solids Removal

Suspended and colloidal solids are removed by sedimentation, filtration through the grass and litter, and adsorption on the biological slime layer. Because of the low flow velocities and shallow flow depths on the OF slopes, most SS are removed within a few meters from the point of application.

Removal of algae from stabilization pond effluent by OF systems is somewhat variable and depends on the nature of the algae. If OF is not being used in the locality for treatment of pond effluent, pilot studies may be advised to ascertain treatability.

Removal of SS requires that a thick stand of vegetation be maintained and that gullies or other short-circuiting down the slopes be avoided. Removal of SS is relatively unaffected by cold weather or changes in process loading parameters compared to BOD removal.

6.2.3 Nitrogen Removal

Important mechanisms responsible for nitrogen removal by OF include crop uptake, biological nitrification-denitrification, and ammonia volatilization. Removal of nitrogen by crop harvest depends on the nitrogen content of the crop and the dry matter yield of the crop as discussed in Section 4.3.2.1. The water tolerant forage grasses used for OF generally have high nitrogen uptake capacities.

Annual nitrogen uptake measured at the Utica, Mississippi, system for a grass mixture of Reed canary, Kentucky 31 tall fescue, perennial ryegrass, and common Bermuda ranged between 222 and 179 kg/ha (198 and 160 lb/acre). Crop uptake at the Utica system accounted for approximately 11 and 33% percent of the applied nitrogen at the high and low hydraulic loading rates, respectively (see Table 6-3) [7].

Ammonia volatilization is known to occur during OF. Researchers at the Utica site estimated volatilization losses to be about 9% of the applied pond effluent nitrogen [7].

Nitrification-denitrification is usually the major removal mechanism. At Utica, the losses attributable to denitrification ranged from 34 to 42% of the applied nitrogen [7].

Nitrification takes place in the aerobic environment at the soil surface. The nitrates then diffuse through the organic-rich surface materials where anaerobic conditions necessary for denitrification exist. Denitrification requires the presence of a readily available carbon source. Consequently, the best nitrogen removals are found using raw wastewater or primary effluent that have high carbon to nitrogen ratios (>3). Lesser nitrogen removals are found using secondary or pond effluent when the carbon to nitrogen ratios are about one.

Typical effluent values for the different nitrogen forms are indicated in Table 6-3. The effects of operating parameters on nitrogen removal are not well understood. Specific design and operating criteria to optimize nitrogen removal or ammonia conversion have not been established. However, some general relationships can be stated:

1. Total nitrogen and ammonia removal is inversely related to application rate and directly related to slope length.

2. The rate of nitrification is reduced if wastewater is applied continuously.

3. The overall nitrogen removal and ammonia conversion efficiency is reduced as the soil temperature drops below 13 to 14 °C (55 to 57 °F). With pond effluent at the Utica system, nitrogen removal efficiency decreased from 90% in the spring and summer to less than 80% during the winter [12]. Results obtained at the Hanover system with primary and secondary effluents, showed that nitrogen removal efficiency dropped to about 30% during the

inter [5]. The reduced efficiency in colder temperatures is attributed to the decreased rate of the biological nitrification-denitrification process as well as reduced plant uptake.

6.2.4 Phosphorus Removal

The major mechanisms responsible for phosphorus removal by OF include sorption on soil clay colloids and precipitation as insoluble complexes of calcium, iron, and aluminum. When low permeability surface soils are present, as is the case for most OF systems, much of the applied wastewater flows over the surface and does not contact the soil matrix and phosphorus adsorption sites. <u>As a result of this limited soil contact, phosphorus removals achieved at existing OF systems generally range from 40 to 60%</u>. phosphorus data from some OF systems are shown in Table 6-3.

Improved phosphorus removal efficiency can be achieved by the addition of aluminum sulfate to the wastewater prior to application to the land. Applications of aluminum sulfate to raw sewage at a concentration of 20 mg/L reduced the phosphorus concentration from 8.8 mg/L to 1.5 mg/L or 85% removal efficiency in experiments at Ada, Oklahoma [9]. Addition of aluminum sulfate to stabilization pond effluent in amounts equal to 1:1, aluminum to phosphorus, prior to application resulted in significant reduction of phosphorus in the runoff to about 1 mg/L or removal efficiency better than 80% at the Utica system [10].

6.2.5 Trace Element Removal

The major mechanisms responsible for trace element removal include sorption on clay colloids and organic matter at the soil surface layer, precipitation as insoluble hydroxy complexes, and formation of organometallic complexes with the organic matter at the slope surface. The largest proportion of the heavy metals accumulate in the biomass on the soil surface and close to the point of effluent application. Trace metal removal data reported from the Utica system are presented in Table 6-4 to illustrate the removal levels that can be achieved with OF.

6.2.6 Microorganism Removal

The major mechanisms responsible for removal of microorganisms in OF systems include sedimentation, filtration through surface organic layer and vegetation, sorption to soil particles, predation, irradiation, and desiccation during drying periods.

TABLE 6-4
REMOVAL EFFICIENCY OF HEAVY METALS
AT DIFFERENT HYDRAULIC RATES AT
UTICA, MISSISSIPPI [7]

Hydraulic loading rate, cm/d	Runoff concentration, mg/L				Removal efficiency, %			
	Cadmium	Nickel	Copper	Zinc	Cadmium	Nickel	Copper	Zinc
1.27	0.0046	0.0131	0.0129	0.0558	85.4	92.1	93.1	88.4
2.54	0.0036	0.0217	0.0293	0.0525	90.9	87.6	82.4	87.4
3.81	0.0079	0.0302	0.0382	0.0757	77.7	79.6	73.5	78.8
5.08	0.0142	0.0486	0.0524	0.0853	63.2	66.0	64.4	75.4

Generally, the removal, efficiency of OF systems for pathogenic organisms such as viruses and indicator organisms is comparable to that which is achieved in conventional secondary treatment systems without chlorination. Disinfection may be required by the regulatory agency.

6.2.7 Trace Organics Removal

Removal of trace organics in OF systems is achieved by the mechanisms of sorption on soil clay colloids or organic matter, biodegradation, photodecomposition, and volatilization. The importance of one or a combination of these mechanisms will depend on the nature of the trace organic substance.

6.2.8 Effect of Rainfall

The effect of rainfall on OF process performance was studied at Paris, Texas; Utica, Mississippi; Ada, Oklahoma; and Hanover, New Hampshire [11, 7, 4]. In all of these studies, it was observed that precipitation events occurring during application did not significantly affect the concentration of the major constituents in the runoff. However, the mass discharges of constituents did increase due to the increased water volume from the storm events. In situations where discharge permits are based on mass discharge, discussions with regulatory officials should be held to determine if permits can be written to reflect background loadings occurring as a result of rainfall runoff from OF fields or to allow higher mass discharges during periods of high flow in receiving waters. In some cases, collection and recycle of stormwater may be necessary.

6.2.9 Effect of Slope Grade

The effect of slope grade on treatment performance has been evaluated at several systems [2, 7, 8]. The conclusion from all studies was that slope grade in the range of 2 to 8% does not significantly affect treatment performance when systems are operated within the range of application rates reported in Table 6-2.

6.2.10 Performance During Startup

A period of slope aging or acclimation is required following initial startup before process performance approaches satisfactory levels. During this period, the microbial population on the slopes is increasing and slime layers are forming. The initial acclimation period may be as long as 3 to 4 months. If a variance to allow discharge during this period can not be obtained, provisions should be made to store and/or recycle the effluent until effluent quality improves to the required level.

An acclimation period also should be provided following winter storage periods for those systems in cold climates. Acclimation following winter shutdown should require less than 1 month. Acclimation is not necessary following shutdown for harvest unless the harvest period is extended to more than 2 or 3 weeks due to inclement weather.

6.3 Preapplication Treatment

Preapplication treatment before OF is provided to (1) prevent operating problems with distribution systems and, (2) prevent nuisance conditions during storage. Preapplication treatment to protect public health is not usually a consideration with OF systems because public contact with the treatment site is usually controlled and no crops are grown for human consumption.

Except in the case of harmful or toxic substances from industrial sources (see Section 4.4.3), preapplication treatment of municipal wastewater is not necessary for the OF process to achieve maximum treatment. The OF process is capable of removing higher levels of constituents than are normally present in municipal wastewater and maximum use should be made of this renovating capacity. Consequently, the level of preapplication treatment provided should be the minimum necessary to achieve the two stated objectives. Any additional treatment, in most cases, will only increase costs and energy use, and, in some cases, can impair or reduce the consistency of process performance. Algal solids have proven difficult to remove from some stabilization pond effluents and reduced nitrogen removals have been observed with secondary effluents. These statements do not imply that existing treatment facilities should not be considered for use in preapplication treatment.

The EPA has issued guidelines for assessing the level of preapplication treatment necessary for OF systems. The guidelines are as follows:

1. Screening or comminution--acceptable for isolated sites with no public access.

2. Screening or comminution plus aeration to control odors during storage or application--acceptable for urban locations with no public access.

Municipal wastewater contains rags, paper, hair, and other large articles that can blind and clog orifices and valves in surface and sprinkler distribution systems. Comminution is generally not sufficient to eliminate clogging problems. Fine screening or primary sedimentation with surface skimming is necessary to prevent operating difficulties. For sprinkler distribution systems, screen sizes should be less than one-third the diameter of the sprinkler nozzle. Static inclined screens with 1.5 mm (0.06 in.) openings have been used successfully for raw wastewater screening.

Grit removal is advisable for wastewaters containing high grit loads. Grit reduces pump life and can deposit in low velocity distribution pipelines.

6.4 Design Criteria Selection

The principal OF design and operating parameters are defined in Section 6.1 and values used at existing systems are given in Table 6-1. Traditionally, OF design and operation has been an empirical procedure based on a set of general guidelines established through successive trials with the various process parameters at different OF systems. The guidelines, as presented here, reflect successful construction and operation of full-scale systems, but the degree of conservation inherent in the guidelines has not been established. The design criteria shown in Table 6-5 have been used at existing OF systems during spring, summer, and fall to achieve effluent BOD and suspended solids concentrations less than 20 mg/L, total nitrogen less than 10 mg/L, ammonia nitrogen less than 5 mg/L, and total phosphorus less than 6 mg/L.

TABLE 6-5
OVERLAND FLOW DESIGN GUIDELINES

Preapplication treatment	Hydraulic loading rate, cm/d	Application rate, $m^3/m \cdot h$	Application period, h/d	Application frequency, d/wk	Slope length, m
Screening	0.9-3	0.07-0.12	8-12	5-7	36-45
Primary sedimentation	1.4-4	0.08-0.12	8-12	5-7	30-36
Stabilization pond	1.3-3.3	0.03-0.10	8-18	5-7	45
Complete secondary biological	2.8-6.7	0.10-0.20	8-12	5-7	30-36

6.4.1 Hydraulic Loading Rate

Traditionally, hydraulic loading rate has been used as the principal OF design parameter. Current guidelines call for hydraulic loadings rates to be varied with the degree of preapplication treatment as indicated in Table 6-5. For systems operating year-round, the hydraulic loading rates generally have been reduced during the winter to compensate for the reduction in BOD and nitrogen removal efficiency when soil temperatures drop below 10 to 15 °C (50 to 59 °F) (see Sections 6.2.1 and 6.2.3). Reductions in hydraulic loading rates during the winter have been somewhat arbitrary and guidelines are not well established. A 30% reduction from summer rates has been used at the Ada system while a 50% reduction has been recommended at the Utica system.

The performance of OF systems is dependent on the detention time of the wastewater on the slope. The detention time is in turn directly related to the application rate. Therefore, it is possible to compensate for lower winter temperatures by decreasing the application rate and increasing the application period while maintaining the hydraulic loading rate constant. It is also possible to increase hydraulic loading rates for short periods, such as when a portion of the system is shutdown for harvesting or repair, without affecting performance, by increasing the application period and maintaining the application rate constant.

6.4.2 Application Rate

Design guidelines for application rates based on existing systems are presented in Table 6-5. Values at the high end of the range may be used during spring, summer, and fall, while values at the low end should be used when soil temperatures drop below about 10 °C or if maximum removal efficiency for any constituent is desired. These rates are based on slope lengths in the range of 30 to 40 m (98 to 131 ft). Application rates less than the minimum values shown in Table 6-5 may be difficult to distribute uniformly with surface distribution systems.

Hydraulic loading rate is related to application rate, period, and the slope length as shown in Equation 6-1.

$$L_w = \frac{(Ra)(P)}{S}\ (100\ cm/m) \qquad (6-1)$$

where L_w = hydraulic loading rate, cm/d

R_a = application rate, $m^3/h \cdot m$

P = application period, h/d

S = slope length, m

The calculation can be started in one of two ways:

1. Select application rate, period, and slope length and calculate hydraulic loading rate, or

2. Select application period, slope length, and hydraulic loading rate and calculate application rate.

6.4.3 Application Period

A wide range of application periods has been used successfully, ranging from just a few hours to as high as 24 h/d. The application periods that have been used most frequently in existing OF projects range between 6 and 12 h/d.

Use of design application periods of 12 h/d or less allows more operating flexibility during periods when parts of the system must be shutdown for harvest or repair. For instance, if the design application period is 8 h/d, wastewater normally would be applied to one-third of the total land area at any given time assuming a 24-hour system operation. If one-third of the system were shutdown for harvest, the application period could be increased to 12 h/d on the remaining two portions of the system, and the entire flow could be applied without increasing the application rate.

Systems generally are designed to operate on a 24 hour basis to minimize land requirements. For small systems, it may be more convenient or cost effective to operate only during one working shift. In this case, the entire land area would receive the full design daily wastewater flow during the 8 hour application period. Storage facilities would be required to hold wastewater flow during the 16 hour nonoperating period.

6.4.4 Application Frequency

A design application frequency of 7 d/wk is generally used to minimize land area requirements and eliminate or reduce storage requirements. There does not appear to be any advantage in terms of process performance to using less frequent applications. For small systems with storage facilities, it may be more convenient to use an application frequency of 5 d/wk and shut down on weekends.

6.4.5 Constituent Loading Rates

Historically, OF design and operation has not been based on mass loading rates of wastewater constituents such as BOD, suspended solids, and nitrogen. The rates used at existing systems apparently are well below those that might affect process performance, since no correlations between process performance and constituent loading have been found.

6.4.6 Slope Length

In general, OF process performance has been shown to be directly related to slope length and inversely related to application rate (see Section 6.11). Thus, longer slope lengths should be used with higher application rates or, conversely, shorter slope lengths should be used with lower application rates to achieve an equivalent degree of treatment. The combinations of slope lengths and application rates that are suggested for design are indicated in Table 6-5.

The minimum slope lengths indicated have been used with surface distribution systems or low-pressure spray systems that distribute the wastewater across the top of the slope. Traditionally, longer slope lengths (45 to 60 m or 150 to 200 ft) have been used with full-circle, high-pressure impact sprinklers. However, nearly all of the experience with impact sprinkler OF distribution systems has been with high strength food processing wastewater. There are no data to indicate the need for longer slope lengths when using sprinklers to apply municipal wastewater. Without such information, the recommended minimum slope length for sprinkler distribution systems is 45 m (150 ft) for part circle sprinklers. For full circle sprinklers, the recommended minimum slope length is the sprinkler diameter plus about 20 m (65 ft).

From a process control standpoint, it is desirable to have all slopes approximately the same length. However, this may not always be possible due to the shape of the site boundaries or site topography. If slope length must differ substantially (>10 m or 33 ft) from the design value, then the application rate used on these slopes may need to be adjusted. For design, a first approximation to the adjusted rate may be made by equalizing the hydraulic loading rate on all slopes. Equation 6-1 may be used to estimate the necessary application rate. Adjustment in the field during operation may be necessary to achieve equivalent treatment.

6.4.7 Slope Grade

Although slope grades ranging from less than 1% to 10 or 12% have been used effectively for OF, experience has shown the optimum range to be between 2 and 8%. Slope grades less than 2% increase the potential for ponding, while those greater than 8% increase the risk of erosion. It has been shown through several studies that slope grades in the range of 2 to 8% do not affect process performance. Therefore, there is no need to adjust slope length or application rate for changes in slope grade within this range. Slope grades greater than about 8% also increase the risk of short circuiting and channeling and may require lower application rates or longer slope lengths to achieve adequate treatment, although there are no performance data to confirm this.

Although there exist some circumstances where natural ground contours can provide the slope grade necessary for effective treatment, few sites offer conditions that are ideal for the smooth sheet flow of water along the ground surface, which is important to the OF concept. Therefore, it is almost always necessary to reshape the site into a network of slopes that conform to the length and grade guidelines outlined previously. The grade of each slope is established by the existing site conditions. For example, if the site has a general slope grade of 4%, the slope should also be shaped to 4% grades. If the site is very flat, 2% grades should be used. If the site is quite steep, the slope grades should be reduced to 8%. This procedure will minimize the cost required to reshape the site. Since natural grades can vary considerably within the confines of a specific site, the individual OF slopes can vary in grade although each should be within the 2 to 8% range.

6.4.8 Land Requirements

The area of land to which wastewater is actually applied is termed slope area. In addition to the slope area, the total land area required for an OF system includes land for preapplication treatment, administration and maintenance buildings, service roads, buffer zones (see Section 4.5.4.2), and storage facilities. At existing systems, other area requirements (not including buffer zones or storage facilities) have ranged from 15 to 40% of the slope area.

For systems where storage is provided, the slope area requirement may be calculated using the following equations.

$$A_s = \frac{Q(365\ d/yr) + \Delta V_s}{(D_a)(L_w)(10^4\ m^2/ha)(10^{-2}\ m/cm)} \qquad (6\text{-}2)$$

where A_s = slope area, ha

ΔV_s = net loss or gain in storage volume due to precipitation, evaporation, and seepage, m^3/yr

Q = average daily flow, m^3/d

D_a = number of operating days/yr

L_w = design hydraulic loading rate, cm/d

The value of ΔV_s depends on the area of the storage reservoir. Thus, the final design slope area must be determined after the storage reservoir dimensions are determined.

Combining equations 6-1 and 6-2 allows calculation of A_s based on application rate and slope length. Equations and 6-3 can also be used for systems with no storage since the term ΔV_s will then be equal to zero.

$$A_s = \frac{Q(365\ d/yr) + \Delta V_s}{\frac{(D_a)(R_a)(P)}{S}(10^4\ m^2/ha)} \qquad (6\text{-}3)$$

where A_s = slope area, ha

Q = average daily flow, m^3/d

ΔV_s = net storage gain or loss, m^3 /yr

D_a = number of operating days per year

R_a = design application rate, $m^3/h \cdot m$

P = design application period, h/d

S = slope length, m

Equations 6-2 and 6-3 may also be used for systems in warmer climates that operate year-round without reducing hydraulic loading rates during the winter. As stated previously, it is possible to compensate for lower removal efficiency at low soil temperatures, without reducing hydraulic loading rates, by decreasing the application rate and increasing the application period. This winter operating procedure will minimize slope area requirements and eliminate the need for any winter storage.

If lower hydraulic loading rates are used during the winter, for a system operating year-round, the designer has two alternative approaches that may be used to determine the slope area requirements. Under the first alternative, slope area requirement is based only on the winter hydraulic loading rate, in which case no winter storage will be required. Under the second alternative, slope area would be based on the higher hydraulic loading rates used during the rest of the year, in which case a portion of the winter flow would have to be stored. The first approach would result in maximum land area requirements and conservative loadings during the warmer periods of the year, but would eliminate storage requirements. The second approach would minimize land area requirement but may require preapplication treatment facilities for storage. An economic analysis should be performed to determine which alternative is most cost-effective. If storage facilities are going to be provided for other reasons (see Section 6.5), then the second alternative will probably prove most cost effective.

Slope area requirements using the first alternative may be computed using the following equation, assuming a 7 d/wk application frequency:

$$A_s = \frac{Q_w}{(L_{ww})(10^4\ m^2/ha)(10^{-2}\ m/cm)} \qquad (6\text{-}4)$$

where A_s = slope area, ha

Q_w = average daily flow during winter, m^3/d

L_{ww} = winter hydraulic loading rate, cm/d

Slope area requirements using the second alternative may be computed using the following equation:

$$A_s = \frac{(Q)(365\ d/yr) + \Delta V_s}{(L_{ww})(D_{aw}) + (L_{ws})(D_{as})(10^4\ m^2/ha)(10^{-2}\ m/cm)}$$

where A_s = slope area, ha

Q = annual average daily flow, m^3/d

ΔV_s = net gain or loss of water from storage, m^3/yr

L_{ww} = winter hydraulic loading rate, cm/d

D_{aw} = number of operating days at winter rate

L_{ws} = non-winter hydraulic loading rate, cm/d

D_{as} = number of operating days at non-winter rates

6.5 Storage Requirements

Storage facilities may be required at an OF system for any of the following three reasons:

1. Storage of water during the winter due to reduced hydraulic loading rates or complete shutdown.
2. Storage of stormwater runoff to meet mass discharge limitations.
3. Equalization of incoming flows to permit constant application rates.

Estimating storage volume requirements for the above reasons is discussed in this section. Storage reservoir design considerations are discussed in Section 4.6.3.

6.5.1 Storage Requirements for Cold Weather

Due to the limited operating experience with OF in different parts of the country, cold weather storage requirements are not well defined. In general, OF systems must be shut down for the winter when effluent quality requirements cannot be met due to cold temperatures even at reduced application rates or when ice begins to form on the slope. The duration of the shutdown period and, consequently, the required storage period will, of course, vary with the local climate and the required effluent quality.

In studies at the Hanover system, a storage period of 112 days including acclimation was estimated to be required when treating primary effluent to BOD and suspended solids limits of 30 mg/L [4]. This estimate was reasonably close to the 130 storage days predicted by the EPA-l program using 0 °0C (32 °F) mean temperature (see Section 4.6.2). For design purposes, the EPA-l or EPA-3 programs may be used to conservatively estimate winter storage requirements for OF. A map showing estimated storage days from the EPA-1 program is shown in Figure 2-5 and tabulated data are presented in Appendix F. In areas of the country below the 40 day storage contour, OF systems generally can be operated year-round. However, winter temperature data at the proposed OF site should be compared with those at existing systems that operate year-round to determine if all year operation is feasible.

Storage is required at OF systems that are operated year-round but at reduced hydraulic loading rates during the winter. The required storage volume for such systems can be estimated using the following equation:

$$V_s = (Q_w)(D_w) - (A_s)(L_{ww})(D_{aw})(10^{-2}\ m/cm) \qquad (6\text{-}6)$$

where V_s = storage volume, m^3

Q_w = average daily flow during winter, m^3/d

D_w = number of days in winter period

A_s = slope area,

L_{ww} = hydraulic loading rate during winter, cm/d

D_{aw} = number of operating days in winter period

The duration of the reduced loading period at existing systems generally has been about 90 days.

Unless the winter storage reservoir is an integral part of the preapplication treatment system, the winter storage reservoir should be bypassed during the warm season operation to minimize algae production in the applied wastewater and to minimize energy costs for prestorage treatment. Stored water should be blended with fresh incoming wastewater before application on the OF slopes.

6.5.2 Storage for Stormwater Runoff

In some cases, discharge permits may allow discharge of stormwater runoff from the OF system but require monthly mass discharges for certain constituents to be within specified limits. In such cases, stormwater runoff may need to be stored and discharged at a later time when mass discharge limits would not be exceeded. A procedure for estimating storage requirements for stormwater runoff is outlined below.

1. Determine the maximum monthly mass discharge allowed by the permit for each regulated constituent.

2. Determine expected runoff concentrations of regulated constituents under normal operation (no precipitation).

3. Estimate monthly runoff volumes from the system under normal operation by subtracting estimated monthly ET and percolation losses from design hydraulic loading.

4. Estimate the monthly mass discharge under normal operation by multiplying the values from Steps 2 and 3.

5. Calculate the allowable mass discharge of regulated constituents resulting from storm runoff by subtracting the estimated monthly mass discharge in Step 5 from the permit value in Step 1.

6. Assuming that storm runoff contains the same concentration of constituents as runoff during normal operation, calculate the volume of storm runoff required to produce a mass discharge equal to the value in Step 5.

7. Estimate runoff as a fraction of rainfall for the particular site soil conditions. Consult the local SCS office for guidance.

8. Calculate the total rainfall required to produce a mass discharge equal to the value in Step 5 by dividing the value in Step 6 by the value in Step 7.

9. Determine for each month a probability distribution for rainfall amounts and the probability that the rainfall amount in Step 8 will be exceeded.

10. In consultation with regulatory officials, determine what probability is an acceptable risk before storm runoff storage is required and use this value (P_d) for design.

11. Storage must be provided for those months in which total rainfall probability exceeds the design value (P_d) determined in Step 10.

12. Determine the change in storage volume each month by subtracting the allowable runoff volume in Step 6 from the runoff volume expected from rainfall having an occurrence probability of P_d. In months when the expected storm runoff exceeds the allowable storm runoff, the difference will be added to storage. In months when allowable runoff exceeds expected runoff, water is discharged from storage.

13. Determine cumulative storage at the end of each month by adding the change in storage during one month to the accumulated quantity from the previous month. The computation should begin at the start of the wettest period. Cumulative storage cannot be less than zero.

14. The required storage volume is the largest value of cumulative storage. The storage volume must be adjusted for net gain or loss due to precipitation and evaporation (see Section 4.6.3).

If stored storm runoff does not meet the discharge permit concentration limits for regulated constituents, then the stored water must be reapplied to the OF system. The amount of stored storm runoff is expected to be small relative to the total volume of wastewater applied, and therefore, increases in slope area should not be necessary. The additional water volume can be accommodated by increasing the application period as necessary.

6.5.3 Storage for Equalization

From a process control standpoint it is desirable to operate an OF system at a constant application rate and application period. For systems that do not have storage facilities for other reasons, small equalizing basins can be used to even out flow variations that occur in municipal wastewater systems. A storage capacity of 1 day flow should be sufficient to equalize flow in most cases. The surface area of basins should be minimized to reduce intercepted precipitation. However, an additional half day of storage can be considered to hold intercepted precipitation in wet climates.

For systems providing only screening or primary sedimentation as preapplication treatment, aeration should be provided to keep the basin contents mixed and prevent anaerobic odors.

The added cost of aeration, in most cases, will be offset by savings resulting from reduced pump sizes and peak power demands. The designer should analyze the cost effectiveness of this approach for the system in question.

6.6 Distribution

Wastewater distribution onto OF slopes can be accomplished by surface methods, low pressure sprays, and high pressure impact sprinklers. The choice of system should be based on the following factors:

1. Minimization of operational difficulties, such as

    - Uneven wastewater distribution onto the slopes and the creation of short-circuiting and channeling

    - Solids accumulation at the point of application

    - Physical damage due to maintenance activities and freezing

2. Capital, operating, and energy costs

6.6.1 Surface Methods

Surface distribution methods include gated aluminum pipe commonly used for agricultural irrigation (Section 4.7.2), and slotted or perforated plastic pipe. Commercially available gated pipe can have gate spaces ranging from 0.6 to 1.2 m (2 to 4 ft) and gates can be placed on one or both sides of the pipe (see Figure 6-2). A 0.6 m (2 ft) spacing is recommended to provide operating flexibility. Slide gates rather than screw adjustable orifices are recommended for wastewater distribution. Gates can be adjusted manually to achieve reasonably uniform distribution along the pipe. However, the pipe should be operated under low pressure, 1.5 to 3.5 N/cm (2 to 5 $lb/in.^2$), to achieve good uniformity at the application rates recommended in Table 6-5, especially with long pipe lengths. Pipe lengths up to 520 m (1,700 ft) have been used, but shorter lengths are recommended. For pipe lengths greater than 100 m (300 ft), inline valves should be provided along the pipe to allow additional flow control and isolation of pipe segments for separate operation.

FIGURE 6-2
SURFACE DISTRIBUTION USING GATED PIPE FOR OF

Slotted or perforated plastic pipe have fixed openings at intervals ranging from 0.3 to 1.2 m (1 to 4 ft). These systems operate under gravity or very low pressure and the pipe must be level to achieve uniform distribution. Consequently, such methods should be considered only for small systems having relatively short pipe lengths that can be easily leveled.

The principal advantages of surface systems are low capital cost and low energy consumption and power costs. The major disadvantage with surface systems is the tendency of discharge orifices to accumulate debris and become partially plugged; Consequently, orifices must be inspected regularly and cleaned as necessary to maintain proper distribution. Another disadvantage of surface systems is the potential for deposition of solids at the point of application when treating wastewaters with high concentrations of suspended solids. Deposition problems have not been reported with surface distribution systems applying municipal wastewater, either screened raw or primary effluent, at conventional hydraulic loading rates and application rates. However, solids buildup has occurred when applying food processing wastewater with solids concentrations >500 mg/L.

6.6.2 Low Pressure Sprays

Low pressure, 10 to 15 N/cm^2 (15 to 20 $lb/in.^2$), fan spray nozzles mounted on fixed risers that distribute wastewater across the top of the slope have been used successfully with stabilization pond effluent (see Figure 6-3). However, experience using this method for screened raw wastewater has been mixed. Preapplication treatment with fine screens is essential for this method to be used with raw wastewater or primary effluent.

FIGURE 6-3
DISTRIBUTION FOR OF USING LOW PRESSURE FAN SPRAY NOZZLES

Low pressure fan nozzles mounted on rotating booms were used previously but found to require too much maintenance to be practical.

6.6.3 High Pressure Sprinklers

High pressure, 35 to 55 N/cm^2 (50 to 80 lb/in. 2), impact sprinklers have been used successfully with food processing wastewaters containing suspended solids concentrations >500 mg/L. The position of the impact sprinkler on the slope depends on whether the sprinkler rotation is fullcircle or half-circle and on the configuration of the slopes. Several possible sprinkler location configurations are illustrated in Figure 6-4. With configuration (a), slope lengths in the range of 45 to 60 m (150 to 200 ft) are required to prevent spraying into runoff channels and to provide some downslope distance beyond the spray pattern. Use of half-circle sprinklers, configurations (c) and (d), or full-circle sprinkler in configuration (b) allows the use of slope lengths less than 45 m (Section 6.4.6).

The spacing of the sprinkler along the slope depends on the design application rate and must be determined in conjunction with the sprinkler discharge capacity and the spray diameter. The relationship between OF application rate and sprinkler spacing and discharge capacity is given by the following equation:

$$q = \frac{(Q_s)(10^{-3}\ m^3/L)(3{,}600\ s/h)}{(S_s)} \qquad (6\text{-}7)$$

where q = OF application rate, $m^3/h \cdot m$

Q_s = sprinkler discharge rate, L/s

S_s = sprinkler spacing, m

The sprinkler spacing should allow for some overlap of spray diameters. A spacing of about 80% of the spray diameter should be adequate for OF. Using the design OF application rate and the above criteria for spray diameter, a sprinkler can be selected from a manufacturer*s catalog. Sprinkler selection is discussed in Appendix E. Application rate can be adjusted by regulating the sprinkler operating pressure.

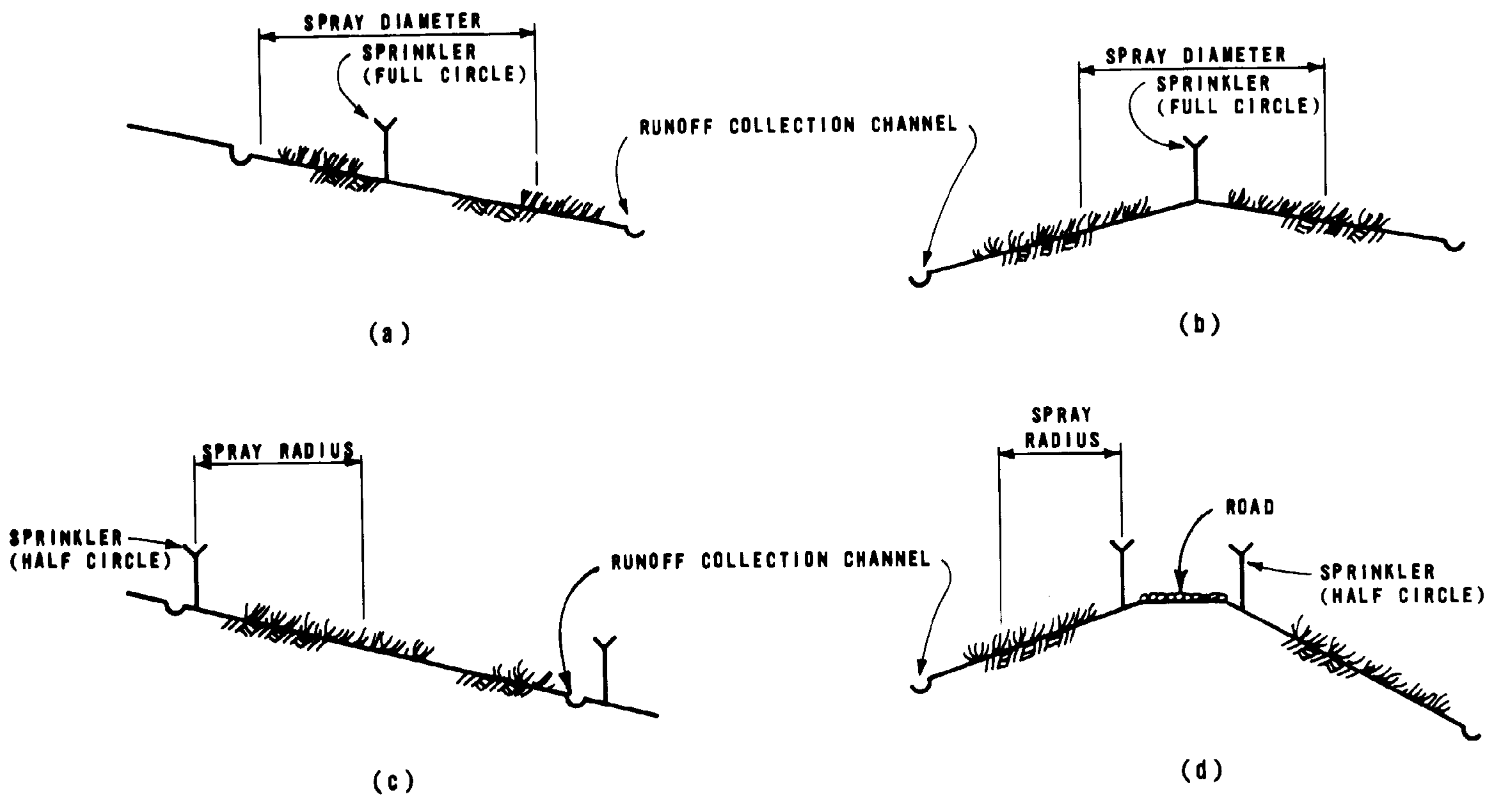

FIGURE 6-4
ALTERNATIVE SPRINKLER CONFIGURATIONS
FOR OVERLAND FLOW DISTRIBUTION

Sprinkler distribution systems are capable of providing a uniform distribution across the slope and distributing a high solids load over a large area to avoid accumulation. Operator attention requirements are expected to be less with sprinkler systems than with surface systems. Disadvantages associated with sprinkler distribution include relatively high capital costs, high energy requirements, and potential short—circuiting due to wind drift of sprays. Preapplication treatment must be sufficient to prevent nozzle clogging (Section 6.3).

6.6.4 Buried Versus Aboveground System

Low pressure sprays and sprinkler systems may have either aboveground or buried piping. Surface piping generally has a lower capital cost, but buried pipe has a longer service life and is not as susceptible to damage from freezing or harvesting equipment.

6.6.5 Automation

Both gravity and pressure distribution systems can be automated to any degree that is desired. The value of automation increases with the size of the system. The components required to effectively automate an OF system are relatively simple and trouble-free. Care should be exercised to avoid over-designing an automatic control system. The primary objective is to allow the operator to program any portion of the system to operate at any time for any length of time. Pneumatically or hydraulically operated diaphragm valves, tied into a centrally located control station, are commonly used. A clock-timer system coupled with a liquid level controller for the pumping system is usually adequate to provide a satisfactory control system.

6.7 Vegetative Cover

6.7.1 Vegetative Cover Function

A close growing grass cover crop is essential for efficient performance of OF systems. The cover crop serves the following functions in the process.

1. Erosion protection — crop provides surface roughness which acts to spread the water flow over the surface and reduces the velocity of surface flow thus helping to prevent channeling.

2. Support media for microorganisms - the biological slime layer that develops on the slope surface is supported by the grass shoots and vegetative litter.

3. Nutrient uptake - crop takes up nitrogen and phosphorus which can be removed by harvesting.

6.7.2 Vegetative Cover Selection

An OF cover crop should have the following characteristics: perennial grasses; high moisture tolerance; long growing season; high nutrient uptake; and suited for the local climate and soil conditions.

A mixture of grasses is generally preferred over a single species. The mixture should contain grasses whose growth characteristics compliment each other, such as sod farmers and bunch grasses and species that are dormant at different times of the year. Another advantage of using a mixture is that, due to natural selection, one or two grasses will often predominate. One particular mixture which has been found to be quite successful is Reed canarygrass, tall fescue, redtop, dallisgrass, and ryegrass. In northern climates, substitution of orchardgrass for the redtop and dallisgrass is suggested. Although this mixture has proven effective in a variety of climates, it is always best to consult with a local agricultural advisor when selecting a seed mix to meet the criteria given above.

Salt sensitive plants, such as most varieties of clover, should be avoided. Pure stands of grasses whose growth characteristics are dominated by a single seed stalk such as Johnson grass, yellow foxtail, and most of the grains should be avoided. In the early stages of growth, these grasses provide a quick and effective cover. However, as the plant matures, the bottom leaves wither and disappear, leaving only the primary seed stalk which eventually produces the grain crop. When this happens, the value of these crops as OF cover vegetation is greatly reduced. Of course, crops having low moisture tolerance, such as alfalfa, should not be used.

6.8 Slope Construction

6.8.1 System Layout

The general arrangement of individual slopes should be such that gravity flow from the slopes to the runoff collection channels and finally to the main collection channels will be possible. A grading plan should be prepared that will minimize earthwork costs. Criteria for selecting slope grades are given in Section 6.4.7. From an operational standpoint, it is preferable to have the grading plan result in a single final discharge point, occasionally, however, existing terrain features will make a single point discharge impractical. In such cases, it is usually more cost effective to create multiple discharge points (and monitoring stations) rather than attempt to overcome the terrain constraints with extensive earthwork.

6.8.2 Grading Operations

Since the principle of smooth sheet flow down the slope is of critical importance to consistent OF process performance, appropriate emphasis must be placed on the proper construction of the slopes. Naturally occurring slopes, even if they are within the required length and grade range, seldom have the uniform overall smoothness required to prevent channeling, short-circuiting, and ponding. Therefore, it is necessary to completely clear the site of all vegetation and to regrade it into a series of OF slopes and runoff collection channels. The first phase of the grading operation is commonly referred to as rough grading and should be accomplished within a grade tolerance of 3 cm (0.1 ft). If a buried distribution system is being used, the rough grading phase is generally followed by the installation of the distribution piping and appurtenances.

After the slopes have been formed in the rough grading operation, a farm disk should be used to break up the clods, and the soil should then be smoothed with a land plane (see Figure 6-5). Usually, a grade tolerance of plus or minus 1.5 cm (0.05 ft) can be achieved with three passes of the land plane. Surface distribution piping may be installed at this stage.

Soil samples of the regraded site should be taken and analyzed by an agricultural laboratory to determine the amounts of lime and fertilizer that are needed. The appropriate quantities should then be added prior to seeding. A light disk should be used to eliminate any wheel tracks on the slopes as final preparation for seeding.

6.8.3 Seeding and Crop Establishment

It has been found that a Brillion seeder is capable of doing an excellent job of seeding the slopes. The Brillion seeder carries a precision device to drop seeds between cultipacker-typer rollers so that the seeds are firmed into shallow depressions, allowing for quick germination and protection against erosion. Hydroseeding may also be used if the range of the distributor is sufficient to provide coverage of the slopes so that the vehicle does not have to travel on the slopes. When seeding is completed, regardless of the means, there should be no wheel tracks on the slopes.

FIGURE 6-5
LAND PLANE USED FOR FINAL GRADING

It is important to establish a good vegetative cover prior to applying wastewater to the slopes. Good planning will minimize the effort and cost required to achieve this. The construction scheduling should be organized so that the seeding operation is accomplished during the optimum periods for planting grass in the particular project locality. This is generally sometime during the fall or spring of each year. During these periods, sufficient natural precipitation is often available to develop growth. In arid and semiarid climates or whenever seed is planted during a dry period, it may be necessary to irrigate the site with fresh water, if wastewater is unavailable, to establish the grass crop. In these cases, a portable sprinkler irrigation system should be used to provided irrigation water coverage over the entire slope area, since use of the OF distribution system would cause erosion of the bare slopes. It may be necessary to sow additional seed or to repair erosion that may occur as a result of heavy rains prior to the stabilization of the slopes.

As a general rule, wastewater should not be applied at design rates until the crop has grown enough to receive one cutting. Cut grass from the first cutting may be left on the slope to help build an organic mat as long as the clippings are short

(0.3 m or 1 ft); long clippings tend to remain on top of the cut grass thus shading the surface and retarding regrowth.

6.9 Runoff Collection

The purpose of the runoff collection channels is to transport the treated runoff and storm runoff to a final discharge point and allow runoff to flow freely off the slopes. The collection channels are usually vegetated with the same species of grasses growing on the slopes and should be graded to prevent erosion. There are some cases, however, where additional construction is necessary. Sharp bends or steep grades along runoff channels will increase the potential for erosion, and it may be necessary to provide additional protection in the form of riprap, concrete, or other stabilizing agent at these points. Runoff channels should be graded to no greater than 25% of the slope grade to prevent cross flow on the slope.

In humid regions, particularly where the topography is quite flat and the runoff channels have small grades, grass covered channels may not dry out entirely. This may increase channel maintenance problems and encourage mosquito populations. In these cases, concrete or asphalt can be used or a more elaborate system involving porous drainage pipe lying in the channel beneath a gravel cover. It should be emphasized, however, that it is usually not necessary to go to these lengths to obtain free-flowing yet erosion-protected runoff channels. Small channels are normally Vshaped, while major conveyance channels have trapezoidal cross–sections.

In addition to transporting treated effluent to the final discharge point, the runoff channels must also be capable of transporting all stormwater runoff from the slopes. The channels should be designed, as a minimum, to carry runoff from a storm with a 25 year return frequency. Both intensity and duration of the storm must be considered. A frequency analysis of rainfall intensity must be performed and a rainfall-runoff relationship developed to estimate the flowrate due to storm runoff that must be carried in the channels. The local SCS office can provide assistance in performing this design. References [12, 13] can also be consulted. In some cases, it may be desirable to provide a perimeter drainage channel around the OF site to exclude offsite stormwater from entering the OF drainage channels.

6.10 System Monitoring and Management

The primary objective of the OF system is to produce a treated effluent that is within the permit requirements. Therefore, a monitoring program and a preventive maintenance program are necessary to ensure continued compliance with discharge requirements.

6.10.1 Monitoring

6.10.1.1 Influent and Effluent

The influent and effluent monitoring requirements will usually be dictated by the discharge permit established for the system by the regulatory authorities. An open channel flow measuring device (Parshall flume, weir, etc.) equipped with a continuous flow recorder is generally satisfactory for monitoring the treated effluent. Most types of portable or permanent automatic samplers can be used for sampling.

6.10.1.2 Ground Water

The need to install ground water monitoring wells will generally be determined by the regulatory authorities. In certain cases, the authorities will also establish the number and location of monitoring wells. If those decisions are left to the designer, however, it is advisable to consider a minimum of two ground water monitoring wells, one located upstream of ground water movement through the treatment site which will serve as a background well, and the second immediately downstream from the site to show any impacts from the treatment operation.

6.10.1.3 Soils and Vegetation

Suggested monitoring programs for soils and vegetation given in Sections 4.10.2 and 4.10.3 for SR systems are also applicable to OF systems. If the vegetation on the treatment site is harvested and used for fodder, samples may be taken at each harvest and analyzed for various nutritive parameters such as percent protein, fiber, total digestible nutrients, phosphorus, and dry matter.

6.10.2 System Management

6.10.2.1 Operation and Maintenance

Process control involves regulating the distribution system to provide design application rates and application periods, and adding water to and releasing water from storage at the appropriate times (see Section 6.4 and 6.5). A routine operation and maintenance schedule should be followed including a daily inspection of system components (pumps, valves, sprinklers, distribution orifices on surface systems, flowmeters). Application rates and periods should be checked and maintained within design limits.

6.10.2.2 Crop Management

After the cover crop has been established, the slopes will need little, if any, maintenance work. It will, however, be necessary to mow the grass periodically. A few systems have been operated without cutting, but the tall grass tends to interfere with maintenance operations. Normal practice has been to cut the grass two or three times a year. As mentioned previously, the first cutting may be left on the slopes. After that, however, it is desirable to remove the cut grass. The advantages of doing so are that additional nutrient removal is achieved, channeling problems may be more readily observed, and revenue can sometimes be produced by the sale of hay. Depending on the local market conditions, the cost of harvesting can at least be offset by the sale of hay.

Slopes must be allowed to dry sufficiently such that mowing equipment can be operated without leaving ruts or tracks that will later result in channeling of the flow. The drying time required before mowing varies with the soil and climatic conditions and can range from a few days to a few weeks. The downtime required for harvesting can be reduced by a week or more if green-chop harvesting is practiced instead of mowing, raking, and baling. However, local markets for green-chop must exist for this method to be feasible.

It is common for certain native grasses and weeds to begin growing on the slopes. Their presence usually has little impact on treatment efficiency and it is generally not necessary to eliminate them. However, there are exceptions and the local extension services should be consulted for advice.

Proper management of the slopes and the application schedule will prevent conditions conducive to mosquito breeding. Other insects are usually no cause for concern, although an invasion of certain pests such as army worms may be harmful to the vegetation and may require periodic insecticide application.

6.11 Alternative Design Methods

Recently, two rational methods have been developed for determining OF design criteria. One, based on detention time on the slope, was developed at the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) [14]. The other, based on slope distance and application rate was developed at the University of California, Davis [15] . Both approaches have been validated with results from other studies and have been used for preliminary or pilot scale design of OF systems. A design example comparing the traditional empirical approach with these two methods can be found in Appendix C.

6.11.1 CRREL Method

6.11.1.1 Method Description

The basis of the CRREL method is a relationship between detention time and mass BOD reduction using performance data from the CRREL system, and validated with data from the Utica and University of California, Davis, systems. With this relationship, the required detention time can be calculated for a specified mass BOD reduction. This detention time is then used in an equation which relates detention time, slope length, and slope grade to application rate. Thus, for an OF slope with a given length and grade, the required application rate can be determined for a specified detention time or, indirectly, for a specified BOD reduction. The application rate is then used to calculate. the required land area.

6.11.1.2 Design Procedure

1. Calculate detention time.

The relationship between detention time and mass BOD reduction is expressed as:

$$E = (1 - Ae^{-Kt})100 \qquad (6\text{-}8)$$

where E = percent mass BOD removal

A = nonsettleable fraction of BOD in applied wastewater (constant = 0.52)

K = average kinetic rate constant (0.03 min^{-1})

t = detention time, min

2. Calculate average OF rate.

The average OF rate needed to obtain this required detention time is calculated using the following equation:

$$q = (0.078S)/(G^{1/3}t) \tag{6-9}$$

where q = average OF flowrate $(q_{applied} + q_{runoff})^{½}$, $m^3/h\text{~}m$ of slope width

S = length of section, m

G = slope of section, m/m

t = detention time, min

To use Equation 6-9, section length (S) and section slope (G) must first be determined by an investigation of the proposed site. This investigation should yield a section with length and width dimensions and with a specific section slope which will be used when determining area requirements. Actually, more than one section size can be selected if the topography of the site is such that less land forming would be required if the site were not composed of uniform sections. Equation 6-9 would then be used with the parameters from each section to determine the average OF rate for each section.

3. Calculate application rate.

The following equation is used to determine the application rate for each section:

$$Q = qw/r \tag{6-10}$$

where Q = application rate, m^3/h per section

q = average OF flowrate $[q_{applied} + q_{runoff}]^{]/2}$, $m^3/h{\cdot}m$

w = width of section, m

r = (1.0 + runoff fraction)/2

The runoff fraction is the fraction of the applied wastewater which reaches the runoff collection ditches. The runoff fraction must be assumed in order to use Equation 6-10. The runoff fraction ranges from 0.6 to 0.9 depending on the permeability of the soil and evaporation losses.

4. Calculate annual loading rate.

The annual loading rate (m^3 /yr) must be determined for each section. To do this, the number of days of application per year must be calculated and the application period must be selected. Given these values and the loading rates, the annual loading rates for each section can be calculated.

5. Calculate total annual water volume.

An estimate of the volume of precipitation minus evapotranspiration that will collect in the storage or preapplication treatment basin must be made and added to the annual wastewater volume to obtain the total annual water volume.

6. Calculate land area requirements.

The number of sections are calculated using the total annual water volume and annual application rate to each section. However, the number of sections of a particular size may be determined by physical constraints at the site. The land requirement is now calculated by multiplying the number of sections of each particular size by its area.

6.11.2 University of California, Davis, (UCD) Method

6.11.2.1 Method Description

The basis for the UCD method is a model which describes BOD removal as a function of slope length and application rate, where the application rate has the units m /hm of slope width. This model was developed using performance data from the UCD system and was substantiated using data from the CRREL system. By knowing the influent BOD requirements, the model can predict either the required slope length or application rate, once the other parameter has been fixed. Once both parameters are known and a design daily flowrate is given, the area requirements can be determined.

6.11.2.2 Design procedure

1. Determine slope length or application rate.

Either slope length or application rate can be calculated, once the other parameter has been fixed, using the following equation:

$$C_s/C_o = A_e[(-KS)/(q^n)] \qquad (6\text{-}11)$$

where C_s = concentration BOD at point S, mg/L

C_0 = initial BOD concentration, mg/L

A = constant = 0.72

K = rate coefficient (constant = 0.01975 m/h)

S = distance downslope, m

q = application rate, $m^3/h \cdot m$ slope width

n = exponent (constant = 0.5)

Site conditions may dictate the allowable slope length, in which case slope length would be the independent parameter and application rate would be the computed parameter. If slope length is not restricted, then application rate should be used as the independent parameter. Currently, the model is valid in the range of 0.08 to 0.24 $m^3/h \cdot m$ and so the application rate selected for a design should be within this range.

The effect of water loss due to evaporation and percolation is incorporated into the rate coefficient (K). Significant changes in the value of K are not expected as a result of changes in water losses normally experienced with OF systems. Additional field testing is necessary to confirm this.

2. Select an application period.

See Section 6.4.4 for a discussion on selecting an application period.

3. Compute the average daily flow to OF system.

To compute the average daily flowrate, the application season (days of application per year) must be calculated. Also, the volume of precipitation minus evapotranspiration that will collect in the storage basin or preapplication treatment basin must be estimated. With this information and the average daily wastewater flowrate, the average daily flow to the OF system can be calculated.

4. Compute the required wetted area.

The wetted area is computed using the following equation:

$$\text{Area} = QS/qP \qquad (6\text{-}12)$$

where Q = average daily flow to the OF system, m^3/d

S = slope length, m

q = application rate, $m^3/h\cdot m$

P = application period, h/d

6.11.3 Comparison of Alternative Methods

Although the CRREL and UCD equations appear different, the basic approach and calculation method are quite similar. Combining and rearranging Equations 6-8 and 6-9 from the CRREL method produces:

$$M_s/M_o = 0.52e(-0.00234S)/(G^{1/3}q) \qquad (6\text{-}13)$$

where M_s = mass of BOD at point S, kg

M_o = ass of BOD at top of slope, kg

S = slope length, m

G = slope grade, m/m

q = average overland flow, $m^3/h\cdot m$

This is quite similar to the UCD Equation 6-11:

$$C_s/C_o = 0.72e(-0.0l975S/q^{0.5}) \qquad (6\text{-}14)$$

All terms are defined previously.

The major differences in these two rational approaches are:

1. Use of slope grade as a variable in CRREL equation and not in UCD equation.

2. Use of mass units in CRREL equation and concentration units in UCD equation.

3. Value of exponents and coefficients.

6.12 References

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