CHAPTER 7

SMALL SYSTEMS

7.1 Introduction

The procedures in this chapter are intended primarily for systems with wastewater flows of 950 m /d (250,000 gal/d) or less, but, in some situations, may be used for flows up to 3,785 m /d (1 Mgal/d). The objectives for land treatment systems are the same regardless of the community size. However, the design of small systems should include special emphasis on the ease of operation and on minimizing construction and operating costs. Most communities in this size range cannot hire full-time treatment plant operators, and the treatment system must be capable of providing consistent, reliable treatment in the absence of frequent attention. In general, most treatment systems that meet these objectives are nonmechanical and have no discharge to surface waters.

The procedures described in this chapter can be used to streamline Phase 1 of the planning process. Limited field work should be conducted during phase 2 to verify Phase 1 assumptions and to optimize design criteria, particularly when designing RI systems. When more detailed planning or design procedures are needed, the engineer should refer to Chapters 4, 5, and 6.

7.2 Facility Planning

The procedures for planning and design of small systems are similar to, but less detailed than, the requirements for large facilities. Maximum use is made of local expertise and existing published information. The area Soil Conservation Service (SCS) staff, the county agent, and local farmers can all provide assistance and advice. The types of information that should be obtained from these local or published sources are summarized in Table 7-1. The level of detail and the period over which data have been recorded will vary with the community.

7.2.1 Process Considerations

Any of the three major land treatment processes (SR, RI, and OF) or combinations of these processes are suitable for small communities. Seepage ponds have been used successfully in many small communities and are similar to RI in that relatively high hydraulic loading rates are used and treatment occurs as wastewater percolates through the soil.

The primary difference is that seepage ponds are loaded continuously, whereas RI systems use a loading cycle that includes both application and drying periods, resulting in improved treatment and maximum long-term infiltration rates. Other processes, including complete retention and controlled discharge pond systems, also have potential for small communities. Information on these pond systems can be found in the EPA Process Design Manual for Wastewater Treatment Ponds [1].

TABLE 7-1
TYPES AND SOURCES OF DATA REQUIRED FOR DESIGN
OF SMALL LAND TREATMENT SYSTEMS

Type of data	Principal sources
Wastewater quantity and quality	Local wastewater authorities
Soil type and permeability	SCS soil survey
Temperature (mean monthly and growing season)	SCS soil survey, NOAA, local airports, newspapers
Precipitation (mean monthly, maximum monthly)	SCS soil survey, NOAA, local airports, newspapers
Evapotranspiration and evaporation (mean monthly)	SCS soil survey, NOAA, local airports, newspapers, agricultural extension service
Land use	SCS soil survey, aerial photographs from the Agricultural Stabilization and Conservation Service, and county assessors' plats
Zoning	Community planning agency, city or county zoning maps
Agricultural practices	SCS soil survey, agricultural extension service, county agents
Surface and ground water discharge requirements	State or EPA
Ground water (depth and quality)	State water agency, USGS, drillers' logs of nearby wells

Design features, site characteristics, and renovated water quality of the three major land treatment processes are summarized in Tables 1-1, 1-2, and 1-3. General characteristics of small land treatment systems are summarized in Table 7-2. This table should be used as a guide to process selection. Final criteria should be determined during facilities design.

7.2.1.1 Operation and Ownership Alternatives

Small systems may be owned and operated by a municipality or wastewater authority, although municipal ownership and operation are not always necessary. In all cases, overall system management should be under the control of the municipal agency held responsible for performance. Opportunities often exist, and should be sought, for contractual agreements with local farmers to take and use partially treated wastewater for irrigation and other purposes. By taking advantage of such agreements, a community can avoid investments in equipment and land, and can eliminate the need to hire and train new employees.

TABLE 7-2
GENERAL CHARACTERISTICS OF SMALL
(<950 m^3/d OR <250,000 gal/d) LAND TREATMENT SYSTEMS

Process	Minimum preapplication treatment	Crops	Application season	Application schedule	Storage requirements
Slow rate		Annuals	Growing season (3-5 months)	8 h, 1 d/wk	See Figure 2-5
Surface application	Primary				
		Perennials or double cropping	Year-round with exception of down-time for planting, harvesting, maintenance, and cold-weather storage if necessary	8 h, 1 d/wk	See Figure 2-5
Sprinkler application	Ponds				
Rapid infiltration	Primary	Not applicable	Year-round	2 d application, 10-18 d drying	7-30 d for emergencies
Overland flow	Screening and comminution	Perennial grasses	Year-round with exception of down-time for planting, harvesting, maintenance, and cold-weather storage if necessary	8-12 h/d, 5-7 d/wk	See Figure 2-5

Arrangements between local farmers and communities can involve any of several alternatives. For example, the community can provide partially treated wastewater to a farmer, who is then responsible for all components of the land treatment process. Alternatively, the community may provide and maintain irrigation equipment that is used by a farmer who is responsible for all farming operations. In either case, the farmer agrees to take a predetermined amount of water each year to use on his own land. A third alternative is for the community to purchase or lease land and equipment for land treatment and assume responsibility for all aspects of the system except planting, cultivating, and harvesting. These three tasks are accomplished by the local farmer on a contractual or crop sharing basis.

Land used for wastewater application either can be purchased outright (fee-simple acquisition) or leased on a long-term basis. Long-term leases should include the items summarized in Table 2-15. Grant eligible costs of a long-term lease are paid to the community in a lump sum at the beginning of the leasing term.

Contractual arrangements between local farmers and communities should specify the following:

- The duration of the agreement.
- Projected quality of water that will be delivered to farmers.
- Any limits on application rates, buffer zones, or runoff control.
- Any limitations on crop types due to local or state requirements.
- Cost to local farmer and/or community.
- Method and timing of payments (generally annual).
- Method of transferring contract.

Arrangements between local farmers and communities are most practical when forage grasses or grazing animals are involved, since there is less constraint on application of wastewater in years of high rainfall. Other agricultural crops with shorter growing seasons or which are less water tolerant than forage grasses may require additional storage or other considerations. Most arrangements have involved SR systems. Overland flow systems normally are owned by the community to ensure control over system operation. However, contract harvest of OF grasses is advantageous in communities that lack the necessary equipment and expertise.

Rapid infiltration systems also tend to be municipally owned and operated to ensure control over the wastewater treatment process. No crops are involved; thus, the only potential agreements between farmer and community are for land leasing, property easements, or use of recovered water.

7.2.1.2 Water Rights Considerations

In the western states, water rights must be considered. Return of renovated water, including OF runoff and SR and RI percolate, to the original point of community discharge may be necessary. Sometimes, RI basins can be located so that seepage and subflow proceed directly to the stream or water body (Figure l-2c; Section 5.7.1) that received discharge from the previous system. The local water rights situation should be checked with the state agency in charge.

7.2.1.3 Preapplication Treatment

Most land treatment systems include a preapplication treatment step. In small communities, wastewater storage often is provided in the preapplication treatment process. The use of existing treatment facilities may reduce the capital cost of a land treatment system but may necessitate construction of separate storage facilities.

Preapplication treatment facilities should be as close to the application site as the topography, land availability, and system objectives allow. Most existing treatment facilities serving small communities are located at a relatively low elevation to allow a gravity sewer system. Thus, if existing facilities are used, it probably will not be possible to locate the application site near the preapplication treatment system. Instead, it is often necessary to pump the partially treated wastewater to the application site.

7.2.1.4 Staffing Requirements

Staffing requirements depend on the types of preapplication treatment and land treatment, the size of the system, and whether the community or a farmer operates the land treatment portion of the system. Staffing requirements for municipally owned and operated systems are presented in Figure 2-9. Staffing requirements at a variety of smaller systems are shown in Table 7-3.

7.2.2 Site Selection

Before a community can begin the site selection process, it must be able to estimate the amount of land that a land treatment system will require. Approximate land area requirements have been plotted as a function of average design flow for each of the three major types of land treatment in Figure 7-1. Although land area estimates are shown only for flows of 950 m^3/d (250,000 gal/d) or less, land requirements for flows of up to 3,785 m^3/d (1 Mgal/d) can be extrapolated from the curves.

In addition, for SR application periods between 6 and 12 months per year, land area requirements can be interpolated from the two SR curves. For OF application periods greater than or less than 10.5 months per year and RI application periods less than 12 months per year, land area requirements can be extrapolated from the OF and RI curves, respectively. Figure 7-1 can be used to determine what size site to search for during the site selection process, <u>but should not be used for design purposes</u>. Final land requirements will vary with the crop grown, site characteristics, and whether the site is operated by the community or a local farmer.

TABLE 7-3
TYPICAL STAFFING REQUIREMENTS
AT SMALL SYSTEMS

	1980 flow				Municipal staff requirements		
Location	m^3/d	gal/d	Site use	Site control	Pre-application components, man-days/yr	Land treatment components, man-days/yr	Annual total, man-days
Chapman, Nebraska	66	17,400	Grass (RI)	City	--	--	<165[a]
Falkner, Mississippi	106	28,000	Grasses (OF)	City	<89	<93	<182
Kennett Square, Pennsylvania	190	50,000	Forest	City	130	68	198
Ravenna, Michigan	275	72,000	Open, un-cultivated fields	City	68	7	75
Santa Anna, Texas	285	75,000	Alfalfa, grass, pasture	Farmer owns, city operates equipment	54	46	100
Wayland, Michigan	950	250,000	Hay, corn	City owns, farmer harvests	104	68	172
Winters, Texas	1,130	297,000	Hay	Farmer owned	52	0	52

Note: Preapplication treatment by ponds.

a. Includes labor spent maintaining three pumping stations in collection system.

The site selection process can be divided into parts: site identification and site screening (Sections 2.2.4 and 2.2.5). In small communities, the first step in identifying potential land treatment sites is to determine whether any of the local farmers are willing to participate in a land treatment project or are interested in selling or leasing property for a land treatment site. Questionnaires and meetings with local groups can be particularly helpful when making this determination. If one or more farmers are interested in participating and have enough land to take and use the wastewater, or are interested in selling or leasing enough property for a land treatment site, site investigation can begin. If the local farmers are not interested or if the interested farmers do not have enough suitable land, it will be necessary to identify and screen potential sites using existing soils, topographical, hydrogeological, and land use data. The identification and

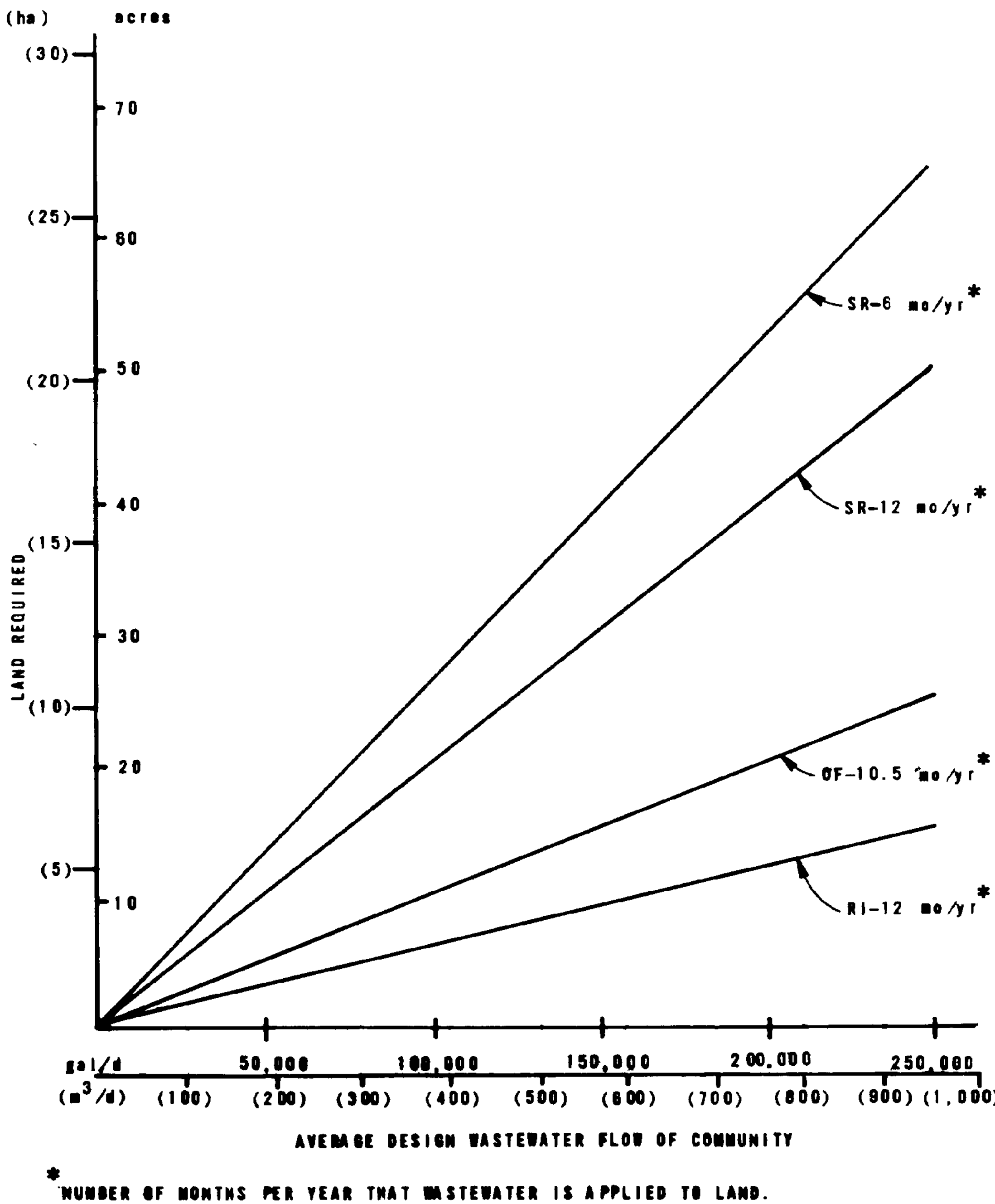


FIGURE 7-1
LAND AREA ESTIMATES FOR PRELIMINARY PLANNING PURPOSES
(INCLUDING LAND FOR PREAPPLICATION TREATMENT)

screening processes are detailed in Chapter 2; only the highlights are presented in this chapter.

As discussed in Section 2.2.4, existing data can be used to classify broad areas of land near the community according to their land treatment suitability. Factors that should be considered include current and planned land use, parcel size, topography, present vegetative cover, susceptibility to flooding, soil texture, geology, distance from the area where wastewater is generated, and need for underdrainage (based on recommendations of local SCS representative). Generally, the characteristics of the closest suitable site will greatly influence the selection of the land treatment system type to be designed. The detailed rating factor approach in Chapter 2 is usually unnecessary because economics will limit the number of sites that can be considered.

7.2.3 Site Investigations

As in larger communities, field investigations are conducted to verify any data used to select sites and to verify overall land treatment suitability. However, the level of effort needed to conduct site investigations in smaller communities is much lower. In smaller communities, it is more practical to conduct minimal field investigations and assume relatively conservative design criteria than to complete the extensive and expensive investigations needed to pinpoint optimal design criteria.

Generally, soils information available from the area SCS office and limited field observations will yield sufficient information for most SR and OF system designs. The first step in the site investigation procedure should be to visit the potential site with a local SCS representative. The primary purpose of these site visits is to confirm the data used to identify and select suitable sites. A few, shallow, hand-auger borings to identify the soil profile should be conducted to confirm the SCS data and check for impermeable layers or shallow ground water. Infiltraton tests (see Section 3.4.1) are usually only needed for RI sites. For RI sites, a few backhoe pits to 3 m (10 ft) or more are also recommended, but drill holes are usually deferred until preliminary design.

If crops will be grown, a site visit with the county agent or local agricultural or forestry advisor is recommended. The purpose of this site visit is to obtain advice on the type of crops to use and on crop management practices.

7.3 Facility Design

Because only limited field investigations are conducted in small communities, it is important to use conservative design criteria. The application schedules and storage requirements presented in Table 7-2 are examples of conservative criteria. Other design criteria that must be identified include the level and type of preapplication treatment and storage, the land area required, wastewater loading rates and schedules, and pumping needs and other mechanical details. Land area requirements are estimated during the planning process and are refined as the hydraulic loading rate, method of preapplication treatment, and storage requirements are defined more precisely.

7.3.1 Preapplication Treatment and Storage

EPA guidance on minimum levels of preapplication treatment is summarized in Table 7-4.

TABLE 7-4
RECOMMENDED LEVEL OF
PREAPPLICATION TREATMENT

Type of land treatment	Situation	Recommended preapplication treatment
Slow rate	Isolated location; restricted public access; crops not for human consumption.	Primary.
	Controlled agricultural irrigation; crops not to be eaten raw by humans.	Biological (ponds or in-plant processes) with control of fecal coliforms to <1,000 MPN/100 mL.
	Public access areas such as parks, golf courses.	Biological (ponds or in-plant processes) with disinfection to log mean fecal coliforms of ≤200 MPN/100 mL.
Rapid infiltration	Isolated location; restricted public access.	Primary.
	Urban location; controlled public access.	Biological (ponds or in-plant processes).
Overland flow	Isolated site; no public access.	Screening or comminution.
	Urban location; no public access.	Screening or comminution with aeration to control odors during storage or application.

In small communities, ponds are usually the most practical form of preapplication treatment and storage. They are relatively easy to operate, require minimal maintenance, are less expensive than many types of treatment, and eliminate the need for separate storage facilities. Although some communities will want to use or upgrade other existing facilities for use as preapplication treatment facilities, many small communities will find it advantageous to convert to pond systems because of their consistency, reliability, flexibility, ease of operation and maintenance, and cost.

Generally, ponds are constructed with one to three cells. In a three-cell system, the first cell is usually small and may be aerated to control odors. Alternatively, if sufficient land is available, the first cell may be designed as a facultative cell with a BOD loading of about 120 kg/had (107 lb/acre·d). The water level in this cell is usually constant and can be controlled with an adjustable overflow weir or a gated manhole. The final cells can be used for storage and flow equalization. For this reason, these two cells are made as deep as possible. Typical design parameters for several types of ponds are presented in Table 7-5.

TABLE 7-5
TYPICAL DESIGN PARAMETERS FOR SEVERAL
TYPES OF PONDS [2]

	Aerobic	Facultative	Anaerobic
Pond size (individual cells), ha	<4	1-4	0.2-1
Detention time, d	10-40	7-30	20-50
Depth, m	1-1.5	1-2.5	2.5-5
BOD_5 loading, kg/ha·d	40-120	15-200	200-500
BOD_5 removed, %	80-95	80-95	50-85
Effluent suspended solids, mg/L	80-140	40-100	80-160

1 ha = 2.47 acres

1 m = 3.28 ft

1 kg/ha·d = 0.893 lb/acre·d

An additional benefit of using ponds is that the long detention times (30 days or more) promote nitrogen removal and pathogen inactivation, preliminary models to estimate nitrogen and bacterial removals in ponds are given in Section 4.4.1.

7.3.2 Hydraulic Loading Rates

The first step in designing the land treatment portion of the system is to select a hydraulic loading rate. As an initial assumption, the hydraulic loading rate for SR and RI systems is based on the most limiting SCS permeability classification of the soils at the selected site. Hydraulic loading rates that may be used in each of the three major types of land treatment systems have been plotted as a function of SCS permeability classification in Figures 7-2 and 7-3. Both figures represent average hydraulic loading rates. In Figures 7-2 and 7-3, whenever a range of loading rates is given, the lower end of the range should be used for primary effluents, the mid zone for pond effluents, and the upper portion of the range for secondary effluent. Lower loading rates than shown in Figures 7-2 and 7-3 can be used but will require more land. If OF is used to polish trickling filter or activated sludge effluent, loading rates of 30 to 40 cm/wk (12 to 16 in./wk) can be used.

Loading rates at SR and RI systems that overlie potential drinking water aquifers may be limited by nitrogen loading rather than soil permeability. At these systems, the ground water concentration of nitrate is limited to 10 mg/L as nitrogen at the project boundary (or the background nitrate concentration, if it is greater than 10 mg/L). Rapid infiltration systems should not be located above drinking water aquifers unless thorough field testing is conducted to verify that the nitrate standard can be met or unless the renovated water will be recovered (Sections 5.4.3.1 and 5.7).

7.3.2.1 Slow Rate

For SR systems located above drinking water aquifers, the following equation should be used to calculate the maximum allowable nitrogen loading rate based on nitrogen limits:

$$L_{w(n)} = \frac{C_p(Pr - ET) + 10U}{(1 - f)(C_n - C_p)} \qquad (7\text{-}1)$$

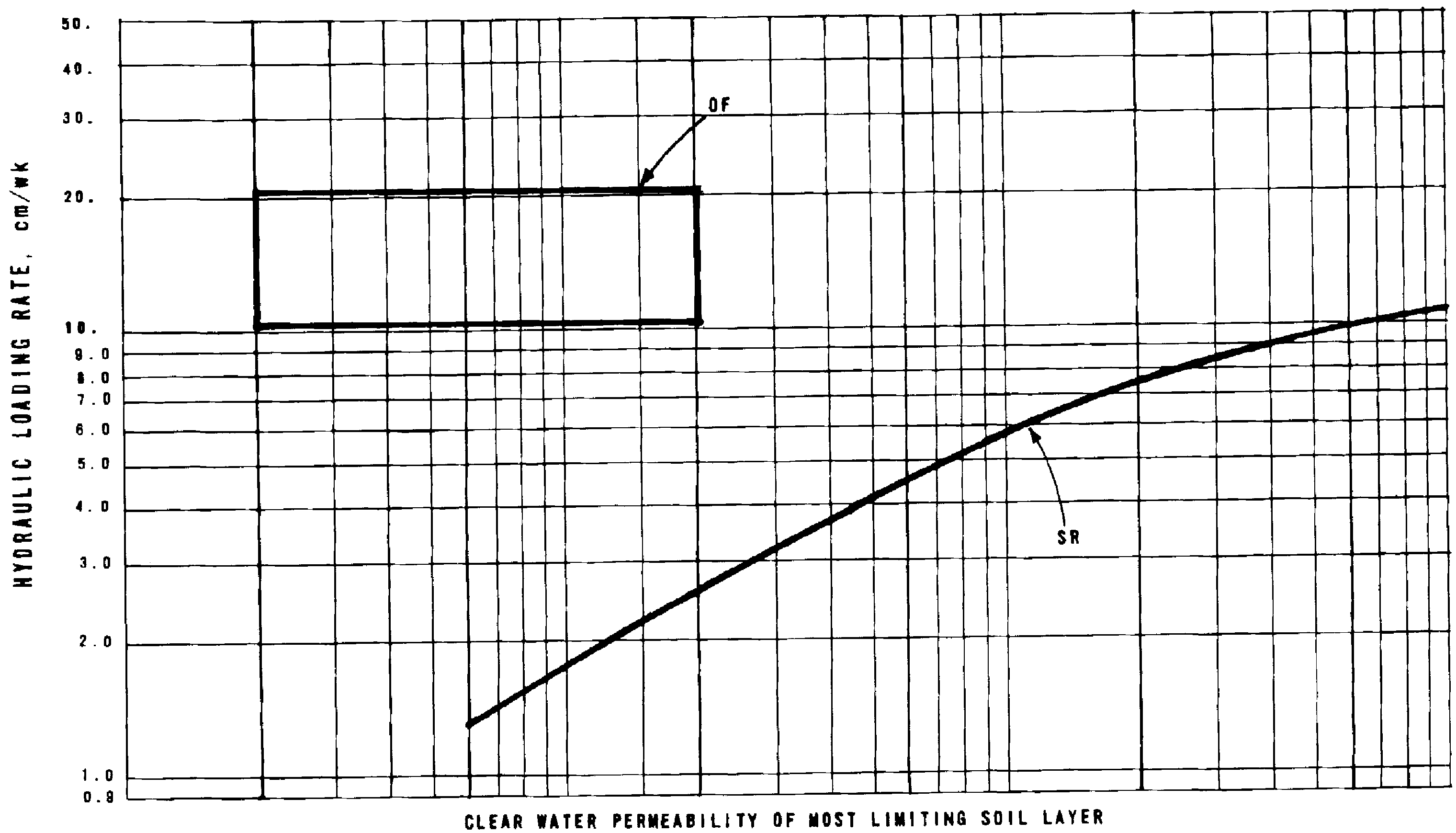
where $L_{w(n)}$ = wastewater hydraulic loading rate based on nitrogen limits, cm/yr (in./yr)

C_p = percolate nitrogen concentration, mg/L = 10 mg/L

Pr = precipitation rate, cm/yr (in./yr)

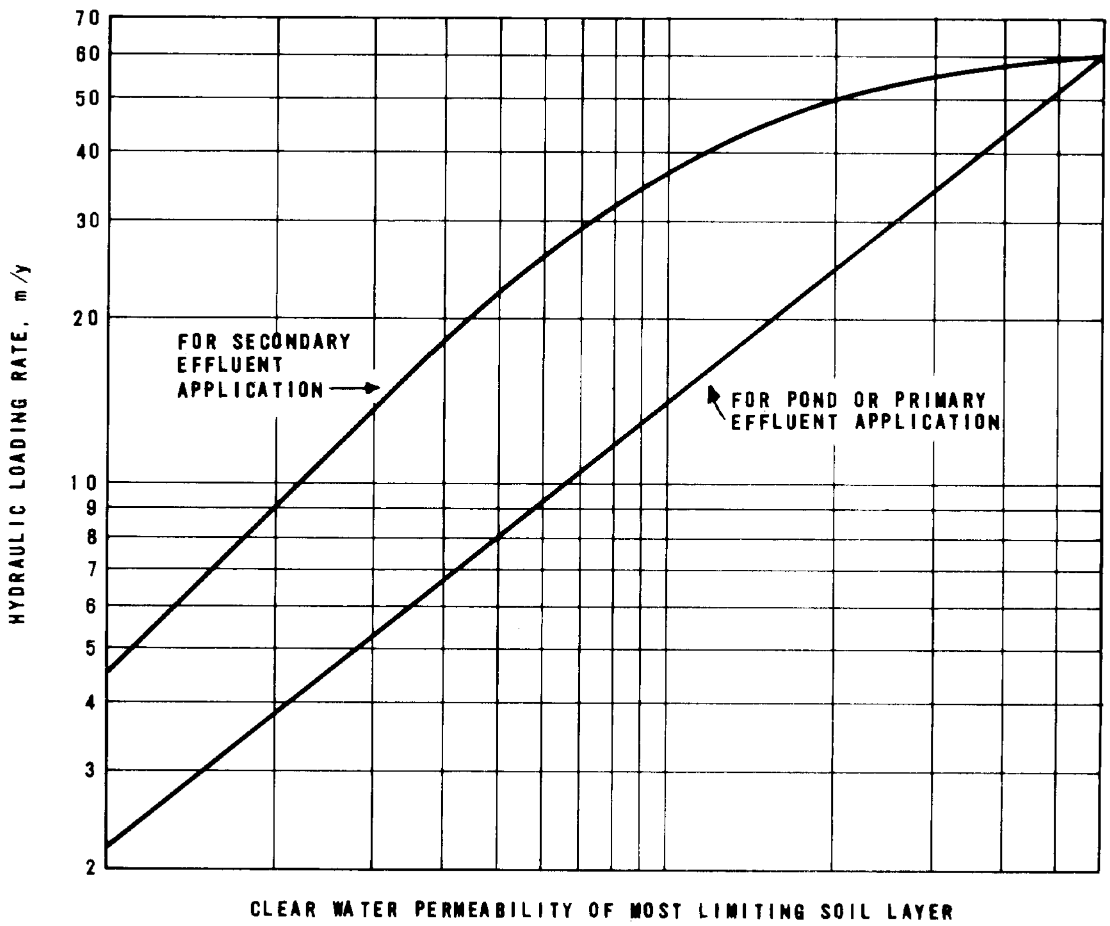
ET = evapotranspiration rate, cm/yr (in./yr)

U = crop nitrogen uptake rate, kg/ha·yr (lb/acre·yr)



in./h	< 0.06	0.06–0.2	0.2–0.6	0.6–2.0	2.0–6.0	> 6.0
cm/h	< 0.15	0.15–0.51	0.51–1.5	1.5–5.1	5.1–15	> 15

FIGURE 7–2
TYPICAL ANNUAL HYDRAULIC LOADING RATE OF SMALL SR AND OF SYSTEMS



in./h	< 2.0	2-6	6-20	> 20
cm/h	< 5.1	5.1-15	15-51	> 51

FIGURE 7-3
TYPICAL ANNUAL HYDRAULIC LOADING RATE OF SMALL RI SYSTEMS

f = fraction of applied nitrogen removed by volatilizaton, denitrification, and storage = 0.15

C_n = nitrogen concentration in applied wastewater, mg/L

Conservative values should be assumed for nitrogen losses and crop uptake rates to ensure adequate nitrogen removal. For this reason, nitrogen storage and ammonia volatilization are ignored in Equation 7-1 and the denitrification rate is assumed to equal 15% of the nitrogen loading rate. Nitrogen losses during preapplication treatment depend on the type of treatment. For conventional primary or secondary treatment, nitrogen loss is negligible. As discussed in Section 4.4.1, the nitrogen loss in a pond can be estimated from Equation 4-1.

Conservative nitrogen uptake values are presented for typical crops in Table 7-6.

TABLE 7-6
NITROGEN UPTAKE RATES FOR SELECTED CROPS[a]

Crop	Nitrogen uptake rate, kg/ha·yr
Forage	
Alfalfa	300
Bromegrass	130
Coastal bermudagrass	400
Kentucky bluegrass	200
Quackgrass	240
Reed canarygrass	340
Ryegrass	200
Sweet clover	180
Tall fescue	160
Field	
Barley	70
Corn	180
Cotton	80
Milomaize (sorghum)	90
Potatoes	230
Soybeans	110
Wheat	60

a. Values represent lower end of ranges presented in Table 4-12 and are intended for use in Equation 7-1.

1 kg/ha·d = 0.893 lb/acre·d

The calculated value from Equation 7-1 of $L_{w(n)}$ is then divided by the number of weeks per year of expected operation and compared with the hydraulic loading rate obtained from Figure 7-2. At this point, the engineer should check with the local agricultural or forestry adviser to verify that the selected crop is tolerant of the lower of the two calculated loading rates. If so, the lower of the two loading rates should be used for design purposes. If the selected crop cannot tolerate the design loading rate, a crop with higher moisture tolerance or nitrogen uptake should be selected.

In small communities, the application schedules presented in Table 7-2 are recommended. Again, if a farmer agrees to take and use the wastewater on his own land, he may continue to use any application schedule that has resulted in a well-managed agricultural system.

7.3.2.2 Rapid Infiltration

Hydraulic loading rates for small RI systems can be estimated using Figure 7-3. The permeability of the most restricting soil layer in the soil profile can be measured using techniques described in Section 3.4. In Figure 7-3, the lower curve should be used when primary or pond effluent is to be applied, and the upper curve can be used when secondary effluent is to be applied.

7.3.2.3 Overland Flow

The hydraulic loading rates for- small OF systems are the same as recommended in Chapter 6, Table 6-5. Because of operational considerations, it is recommended that either 8 or 12 h/d application periods be used, whichever is most convenient. Simple automation using time switches and solenoid valves allows flexibility in selecting application periods.

7.3.3 Land Area Requirements

Once the hydraulic loading rate has been determined, the amount of land required for land treatment can be calculated. For systems that operate year-round, the land required is simply the design average wastewater flow divided by the annual hydraulic loading rate. For systems that are not operated year-round, the area required is calculated as follows:

$$A = \frac{Q(365)(100)}{(L_w)(t)(10{,}000)} \quad \text{(Metric units)} \qquad (7\text{-}2)$$

$$A = \frac{Q(365)(100)}{(L_w)(t)(7.48)(43,560)} \quad \text{(U.S. customary units)}$$

where A = area required, ha (acres)

Q = design average wastewater flow, m 3/d (gal/d)

L_w = hydraulic loading rate, cm/wk (in./wk) (see Section 7.3.2)

t = number of weeks per year during which wastewater is applied

For example, if a system is operated 43 weeks out of the year, the acceptable hydraulic loading rate is 5.8 cm/wk (2.3 in./wk), and the design average wastewater flow is 900 m^3/d (240,000 gal/d), the area required for land treatment is:

$$A = \frac{(Q)(365)(100)}{(L_w)(t)(10,000)}$$

$$= \frac{(900)(365)}{(5.8)(43)(10,000)}$$

$$= 13.2 \text{ ha } (32.5 \text{ acres})$$

Additional land is required for preapplication treatment, storage, access roads, and in some cases buffer- zones. A preliminary allowance of 15 to 20% of the field area is often made for roads, buffer zones, and small unusable land areas. Land requirements for preapplication treatment and storage are determined in the preliminary design of these components.

7.3.4 Distribution Systems

Detailed information on SR distribution systems is presented in Section 4.7 and Appendix E. Additional considerations for small communities are presented in this section.

Distribution methods are selected on the basis of terrain, type of land treatment system, and local practice. In small communities, it is prudent to choose a distribution method that is used locally or that will result in a system that requires only part-time operational attention. If a locally used distribution method is selected, any specialized equipment and necessary expertise will be more readily available.

Traveling guns require relatively high amounts of labor and are more adaptable to systems where several, odd-shaped fields are irrigated each season, so they are usually owned and operated by a local farmer. Both solid set and center pivot irrigation systems can be adapted to either municipally owned or farmer owned small irrigation systems. Center pivots will generally not be applicable for very small SR systems (below 16 ha or 40 acres).

Distribution systems for RI and OF facilities are described in Sections 5.6.1 and 6.6, respectively.

7.4 Typical Small Community Systems

To illustrate some of the features of small scale land treatment systems, four cases are described in this section. These include two SR options, one RI, and one OF system. It is not intended that the site specific criteria for these four systems be applied for process design elsewhere. The concepts will be valid, but specific criteria will depend on individual site characteristics.

7.4.1 Slow Rate Forage System

7.4.1.1 Introduction

A pond system using SR application of wastewater onto several grassed plots is often a workable design for a small community that does not generate sufficient wastewater flow to be economically beneficial for irrigating a cash crop.

7.4.1.2 Population

The community, located in eastern Nebraska, has a present population of approximately 300. The design population for the treatment facility is 310.

7.4.1.3 Flow

The flow to the treatment facility is strictly domestic wastewater, because there are no industries in the community. The system is designed to treat an average per capita flow of 0.25 m^3/d (65 gal/d), or a total flow of 76 m^3/d (20,000 gal/d). Low per capita flows are very common for small communities having no industries and very minimal commercial development. Actual flows to the system have gradually increased as residents switched from their old septic tank systems to the municipal collection system. Flows are commonly in the 57 to 95 m^3/d (15,000 to 25,000 gal/d) range.

7.4.1.4 Climate

The normal annual precipitation is 84 cm/yr (33 in./yr) and the average annual gross lake evaporation is 109 cm/yr (43 in./yr). The mean number of days in which the maximum daily temperature exceeds 32 °C (90 °F) is 40, and the mean number of days in which the minimum daily temperature falls below 0 °C (32 °F) is 130. In an average year, there are 232 days between the last killing frost in the spring and the first frost in the fall.

7.4.1.5 Site Characteristics

The silt loam soils at the proposed treatment site are deep, nearly level, and well drained. Surface soils are silt loam and the subsoils are silty clay loam. Permeability is moderately slow in the 1.0 to 1.5 cm/h (0.4 to 0.6 in./h) range. The site is relatively level and does not overlie a potable aquifer.

7.4.1.6 Treatment Facility Design

The treatment facility consists of a single cell unaerated pond followed by a series of four grassed plots which receive wastewater from the pond. Effluent is not disinfected. The pond provides both wastewater treatment and storage. The degree of treatment in the pond is not a significant factor in design, other than providing at least the necessary primary treatment for removal of heavy solids and rags that could plug distribution piping. The storage volume facilitates operation of the system, since it is not necessary to have an overflow during periods of heavy precipitation or other unfavorable conditions, and the grassed plots can be allowed to dry between applications to allow mowing and maintenance. The design information is summarized in Table 7-7.

The single cell pond is sized similarly to the first cell of a conventional facultative pond system. The design BOD loading is 34 kg/ha:d (31 lb/acre:d), a generally accepted loading rate in Nebraska, and results in minimal septicity or blue-green algae problems. Higher loadings may be allowed by other states where ponds do not become ice covered in the winter. By having a 1.8 m (6 ft) water depth, 1.2 m (4 ft) of storage volume is provided above the 0.6 m (2 ft) water level. The storage volume in the 0.7 ha (1.7 acre) pond is 7,378 m^3 (1.95 Mgal) above the 0.6 m (2 ft) depth. This capacity provides adequate storage during the approximately

133 days (19 weeks) each winter that the plots are not irrigated, based on the design flow and seepage losses of 0.3 cm (0.125 in.) per day.

TABLE 7-7
DESIGN INFORMATION
FOR SR SYSTEM

Design flow, m^3/d	76
BOD loading, kg/d	24
Design population	310
Treatment pond	
Size, ha	0.7
Depth, m	1.8
Capacity above 0.6 m level, m^3	7,378
Bermed grassed plots	
Number	4
Size (each), ha	0.35

The total size of the grassed plots was determined as follows. Calculated design losses from the pond, including seepage and net evapotranspiration, totaled 142 cm/yr (56 in./yr). Using this value, the design overflow from the pond (Q_0) was calculated:

$$Q_o = (76\ m^3/d \times 365\ d/yr) - (142\ cm/yr \times 1\ m/100\ cm \times 7{,}000\ m^2) \quad (7\text{-}3)$$

$$= 17{,}800\ m^3/yr\ (4.7\ Mgal/yr)$$

Using the limiting soil permeability of 1.0 cm/h (0.4 in./h), a hydraulic loading rate of 3.8 cm/wk (1.5 in./wk) was obtained from Figure 7-2. Next, the area required for SR was calculated (Equation 7-4):

$$A = [(17{,}800\ m^3)/(3.8\ cm/wk \times 33\ wk)] \quad (7\text{-}4)$$

$$\times (100\ cm/m) \times (ha/10{,}000\ m^2)$$

$$= 1.4\ ha\ (3.5\ acres)$$

Four grassed plots, each 0.35 ha (0.88 acre) were designed.

Multiple small plots were selected for several reasons. Each plot is small enough to facilitate uniform flooding. Also, the use of multiple plots makes it possible for the operator to mow or make repairs on a dry plot while the other plots are being used for wastewater application.

Any one plot does not receive more water than can percolate within 12 hours. This helps prevent damage to the grass cover and also provides some leeway in case precipitation is received after a cell has been flooded. Ignoring evapotranspiration, the limiting soil permeability rate of 1.0 cm/h (0.4 in./h) dictates that not more than 12 cm (4.7 in.) can be applied per each 1 day application period. To obtain an average hydraulic loading rate of 3.8 cm/wk (1.5 in./wk), each application period must be followed by 21 days of drying. In practice, one plot is flooded on each of 4 consecutive days. After an additional 18 days of drying, flooding is resumed. This sequence continues for approximately 232 days. During the winter (approximately 133 days), all wastewater is stored in the pond.

The overflow control structure designed for this system requires minimal operator attention. The structure uses an overflow pipe that can be raised or lowered in increments to release the necessary volume of effluent. A cross–sectional detail of the structure is included in Figure 7-4.

The grassed plots are quite shallow, having only 0.6 m (2 ft) high dikes. The slopes are 4:1, making the basins readily accessible to mowing equipment. This design helped minimize the amount of earthwork necessary during construction and also maximized the amount of usable area since less dike area was required. Local SCS offices and publications were consulted to obtain the necessary information for selecting a seeding mixture, which needed to be suitable for periodic flooding. A mixture of Reed canarygrass, switchgrass, redtop, and intermediate wheatgrass was planted.

Effluent distribution to the grassed plots is by gated pipe along the toe of the inner slope of one side. This allows more uniform flooding of the basin as compared to a single inlet structure. The area under the pipe and in the direction of flow from the pipe has a layer of rock to minimize erosion and channelization of the flow.

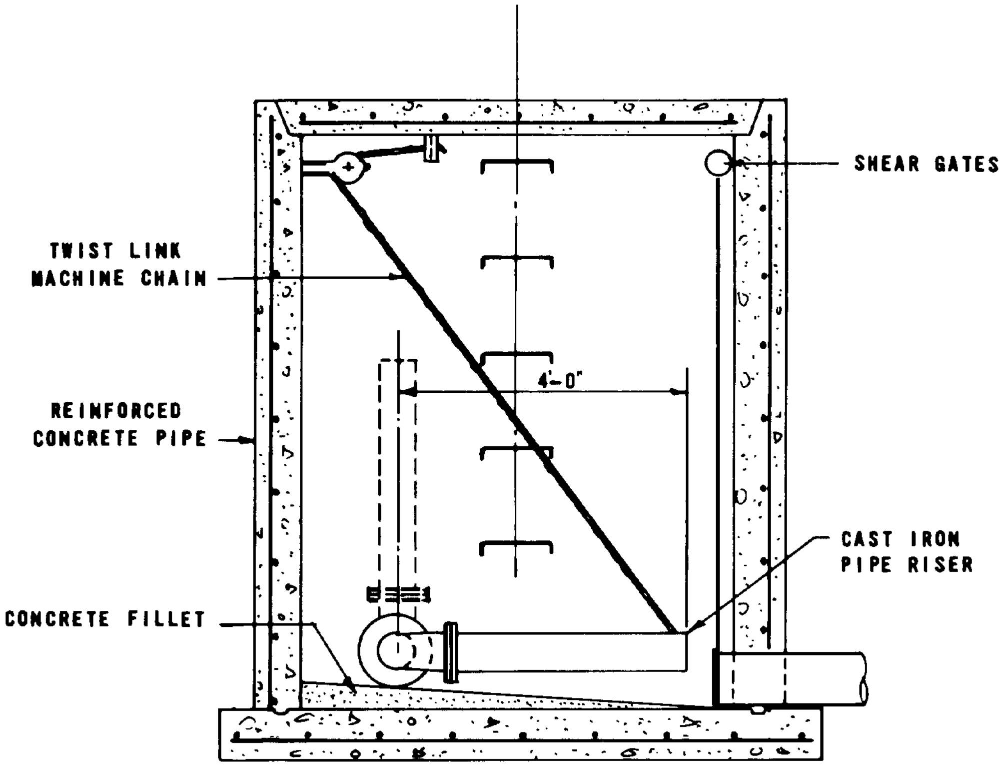


FIGURE 7-4
OVERFLOW CONTROL STRUCTURE FOR POND DISCHARGE TO SR SYSTEM

7.4.1.7 Performance

When the facility was first started up, flows were quite low until all of the residences were connected. The pond provided complete retention of all flows during the first 2 years of operation, with no overflow to the grassed plots. In the third year, only two application periods were used: one in the spring and one in the fall. The number of applications per year has been gradually increasing as flows have approached the anticipated design loadings. A good stand of grass has been maintained in the application plots. This grass cover enhances infiltration and provides maximum evapotranspiration of the wastewater applied.

7.4.1.8 Staffing

The system requires only one part-time operator. Duties at the pond include mowing, valve operation, weed control, and maintenance of fences, access road, valves, and distribution piping.

7.4.2 Slow Rate Forest System

7.4.2.1 Introduction

This forested SR system is located at Kennett Square in southeastern Pennsylvania. The system, consisting of a series of treatment ponds followed by sprinkler application, has been operated since 1973. The system serves two retirement communities and is operated by the wastewater authority.

7.4.2.2 Population and Flow

The population of the two communities totals 725. The flow, which is entirely domestic wastewater, is currently 189 m^3/d (50,000 gal/d). The design flow is 265 m^3/d (70,000 gal/d).

7.4.2.3 Climate

Precipitation and evaporation are nearly equal with average annual precipitation at 110 cm (43 in.) and average annual pan evaporation estimated to be 120 cm (47 in.). Average annual temperature is 11.9 °C (53.4 °F).

7.4.2.4 Site Characteristics

The application area is covered with a native stand of beech, maple, poplar, and oak trees. The soils are basically silt loams with predominant slopes between 3 and 8%. Soils are moderately deep and permeable with slightly acidic pH values. The soil permeability of 1.5 to 5 cm/h (0.6 to 2 in./h) would support a loading rate of 5 cm/wk (2 in./wk) or more on a hydraulic loading basis (Figure 7-2).

7.4.2.5 Treatment Facility Design

The layout of treatment facilities is presented in Figure 7-5; photographs of the treatment pond and sprinkler application are shown in Figure 7-6. Wastewater is treated in three treatment ponds, disinfected, and applied via sprinklers onto 3.24 ha (8 acres). The first pond is aerated, covers a surface area of 0.128 ha (0.3 acre), and is 4 m (13 ft) deep. Aeration is provided by a 7.5 kW (10 hp) floating surface aerator. Wastewater then flows by gravity through two nonaerated ponds that are 2.1 m (7 ft) and 2.4 m (B ft) deep and cover 0.68 ha (1.69 acres) and 0.30 ha (0.75 acre), respectively. Total detention in the three ponds is 80 d at current flows.

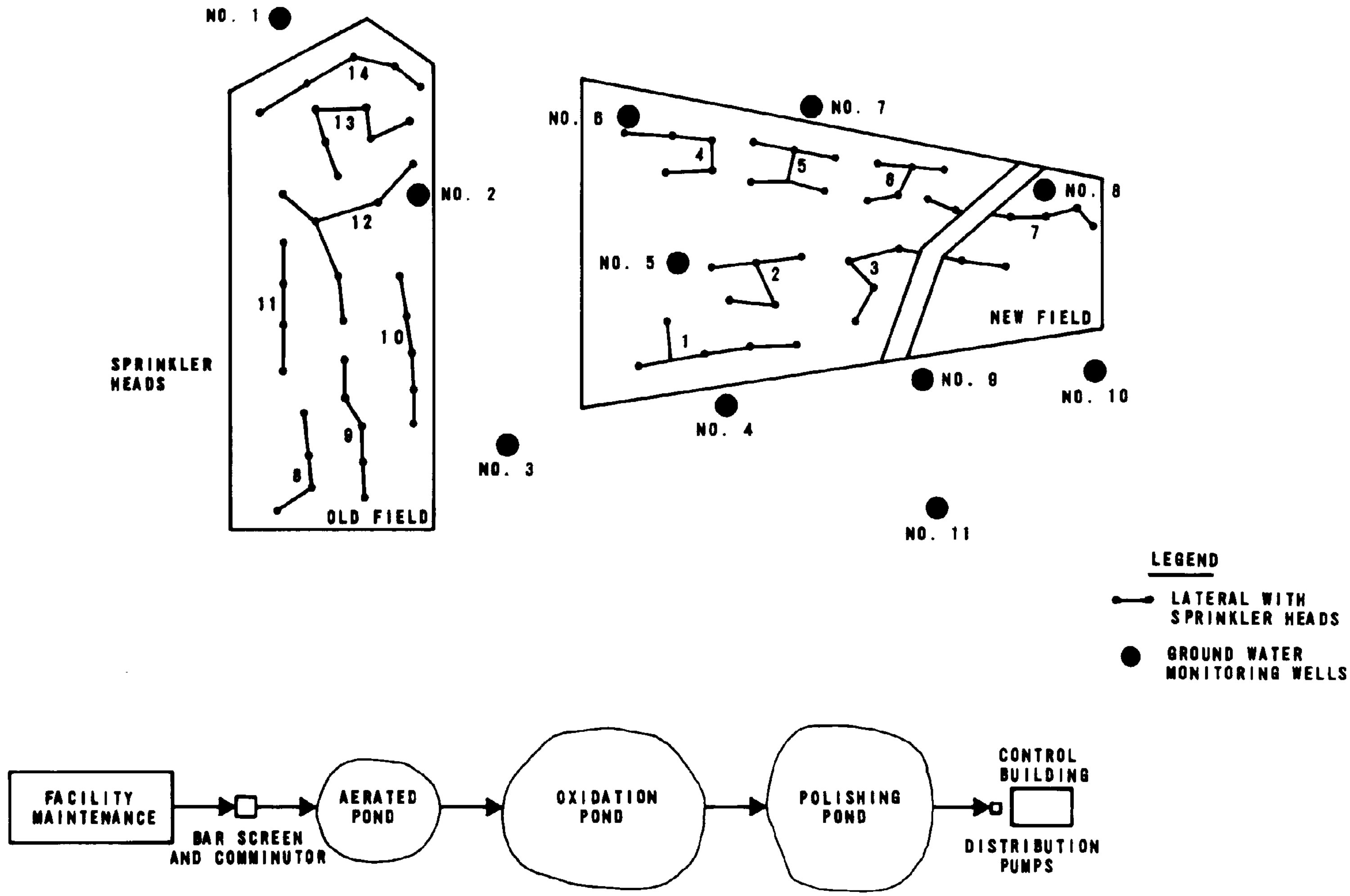


FIGURE 7-5
TREATMENT FACILITY LAYOUT - KENNETT SQUARE, PENNSYLVANIA, SR SYSTEM

TREATMENT POND

SPRINKLER APPLICATION IN EXISTING HARDWOOD FOREST

FIGURE 7-6
SR FACILITIES AT KENNETT SQUARE, PENNSYLVANIA

The design hydraulic loading rate is 5.1 cm/wk (2 in./wk), which is the State of Pennsylvania guideline. The nitrogen loading is 279 kg/ha·yr (248 lb/acre·yr) for the design flow which is somewhat high for application to an existing hardwood forest. Because of the relatively mild climate, year–round application was planned.

The application area is divided into 14 separate areas or plots. Wastewater is applied for 24 hours on 4 to 6 plots each day, 5 days per week. On this schedule, an individual plot receives effluent every fourth day. Storage for weekends and cold weather is possible in the treatment ponds. The main lines and laterals are buried with drain valves to drain the lines after applications are complete.

A buffer zone of approximately 46 to 61 m (150 to 200 ft) is maintained between the application site and the nearest residence. This area is covered with grass and trees. All stormwater runoff from the community is diverted around the site. Stormwater generated onsite is allowed to run off onto adjacent land. Site access is controlled by signs and fencing; however, there are some nature trails in the area to which access is permitted.

7.4.2.6 Operation and Performance

The system has operated satisfactorily for 8 years. During winter operation, sprinkling is practiced until the temperature drops to -6.7 °C (20 °F). Frost heave problems have affected valve boxes placed in the forest. Screening of the applied water is needed to avoid nozzle clogging from debris that falls into the ponds.

Treatment performance of the system can be measured using the ground water monitoring wells. The depth to ground water varies from 3.6 to 9.1 m (12 to 30 ft) in the 11 monitoring wells. The range of nitrate nitrogen concentrations is from 0 to 4.8 mg/L and indicates satisfactory performance, in spite of the relatively high nitrogen loading (Section 7.4.2.5).

7.4.2.7 Staffing and Budget

One operator spends approximately 6 h/d, 5 d/wk operating and maintaining the wastewater treatment system. Of this total, 2 h/d is associated with the SR land treatment system.

A total of $15,000/yr is budgeted for operation and maintenance of the system. Of this total, 37% or $4,070/yr is associated with land treatment.

7.4.3 Rapid Infiltration

7.4.3.1 Introduction

An RI system for a small community need not be designed for intensive wastewater applications at maximum RI rates, which could involve the need for recovery of renovated water and a relatively high level of operation and management. Instead, the design can be simplified to meet the objectives of wastewater treatment and still maintain ease of operation. The following example illustrates an adaptation of an RI system that normally operates at very low application rates, but has the capability of treating the exceptionally high flows that occur occasionally.

7.4.3.2 Population

The facility serves the small, rural community of Chapman in east central Nebraska. The community is primarily residential, with a small commercial district, but with no industries. The present population is estimated to be 400.

7.4.3.3 Flow

The treatment pond was designed to serve a population of 500. When the treatment facility was designed, there was no past history of wastewater flows and an average per capita contribution of 0.26 m^3/d (70 gal/d), or total flow of 132.5 m3/d (35,000 gal/d), was assumed. Actual dry-weather flows have averaged approximately 66 m^3/d (17,400 gal/d). This flow amounts to less than 0.19 m /capita·d (50 gal/capita·d), but is typical for this type of small, rural community where average water use is low. The fact that the town does not have a municipal water system is another reason that water use and wastewater flows are very low.

In contrast to the low average dry-weather flows, however, are very high peak flows during periods when parts of the collection system are subject to infiltration from high ground water elevations. Peak flows have ranged to as high as 1,341 m^3/d (354,400 gal/d) on a monthly average. The peak flows are sustained, and have in the past stayed high for as long as 6 months at a time. This is a significant factor affecting a treatment facility since the pond system must handle, at times, flows ranging from 2 to 10 times the design average flow.

7.4.3.4 Climate

The normal annual precipitation is 63.5 cm/yr (25 in./yr) and the average annual gross lake evaporation is 114.3 cm/yr (45 in./yr). There are 45 days per year when maximum daily temperatures exceed 32 °C (90 °F) and 150 days when the minimum temperature is below 0 °C (32 °F). The mean length of the frost-free period in the area is 160 days.

7.4.3.5 Site Characteristics

Soils in the area formed in alluvium on river bottom lands, and the topography is relatively flat. At the pond site, the predominant soil type is a moderately deep, nearly level, somewhat poorly drained loam formed in calcareous loamy alluvium. The depth to the water table ranges from 0.6 to 1.2 m (2 to 4 ft). The loam surface layer and subsoil have moderate permeability of 1.5 to 5.1 cm/h (0.6 to 2.0 in./h). The underlying gravelly sand, which is found 51 to 102 cm (20 to 40 in.) below the ground surface, has very rapid permeability of over 51 cm/h (20 in./h).

7.4.3.6 Treatment Facility Design and Performance

The treatment facility includes a pond and a single RI basin; design criteria for these facilities are summarized in Table 7-8. The pond consists of two cells, one having a suface area of 0.7 ha (1.8 acres) and the other having 0.4 ha (1.0 acre). The maximum water depth of the cells is 1.5 m (5.0 ft). Dikes around the pond have an overall height of 2.4 m (8 ft). The soils at the bottom of the pond were medium and fine sands. Bentonite was added at the rate of 4.5 kg/m^2 (20 tons/acre) to the bottom of the pond to limit seepage to less than 0.64 cm/d (0.25 in./d).

TABLE 7-8
DESIGN INFORMATION FOR CHAPMAN RI SYSTEM

Design flow, m^3/d	132.5
BOD loading, kg/d	45
Year built	1965
Design population	500
Pond cell No. 1	
Surface area, ha	0.7
Depth, m	1.5
Capacity above drawoff level, m^3	6,190
Pond cell No. 2	
Surface area, ha	0.4
Depth, m	1.5
Capacity above drawoff level, m^3	3,160
Total detention time above drawoff level at design flow, d	70
Infiltration basin size, ha	0.6
Hydraulic loading rate at design flow, m/yr	5

The design of the pond is such that the two cells can be operated either in series or parallel. The overflow control box can be adjusted so that the water level in either of the cells can be drawn down or set for constant overflow from one or both cells. Water is drawn from the pond cells at the 0.6 m (2 ft) depth.

The normal operating sequence for the system has been series flow through the two cells when the pond is not ice covered, with a constant overflow from the second cell in series to the infiltration basin. During the winter when the pond cells are ice covered, operation is switched to parallel to spread the incoming load over the maximum surface area. This results in a shorter recovery period in the spring when the ice cover melts and the cells go from the anaerobic to the aerobic state. There is normally some overflow to the infiltration basin during the winter. At the design flow, the net early overflow to the infiltration basin would be 29,300 m^3 (7,444,000 gal).

The two pond cells are followed by a single RI basin. To take advantage of the higher permeability of the- underlying soil materials, the top 0.9 m (3 ft) of RI basin soil was stripped during basin construction. However, the design hydraulic loading rate was limited to 5.0 m/yr (16.4 ft/yr) to simplify basin operation. A basin area of 0.6 ha (1.4 acres) was necessary to allow the design loading rate at the design pond overflow rate. Following construction, the basin was seeded with a mixture of Reed canarygrass and bromegrass. A grass cover has been maintained to help preserve the soil*s permeability.

Currently, the average influent flow is approximately half the design flow (Table 7-9) and the net overflow to the infiltration basin averages 5,150 m^3/yr (1,360,000 gal/yr). The resulting hydraulic loading rate is 0.9 m/yr (2.9 ft/yr). However, during periods of heavy infiltration into the collection system, the average daily flow to the RI basin is 1,375 m^3/d (350,000 gal/d). This results in a periodic hydraulic loading rate of 22.6 cm/d (8.9 in./d), or 82.5 m/yr (271 ft/yr) expressed as an annual rate. Although this temporary rate is well below the measured soil permeability of at least 51 cm/h (20 in./h), it exceeds the recommended loading shown in Figure 7-2 somewhat.

TABLE 7-9
WASTEWATER FLOWS TO CHAPMAN RI SYSTEM
m^3/d

Year	Avg daily flow	Monthly flows	
		Minimum	Maximum
1974			
Jan-Jun	870.6	292	1,341
Jul-Dec	63.0	55.1	79.0
1976	65.5	58.7	82.1
1977	65.9	60.2	78.3
1979[a]	86.3	71.9	132.1

a. During the months of May, June, and July, flows were above normal and were in the 122-132 m^3/d range. This corresponded to a period of high ground water elevations.

Although the design and actual average hydraulic loading rates are considerably lower than the range of 50 to 60 in/yr (165 to 200 ft/yr) recommended in Figure 7-2, the use of a lower rate was advantageous for several reasons, including:

! A grass cover can be maintained in the bottom of the basin to help preserve soil permeabiity.

! The treatment facility is able to treat peak wastewater flows that greatly exceed design average flows.

7.4.3.7 Ground Water Quality

Since high ground water levels are typical of the area in which the treatment facility is located, the performance of the facility in terms of possible ground water contamination is an important consideration. The pond has been in operation for 15 years, so there has been adequate time for possible water quality changes caused by pond operation to have been detected. The data indicate that the facility has not caused increased ground water levels of nitrates or chlorides that could be associated with wastewater discharges.

7.4.3.8 Costs and Staffing

The total cost for constructing the collection system and treatment ponds in 1965 was $110,958. The treatment facility portion of the total amounted to $40,520.

The entire system has been operated by one part-time operator whose duties include maintenance of three pumping stations in the collection system and operation and maintenance at the pond site. Work at the treatment facilities consists of operating valves, mowing, weed control around the edge of the water in the pond cells and in the RI basin, and maintenance of access road and fences. Since there is no surface discharge of effluent from the facility, laboratory testing of water quality has not been required.

7.4.4 Overland Flow

7.4.4.1 Introduction

A small, full-scale OF system is operating at Carbondale, Illinois, treating pond effluent. The wastewater is domestic in nature and generated at the 54 unit Cedar Lane Trailer Court. The population of 135 has been relatively stable since construction in the 1950s. Wastewater flow is 38 m^3/d (10,000 gal/d).

Prior to 1976, wastewater was treated using a septic tank followed by a 0.28 ha (0.7 acre) stabilization pond and surface water discharge. Effluent from the pond did not meet Illinois intermittent stream requirements, which include a 1.5 mg/L ammonia nitrogen limit on the discharge. An upgrading of the treatment, therefore, was required.

7.4.4.2 Site Characteristics

The terrain is rolling and the grass covered site, which is near the pond, has slopes ranging from 7 to 12%. The soil is fine granular glaciated material with low permeability. A section of the slope 10 m (30 ft) wide and 60 m (200 ft) long (downslope) was used.

7.4.4.3 Treatment Facility Design

The hydraulic loading rate is 44 cm/wk (17.3 in./wk), which is higher than recommended in Figure 7-2. The first 30 m (100 ft) of slope is at 7% grade and the last 30 m is at 12%. The pond effluent is pumped to the top of the slope and applied uniformly across the top of the slope via a 10 cm (4 in.) perforated pipe. The predominant grass on the slope is tall fescue. The system was constructed by Southern Illinois University and used for several years as a research facility. No storage is provided other than the existing stabilization pond [3].

7.4.4.4 Operation

During 1976 and 1977, application rates varied from 0.29 to 0.57 m^3/m·h (24 to 42 gal/ft·h). The application period varied from 4 to 24 h/d. A typical application period was 9 h/d. Runoff from the slopes accounted for over 80% of the applied wastewater. Erosion was not a problem.

7.4.4.5 Performance

The treatment performance of the OF system was monitored relatively intensely in the fall of 1976. The results are presented in Table 7-10.

TABLE 7-10
TREATMENT PERFORMANCE OF CARBONDALE OF SYSTEM [4]
mg/L except as noted

Constituent	Applied wastewater	Treated runoff
BOD	30-110	4-7
SS	20-60	4-7
Phosphorus, total	3-4	0.2-0.5
Ammonia nitrogen	20-40	0.1-1.5
Fecal coliforms, colonies/100 mL	35,000	600-2,500

In 1977 when application rates and daily application periods were increased, the treatment performance declined. For example, when application times of 24 h/d were used, removal of ammonia dropped off significantly. The runoff after 60 m (200 ft), however, contained less than 1 mg/L ammonia when application periods were 12 h/d or less.

7.5 References

1. Environmental Protection Agency. Process Design Manual for Wastewater Treatment Ponds. (In Preparation).

2. Metcalf & Eddy, Inc. Wastewater Engineering: Treatment, Disposal, Reuse. McGraw Hill Book Company. New York, N.Y. 1979.

3. Hinrichs, D.J. et al. Assessment of Current Information on Overland Flow Treatment of Municipal Wastewater. Environmental Protection Agency, Office of Water Programs. EPA 430/9-80-002. MCD-66. May 1980.

4. Muchmore, C.B. Overland Flow as a Tertiary Treatment Procedure Applied to a Secondary Effluent. presented at Illinois Workshop on Land Application of Sewage Sludge and Wastewater. Champaign, Illinois. October 18-20, 1976.