DEPARTMENT OF THE ARMY
U. S. Army Corps of Engineers
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Engineer Manual
No. 1110-2-504

30 November 1983

Engineering and Design
LAND TREATMENT SYSTEMS
OPERATION AND MAINTENANCE

1. Purpose. This manual has two basic purposes. It can be used by the operators of existing and future systems to supplement the operation and maintenance (O&M) information furnished to them on the mechanical elements in their systems. It can also be used as a guide for the preparation of future O&M manuals.

2. Applicability. This manual applies to all field operating activities having civil works design responsibilities.

3. General. This manual presents general guidance for the preparation of site-specific operation and maintenance manuals for the basic land treatment systems used to treat wastewaters, and to supplement O&M information already provided for existing systems.

FOR THE COMMANDER:

PAUL F. KAVANAUGH
Colonel, Corps of Engineers
Chief of Staff

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CHAPTER 1
INTRODUCTION

1-1. General. This manual presents general guidance for the preparation of site-specific operation and maintenance (O&M) manuals for the basic land treatment systems used to treat wastewaters, and to supplement O&M information already provided for existing systems. There are three basic systems that differ in the rate at which water is applied and in the flow path of that water after application. These systems are as follows.

a. Slow rate. This type of system is similar to conventional agricultural irrigation practice. Wastewater is applied to an area covered by vegetation. The vegetation is an essential component in the system and the applied wastewater is treated as it trickles down through the soil and the root zone of the crop. A typical loading for a site in the northern U.S. might be about 2-1/2 million gallons of wastewater per year per acre. Chapter 2 provides additional details on the process and necessary site conditions.

b. Overland flow. In this type of system, wastewater is applied at the top of gently sloping grassed fields. The surface has been smoothed during construction so the wastewater flows down the slope in a shallow sheet to collection ditches at the toe. The soils are usually clays or other impermeable types. The wastewater is treated as a result of contact between it and the grasses, the soil surface and the organic mat on the slope. Annual loading for a site in the northern U.S. might be about 5 million gallons of wastewater per year per acre. Chapter 3 provides additional details on the process.

c. Rapid infiltration. This type of system uses flooding of open basins in sandy soils. Vegetation in the basins is not necessary for treatment. The wastewater is treated as it percolates through the upper soil layers. A typical loading for a site in the northern U.S. might be about 32 million gallons per year per acre. Chapter 4 provides additional details on the process.

1-2. Purpose and scope. This document has two basic purposes. It can be used by the operators of existing and future systems to supplement the O&M information furnished to them on the mechanical elements in their systems. It can also be used as a guide for the preparation of future O&M manuals. The writer of the O&M manual can take the necessary chapters from this document and add them to the specific information on operation and maintenance of the equipment involved. Operators of existing systems only need to be concerned with those chapters covering the type of process they are responsible for. The types of equipment that can be used and the possible combinations are almost infinite, so this document cannot possibly cover all of that material. This manual does provide the fundamental procedures that are common to the basic land treatment systems. Special conditions that are unique to a single site are also beyond the scope of this document and must be included in portions of the site-specific O&M manual. There is some duplication in this document between the technical chapters because there are common elements in the various processes and each chapter is intended to stand independently. The operators and future manual writers using this document should be primarily concerned with the chapter describing the process of interest to them and appendix A. However, chapter 2 does contain the most detail on monitoring procedures that may also be applicable to the other systems, so these sections should be consulted if monitoring is an issue of concern.

1-3. Definitions.

Acre-foot — A liquid measure of a volume equal to covering a 1-acre area to 1-foot of depth.

Aerosol — A suspension of colloidal solid or liquid particles in air or gas, having small diameters ranging from 0.01 to 50 microns.

Aquiclude — A geologic formation which, although porous and capable of absorbing water slowly, will not transmit it rapidly enough to furnish an appreciable supply for a well or spring.

Available moisture — The part of the water in the soil that can be taken up by plants at rates significant to their growth; the moisture content of the soil in excess of the ultimate wilting point.

Available nutrient — That portion of any element or compound in the soil that can be readily absorbed and assimilated by growing plants. ("Available" should not be confused with exchangeable.)

Evapotranspiration — The combined loss of water from a given area and during a specified period of time by evaporation from the soil surface, snow or intercepted precipitation, and by plant transpiration and tissue building.

Field area — The "wetted area" where treatment occurs in a land application system.

Field capacity (field moisture capacity) — The moisture content of soil in the field 2 or 3 days after saturation and after free drainage has practically ceased; the quantity of water held in a soil by capillary action after the gravitational or free water has been allowed to drain; expressed as moisture percentage, dry weight basis.

Fragipan — A loamy, dense, brittle subsurface horizon that is very low in organic matter and clay but is rich in silt or very fine sand. The layer is seemingly cemented and slowly or very slowly permeable.

Horizon (soil) — A layer of soil, approximately parallel to the soil surface, with distinct characteristics produced by soil-forming processes.

Infiltrometer — A device by which the rate and amount of water infiltration into the soil is determined (cylinder, sprinkler or basin flooding).

Lysimeter — A device for measuring percolating and leaching losses from a column of soil. Also a device for collecting soil water in the field.

Micronutrient — A chemical element necessary in only trace amounts (less than 1 mg/L) for microorganism and plant growth. Essential micronutrients are boron, chloride, copper, iron, manganese, molybdenum and zinc.

Mineralization — The conversion of a compound from an organic form to an inorganic form as a result of microbial decomposition.

Sodic soil — A soil that contains sufficient sodium to interfere with the growth of most crop plants, and in which the exchangeable sodium percentage is 15:1 or more.

Soil water — That water present in the soil pores in an unsaturated (aeration) zone above the groundwater table. Such water may either be lost by evapotranspiration or percolation to the groundwater table.

Tensiometer — A device used to measure the negative pressure (or tension) with which water is held in the soil; a porous, permeable ceramic cup connected through a tube to a manometer or vacuum gauge.

Till — Deposits of glacial drift laid down where the glacier melts, consisting of a heterogeneous mass of rock flour, clay, sand, pebbles, cobbles and boulders intermingled in any proportion; the agricultural cultivation of fields.

Tilth — The physical condition of a soil as related to its ease of cultivation. Good tilth is associated with high noncapillary porosity and stable, granular structure, and low impedance to seedling emergence and root penetration.

Transpiration — The net quantity of water absorbed through plant roots that is used directly in building plant tissue or given off to the atmosphere as a vapor from the leaves and stems of living plants.

Volatilization — The evaporation or changing of a substance from liquid to vapor.

Wilting point — The minimum quantity of water in a given soil necessary to maintain plant growth. When the quantity of moisture falls below this, the leaves begin to drop and shrivel up.

CHAPTER 2
SLOW RATE SYSTEMS

Section I. Process Description

2-1. Introduction. Slow rate land treatment is the controlled application of wastewater to a vegetated land surface. A portion of the flow is used by the vegetation and the remainder percolates below the root zone into deeper soil layers or the groundwater table. The wastewater is treated as it passes through the topsoil, the root zone and the deeper soil layers. When the groundwater is a drinking water aquifer, the system is designed and operated so that drinking water standards can be maintained at the project boundaries. Slow rate systems resemble conventional irrigation both in layout and operation. Sprinkler units can be fixed risers or moving systems such as center pivot rigs. Surface application techniques include ridge and furrow, and border strip flooding. Slow rate systems are the most common type in use at Corps of Engineers facilities. Table 2-1 summarizes the typical site characteristics, design features and performance expectations from slow rate land treatment. Figure 2-1 illustrates the various hydraulic pathways in slow rate systems.

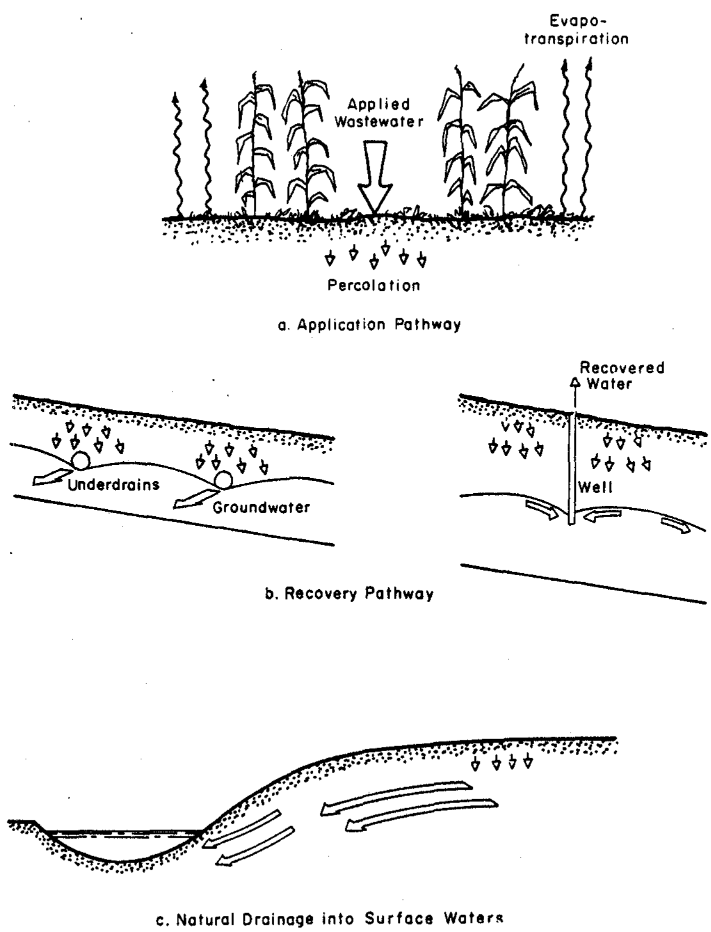


Figure 2-1. Slow rate hydraulic pathways.

Table 2-1. Typical characteristics of slow rate land treatment systems.

Site characteristics

Grade	Less than 20% on cultivated land; less than 40% on uncultivated land.
Soil permeability	Moderately slow to moderately rapid.
Depth to groundwater	2-3 feet (minimum).[a]
Climatic restrictions	Storage often needed for cold weather and during heavy rainfall.

Design features

Application method	Sprinkler or surface flooding
Annual loading rate (feet)	1.5 to 20 = (11-150 gal./ft^2 per year)
Field area required (acres)[b]	60 to 700
Typical weekly loading (inches)	0.5 to 25
Minimum preapplication treatment in the U.S.	Primary[c]
Vegetation	Required

Expected percolate quality

	Average	Upper range
BOD (milligrams per litre [mg/L])	<2	<5
Suspended solids (mg/L)	<1	<5
Ammonia nitrogen (as N) (mg/L)	<0.5	<2
Total nitrogen (as N) (mg/L)	3[d]	<8[d]
Total phosphorus (as P) (mg/L)	<0.1	<0.3
Fecal coliforms (no./100 mL)	0	<10

a Underdrains often used at sites with high natural groundwater to maintain this level, see figure 2-1.

b Field area is that part of system actually wetted by applied wastewater, it does not include buffer area, roads or ditches. The acres shown are for a typical 1 million-gallon-per-day system.

c Use of primary wastewater requires restriction of public access to site and production of crops not used directly by people.

d Percolate concentration will depend on amount in applied wastewater and type of vegetation used in the system.

2-2. Hydraulic loading.

a. It is typical for most waste treatment processes to be described in terms of the flow volume per unit of time, such as cubic meters per second or gallons per minute, etc. The loadings on the process units are then often defined as that volume divided by the surface area of the tank or pond (i.e. gallons per square foot per day). Slow rate land treatment is different, however. Since it is related to conventional irrigation practice it is typical to describe wastewater loadings in terms of the depth of water applied over the treatment surface area during the time under discussion. These loading units are still in essence the more familiar volume of flow (cubic feet [ft^3]) divided by the surface area involved (square feet [ft^2]) to give the units of depth ($ft^3 \div ft^2 = ft$). As shown in table 2-1 a typical system might apply 3 metres (9.8 feet) of water per year on a field. Conversion to more familiar terms is relatively easy since:

- 1 centimetre (cm) of water on 1 hectare (ha) = 100 cubic metres (m^3)
- 1 metre (m) of water on 1 hectare = 10,000 cubic metres
- 1 inch (in.) of water on 1 acre = 27,152 gallons (gal.)
- 1 foot (ft) of water on 1 acre = 325,829 gallons

So, a loading of 3 metres per year would be equal to 30,000 cubic metres per hectare per year, or 3,207,133 gallons per acre per year, or 73.6 gallons per square foot per year.

b. It is also typical for most community waste treatment systems to be in use 24 hours a day, 365 days per year. This is not true for the land treatment portion of slow rate systems. The site is usually divided into subareas and the application is frequently rotated between fields. A particular subarea might then only receive wastewater a few hours for 1 day each week. Systems in extreme climates might shut down completely for several weeks in the winter and store the wastewater in a pond during that period. If a 10-foot per year system were operated 52 weeks per year the average weekly loading would be:

$$(10 \text{ ft})(12 \text{ in./ft}) \div 52 \text{ weeks} = 2.3 \text{ in./week.}$$

If the system shut down for 12 weeks per year, the operational season would be 40 weeks and the average weekly loading would have to be:

$$(10 \text{ ft})(12 \text{ in./ft}) \div 40 \text{ weeks} = 3.0 \text{ in./week.}$$

The system design might require that a particular field receive its entire weekly loading during an 8-hour (hr) period, 1 day per week. The actual application rate would then be:

$$3 \text{ in.} \div 8 \text{ hr} = 0.375 \text{ in./hr}$$

It is this final, short-term application rate that is the basis for the design of the delivery pipes and pumping systems. For example, 0.375 in./hr on a 25 acre field would require a pumping capacity of (minute [min], second [s]):

$$(0.375 \text{ in./hr}) \div (12 \text{ in./ft}) \div (60 \text{ min/hr}) \div (60 \text{ s/min}) = 0.0000087 \text{ ft/s}$$

$$(0.0000087 \text{ ft/s})\ (25 \text{ acres})\ (43{,}560 \text{ ft}^2\text{/acre}) = 9.45 \text{ ft}^3\text{/s}$$

or $(9.45 \text{ ft}^3)\ (448.8) = 4241$ gallons per minute (gpm).

c. The hydraulic pathways for the applied wastewater are illustrated in figure 2-1. The recovery or subsurface pathway used in a system is particularly important for determining monitoring requirements, which are discussed in section III.

2-3. System types and management. The type of slow rate system can range from a remote forested site with no public access to a golf course or park with daily public use. These systems can be managed by the Corps of Engineers or contract personnel, or be built by the Corps of Engineers and operated by state or local agencies. These various combinations and the critical factors to be considered for each are summarized in table 2-2. Both the type of system and the management plan are decided on during design; however, either can be changed later, so the system operator should be aware of the implications of such a change. In general, a change from

Table 2-2. Slow rate system types and management needs.

	Management needs		
System type	Corps of Engineers built and operated	Corps of Engineers built, contractor operated	Corps of Engineers, state or local agency operated
1. Forest site, remote, no public access.	Primary effluent suitable. Tree harvest program if nitrogen removal is system requirement. Operation often seasonal.	Same as Corps of Engineers operated.	Same as Corps of Engineers operated. State or local agency may have additional requirements.
2. Forest site, limited public assess for hiking, hunting, etc.	Pond effluent suitable if access limited to nonapplication season. Tree harvest program as above if needed.	Pond effluent, with fecal coliform <1000/100 mL if access not restricted during season. Otherwise same as no. 1.	Same as contractor operation with any additional state or local requirements.
3. Agricultural site, pasture with animal grazing. No public access.	Not typical for Corps of Engineers systems, could lease rights. Primary effluent suitable. Avoid dairy animals.	Pond effluent with fecal coliform <1000/100 mL since less direct control over type of animal or periods of access.	Same as contractor operation with any additional state or local requirements.
4. Agricultural site, crop production and harvest. No public access.	Not typical for Corps of Engineers systems, except lease for forage grass or hay harvest. One to three cuttings per season depending on location and climate. Primary effluent suitable.	Could be farmed by contract operator or by subcontractor; transmission of wastewater to local farmers possible. To cover all cases need pond effluent with fecal coliform <1000/100 mL. Avoid human food crops that are eaten raw.	Minimum requirements same as contractor operation. State may limit types of crop to be produced or have other restrictions.
5. Recreational site, continuous public access (golf courses, playgrounds, athletic fields, etc.).	More common in water short areas. Needs biological treatment, in pond or similar, and an oxidized, stable effluent with fecal coliform <200/100 mL.	Same as Corps of Engineers operated.	Same as Corps of Engineers operated. Additional polishing step (chemical treatment, filters, microscreens) sometimes used for consistently low suspended solids.

forest to crop production or a decision to allow public access may require higher levels of preapplication treatment and disinfection. A shift from direct Corps of Engineers operation to contract or local agency management may require similar considerations, particularly if the Corps of Engineers is still responsible for performance.

Section II. Staffing Requirements

2-4. Introduction. The number of operating personnel and the skill levels required of them will depend on the type of system (table 2-2) and on its size. Figure 2-2 presents an estimate of the personnel needs of typical slow rate land treatment systems. The figure shows the approximate number of man-hours per day for the smaller systems and the number of full-time employees required for the larger systems. These estimates are only for the land treatment portion of the system. Additional time will be required for operation and maintenance of any sewer systems, sewer system pump stations and the pretreatment processes that are used prior to land treatment. These estimates are for a "typical" system; an agricultural operation producing row crops will require more time for O&M than indicated, a forested site will require less. The time required will also vary with the equipment used. For instance, a center pivot unit would require less time than solid-set sprinklers or a surface flooding operation. The level of preapplication treatment also has an influence; the use of primary effluent will require more attention than the use of pond or secondary effluent because of sprinkler cleaning, etc.

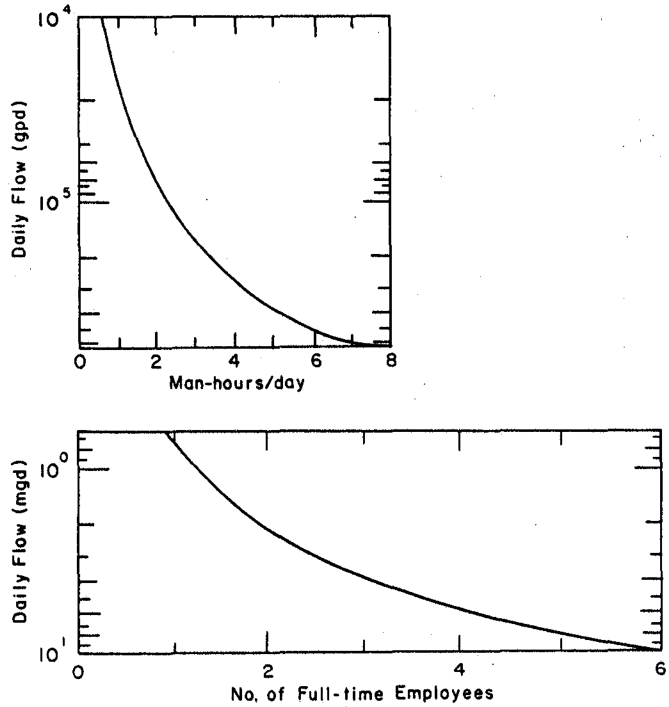


Figure 2-2. Personnel needs for land treatment portion of slow rate systems.

2-5. General skills. The general skills required for routine operation of all types of slow rate systems are essentially the same as those needed for routine operation of any simple waste treatment system. The major mechanical tasks involve operating and servicing pumps, motors and valves. The only "new" mechanical elements are center pivots or similar rigs and the sprinkler nozzles. The mechanical components of the former are all familiar (drive motors, grease fittings, etc.) and are not difficult to service. Sprinkler nozzles will require attention but manufacturer's literature provides clear instructions for servicing the type chosen for a particular project. A unique requirement for slow rate land treatment is deciding when to turn the water on and off or when to switch the application to a different part of the site. A basic program and schedule of operations will have been determined for each project during final design. However, this may require adjustment by the operator if flow increases, if a year is especially wet or dry, or if the vegetation used in the system changes. Section I of this chapter introduced the hydraulic loading concepts, section IV will present further details on specific operating procedures.

2-6. Special skills. The operator of a forested site will sometimes need expert advice to help with problems such as insect infestations or plant diseases, or to determine which trees to cull or when to clearcut. The operator of an agricultural site will require all of the farming skills normally associated with the particular activity (pastures, hay crops, row crops, etc.). Recreational sites require particular attention to water quality to maintain adequate health protection (see section III for information on monitoring). In addition, the wastewater application scheduling for recreational sites requires careful control so as not to interfere with recreational activities. That will usually involve nighttime or off-season application. Many recreational sites will include a carefully maintained turfgrass cover. The operator may need expert advice from time to time on procedures for reseeding, weed control, supplemental fertilization, etc. Most states now have licensing programs for wastewater treatment plant operators. Although these programs tend to focus on the conventional mechanical systems for wastewater treatment, it would still be beneficial, and possibly necessary, for land treatment system operators to obtain operator licenses. The training involved in these programs should help the operator to better understand the health and safety requirements of wastewater treatment as well as operation of the mechanical components common to all systems.

Section III. Process Control and Monitoring

2-7. Introduction. The information needed for operation of the system is obtained through the monitoring program. Monitoring needs can be divided into two categories. There is compliance monitoring to certify that the system is meeting the requirements of the Federal, state and local agencies that are responsible. There is also routine process monitoring to ensure that all internal components in the system are cost effective and functioning as designed. This type of monitoring is necessary even if regulatory requirements did not exist. However, it is often possible to satisfy both regulatory and operating needs at the same time if the monitoring program is carefully planned.

2-8. Compliance monitoring.

a. General. The Federal government and all states have regulations controlling discharges to surface waters. Land treatment systems with a point source discharge will require a National Pollution Discharge Elimination System (NPDES) permit from the appropriate agencies. However, not all land treatment systems have a point discharge to surface waters so an NPDES permit is not always required. Land treatment systems that collect the treated water with underdrains or wells and then discharge it to surface waters will need a permit, as will most overland flow systems (chap. 3). In general, the hydraulic pathways shown in figure 2-1b for slow rate systems will require an NPDES permit, the others will not.

(1) Although a discharge permit may not be required for the case where the treated water remains in the ground or emerges into surface water at some remote place (fig. 2-1c) these systems are not ignored by the regulatory agencies. Many states now require permits to discharge to groundwater. Their criteria range from very specific regulations that have the force of law to general guidelines that may be strongly recommended but which are more flexible in application than regulations; there are also case-by-case determinations that depend on the site conditions and operational plan of a particular system.

(2) These controls protect the health of the operators and the general public, as well as safeguard the environment. The concern goes beyond water quality and can include the type of crop to be grown, the condition of the soil and the presence of airborne aerosol particles. As a result, some agencies issue specific criteria relative to the type of system that can be operated as well as specific monitoring requirements to ensure compliance.

b. Federal guidelines. The U.S. EPA has issued guidelines for the level of preapplication treatment believed suitable for various types of land treatment systems. These guidelines are intended to protect the public health and they become more stringent as public access increases or when the crops grown enter the human food chain directly. Table 2-3 presents the U.S. EPA guidelines for all three of the major land treatment systems. The U.S. EPA does not have monitoring requirements for land treatment systems that don't have point source discharges. Generally, the normal process control monitoring (para. 2-9) that should be undertaken for all systems will be adequate to guarantee successful operation of the system.

Table 2-3. Guidance for assessing level of preapplication treatment.

Slow rate systems (reference sources include U.S. EPA water quality criteria and various state guidelines).

- Primary treatment -- acceptable for isolated locations with restricted public access and when limited to crops not eaten raw by people.

- Biological treatment by lagoons or in-plant processes plus control of fecal coliform count to less than 1000/100 mL-- acceptable for controlled agricultural irrigation, except for human food crops to be eaten raw.

- Biological treatment by lagoons or in-plant processes with additional BOD or suspended solids control as needed for aesthetics, plus disinfection to log mean of 200/100 mL (EPA fecal coliform criteria for bathing waters) -- acceptable for application in public access areas such as parks and golf courses.

Rapid-infiltration systems.

- Primary treatment -- acceptable for isolated locations with restricted public access.

- Biological treatment by lagoons or in-plant processes -- acceptable for urban locations with controlled public access.

Overland flow systems.

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

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

c. State requirements. All of the 50 states have an interest in and some level of control over the monitoring of land treatment systems, even though there is no surface discharge. Table 2-4 is a listing of the states that have monitoring criteria and the level of control that they impose (as of 1 January 1982). The monitoring requirements for a particular system will have been determined during design and will be written into the site-specific portion of the O&M manual. Where applicable, the guidelines or regulations from the state agency should be included in the manual. The operator must then be aware that if he changes the mode of operation, or if he allows public access or changes the crops to be grown, there may be a change in the monitoring program. In the first two categories of table 2-4 the operator can determine what changes might be needed by reading the guidelines or regulations. In the last category direct contact with the state agency will be needed.

Table 2-4. State control of monitoring.

Regulation

California, Delaware, Michigan, Minnesota, Oregon, Pennsylvania, South Carolina, Vermont, Wisconsin, Wyoming

Guidelines

Georgia, Illinois, Maryland, Nebraska, New Hampshire, New Mexico, New York, Oklahoma, Texas, Virginia, West Virginia

Case-by-Case

All others - 28 states

d. Monitoring locations. It is not possible to present here all of the states' specific requirements for the type and frequency of testing of the applied wastewater, percolate-groundwater, soils and crops. Such a listing would be too complex to be of value and would rapidly be out of date since many agencies frequently update and revise their criteria. However, it is possible, based on present criteria, to summarize the areas of most concern to the state agencies. Table 2-5 summarizes the number of states that monitor the major components of a land treatment system: the applied wastewater, the groundwater, the soil, the crop and aerosols. Their level of concern ranges from required monitoring to case-by-case judgment to no concern at all.

Table 2-5. Number of states with monitoring criteria.

Monitoring	Applied wastewater	Groundwater	Soil	Crop	Aerosol
Required-recommended	25	14	5	2	0
Suggested	0	0	2	2	0
Case-by-case	20	31	20	23	15
No concern	5	5	23	23	35

e. Wastewater monitoring. The majority of states are concerned about the quality of the wastewater to be applied, and 25 have specific regulations or guidelines. Groundwater protection is a case-by-case concern and it depends largely on the groundwater use in the vicinity of the facility and the classification of the aquifer. Monitoring of the soil is usually of the process control type to make sure the system operates properly or to warn of long-term effects that might inhibit the future use of the site for other purposes. Crops are also monitored for operational purposes but the level of concern increases when the crop is consumed directly by people. The potential for aerosol contamination is of little concern to most state agencies, except on a case-by-case basis for recreational operations and those that are close to the public.

(1) A typical example of the type and frequency of monitoring required for the applied wastewater is shown in table 2-6. The Biochemical Oxygen Demand (BOD), pH, nitrogen and phosphorus are familiar water quality parameters tested for in most systems. However, in this case the main purpose for monitoring the pH, nutrients and other critical chemical inputs is to make successful operation of the system certain. This is essentially process control monitoring since the purpose is to ensure healthy vegetation and successful operation, which in turn will ensure realization of design goals and compliance with water quality requirements. Many parameters (metals, etc.) are not shown in table 2-6. Either they are not generally present in sufficient concentration in the typical domestic-municipal wastewaters or their presence has no direct effect on the proper operation of the system.

Table 2-6. Typical monitoring schedule for applied wastewater.*

Parameter	Size of system (mgd) 0 - 0.075	more than 2.0
BOD	once/3 months	twice/week
Suspended solids	once/3 months	twice/week
pH	once/3 months	twice/week
Kjeldahl-nitrogen	once/3 months	twice/week
Ammonium-nitrogen	once/6 months	once/week
Nitrate-nitrogen	once/6 months	once/week
Phosphorus	once/6 months	once/week
Chloride	once/6 months	once/week
Sodium	once/year	once/month
Calcium	once/year	once/month
Magnesium	once/year	once/month
Potassium	once/year	once/month

* For systems without significant storage. Use criteria in table 2-7 for effluent applied from storage ponds. Interpolate for intermediate sizes.

(2) A similar listing will be included as part of the site-specific O&M manual for every system. If there are no specific requirements from state or local agencies, then the listing in table 2-6 is recommended for Corps of Engineers systems receiving typical domestic-municipal wastewaters. Composite samples should be taken, if possible, during 1 day's operation either at the pumping station or at the actual application site.

f. Groundwater monitoring. Groundwater is usually monitored at the system boundaries when the quality of drinking water supplies are a factor. Nitrate-nitrogen (NO_3^--N) is the parameter of greatest concern, but it is advisable to measure the other forms of nitrogen (TKN, NH_4^+) as well since they might subsequently oxidize to nitrate. In general, slow rate systems that can remove enough nitrogen to meet drinking water standards at the project boundaries will also remove all of the other constituents of concern in typical domestic-municipal wastewaters. Frequent sampling is not necessary because groundwater moves relatively slowly and rapid changes in quality will not be observed. Samples taken once or twice per year should be sufficient. The design of those systems that operate only seasonally should include an estimate of the travel time for the percolate to reach the project boundary and the sampling operation should be scheduled accordingly.

(1) Since there may be little vertical mixing of the groundwater and the system percolate, the sampling depth of the monitoring wells must be carefully selected during design. Wells that are too deep will probably not obtain samples that have been influenced by the land treatment operation. The original location and depth of monitoring wells should be deter-

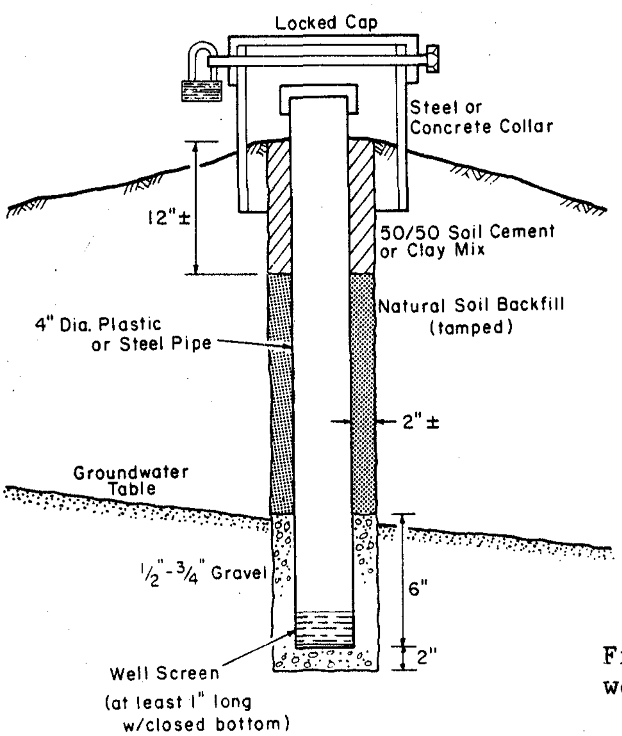
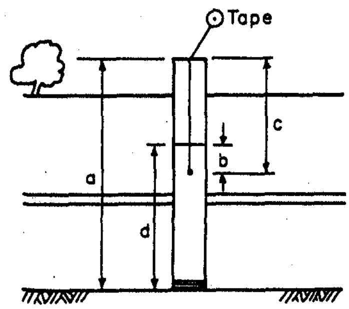


Figure 2-3. Typical shallow monitoring well.

mined during design. However, it may be necessary to add new wells if operational conditions change or if groundwater levels were not properly determined during design. Figure 2-3 illustrates the design features for a typical shallow monitoring well that, depending on soil conditions, could be installed to depths of 10-15 feet by the system operator. Deeper wells will generally require mechanical drilling techniques.

(2) Groundwater monitoring wells are sometimes installed within the application site as well as at the project boundaries. These wells monitor performance immediately beneath the application site and measure the depth of groundwater under the application site. Figure 2-4 illustrates one relatively easy technique for measuring the depth of water in monitoring wells. Since samples are taken infrequently from these monitoring wells, the water standing in the casing will not be representative of the true groundwater quality. At least three casing volumes should be pumped or removed with a well bailer prior to well sampling.



a = top of casing elevation above datum
b = length of wetted tape
c = tape reading--read exactly at the top of the casing
d = piezometric head, relative to a given datum
c-b = dtw (depth to water)
a-dtw = d (piezometric head at the center of the screen, relative to indicated datum plane).

Figure 2-4. Water level determination in observation well.

(3) The location of monitoring wells is based on the determination of the groundwater flow direction made during system design. As shown in figure 2-5 the perimeter wells are installed on the hydraulical downgradient of the site. In addition a monitoring well should be installed on the upgradient side to measure water quality before the groundwater flows beneath the site. Measuring the groundwater elevation in these wells can confirm that the direction of flow is as predicted in design. Springs or seeps in unexpected locations after the system starts up are usually a sign of groundwater movement, and additional wells may be needed in those directions.

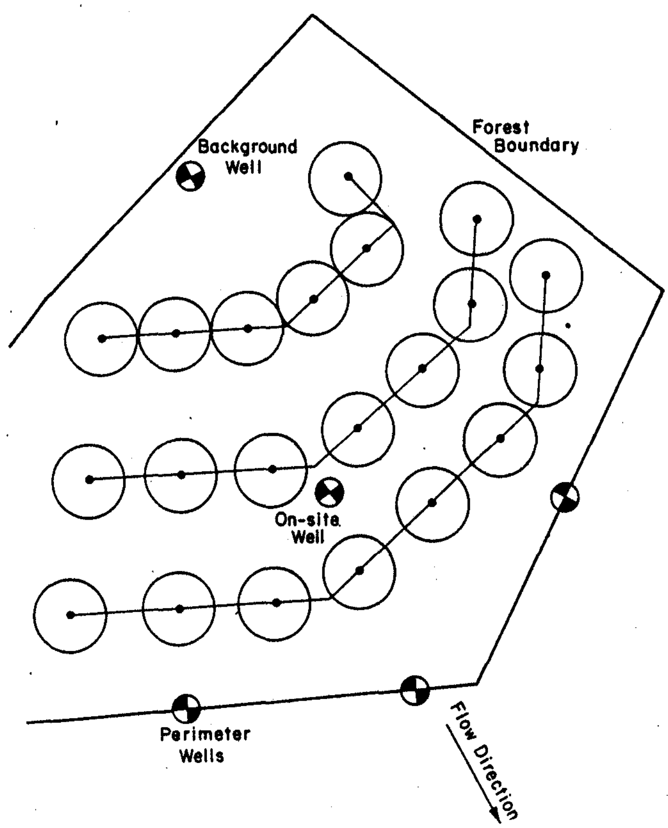


Figure 2-5. Typical monitoring layout.

g. Soil and vegetation monitoring. Case-by-case monitoring of site soil and vegetation is required by a number of state agencies. The long-term purpose is to document accumulation of critical pollutants. The short-term (annual) purpose is really process control monitoring to make sure that the system is working well and is in optimum condition. Since this is critical to operation, monitoring of soil and vegetation is covered in the next paragraph.

2-9. Process control monitoring. This is information the operator should obtain to make sure his system is operating efficiently with the least possible cost and energy use. The compliance monitoring discussed previously is usually concerned with the initial input and final output of most systems. Process control monitoring is also concerned with those aspects, as well as with the performance of the internal components in the system.

a. Preapplication treatment. In addition to the testing of the incoming wastewater discussed in the previous paragraph, this will also include monitoring the components, mechanical or other, that are included in the preapplication treatment for a particular system. This could range from a simple pond to a complete trickling filter plant with recycle and regular sludge removal requirements. Details on these types of monitoring needs will be included in the site-specific portion of the O&M manual.

b. Storage ponds. Some type of storage pond is often included in most slow rate land treatment systems. Their purpose can range from equalizing the daily variations in flow to seasonal storage for wet or cold weather, for harvest periods, or for emergencies. Many of the newer slow rate systems combine preapplication treatment and storage in a single pond system. Monitoring needs include regular measurement of water level in the storage pond as well as water quality tests just before and during the period of land application for seasonal systems. In some cases ponds may require a liner to prevent uncontrolled release of wastewater to groundwaters.

(1) Water level. Water level in the pond should be measured at least weekly during the operating season. The method of observation can range from a simple marker board or staff gauge visually observed, to automatic, and sometimes transmitting, water level recorders. Direct observation by the operator is recommended, even if automated equipment is installed, to allow him to also observe dikes and other pond structures. As shown in appendix A, the water level data are used to determine how much water is to be applied to the land treatment site. The capacity of the storage pond, determined during design, provides storage for a maximum combination of wastewater flow and rainfall. The application schedule, also determined during design, is then based on moving that much water to the land treatment site during the application season. In any particular year there may be more or less water in the storage pond than was predicted during design either due to changes in wastewater flows or very wet or very dry years. The operator must then revise the application schedule accordingly to make certain that the vegetation on the site gets enough water and also to keep the pond to the specified low level at the end of the season. The adjustments used will depend on the type of system and whether the site is in a humid or dry climate. Usually, the pumping system has been designed to deliver a certain volume of water per minute and is not adjustable. However, the operator can vary operation time for the pumps, start the application season earlier, extend it, or change the amount of water put on particular parts of the site. Suggestions for appropriate action on each case are listed in the following subparagraphs.

(a) Operation procedures for more water than normal in storage.

1. Forest, pasture and hay crop sites. Start application season earlier (as soon as frost is out of the ground) and extend the season into late fall. If different soils exist, apply more water to areas with coarser soils by increasing pumping time. Apply more water to the entire site by increasing pumping time, but do not allow ponding or runoff of wastewater.

2. Agricultural row crops. Continue application for longer period after crop harvest. Consult with county agricultural extension agent and plant a more water tolerant crop that year. Increase application to the maximum amount recommended by the extension agency for the crop grown. Plant a rye grass mixture on the coarsest soils on the site, continue normal row cropping and application practice on rest of the site.

Apply at highest possible rates (see para. 2-5 and app. A) on the grassed plot, and plow under grass and return to normal practice the following year.

3. Recreational Sites. Increase the application period to the maximum possible without interfering with public access, and/or restrict access to a portion of the site and apply at higher rates on that portion, and/or continue application after the recreational season has ended.

(b) Operation procedures for less water than normal in storage.

1. Forest, pasture and hay crop sites. In arid climates, reduce the amount to be applied per week but continue applications to the whole site. In humid climates, take a portion of the site out of service, continue application on the rest at design rates; if vegetation on out-of-service portion shows stress then apply some water.

2. Agricultural row crops. In both arid and humid climates, use the procedure in appendix A to calculate how much water is available for application, and determine the water needs per acre of the crop to be grown. Plant only the number of acres that can be supported with available flow.

3. Recreational sites. Reduce the amount to be applied per week but continue applications to the whole site. In dry climates this will probably require extra water the following year to leach salts from the root zone if the application has been reduced severely.

(2) Water quality. Wastewater will be treated further in storage ponds. The additional treatment can be very significant in seasonal storage ponds with a long detention time. The BOD and suspended solids will be reduced, the bacteria and viruses will be reduced, and the nitrogen concentration can be reduced, depending on conditions in the pond. The size of the land treatment site and the application rate may both depend on the amount of nitrogen in the wastewater if the groundwater is a potential or actual drinking water source. More or less nitrogen than expected in the pond effluent can then change either the amount of land in service and the amount of wastewater applied or both. Procedures in appendix A and in later paragraphs of this chapter show how to make the necessary calculations and adjustments. Nitrogen is also important to meet the fertilizer needs of the vegetation grown on the site. If there is less nitrogen than expected in the storage pond effluent, then supplemental fertilizers may be needed.

c. Disinfection.

(1) Disinfection is usually required for recreational sites and may be required for agricultural sites growing food crops for human use. Systems without long-term storage will not usually remove bacteria and viruses to levels required by the regulatory agencies for recreation or food production. Disinfection is not technically necessary for other types of slow rate systems, but may still be required by regulatory authorities.

When disinfection is needed, the decision will be made during design and appropriate facilities included in the system. These will usually be some form of chlorination, and instructions for operation and for monitoring residuals will be included in the site-specific portions of the O&M manual. Residual chlorine can be harmful to some vegetation so dechlorination may be needed in arid states.

Table 2-7. Monitoring of storage pond effluents.

Parameter	Design flow (mgd) 0-0.015	Design flow (mgd) more than 2.00
BOD	1 week prior to application season, once every 3 months during application season.	1 week prior to application season, then twice per week during season.
Suspended solids	Same as BOD.	Same as BOD.
pH	Same as BOD.	Same as BOD.
Kjeldahl-nitrogen	1 week prior to application season, 1 sample at mid-point of season.	1 week prior to application season, once per week during season.
Ammonia-nitrogen	Same as Kjeldahl-nitrogen.	
Nitrate-nitrogen	Same as Kjeldahl-nitrogen.	
Phosphorus	Same as Kjeldahl-nitrogen.	
Chloride	1 week prior to application season.	1 week prior to application season, once per month thereafter during season.
Sodium	Same as chloride.	
Calcium	Same as chloride.	
Magnesium	Same as chloride.	
Potassium	Same as chloride.	
Bacteria: total coliforms and/or fecal coliforms	1 week prior to application season, once per month thereafter during season.	1 week prior to application season, then twice per week during season.

(2) Systems with long-term treatment or storage in ponds (for more than 30 days) deserve special consideration. Although a disinfection capability may be provided it may not be necessary to use it continuously, depending on the concentration of indicator bacteria in the effluent drawn from the storage pond. The design engineer should ask the regulatory agency for a permit requirement in terms of a bacteria count per 100 milliliters (mL) instead of a simple chlorine residual. Then, during operation, if the coliform or fecal coliform counts are below the specified limit, chlorine disinfection would not be required. A stand-by capability for chlorination to meet emergency conditions is recommended. This would range from bottles of household chlorine bleach for very small systems to a supply of hypochlorite powder or liquid for larger systems. The testing frequency for coliforms or fecal coliforms in table 2-7 assumes the count remains below the specified permit level. If the test indicates a higher level, disinfection should be started and continued until the level (measured prior to chlorination) is again within limits. Testing under those conditions should be weekly for small systems and every other day for large systems. When the bacteria count drops to an acceptable level the disinfection can be stopped.

d. Application site monitoring. Monitoring at the application site is necessary to ensure that the system operates properly. Monitoring tasks will include observing the sprinklers, pumps and other mechanical equipment and determining soil fertility and crop quality at agricultural sites.

(1) General requirements. These requirements usually apply to all sites and essentially consist of routine visual observations and record-keeping. With seasonally operated systems it is essential to know when the soils thaw in the spring and when they freeze in the winter if these factors control the application schedules developed during design. The actual time of freezing and thawing will vary from year to year and may be different than the design assumptions. An especially heavy rainfall during the application season may require adjustment in the routine weekly schedule. If the amount of rainfall from a single storm or closely spaced storms is equal to the amount of wastewater scheduled for application it may be necessary to wait for a few days so that there is no runoff. The operator must also observe areas where there might be ponding in low spots. These shallow puddles can lead to odor and insect problems and must be eliminated. Watching the sprinkler patterns will reveal clogged nozzles or other mechanical problems in the system. If the site is underdrained the drain outlets should be routinely inspected to make certain that they are flowing. If monitoring wells exist on the site, the depth of water in the well should be regularly measured. In general, if the groundwater table gets within 5 feet of the surface, wastewater applications should be temporarily stopped. There may be exceptions for special situations but these will be defined in the portions of the site-specific O&M manual.

(2) Agricultural sites. The short-term monitoring helps the operator determine if adjustments are needed in application rates and schedules and helps him make sure that all equipment is functioning as it is supposed to. The longer-term monitoring aids the operator in maintaining soil fertility and ensuring good crop quality, and these require periodic

sampling and testing. Table 2-8 presents a suggested monitoring program for the soils at an agricultural site. The number of samples taken will depend on the number of different soil types at the site and the size of the site. Specific guidance can be obtained from the county agricultural extension agent, but for the general case there should be a composite soil sample representing each of the major soil types on the site.

Table 2-8. Soil monitoring on agricultural sites.

<u>Annual sample and test</u>

pH (for lime needs)

Available phosphorus

Exchangeable/extractable
- Potassium
- Sodium
- Magnesium
- Calcium

<u>Baseline and every 5 years</u>

pH (for lime needs)
Nitrogen

Cation exchange capacity, percent organic matter

Exchangeable/extractable
- Potassium
- Phosphorus
- Copper
- Zinc
- Nickel
- Cadmium

Total
- Boron
- Copper
- Zinc
- Nickel
- Cadmium

Sodium adsorption ratio (SAR) in western states or arid climates.

(a) Baseline samples should be taken and tested either during the final stages of design or just before the system is put into operation. A pH determination is needed to see if lime is required to adjust soil pH for the crop to be grown. Phosphorus and potassium results are needed to decide if supplemental fertilization is required. These tests should be repeated annually for high value crops; however, once every 3 years is suitable for hay and similar crops. The county agricultural extension agent can help interpret these test results and tell the operator how to correct any problems.

(b) The effluent should be analyzed for the heavy metals listed in table 2-8 so that an undesirable accumulation in the soil can be avoided. Composite samples are usually taken from the topsoil layer and the root zone of row crops. A heavy metal buildup is not likely from the effluents in Corps of Engineers systems. Even if heavy metals do accumulate, this is not likely to affect the operation of the system during its life. The presence of some heavy metals such as excess cadmium can, however, affect the future use of the site for food production after the waste treatment operation is stopped. Hence, the metals in the soils are measured for long-term recordkeeping rather than for short-term operational reasons.

(c) Table 2-9 lists the suggested tests and frequency of these tests for vegetation monitoring at agricultural sites. If a system is supposed to remove nitrogen or phosphorus, then the total nitrogen and phosphorus concentration in the harvested crops should be measured and crop yield should be determined. This will allow calculation of removal performance by the crop to ensure that the system is functioning as designed. If forage grasses or silage are the crop and if these are fed to livestock, then the nitrate content in grasses can cause health problems in the livestock. The analysis is particularly important if wastewater with a high nitrogen content is used and if the application season has been unusually wet and cool. The county agricultural extension agent should be consulted for advice on the testing need in a particular year. The vegetation should be tested for the metals listed in table 2-9 every 5 years, as the soil is (table 2-8), to establish long-term trends.

Table 2-9. Vegetation monitoring on agricultural sites.

Component	Frequency
Total nitrogen and phosphorus	Annual sample if N or P removal is required by system.
Nitrate (NO_3) for forage grasses and silage	At harvest if recommended by extension agent for livestock protection.
Copper, zinc, nickel, cadmium	At first harvest and every 5 years thereafter to establish trends.

(d) The number of samples required for these tests and the part of the plant to sample are critical to the reliability of results. Hay cuttings and green chop for silage from small fields can be sampled immediately after harvest since a representative composite sample can be obtained from the mixed materials. Large or scattered fields and other crops should be sampled in the field with recommended sampling patterns. It is best to sample the leaves rather than the plant fruits since the leafy matter will usually show increases in metal content first and thereby give an earlier warning of potential problems. Table 2-10 recommends techniques for vegetation sampling.

Table 2-10. Vegetation sampling - field pattern and plant part.

Crop	Pattern	Plant part
Alfalfa	X diagonals of field, 50-100 clumps.	Upper stem cutting in early flower stage.
Corn	X diagonals or along row at least 50 plants into field.	Center one-third of leaf, just below lower center; at full tassle.
Wheat and grains	X diagonals, 200 or more leaves.	First four leaf blades from top of plant.
Grass and sod	X diagonals.	Clippings or whole tops.
Soybeans	Random leaves from at least 5% of plants, 50 to 100 leaves.	Youngest mature leaves, after pod formation.
Tree fruits	X diagonals in orchard, one leaf from north, south, east and west sides of tree.	Mature leaves, shoulder height, 8-12 weeks after full bloom.

(3) Forested sites. Monitoring is usually limited to the operator noticing thing that should be done to help the system operate properly. This will include culling dead wood and thinning the stand to encourage more vigorous growth of desirable trees. The operator must ensure that brush and other low growth does not interfere with sprinkler operation or the intended distribution pattern.

(4) Recreational sites. The basic monitoring requirements for operation are the same as described for grass-covered agricultural sites. Maintenance of a healthy grass cover and no interference with the recreation are the two major operational concerns. Monitoring for compliance with regulatory standards is usually most stringent for this type of site.

2-10. Laboratory equipment and procedures. Systems with a design flow of 100,000 gallons per day (gpd) or more will usually have an on-site laboratory for sample preparation, storage and some water quality testing. The size of the laboratory and the equipment and chemicals provided are determined during design. These facilities are essentially the same as would be required for water quality testing at mechanical treatment plants. An on-site capability for soils and vegetation testing is not necessary except for very large systems (more than 15 million gallons per day [mgd]) because of the infrequent testing required. Operators for systems of all sizes should be properly trained in approved sampling and sample preservation procedures. In this way the operator can reliably obtain samples on the specified schedule and then ship them to a laboratory for analysis if there is no laboratory at the site.

Section IV. Routine Operating Procedures

2-11. Preapplication treatment components. The procedures for preapplication treatment components will be determined during design and be included in the site-specific portion of the O&M manual. The range of possible components is too large for inclusion here.

2-12. Storage ponds. The operational schedule for storage ponds will be developed during design and be included in the site-specific portions of the design manual. This schedule may have to be changed for particularly wet or dry years or if the type of vegetation grown on the site is changed. Paragraphs 2-2 and 2-13, and appendix A provide guidance on how to calculate the needed change.

2-13. Application rates and schedules. Control of the water to be applied is common to all systems and requires the following operator decisions:

- Startup and shutdown schedule
- Quantity of wastewater to be applied each shift
- Frequency of application
- Field or section to be used.

The details of these decisions may change from year to year depending on the climate, rainfall and type of crop but the final result must be to apply the total amount of wastewater required during the application season. A specific program will have been formulated during design and instructions will be included in the site-specific portion of the O&M manual. However, the operator must have the knowledge and the capability to alter the schedule to accommodate special conditions.

a. Year-round operations. At sites where the wastewater is treated year-round and where there is usually little storage volume, the operator has little or no flexibility to make adjustments. The daily land treatment applications must match the daily wastewater flow. In most cases the operator can decide which field to use and how long to continue the application to that field. During the startup phase the operator should use the schedule provided by the design engineer. However, the design is often based on average site conditions. The operator should carefully watch each area to see if the water is rapidly infiltrating, ponding or running off. Some parts of the site may be able to take more water than the design value and some parts less. The operator can then make adjustments to controls and valves to put more water on the better soils and less on the poorer locations. Most systems will have a fixed capacity pump so it is not usually possible to increase the rate of flow to a particular location, but the time period for application can be adjusted.

b. Seasonal flow operations.

(1) General. Systems where the wastewater flow is seasonal are not uncommon. These might include camp grounds, ski resorts and intermittently occupied training stations. Wintertime flow in cold climates will usually require wastewater storage for land application later in the warm months. Wastewater application can usually start as soon as the frost is out of the ground and can continue into the fall until either frozen ground or icing prevents further infiltration of the water. Ponds are often included in these types of systems, either for treatment or for storage. The pond should contain a graduated staff (feet and tenths of feet) so the operator can easily see the depth of water. In addition the operator needs to know the other dimensions of the pond, the length of the application season, the amount of wastewater that will flow into the pond during the season, and an estimate of rainfall or evaporation during the season. With this information he can calculate the applications and time schedules for each week. Appendix A provides details on the basic calculations; an example is shown below where precipitation exceeds evaporation at the site.

(2) Example: precipitation exceeding evaporation.

Conditions:

- Pond dimensions 100 ft x 200 ft x 5 ft working depth
- Distribution pump capacity 75 gpm
- Wastewater flow during season 20,000 gpd (35 week season)
- Estimated rainfall during season 6.6 inches more than evaporation.

Staff gauge indicates 1 foot of water in the pond above the minimum level at start of season (this water is from snowmelt and rainfall because the pond was pumped down to the required level by the end of the previous season). Total water to be applied:

- Initial pond content: (1 ft)(100 ft)(200 ft) = 20,000 ft^3

- Wastewater flow:
  (20,000 gpd)(35 weeks)(7 days/week)(0.1337 ft^3) = 655,130 ft^3
- Net rainfall on pond:
  (6.6 in.)(1 ft/12 in.)(100 ft)(200 ft) = 11,000 ft^3
- Total to be applied over entire season: 666,130 ft^3

- Application per week: $\frac{666,130\ ft^3/season}{35\ weeks/season} = 19,032\ ft^3/week$

- Pumping time per week: $\frac{(19{,}032\ ft^3/week)(7.48\ gal./ft^3)}{(75\ gpm)(60\ min/hr)} = 31.6\ hr/week.$

The application site has a total area of 2.25 acres, divided into five equal plots of 0.45 acres each. The system has manual valves and pump controls and the operator is usually only available 5 days per week. Therefore, the schedule has been set up to apply wastewater to one plot per day, Monday through Friday, with no applications on Saturday or Sunday. So:

- Pumping time per day: (31.6 hr/week) ÷ (5 days/week) = 6.32 hr/day.

- Amount pumped during that time:

  $(6.32\ hr/day)(60\ min/hr)(75\ gpm)(0.1337\ ft^3/gal.) = 3802\ ft^3/day.$

The hydraulic loading on a plot (para. 2-2) would be

$$\frac{(3802\ ft^3/week)(12\ in./ft)}{(0.45\ acres)(43{,}560\ ft^2/acre)} = 2.32\ in./week.$$

A check on these calculations is possible since most systems will have a totalizing flowmeter at the pump. For the example above, the meter should show about 29,340 gallons pumped at the end of each operational day for a total each week of about 146,700 gallons. These values should be recorded in a daily operating log. The operator should observe and record the staff gauge reading in the pond once each week and repeat these calculations every 3 or 4 weeks to be sure that all water will be applied by the end of the season. If it is an especially wet year or if the system is not working part of the time, it may be necessary to increase the pumping time on the more permeable plots at the site.

c. Year-round flow, seasonal applications.

(1) General. The basic procedures are similar to those in the previous case except that the entire annual wastewater flow must be applied during the application season. In addition, if the site is designed for agricultural row crops, startup will usually come after planting and application will be stopped for harvest and cultivation. There must not be any erosion, but with many systems it is possible to resume application to the bare fields after harvest is complete and to continue it until freezeup. Starting with the same basic conditions as the previous case, the example below illustrates the changes that would be needed for year-round wastewater flow to a seasonal row crop operation.

(2) Example: year-round flow with seasonal row crop operation.

Conditions:

- Wastewater flow, year round: 20,000 gpd
- Frost out of ground 31 March
- Cultivation and planting complete by 27 April
- Allow 3 weeks shutdown for cultivation and harvest
- Freezing conditions start by 30 November.

In response to the above:

- Application season: 27 April to 30 November - 3 weeks = 28 weeks
- Wastewater storage season: 52-28 = 24 weeks
- Amount stored:

$$(20{,}000 \text{ gpd})(7 \text{ day/week})(24 \text{ weeks})(0.1337 \text{ ft}^3/\text{gal.}) = 449{,}232 \text{ ft}^3.$$

At a 5-foot working depth, pond area would have to be:

$$\frac{449{,}232 \text{ ft}^3}{5 \text{ ft}} = 89{,}846 \text{ ft}^2.$$

This could be equal to three ponds, each about 150 by 200 feet, instead of the single pond of that size in the previous case. However, a single, deeper pond would probably be used in this case. Annual precipitation on pond (1 ft in winter) + (0.55 ft in summer) = 1.55 ft (from previous case):

$$(1.55 \text{ ft})(89{,}846 \text{ ft}^2) = 139{,}261 \text{ ft}^3.$$

Wastewater flow during application season:

$$(20{,}000 \text{ gpd})(7 \text{ days/week})(0.1337 \text{ ft}^3/\text{gal.})(28 \text{ weeks}) = 524{,}104 \text{ ft}^3$$

Season total to be applied:	- Stored wastewater	449,232 ft^3
	- Net precipitation	139,261 ft^3
	- Season wastewater flow	524,104 ft^3
		1,112,597 ft^3

With the assumption of 2.75 in./week maximum, the hydraulic loading for a season is:

$$(2.75 \text{ in./week})(28 \text{ weeks}) \div (12 \text{ in./ft}) = 6.42 \text{ ft/season}.$$

At this loading, the size of the application site would be:

$$\frac{1{,}112{,}597 \text{ ft}^3}{(6.42 \text{ ft/season})(43{,}560 \text{ ft}^2/\text{acre})} = 4.0 \text{ acres}$$

divided into five equal plots of 0.8 acres each. Amount of water to be applied each week:

$$\frac{1{,}112{,}597 \text{ ft}^3}{28 \text{ weeks}} = 39{,}736 \text{ ft}^3/\text{week}.$$

If the operator is only available during an 8-hour shift, 5 days per week, and if the system is manually operated, the maximum pumping time is 40 hr/week. Pump capacity required:

$$\frac{(39{,}736 \text{ ft}^3/\text{week})}{(40 \text{ hr/week})(0.1337 \text{ ft}^3/\text{gal.})(60 \text{ min/hr})} = 124 \text{ gpm}$$

(a) It would be desirable to have time switches on the pump for automatic start and stop, and solenoid valves on the sprinkler lines so that the proper set can be opened in the proper sequence. With center pivot systems, the drive system is controlled by time switches so that the unit can be programmed to make the necessary number of rotations each week. The operator then only needs to make a brief visit to the site each day to ensure proper operation.

(b) As an alternative, assume the 75 gpm pumps from the previous case are used, but they are equipped with automatic time switches. Pumping time per week at 75 gpm:

$$\frac{39{,}736 \text{ ft}^3/\text{week}}{(75 \text{ gpm})(0.1337 \text{ ft}^3/\text{gal.})(60 \text{ min/hr})} = 66 \text{ hr/week}$$

Pumping time per day on the designated 0.8-acre plot:

$$\frac{66 \text{ hr/week}}{5 \text{ plots}} = 13.2 \text{ hr/day}$$

The amount pumped during that time is still equal to the 2.75-in./week maximum loading. Automatic controls will allow use of smaller pumps and savings in operator time. The amount pumped to each 0.8-acre plot per week will be:

$$(13.2 \text{ hr/plot})(60 \text{ min/hr})(75 \text{ gpm})(0.1337 \text{ ft}^3/\text{gal.}) = 7942 \text{ ft}^3/\text{week per plot}$$

(c) Through observation and experience the operator can determine which are the "better," more permeable plots and schedule more water, if necessary, for those areas. However, there is less flexibility with row crops than with hay fields, pastures and forests since many row crops will not tolerate excess water for very long periods. The county agricultural extension agent can give advice for specific crops.

2-14. Operation at agricultural sites. Management of the crop is a major requirement at agricultural sites. A particular crop is usually selected during design and planted early in the first year of operation. It may be possible, thereafter, to change the crop to either improve the performance of the system or to increase the value of the harvest. Guidance on the initial crop will be provided in the site-specific portions of the O&M manual but the operator should be aware that alternatives exist, and he should be able to determine the effect of a change in his system.

2-15. Crop management at agricultural sites. For Corps of Engineers systems, the primary goal is wastewater treatment, not crop production. However, vegetation is essential on slow rate systems to:

- Remove nitrogen and phosphorus from the wastewater
- Prevent runoff and erosion
- Keep soils porous for water infiltration.

Any change in the type of vegetation or in the management practices must maintain these system objectives.

a. Many types of crops have been grown in slow rate systems. The most popular crops are forage grasses and corn. Forage grasses are desirable because they use large amounts of nitrogen. Forage grasses that have done well include orchardgrass, Kentucky bluegrass, reed canarygrass and tall fescue in the north, and the latter two grasses and bermudagrass in the south. Seed mixtures of two or three of these grasses may be expected annually to remove 240 pounds (lb) of nitrogen per acre or more. The major disadvantage of grasses is their lower market value than corn.

(1) Legumes, such as alfalfa, are sometimes considered for slow rate systems because of their high quality as a forage. The major disadvantage of alfalfa in the humid east is its intolerance of wet soils. In slow rate systems where it has survived, the soils were usually well drained and the application rate was low (usually less than 1 inch per week). In drier climates, where application rates are adjusted to meet crop water requirements, alfalfa and other legumes grow well.

(2) Corn is also used widely, principally because of its greater market value. Its major disadvantage is its lower annual nitrogen removal capability (about 120 pounds per acre).

(3) Turfgrasses can also be considered since they have a high market value in urban areas. Kentucky bluegrass turf can remove about 200 pounds of nitrogen per acre each year when the clippings are removed. Both the market value and costs associated with turfgrasses are greater than for forage grases or corn.

b. The type of cutting management for harvesting forage grasses will depend on the desired level of nitrogen removal. If maximum yields and high nitrogen removal are desired, grasses should be cut more frequently and at the proper times: the initial cutting should be at the early heading stage of growth and subsequent cuttings should be every 5 to 6 weeks for the remainder of the season. The early heading stage will vary with climate but it will usually be sometime during middle to late spring.

(1) If lower nitrogen removals, say in the range of about 160 pounds of nitrogen per acre, are needed, then fewer cuttings are needed and operations costs can be saved. Initial cuttings for this purpose should be at the late flowering stage of growth, with one extra cutting toward the end of the growing season. With this cutting method, the majority of the nitrogen will be removed at the initial harvest.

(2) Grasses should be managed properly so that they can survive at the site as long as possible. Under proper management, grasses at the site can persist for 3 years or more. They are usually invaded by weedy grasses, some of which are desirable. The weed quackgrass has performed well in slow rate systems in terms of nitrogen removal and forage quality. When undesirable weeds predominate, fields must be renovated to maintain treatment efficiency. When reseeding, use standard methods for field renovation along with desirable types of forage grasses.

(3) With corn much of the nitrogen is removed during a short 4- to 6-week period in summer. This is usually between the knee-high and the tasseling stages of growth.

(4) Growing another crop with the corn can improve nitrogen removal by an additional 40 to 80 pounds per acre and can lower the percolate nitrogen concentration. In dual cropping, corn is grown during the summer months, while a cereal crop (e.g. rye) or a forage grass (e.g. reed canarygrass) is grown during the spring and fall. The cereal or grass removes nitrogen during the slower corn uptake periods and thereby lengthens the application season. The disadvantages of this system are that the actual corn yields will be lower due to increased competition with the grasses and that a higher level of management is required.

(5) Turfgrasses, grown for sod production or maintained in a lawn, can remove nitrogen during the entire growing season. When started from seed for sod production, nitrogen removal will be lower. The sod is usually harvested after 12 to 18 months. Weekly mowings during periods of active growth are desirable.

c. Since wastewaters vary in their composition, the quantity and type of soil amendments that may be needed to maintain plant productivity will vary. Experience and past work have shown a need for lime or gypsum and potassium in some locations. Liming is important to maintaining soil pH. Past work has shown a decrease in soil pH with continuous wastewater applications to soils in the eastern U.S. Liming will counteract this and also decrease the solubility of metals that may be in the soils. Control of exchangeable sodium can be critical in arid climates, and gypsum or lime are usually added for control.

(1) Potassium fertilizer is sometimes needed by grasses in the central and eastern U.S. The following equation can be used to determine annual potassium fertilization needs:

$$K_f = 1.25\ (0.9U - K_{ww})$$

where

K_f = annual amount of potassium fertilizer applied in the spring (lb/acre)

U = estimated annual crop uptake of nitrogen (lb/acre)

K_{ww} = amount of potassium to be applied in the wastewater (lb/acre).

(2) The following is an example of potassium application (forage grass, U = 240 lb/acre). From the previous example, wastewater application is 973,336 ft^3/season on 4 acres. Assume potassium in wastewater is 10 milligrams per litre (mg/L), so:

$$K_{ww} = \frac{(10\ mg/L)(8.34\ lb{\cdot}L/[mil.gal.]mg)(973{,}336\ ft^3)(7.48\ gal./ft^3)}{(1{,}000{,}000\ gal./mil.gal.)(4\ acres)}$$

$$= 152\ lb/acre$$

$$K_F = 1.25\left[(0.9)(240) - 152\right] = 80\ lb/acre.$$

d. The procedures in paragraph 2-13 assume that the amount of water to be applied in a given year is equal to or slightly greater than the amount predicted by the system design. Distribution to the various plots on the site is then by a straightforward rotation with each plot receiving about the same amount of water. This does not recognize differences in soil characteristics, except by the operator observing ponding and runoff. In very dry or low flow years there may not be enough water to apply the design amount to all plots. However, enough water must be applied to keep the vegetation healthy. This requires some knowledge of the moisture content of the soil at the root zone. This information is also needed to avoid excess water for too long when water-sensitive crops are grown.

Table 2-11. Field estimating of soil moisture content*.

Fine texture	Medium texture	Moderately coarse texture	Coarse texture
No free water after squeezing, wet, outline on hand.	Same as fine texture.	Same as fine texture.	Same as fine texture.
0.0	0.0	0.0	0.0
Easily squeezes out between fingers in ribbons, has slick feeling.	Forms a very pliable ball, sticks readily if high in clay.	Forms weak ball, breaks, easily, will not stick.	Sticks together slightly, may form a very weak ball under pressure.
0.0-0.6	0.0-0.5	0.0-0.4	0.0-0.2
Forms a ball, squeezes out between thumb and forefinger in ribbons.	Forms a ball, sometimes sticks slightly with pressure.	Tends to ball under pressure, but will not hold together.	Appears dry, will not form a ball when squeezed.
0.6-1.2	0.5-1.0	0.4-0.8	0.2-0.5
Somewhat pliable, will form a ball when squeezed.	Somewhat crumbly, but holds together from pressure.	Appears dry, will not form a ball.	Appears dry, will not form a ball.
1.2-1.9	1.0-1.5	0.8-1.2	0.5-0.8
Hard, baked, cracked.	Powdery, dry, sometimes slightly crusted but easily broken down into powdery condition.	Dry, loose, flows through fingers.	Dry, loose, single-grained, flows through fingers.
1.9-2.5	1.5-2.0	1.2-1.5	0.8-1.0

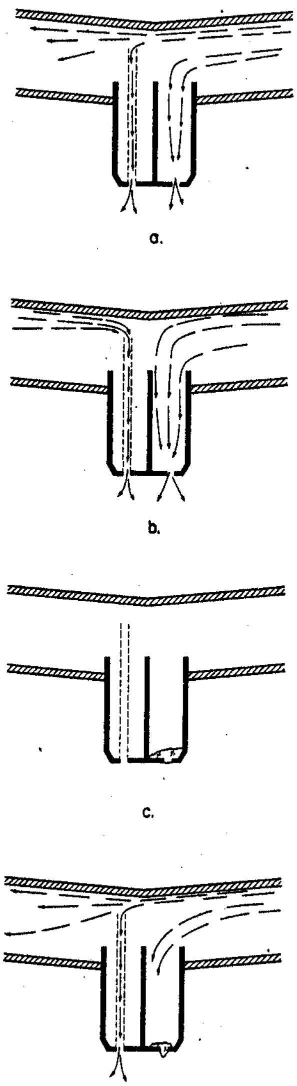
* The numerical values are the amount of water index that would be needed to bring the top foot of the soil to field capacity.

(1) For most plants the best condition is when the soil is at what is called "field capacity" (see para. 1-3). This represents the water that a unit of soil can hold without drainage. A handful of soil at field capacity would feel damp but no free water could be squeezed out if the soil were pressed into a ball. If the moisture content drops to half this amount or less, then the plants will be adversely affected. When water is scarce the goal of the operator should be to place enough water on the site to maintain growth but to avoid waste. The amount of water needed depends on the type of soil involved. Soil moisture can be measured very accurately with various types of probes and tensiometers. These, in turn, can be tied into the system controls to program applications to the locations where water is needed for the necessary period of time. The typical Corps of Engineers system will not have sophisticated controls. However, it is still possible for the operator, with some practice and experience, to estimate the moisture content of the soil using the guidance in table 2-11.

(2) A handful of soil should be taken from the root zone and squeezed in the hand. The feel and appearance of the resulting soil ball should then be compared to the descriptions in table 2-11. The numbers under each description are the amount of water that should be added to bring the top foot of soil up to field capacity. For example, if a handful of silty sand (moderately coarse texture in table 2-11) can be squeezed into a ball, but it then breaks apart when the pressure is relaxed, the water needs are between 0.4 and 0.8 inches to bring the top foot of soil up to field capacity.

2-16. <u>Operations at forested sites</u>. Operations at forested sites will require the same decisions regarding how much water is needed, where to apply it, and how long to let it run, that were discussed in paragraph 2-13. In general, the frost-free season is longer for forests than for an agricultural field, and in northern climates forest soils that have an early snow cover may not freeze at all. In these cases wastewater application can continue all winter. Figure 2-6 illustrates a special nozzle that was used successfully for winter operation in Vermont. Winter operation requires quick drainage of exposed pipes at the end of the application period. If not planned for during design, the operator will have to install drains at all low spots in the piping system before attempting winter operation. Other operational requirements for forested sites relate to tree management and will require expert advice. Every 3 to 4 years, an experienced forester should tour the site and make recommendations on culling or harvest and other management practices that will ensure a healthy stand of trees.

2-17. <u>Recreational sites</u>. Recreational systems have the same basic requirements as the cases previously discussed. They are more difficult to operate since the recreational function and schedule usually take precedence over the wastewater renovation. The operator has to plan his operational schedule for wastewater applications so as not to interfere with the recreation.



a. Spraying.

b. Draining. Brass tube in left half drains quickly, until liquid level is below its top. Then only right half continues to drain.

c. Line drained. Small amount of ice has formed to block right half of nozzle. Brass tube is open and ready for next spray cycle.

d. Next spray cycle. Water initially sprays through the brass tube on the left side. The heat from the liquid melts the ice plug blocking the right half of the nozzle and spraying resumes in the normal manner as shown in a.

Figure 2-6. Special spray nozzle for winter operations.

Section V. Emergency Procedures

2-18. Disruption of schedule. A major concern is disruption of the operating schedule for wastewater applications because there is usually a limited amount of storage capacity available. Since emergencies cannot be predicted, it is prudent for the operator to keep some part of the available storage free. This may require pumping slightly more water than the average schedule would require during the early part of the season.

Extended power failures also disrupt operations. The design should have provided the capability for standby power at the pumping stations and, if not, the operator should arrange for the necessary modifications. Systems that use center pivot distribution rigs with electrical drive motors should also have a portable standby generator for direct field connection when required.

2-19. Odors. If treatment and storage ponds are part of the system and there is public access to the site or if the site is close to a community, odors may be a concern from time to time. Odors are not usually a problem from properly designed and operated land treatment systems but they are possible if wastewater characteristics or pond conditions change suddenly. The operator must be prepared to cope immediately with such a situation.

a. Use of a chemical such as sodium or potassium nitrate will suppress the odors and allow time for the cause of the problem to be identified and corrected. A recommended procedure is to apply 100 pounds of sodium or potassium nitrate per acre of pond surface on the first day and then 50 pounds per acre on each day thereafter if odors persist. The chemical should be applied in the wake of a motor boat.

b. Odors will not occur on the actual land application site unless septic wastes are used or if stagnant puddles and ponds of wastewater are allowed to stand. The latter will also be the cause of insect problems. The operator must routinely inspect the application site and eliminate these low spots by filling with new soil.

Section VI. Maintenance Considerations

2-20. Ponds. The dikes and berms for ponds will require regular maintenance. Earthen dikes must be checked regularly for muskrats and other burrowing animals. Soil-cement, plastic membrane or asphalt liners must be regularly inspected and repaired. Damage from waves or ice in the winter are the most common problems.

2-21. Mechanical equipment. Specific maintenance needs for pumps and other mechanical equipment will be presented in detail in the site-specific portion of the O&M manual. Systems that use sprinklers must have a regular schedule for inspection and cleaning. All lines and pipes in seasonal operations should be regularly drained, even if freezing is not expected, to avoid corrosion. In addition to sprinkler maintenance, the large center pivot rigs require attention to their tires and gear boxes. Tires should be checked for proper pressure and the gear boxes for proper lubrication at the start of the operation season. Other possible problems and potential solutions are summarized in table 2-12, which is a troubleshooting guide.

Table 2-12. Troubleshooting guide.

Indicators/observations	Probable cause	Check or monitor	Solutions
1. Water ponding in irrigated area where ponding normally has not been seen.	1a. Application rate is excessive.	1a. Application rate.	1a. Reduce rate to normal value.
	1b. If application rate is normal, drainage may be inadequate.	1b(1). Seasonal variation in groundwater level.	1b(1). Irrigate portions of the site where groundwater is not a problem or store wastewater until level has dropped.
		1b(2). Operability of any drainage wells.	1b(2). Repair drainage wells or increase pumping rate.
		1b(3). Condition of drain tiles.	1b(3). Repair drain tiles.
	1c. Broken pipe in distribution system.	1c. Leaks in system.	1c. Repair pipe.
2. Lateral aluminum distribution piping deteriorating.	2a. Effluent permitted to remain in aluminum pipe too long causing electrochemical corrosion.	2a. Operating techniques.	2a. Drain aluminum lateral lines except when in use.
	2b. Dissimilar metals (steel valves and aluminum pipe).	2b. Pipe and valve specifications.	2b. Coat steel valves or install cathodic or anodic protection.
3. No flow from some sprinkler nozzles.	3. Nozzle clogged with particles from wastewater due to lack of screening at inlet side of irrigation pumps.	3. Screen, it may have developed hole due to partial plugging.	3. Repair or replace screen.
4. Wastewater is running off of irrigated area.	4a. Sodium adsorption ratio of wastewater (SAR) is too high and has caused clay soil to become impermeable.	4a. SAR, it should be less than 9.	4a. Feed calcium and magnesium to adjust SAR. Add lime or gypsum to reduce exchangeable sodium percentage to 5% or less.
	4b. Soil surface sealed by solids.	4b. Soil surface.	4b. Strip crop area, rip and disc soil when dry.
	4c. Application rate exceeds infiltration rate of soil.	4c. Application rate.	4c. Reduce application rate until compatible with infiltration rate.
	4d. Break in distribution piping.	4d. Leaks in distribution piping.	4b. Repair breaks.
	4e. Soil permeability has decreased due to continuous application of wastewater.	4e. Duration of continuous operation on the given area.	4e. Each area should be allowed to rest (2-3 days) between application of wastewater to allow soil to drain.
	4f. Rain has saturated soil.	4f. Rainfall records.	4f. Store wastewater until soil has drained.
5. Irrigated crop is dead.	5a. Too much (or not enough) water has been applied.	5a. Water needs of specific crop versus application rate.	5a. Reduce (or increase) application rate.

Table 2-12 (cont'd).

Indicators/observations	Probable cause	Check or monitor	Solutions
	5b. Wastewater contains excessive amount of toxic elements.	5b. Wastewater analysis and consult with county agricultural extension agent.	5b. Eliminate industrial discharges of toxic materials.
	5c. Too much insecticide or weed killer applied.	5c. Application of insecticide or weed killer.	5c. Proper control of application of insecticide or weed killer.
	5d. Inadequate drainage has flooded root zone of crop.	5d. Water ponding.	5d. (See item 1). Most critical during germination.
6. Growth of irrigated crop is poor.	6a. Too little nitrogen (N) or phosphorus (P) applied.	6a. N and P quantities applied - check with county agricultural extension agent. Possibly need leaf and tissue analysis.	6a. If increased wastewater application rates are not practical, supplement wastewater N or P with commercial fertilizer. Supplement and adjust soil pH.
	6b. Timing of nutrient application not consistent with crop need. (Also, see 5a - 5c).	6b. Consult with county agricultural extension agent.	6b. Adjust application schedule to meet crop needs.
7. Irrigation pumping station shows normal pressure but above normal flow.	7a. Broken main, lateral, riser or gasket.	7a. Distribution system for leaks.	7a. Repair leak.
	7b. Missing sprinkler head or end plug.	7b. Distribution system for leaks.	7b. Repair leak.
	7c. Too many laterals on at one time.	7c. Number of laterals in service.	7c. Make appropriate valving changes.
8. Irrigation pumping station shows above average pressure but below average flow.	8a. Blockage in distribution system due to plugged sprinklers, valves or screens, or frozen water.	8a. Distribution system for blockage.	8a. Eliminate.
9. Irrigation pumping station shows below normal flow and pressure.	9a. Pump impeller is worn.	9a. Pump impeller.	9a. Replace impeller
	9b. Partially clogged inlet screen.	9b. Screen.	9b. Clean screen.
10. Excessive erosion.	10a. Excessive application rates.	10a. Application rate.	10a. Reduce application rate.
	10b. Inadequate crop cover.	10b. Condition of crop cover.	10b. (See items 5 and 6).
11. Odor complaints.	11a. Sewage turning septic during transmission to irrigated site and odors being released as it is discharged to pretreatment.	11a. Sewage as it leaves transmission system.	11a. Contain and treat off-gases from discharge point of transmission system by covering inlet with building, passing off-gas through deodorizing system.
	11b. Odors from storage reservoirs.	11b. Dissolved oxygen in storage reservoirs.	11b. Improve pretreatment or aerate reservoirs.

Table 2-12 (cont'd).

Indicators/observations	Probable cause	Check or monitor	Solutions
			11c. Add sodium nitrate for temporary relief.
12. Center pivot irrigation rigs stuck in mud.	12a. Excessive application rates.	—	12a. Reduce application rates.
	12b. Improper tires or rigs.	—	12b. Install tires with higher flotation capabilities.
	12c. Poor drainage.	—	12c. Improve drainage (see item 1b).
13. Nitrate concentration of groundwater in vicinity of irrigation site is high.	13a. Application of nitrogen is not in balance with crop needs.	13a. Nitrogen being applied (lb/acre per year) with needs of crops.	13a. Change crop to one with higher nitrogen needs.
	13b. Nitrogen being applied during periods when crops are dormant.	13b. Application schedules.	13b. Apply wastewater only during periods of active crop growth.
	13c. Crop is not being harvested and removed.	13c. Farming menagement.	13c. Harvest and remove crop.

CHAPTER 3
OVERLAND FLOW SYSTEMS

3-1. Process description. As the name implies, overland flow is a process where wastewater flows over land that is carefully graded to encourage sheet flow. Grass is planted on the land to take up nutrients and control erosion. As the wastewater flows over the soil surface it is renovated by various physical, chemical and biological mechanisms. Also, some of the wastewater is lost through evapotranspiration by the grass and by percolation into the soil. The remaining wastewater is collected at the toe of the slope and is usually discharged to a receiving stream. As a result, most overland flow systems must comply with a point source discharge permit.

a. The overland flow site can contain one or several slopes. A slope is a discrete section of the overland flow site where the grade is uniform. Each slope is bounded by the distribution pipe at the top, the runoff collection ditch at the bottom and berms or access roads at the sides. The reason for dividing the site into separate slopes is to allow shutdown of portions of the site for harvesting and during operation and maintenance (O&M).

b. Runoff water quality from an overland flow slope will depend on the amount of time wastewater is allowed to remain in contact with the soil surface. Generally, longer detention times can be expected to produce a better runoff water quality than shorter detention times. The operator can control detention time on an existing slope by adjusting the application rate. The average runoff water quality from a properly operated system with adequate detention time is shown in table 3-1. Since overland flow treatment depends on detention time, it is important to maintain each slope so that water flows uniformly. If channeling occurs water will flow too quickly and detention time will decrease.

Table 3-1. Average runoff water quality.

Constituent	Concentration (mg/L)
BOD	10
Suspended solids	10
Ammonia nitrogen as N	4
Total phosphorus as P	4

c. The slopes should be seeded with a perennial grass mixture that has a high moisture tolerance, a long growing season and a high nutrient uptake, and that is well suited for the local climate and soil conditions. The mixture should contain grasses whose growth characteristics complement each other, such as sod formers and bunch grasses, and early and late maturing types. One mixture used quite successfully is reed canarygrass, tall fescue, redtop, dallisgrass and ryegrass. Although this mixture has proven to be effective in a variety of climates, it is always best to consult a county agricultural extension agent.

3-2. Staffing requirements. Figure 2-2 can be used to estimate staffing requirements for overland flow systems.

3-3. Initial startup. Wastewater should not be applied to an overland flow slope until the grass is well established. Premature wastewater application will cause erosion and channeling. As a general rule, wastewater should not be applied until the grass has grown high enough to be cut once. Grass from the first cutting may be left on the slope to help build an organic mat. Grass clippings should be short enough to quickly fall to the soil surface because long clippings tend to remain on top of the cut grass and retard growth. An acclimation period is usually necessary after initial startup; during this time the microbial populations on the soil surface are increasing and adapting to the wastewater environment. This initial acclimation period may be as long as 4 months, but 1-2 months is typical for primary effluent.

3-4. Process control and monitoring.

a. Compliance monitoring. Most overland flow systems will have a discharge permit and it will specify allowable concentrations of BOD and suspended solids in the runoff. Groundwater monitoring may be required if the soil is relatively permeable and the site is located above a protected aquifer. The parameters to be monitored and the sampling frequency will usually be specified in the permit. It is important to establish background quality levels by taking several samples from all monitoring wells before the application of wastewater to the site. More information on groundwater monitoring can be found in paragraph 2-8,f.

b. Process control monitoring.

(1) Preapplication treatment. The O&M manual will contain the basic monitoring needs for the particular preapplication treatment process.

(2) Storage ponds. The process control monitoring requirements for storage ponds are the same for both overland flow and slow rate systems. Refer to paragraph 2-9,b for further information.

(3) Disinfection. Disinfection prior to application is not necessary except in the unlikely case that general public access is permitted. However, the runoff may have to be disinfected if a discharge permit that has a fecal coliform limitation is required. If this is the case, the operator should follow standard monitoring procedures recommended by the manufacturer of the disinfection equipment.

(4) Application site. The primary method of controlling the performance of an overland flow system is to adjust the application rate. The O&M manual will specify the basic application rate for each slope in the system. However, if this information is not available, the operator can

calculate or adjust the application rate as outlined in appendix A. The operator can control the volume of wastewater applied to a slope by controlling the application cycle. The application cycle is simply the length of time wastewater is applied. The application cycles used most often in existing overland flow systems range from 6 to 12 hours of continuous operation per day, 5 to 7 days per week. Use of an application cycle within this range should produce a consistent runoff water quality. Longer application cycles can be used temporarily to handle diverted flows because of harvesting or maintenance. A 24-hour per day application cycle is not recommended because it may result in anaerobic conditions on the slope, which could cause odors.

3-5. Routine operating procedures.

a. Preapplication treatment. It is beyond the scope of this manual to address all the routine operating procedures associated with various preapplication treatment processes. The procedures required for the processes in use will be described in the site-specific O&M manual for each system.

b. Storage ponds. The basic operating procedures for a storage pond should be the same for an overland flow system as for a slow rate system (see para. 2-12). The storage pond should only be used in the winter during prolonged cold. Once the slopes are back in operation the storage pond should be bypassed, and the stored wastewater should be blended with the incoming wastewater for application to the site. This procedure will reduce pretreatment costs and minimize algae growth in the storage pond. Algae can be difficult to remove by overland flow, since removal is dependent on the type of algae present in the wastewater. The dominant type of algae often changes with the season and control by the operator is not possible.

c. Application site.

(1) Annual startup. In the southern U.S. an overland flow system can generally operate year-round, but temporary shutdowns of 1 or 2 weeks may be necessary during the coldest weather. In the northern U.S., however, the shutdown period may last for several months. It will take approximately 1 month for the system to reacclimate after a prolonged winter shutdown.

(a) If the system has been shut down over the winter it should be restarted whenever frost is out of the topsoil layer. Typically, this will be in the month of March or April. The system should not be restarted too early because poor runoff water quality will result. Experience will dictate the best time to begin operation at a particular site.

(b) Before wastewater is applied to the slopes, all pipelines should be checked for leaks. Distribution lines at the top of the slopes should be releveled to ensure even flow distribution. Obvious channels on the slopes should be filled in with fine topsoil and reseeded. Commercial sod can also be used in areas where the channels are deep. These channels and other barren areas should be reseeded with a mixture of grasses containing a quick growing species such as ryegrass. Application to reseeded areas should not begin until the grass is about 2 inches tall. Premature application could wash topsoil and seeds downslope.

(c) It may be necessary to use a lower application rate than normal for about a month after a prolonged shutdown. Otherwise, the runoff water quality may not meet permit requirements. Wastewater application can then be increased to the recommended rate as discussed in paragraph 2-13.

(d) During the early spring, the runoff may have a slight greenish tinge due to the algae. An algal mat sometimes develops on the surface of some slopes. However, the algae usually disappears as soon as the grass is tall enough to shade the surface. Excessive grass and weed growth in unlined collection channels can be a problem since rank growth will impede the rate of runoff flow. Lined channels may be the best solution since killing the grass with herbicides may then cause soil erosion.

(2) Daily operation. All components (pumps, valves, flowmeters and distribution sprinklers or pipelines) should be checked daily for proper operation. Some gated pipe may have a tendency to clog, which results in uneven flow distribution. If several of the openings become clogged, the flow rate through the remainder will increase, causing channeling and flow short-circuiting on the slope. The application rates and cycles should also be checked and maintained in accordance with paragraph 2-13. Wastewater application to the slopes should be stopped during a heavy rainstorm because continued application may hydraulically overload the terraces and cause channeling. Application can continue during light rain or drizzle even though the hydraulic detention time will decrease. Rainfall runoff from overland flow slopes is at least equal to and usually better in quality than the treated runoff.

(3) Harvesting. The grass should be cut two or three times a year and removed from the slopes. The best time to cut is just after the grass goes to seed. This cutting practice will result in the highest yields and best quality forage. Depending on the local market, the sale of the hay can provide a modest economic return. Also, regular harvesting can improve nutrient removal and allow the operator to look for potential channeling problems on the slopes. Only part of the overland flow site should be harvested at any one time so that the system can keep working.

(a) Before harvesting, each slope must be allowed to dry out so that equipment can travel over the soil surface without leaving ruts. Ruts could develop into channels, especially if they are oriented downslope. The drying time necessary before mowing is usually about 1 to 2 weeks; however, this can vary depending on the soil and climatic conditions. After mowing, the hay should be dried before raking and baling. This may take another week or so depending on the weather. The total time that the slope can't be used for each harvest then is approximately 2 to 3 weeks. This time can be reduced by a week or more if green chop harvesting is practiced instead of mowing, raking and baling. However, local markets may not exist for this type of forage.

(b) The standard equipment recommended for harvesting is a good farm tractor, a rake and a baler. A stake-body truck with a flatbed is also needed to take the hay to market or to a storage area. All equipment should have flotation tires to reduce rutting. Harvesting should be done across the slope so that opportunities for downslope rutting are reduced. All exposed pipelines and collection ditches should be clearly marked to avoid damage.

(c) Suggested monitoring programs for soils and vegetation are the same for overland flow as for slow rate systems (see para. 2-8,a). If the grass is used as fodder, samples may be required during each harvest; they should be analyzed for various nutritive parameters such as protein, fiber, total digestible nutrients, phosphorus and dry matter. These analyses can be conducted by the agricultural department of most state universities.

(d) After several years of operation certain native grasses and weeds will begin to grow on the slopes. In most cases these plants will have no impact on treatment efficiency but could decrease hay yields. Certain annual species such as barnyardgrass should be eradicated before they dominate a slope. When these plants die in the fall, the slope is left bare and is susceptible to soil erosion. Herbicides should be used to control these plants and barren areas should be replanted with perennial grasses. The county agricultural extension agent may be able to give advice on the type and amount of herbicide to use.

(4) Winter shutdown procedure. In general, overland flow systems should be shut down whenever runoff water quality does not meet the discharge permit because of sustained low temperatures. Like any other biological process, the reaction rate slows down as the temperature decreases. The length of the shutdown period will vary with climate and required runoff water quality. Once the system is shut down, it should not be restarted until spring. All distribution lines should be drained after the system has been shut down for the season. Wastewater flows should be diverted to the storage pond and all pumps and valves should be made ready for winter.

3-6. Emergency procedures. Emergency situations that might be of concern on overland flow systems include intense rainstorms, sudden cold spells, insect infestations and shock loadings of toxic wastes. Intense rainstorms should not present a problem if the runoff collection ditches were adequately sized and constructed. The ditches are typically designed, as a minimum, to carry runoff from a storm with a 25-year return frequency. It is usually desirable to install a drainage channel around the perimeter of the site to divert off-site runoff. Insect pests such as mosquitoes and army worms have been reported on some overland flow sites. Mosquitoes should not be a problem if the site is kept free of breeding areas such as stagnant ditches. Army worms, which are harmful to the vegetation, can be controlled with a pesticide. A certified exterminator should be consulted on the proper use of pesticides.

3-7. Maintenance considerations.

a. The key to successful performance of an overland flow system is maintaining "sheet flow" down the length of each slope. If channels develop due to poor construction or hydraulic overloads they should be filled in and reseeded at the earliest convenience. Another maintenance consideration is the health of the vegetation on the slopes. A healthy and prolific grass stand is very important. Barren areas should be reseeded at the earliest possible time.

b. Experience has shown that if surface distribution methods such as gated pipe are used to apply raw or primary wastewater to the overland flow site, solids will eventually accumulate on about the top 10 feet of each slope. This buildup occurs because the shallow depth of water flow allows the suspended particles to settle out quickly. If allowed to accumulate, the solids may smother the grass and become anaerobic. However, this problem can be eliminated by disking-in the solids, which then decompose in the soil. This only has to be done infrequently.

CHAPTER 4
RAPID INFILTRATION SYSTEMS

4-1. Process description.

a. General. In rapid infiltration systems the wastewater is applied to moderately to very permeable soils (such as sands and gravels) by flooding basins or by sprinkling. The wastewater is treated as it travels through the soil matrix, and the treated percolate drains naturally to surface waters or moves downward to the groundwater. The objective of rapid infiltration is wastewater treatment. Uses of the treated water can include:

- Groundwater recharge
- Recovery by wells or underdrains for reuse or discharge
- Recharge of surface streams by interception of groundwater
- Temporary storage of groundwater in the aquifer.

Rapid infiltration systems consist of a number of infiltration basins that are flooded and then allowed to dry before they are flooded again. The drying period allows the organic material that collects on the soil surface to decay. It also allows the soil to reaerate. The hydraulic loading rate at existing rapid infiltration sites ranges from 50 to more than 200 feet per year. The hydraulic loading rate depends on the type of soil and depth to groundwater, as well as on the quality of the applied wastewater and the level of treatment desired.

b. Process requirements. The majority of rapid infiltration systems in the U.S. have some type of conventional wastewater treatment process to treat the wastewater before it is applied to the infiltration basins. The operation and maintenance (O&M) requirements for the particular process in use will be specified in the site-specific O&M manual.

4-2. Staffing requirements.

The numbers of and skill levels of personnel needed to operate a rapid infiltration system depend on two factors: the size of the system and the type of preapplication treatment process. The manpower requirements for the rapid infiltration basins should be less than one-half of the values given in figure 2-2 for slow rate systems.

4-3. Process control and monitoring.

a. Compliance monitoring. Compliance monitoring is required by local, state or Federal regulatory agencies to certify that the system is performing as required. For rapid infiltration systems, this will usually require periodic sampling and analysis of the groundwater from wells beneath and around the perimeter of the site. Nitrate-nitrogen is the greatest concern for groundwaters that enter a drinking water aquifer. Paragraph 2-8,f discusses groundwater monitoring in greater detail.

b. Process control monitoring.

(1) Preapplication treatment. The system is usually monitored by the operator to determine the level of performance of the different unit processes in the entire system, to make sure that the unit processes are operating properly, and to assist him in making operational changes to ensure the continued satisfactory operation of the system.

(2) Storage ponds. The majority of rapid infiltration systems are operated throughout the year; therefore, storage ponds are not typically required. The exception may be the inclusion of a small capacity storage pond for flow equalization or for emergency storage in case of a major mechanical failure. In the event it is necessary to use the pond for emergency storage, the operator must plan to empty the pond as soon as the emergency is resolved. The stored wastewater should be blended into the daily flows for application to the basins. Monitoring of storage basins is covered in paragraph 2-12.

(3) Application site. In order to minimize any problems with the basins the operator should inspect them daily. The operator should document in his daily log sheets the depth of standing water in the various basins and the amount of time it takes them to drain. This will allow calculation of the wastewater infiltration rate and identification of those basins where the infiltration rate has decreased to a level where restoration of the surface is needed. The operator should inspect the berms of the infiltration basins frequently. Vegetation such as tree seedlings and brush should be removed. The operator should also note any signs of erosion on the berms. The operator must also inspect the hydraulic system used to apply the wastewater to the basins to determine if it is functioning properly. Low spots where wastewater can remain ponded should be filled in. During winter operations the operator must inspect the entire system, paying particular attention to problems of freezing and ice formation.

4-4. Routine operating procedures.

a. Preapplication treatment. The routine operating procedures for the preapplication processes will be described in the site-specific portions of the O&M manual (see appendix A).

b. Storage ponds. Storage ponds are usually only included for emergencies and must therefore be empty at all other times. It is important that the operator empty the pond as soon as possible after the emergency.

c. Application site. The operator must keep accurate daily records of the depth of wastewater in each basin. This information should be used by the operator to compare the actual operating infiltration rates to the design rates. With this information he will be able to make the necessary changes in the operation of the system.

(1) An example of the calculations the operator would need to make to determine the new volumes to be applied to each basin are given in appendix A. It is very important that each basin be operated so that it has an adequate drying period before it is flooded again. This drying period is very important because it allows the solids on the soil surface to decompose, and it allows the soil to reaerate.

(2) The operator should also measure and record the depth to groundwater in the observation wells at the site. This information will be used to determine the extent of groundwater mounding beneath the site. Mounding is the rise of the water table above its normal level under the infiltration basins. If the water table rises so that it is within a few feet of the surface it will have adverse effects on the system. It will reduce the rate of movement of the wastewater into the soil and it will reduce the level of treatment. At rapid infiltration sites with recovery wells or underdrains, mounding may be reduced by increasing the pumping rate from the wells or underdrains. If the system does not have recovery wells or underdrains and mounding becomes a problem, the operator should get help from a qualified groundwater hydrologist.

(3) Winter operating procedures for the infiltration basins may, depending on the local climate, require that certain precautions be taken to stop freezing in the distribution network. The operator should check the site daily for these types of problems and correct them immediately.

4-5. Emergency procedures. One of the more serious things that can happen to a rapid infiltration system is an electrical power failure that can affect pumps and motorized valves. An emergency generator should be available. The operator should consider sudden basin clogging an emergency and he should take action to correct it as described in paragraph 4-6.

4-6. Maintenance considerations. Maintaining the soil infiltration capacity should be of prime concern to the operator. As stated previously, the operator should keep accurate records of the infiltration rates of the basins to determine when surface restoration is needed.

a. Restoring the basins to an acceptable infiltration capacity is normally accomplished by discing or scarifying the dry soil surface to break up the organic mat that develops. Another method is to completely remove the top layer of soil and replace it with a suitable soil. This method uses more labor and equipment than discing and it will also require large earth moving equipment. If this method is used, care must be taken to limit the amount of vehicular traffic on the beds to reduce the amount of compaction of the subsurface soil layers.

b. In colder climates the operator should disc the dry surface of the basins about once each year during the late summer and fall. This should keep the basins from clogging during the winter season. Another suggestion for cold climates is to plow the basin surface each fall and leave the ridges and furrows. As the water level in the basins decreases, sheets of floating ice should come to rest on the ridges while the remaining water infiltrates into the furrows. During the next flooding sequence, the wastewater will initially fill the furrows and then as the water level rises, it will float the sheets of ice that are bridging the ridges. This floating ice helps to insulate the wastewater in the basins. Also, basins in cold climates that have grass or weeds growing in them should be mowed in the fall. This will keep ice from freezing to the vegetation near the soil surface; this attached ice will be submerged during the next flooding cycle and prevent infiltration. The standing water will then freeze and the basin won't work.

c. Mechanical equipment such as pumps, valves and flowmeters should be maintained in accordance with the manufacturers' guidelines.

APPENDIX A
SAMPLE CALCULATIONS

A-1. Introduction. This appendix presents calculations that will help an operator manage his land treatment system. The primary concern here is water management: receiving the water into the treatment system, pretreating it, storing it, and distributing it onto the land, with recovery and final discharge if applicable. Also of concern is quality management and energy management. Quality management ensures that the land treatment system is operating within its capabilities, especially the vegetation component, and also satisfies regulatory requirements. The operator can manage energy use by collecting and using power consumption data to make sure that the land treatment system is efficient. This is critical in justifying charges to those people who must pay for the system.

A-2. Water management. Land treatment systems generally consist of three major components, each of which can take several different forms (fig. A-1). Pretreatment can be almost any conventional process, from simple bar screens to primary clarifiers to an activated sludge plant. This is particularly true where the land treatment component has been added to an existing wastewater treatment plant to upgrade or expand it. The purpose of pretreatment is to prepare the wastewater for application onto the land, and to protect the distribution system that discharges the wastewater to the land (pumps, nozzles, weirs, etc.). Operation and maintenance of conventional processes are covered adequately elsewhere. In many modern land treatment systems, pretreatment and storage are combined in a pond, usually of multiple cells. Alternatively, two or more ponds may be provided, the first for pretreatment and the last for seasonal or emergency storage. In general, treatment ponds will maintain a constant depth, whereas storage ponds will vary in depth. Depending on state standards, most ponds are lined to prevent seepage.

Figure A-1. Major components of a land treatment system.

A-3. Ponds. Calculations helpful in managing the pond system are area-depth-volume relationships and water balance equations for the pond system.

$$V = Ad \text{ (at any time t)} \qquad (1)$$

where

V = volume of pond (ft^3)
A = surface area (ft^2)
d = depth (ft).

a. For example, in a pond with an area of 10 acres and a depth of 6 feet, the volume of water contained is

$$V = Ad = (10 \text{ acres})(43{,}560 \text{ ft}^2/\text{acre})(6 \text{ ft}) =$$

$$(2{,}613{,}600 \text{ ft}^3)(7.48 \text{ gal./ft}^3) = 19{,}549{,}728 \text{ gal.}$$

The change in volume for a pond over a given time can be obtained by making a water balance for the pond — essentially accounting for all of the water entering and leaving the pond system:

$$\Delta V = Q_i + P - Q_o - E - S \qquad (2)$$

where

ΔV = change in volume over time t (ft^3)
Q_i = influent wastewater to the pond (ft^3/unit time)
P = precipitation over time t (in.)
Q_o = effluent from pond to land (ft^3/unit time)
E = evaporation over time t (in.)
S = seepage over time t (in.).

Note that P, E and S are depths, and that equation 1 can be used to translate these depths into volumes of water entering the pond.

b. Although an operator cannot control any of the parameters in equation 2 except Q_o, use of these equations, combined with depth measurements of the storage pond and knowledge of the overall system, can give the operator knowledge of when to apply wastewater and how much to apply (within the design limits of the system). It can also give early warning about possible leaks in the storage components, and leaks, infiltration or major new discharges in the collection system.

A-4. Land. Management of water on the land component of the treatment system is constrained primarily by climate and the percolation capacity of the soil. These elements, as well as others, were accounted for during the design of the land treatment system. Key elements in managing the land component of the treatment system are Hydraulic Loading Rate (HLR) and Application Rate (AR). HLR is the amount of wastewater to be applied to the land per year or month (ft/year or ft/month). AR is the depth of water to be applied during each loading cycle (in.). In rapid infiltration and slow rate systems, it is essential that several days without application be allowed between loading cycles so that aerobic conditions in the root zone and soil profile are restored. In overland flow systems, there may be daily loading with no application at night and on weekends. In order to calculate the amount of water to apply during a given loading cycle, it is necessary to know the HLR and the application frequency.

$$V = \left[\frac{HLR}{f}\right] [A][43{,}560 \text{ ft}^2/\text{acre}] \qquad (3)$$

where

V = volume during one loading cycle (ft^3)
f = frequency of application (times/month)
HLR = hydraulic loading rate (ft/month)
A = field area (acres).

For example: A = 25 acres, f = once/week and HLR (for July) = 1 ft. How much wastewater should be applied during each weekly loading cycle?

$$V = (1\ \text{ft})(25\ \text{acres})(43{,}560\ \text{ft}^2/\text{acre}) = 1{,}089{,}000\ \text{ft}^3$$

July has 31 days, or:

$$\frac{31\ \text{Days}}{7\ \text{days/week}} = 4.3\ \text{weeks.}$$

Weekly loading:

$$1{,}089{,}000\ \text{ft}^3 \div 4.43\ \text{weeks} = 245{,}823\ \text{ft}^3/\text{week or } 1{,}839{,}356\ \text{gal./week.}$$

The calculated amount represents the volume to be applied to the field area during 1 week. If the land application site is zoned into areas or basins that are to receive wastewater one at a time, the volume to be pumped during 1 day is divided by the number of basins, and the number of pumping days is equal to the number of basins.

A-5. Water quality. It is important to know how much of various wastewater constituents, particularly nutrients, is actually being applied to the land on a mass basis. To accomplish this, the concentration of the constituent in the applied wastewater must be known as well as the amount of wastewater applied to the land.

$$M_x = (2.72)(c_x)(HLR)$$

where

M_x = mass of constituent x (lb/acre) applied to the site

c_x = concentration of constituent x (mg/L) in the applied wastewater

HLR = hydraulic loading rate of the applied wastewater (ft/month)

2.72 = conversion factor, to convert units to a mass basis.

Example: Area = 30 acres, HLR for July = 1 ft, c_x = total nitrogen = 25 mg/L. How many pounds of nitrogen per acre are applied during the month of July?

$$M_n = (2.72)(25\ \text{mg/L})(1\ \text{ft}) = 68\ \text{lb/acre per month.}$$

The total amount of nitrogen applied in July is:

$$\text{Total nitrogen} = (68 \text{ lb/acre})(30 \text{ acres}) = 2040 \text{ lb.}$$

Note that in this example total nitrogen concentration was given. It is acceptable to assume that the sum of total Kjeldahl nitrogen (TKN) and nitrate (both as N) is approximately equal to total nitrogen. The basic equation is valid for all wastewater constituents and can also be used to calculate mass loadings of storage-treatment lagoons.

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