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Natural Environmental Biotechnology

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Abstract Aquaculture or the production of aquatic organisms (both flora and fauna) under controlled conditions has been practiced for centuries, primarily for the generation of food, fiber, and fertilizer. The water hyacinth and a host of other organisms like duckweed, seaweed, midge larvae, and alligator weeds are used for wastewater treatment. Water hyacinth system, wetland system, evapotranspiration system, rapid rate filtration, slow rate system, overland flow system, and subsurface infiltration have also been applied. This chapter describes the above applications and explains their practice, limitations, design criteria, performance, and costs.

Key Words Natural waste treatment • aquatic organisms • water hyacinth • weeds • wetland • infiltration • design and performance.

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1. AQUACULTURE TREATMENT: WATER HYACINTH SYSTEM

1.1. Description

Aquaculture or the production of aquatic organisms (both flora and fauna) under controlled conditions has been practiced for centuries, primarily for the generation of food, fiber, and fertilizer. The water hyacinth (*Eichhornia crassipes*) appears to be the most promising organism for wastewater treatment and has received the most attention (1). However, other organisms are being studied. Among them are duckweed, seaweed, midge larvae, alligator weeds, and a host of other organisms. Water hyacinths are large fast-growing floating aquatic plants with broad, glossy green leaves and light lavender flowers. A native of South America, water hyacinths are found naturally in waterways, bayous, and other backwaters throughout the South. Insects and disease have little effect on the hyacinth and they thrive in raw, as well as partially treated, wastewater. Wastewater treatment by water hyacinths is accomplished by passing the wastewater through a hyacinth-covered basin (Fig. 12.1), where the plants remove nutrients, BOD_5, suspended solids, metals, etc. Batch treatment and flow-through systems, using single and multiple cell units, are possible. Hyacinths harvested from these systems have been investigated as a fertilizer/soil conditioner after composting, animal feed, and a source of methane when anaerobically digested (2).

1.2. Applications

Water hyacinths are generally used in combination with (following) lagoons, with or without chemical phosphorus removal. A number of full-scale systems are in operation. Most often considered for nutrient removal and additional, treatment of secondary effluent (1–3). Also, research is being conducted on the use of water hyacinths for raw and primary treated wastewater or industrial wastes, but present data favor combination systems. Very good heavy metal uptake by the hyacinth has been reported. Hyacinth treatment may be suitable for seasonal use in treating wastewaters from recreational facilities and those generated from processing of agricultural products. Other organisms and methods with wider climatological applicability are being studied. The ability of hyacinths to remove nitrogen duringactive

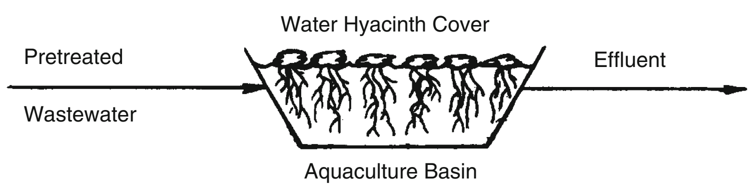

Fig. 12.1. Aquaculture treatment: water hyacinth system. (*source:* US EPA).

growth periods and some phosphorus and retard algae growth provides potential applications in (2, 3):

(a) The upgrading of lagoons
(b) Renovation of small lakes and reservoirs
(c) Pretreatment of surface waters used for domestic supply
(d) Storm water treatment
(e) Demineralization of water
(f) Recycling fish culture water, and
(g) For biomonitoring purposes.

1.3. Limitations

Climate or climate control is the major limitation. Active growth begins when the water temperature rises above 10°C. and flourishes when the water temperature is approximately 21°C. Plants die rapidly when the water temperature approaches the freezing point; therefore, greenhouse structures are necessary in northern locations. Water hyacinths are sensitive to high salinity. Removal of phosphorus and potassium is restricted to the active growth period of the plants.

Metals such as arsenic, chromium, copper, mercury, lead, nickel, and zinc can accumulate in hyacinths and limit their suitability as a fertilizer or feed material. The hyacinths may also create small pools of stagnant surface water which can breed mosquitoes. Mosquito problems can generally be avoided by maintaining mosquito fish in the system. The spread of the hyacinth plant itself must be controlled by barriers since the plant can spread and grow rapidly and clog affected waterways. Hyacinth treatment may prove impractical for large treatment plants due to land requirements. Removal must be at regular intervals to avoid heavy intertwined growth conditions. Evapotranspiration can be increased by two to three times greater than evaporation alone.

1.4. Design Criteria

Ponds, channels, or basins are in use. In northern climates covers and heat would be required. Harvesting and processing equipment are needed. Operation is by gravity flow and requires no energy. Hyacinth growth energy is supplied by sunlight. All experimental data is from southern climates where no auxiliary heat was needed. Data is not available on heating requirements for northern climates, but it can be assumed proportional to northern latitude of location and to the desired growth rate of hyacinths.

Design data vary widely. Table 12.1 shows the design criteria for water hyacinth systems (4). The following ranges refer to hyacinth treatment as a tertiary process on secondary effluent (2):

(a) Depth should be sufficient to maximize plant rooting and plant absorption
(b) Detention time depends on effluent requirements and flow, range 4–15 days
(c) Phosphorus reduction, 10–75%
(d) Nitrogen reduction, 40–75%
(e) Land requirement is usually high, i.e., 2–15 acres/MG/d (2.14–16.04 $m^2/m^3/d$)

Table 12.1
Design criteria for water hyacinth systems

Factor	Aerobic nonaerated	Aerobic nonaerated	Aerobic aerated
Influent wastewater	Screened or settled	Secondary	Screened or settled
Influent BOD_5 (mg/L)	130–180	30	130–180
BOD_5 loading (kg/ha-d)	40–80	10–40	150–300
Expected effluent (mg/L)			
BOD_5	<30	<10	<15
SS	<30	<10	<15
TN	<15	<5	<15
Water depth (m)	0.5–0.8	0.6–0.9	0.9–1.4
Detention time (days)	10–36	6–18	4–8
Hydraulic loading (m^3/ha-d)	> 200	<800	550–1,000
Harvest schedule	Annually	Twice per month	Monthly

Source: US EPA (4).

1.5. Performance

Process appears to be reliable from mechanical and process standpoints, subject to temperature constraints. In tests on five different wastewater streams including raw wastewater and secondary effluents, the following removals were reported (2):

(a) BOD_5: 35–97%
(b) TSS: 71–83%
(c) Nitrogen: 44–92%
(d) Total *P*: 11–74%.

Takeda and Co-workers (3) reported using aquaculture wastewater effluent for strawberry production in a hydroponic system which reduced the final effluent phosphorus concentration to as low as 0.1 mg/L which meets the stringent phosphorus discharge regulations. There is also evidence that in aquaculture system coliform, heavy metals, and organics are also reduced, as well as pH neutralization.

Hyacinth harvesting may be continuous or intermittent. Studies indicate that average hyacinth production (including 95% water) is on the order of 1,000–10,000 lb/d/acre (1,121–11,210 kg/d/ha). Basin cleaning at least once per year results in harvested hyacinths. For further detailed information on water Hyacinth systems the reader is referred to references (5–13).

2. AQUACULTURE TREATMENT: WETLAND SYSTEM

2.1. Description

Aquaculture-wetland systems for wastewater treatment include natural and artificial wetlands as well as other aquatic systems involving the production of algae and higher plants

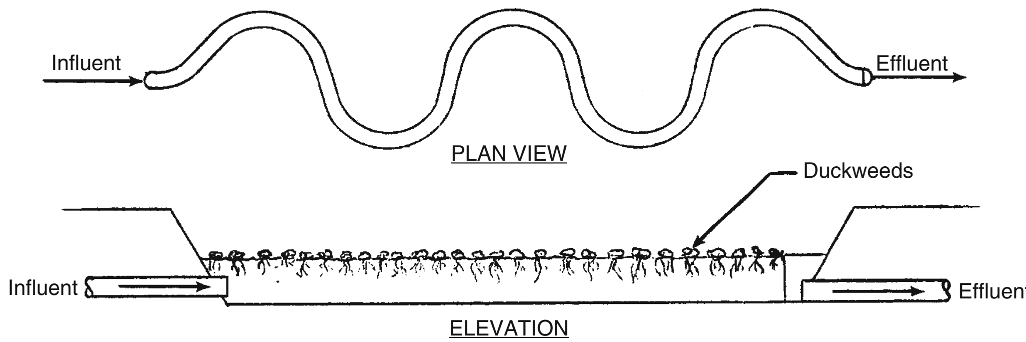

Fig. 12.2. Aquaculture treatment: wetland system. (*source:* US EPA).

(both submerged and emergent), invertebrates and fish. Natural wetlands, both marine and freshwater, have inadvertently served as natural waste treatment systems for centuries; however, in recent years marshes, swamps, bogs, and other wetland areas have been successfully utilized as managed natural "nutrient sinks" for polishing partially treated effluents under relatively controlled conditions. Constructed wetlands can be designed to meet specific project conditions while providing new wetland areas that also improve available wildlife wetland habitats and the other numerous benefits of wetland areas. Managed plantings of reeds (e.g., *Phragmites* spp.) and rushes (e.g., *Scirpus* spp. and *Schoenoplectus* spp.) as well as managed natural and constructed marshes, swamps, and bogs have been demonstrated to reliably provide pH neutralization and reduction of nutrients, heavy metals, organics, BOD_5, COD, SS, fecal coliforms, and pathogenic bacteria (2, 4).

Wastewater treatment by natural and constructed wetland systems is generally accomplished by sprinkling or flood irrigating the wastewater into the wetland area or by passing the wastewater through a system of shallow ponds, channels, basins, or other constructed areas where the emergent aquatic vegetation has been planted or naturally occurs and is actively growing (see Fig. 12.2). The vegetation produced as a result of the system's operation may or may not be removed and can be utilized for various purposes (2):

(a) Composted for use as a source of fertilizer/soil conditioner
(b) Dried or otherwise processed for use as animal feed supplements, or
(c) Digested to produce methane.

2.2. *Constructed Wetlands*

Constructed wetlands are classified as a function of water flow (2, 4): surface and subsurface which are known as free water surface (FWS) and subsurface flow system (SFS) (also termed vegetated submerged bed, VSB). When simply expressed, constructed wetland treatment technology makes artificial receiving water and its vegetation part of the treatment process. In comparison to algae, the higher forms of plants – life-floating (duckweed, water hyacinths), submerged, and emergent (cattails, rushes, and reeds) – perform less efficiently per unit weight of biomass.

FWS constructed wetland treatment conceptually relies on attached growth bacterial performance, receiving oxygen from the evapotranspiration response of the aquatic vegetation. Practically, the dominant bacterial action is anaerobic. The ammonium and nitrogen removal mechanisms (14–17) are a combination of aerobic oxidation, particulate removal, and synthesis of new plant protoplasm.

An FWS wetland is nothing more than a lagoon, except that a far greater expanse is needed to maximize the productivity per unit area. In practice, very large systems may achieve significant, if not complete, nitrogen oxidation, with surface reaeration contributing to the oxygen supply. Some nitrification and denitrification undoubtedly occurs in all systems.

If it is assumed that the wetland vegetation will not be harvested, as is the case with natural wetland systems, its capacity for nitrogen control is finite, reflecting the site-specific vegetation and the ability to expand in the available space. Thus, the bigger the natural wetland that is called part of the process, the better, since there is dilution of the wastewater to the point that it is no longer significant in comparison to the naturally occurring background flow and water quality.

Constructed FWS wetlands yield a managed vegetative habitat that becomes an aquaculture system. Examination of the evolution of this technology shows the emergence of concepts that include organic load distribution or artificial aeration to avoid aesthetic nuisances, and emphasis on plants that grow the fastest. Duckweed and water hyacinth systems (classified as aquaculture) have been reported to achieve long-term total nitrogen residuals of less than 10 mg/L and may be manageable, with harvesting and sensitive operation, to values of less than 3 mg/L on a seasonal, if not sustained, basis.

Submerged-flow constructed wetlands are simply horizontal-flow gravel filters with the added component of emergent plants within the media. They have been classically used for BOD removal following sedimentation and/or additional BOD and SS removal from lagoon effluents as with FWS approaches. This technology has the potential for high-level denitrification when a nitrified wastewater is applied; the naturally occurring environment promotes anoxic (denitrification) pathways for oxidized nitrogen elimination.

Ultimately, the success or failure of the wetland approach for nitrogen control may rest with the harvest of the vegetation, the need for backup (so that areas under harvest have the backup of areas in active growth), and often natural seasonal growth and decay cycles. If biomass production is an unacceptable goal, the designer should think of a more tolerant mixed vegetation system that minimizes the need to harvest the accumulated vegetation and maximizes the promotion of concurrent or staged nitrification and denitrification in some fashion. Conceptually, the optimization has to begin with promotion of nitrogen oxidation systems that may be shallow (better aeration for attached and suspended bacterial growth) with vegetation that minimizes light penetration and avoids as much algal growth as possible. Cyclic staging, recycle, forced aeration, and/or mixing represent some of the enhancements that naturally follow (17).

2.3. Applications

Several full-scale systems are in operation or under construction (18). Wetlands are useful for polishing treated effluents. They have potential as a low cost, low-energy-consuming alternative or addition to conventional treatment systems, especially for smaller flows. Wetlands have been successfully used in combination with chemical addition and overland flow land treatment systems. Wetland systems may also be suitable for seasonal use in treating wastewaters from recreational facilities, some agricultural operations, or other waste-producing units where the necessary land area is available (18). Potential application as an alternative to lengthy outfalls extended into rivers, etc. and as a method of pretreatment of surface waters for domestic supply, storm water treatment, recycling fish culture water and biomonitoring purposes.

2.4. Limitations

Temperature (climate) is a major limitation since effective treatment is linked to the active growth phase of the emergent vegetation. Tie-ins with cooling water from power plants to recover waste heat have potential for extending growing seasons in colder climates. Enclosed and covered systems are possible for very small flows.

Herbicides and other materials toxic to the plants can affect their health and lead to poor treatment. Duckweeds are prized as food for waterfowl and fish and can be seriously depleted by these species. Winds may blow duckweeds to the shore if wind screens or deep trenches are not employed. Small pools of stagnant surface water which can allow mosquitoes to breed can develop, but problems can generally be avoided by maintaining mosquito fish or a healthy mix of aquatic flora and fauna in the system. Wetland systems may prove impractical for large treatment plants due to the large land requirements. They also may cause loss of water due to increases in evapotranspiration.

2.5. Design Criteria

Natural or artificial marshes, swamps, bogs, shallow ponds, channels, or basins could be used. Irrigation, harvesting and processing equipment are optional. Aquatic vegetation is usually locally acquired.

Design criteria are very site and project specific. Available data vary widely. Values below refer to one type of constructed wetland system used as a tertiary process on secondary effluent (2):

(a) Detention time = 13 days
(b) Land requirement = 8 acres/MG/d = 8.55 $m^2/m^3/d$
(c) Depth may vary with type of system, generally 1–5 ft. = 0.30–1.52 m

2.6. Performance

Process appears reliable from mechanical and performance standpoints, subject to seasonality of vegetation growth. Low operator attention is required if properly designed.

Table 12.2
Nutrient removal from natural wetlands

Project	Flow (m^3/d)	Wetland type	Percent reducion			
			TDP[a]	NH_3-N	NO_3-N	TN[b]
Brillion Marsh, WI	757	Marsh	13	–	51	–
Houghton Lake, MI	379	Peatland	95	71	99[c]	–
Wildwood, FL	946	Swamp/Marsh	98	–	–	90
Concord, MA	2,309	Marsh	47	58	20	–
Bellaire, MI	1, 136[d]	Peatland	88	–	–	84
Coots Paradise, Town of Dundas, Ontario, Canada	–	Marsh	80	–	–	60–70
Whitney Mobile Park, Home Park, FL	≈ 227	Cypress Dome	91	–	–	89

Source: US EPA (4).
[a] Total dissolved phosphorus.
[b] Total nitrogen.
[c] Nitrate and nitrite.
[d] May–November only.

Tables 12.2 and 12.3 illustrate the capacities of both natural and constructed wetlands for nutrient removal (4). In test units and operating artificial marsh facilities using various wastewater streams, the following removals have been reported for secondary effluent treatment (10-day detention) (2):

(e) BOD_5, 80–95%
(f) TSS, 29–87%
(g) COD, 43–87%
(h) Nitrogen, 42–94% depending upon vegetative uptake and frequency of harvesting
(i) Total P, 0–94% (high levels possible with warm climates and harvesting)
(j) Coliforms, 86–99%
(k) Heavy metals, highly variable depending on species.

There is also evidence of reductions in wastewater concentrations of chlorinated organics and pathogens, as well as pH neutralization without causing detectable harm to the wetland ecosystem.

Residuals are dependent on the type of system and whether or not harvesting is employed. Duckweed, for example, yields 50–60 lb/acre/d (dry weight) (53.46–64.15 m^2/m^3d) during peak growing period to about half of this figure during colder months. For further detailed information on wetland systems the reader is referred to references (19–23).

Table 12.3
Nutrient removal from constructed wetlands (4)

Project	Flow (m^3/d)	Wetland type	BOD_5 (mg/L)		SS (mg/L)		Percent reduction		Hydraulic surface loading rate (m^3/ha-d)
			Influent	Effluent	Influent	Effluent	BOD_5	SS	
Listowel, Ontario (12)	17	FWS[a]	56	10	111	8	82	93	–
Santee, CA (10)	–	SFSI[b]	118	30	57	5.5	75	90	–
Sidney, Australia (13)	240	SFS	33	4.6	57	4.5	86	92	–
Arcata, CA	11,350	FWS	36	13	43	31	64	28	907
Emmitsburg, MD	132	SFS	62	18	30	8.3	71	73	1,543
Gustine, CA	3,785	FWS	150	24	140	19	84	86	412

Source: US EPA.
[a]Free water surface system.
[b]Subsurface flow system.

3. EVAPOTRANSPIRATION SYSTEM

3.1. Description

Evapotranspiration (ET) system is a means of on-site wastewater disposal that may be utilized in some localities where site conditions preclude soil absorption. Evaporation of moisture from the soil surface and/or transpiration by plants is the mechanism of ultimate disposal. Thus, in areas where the annual evaporation rate equals or exceeds the rate of annual added moisture from rainfall and wastewater application, ET systems can provide a means of liquid disposal without danger of surface or groundwater contamination.

If evaporation is to be continuous, at least three conditions must be met (2):

(a) There must be a continuous supply of heat to meet the latent heat requirement, approximately 590 cal/g of water evaporated at 15°C
(b) A vapor pressure gradient must exist between the evaporative surface and the atmosphere to remove vapor by diffusion, convection, or both. Meteorological factors, such as air temperature, humidity, wind velocity, and radiation influence both energy supply and vapor removal
(c) There must be a continuous supply of water to the evaporative surface. The soil material must be fine-textured enough to draw up the water from the saturated zone to the surface by capillary action but not so fine as to restrict the rate of flow to the surface.

Evapotranspiration is also influenced by vegetation on the disposal field and can theoretically remove significant volumes of effluent in late spring, summer, and early fall, particularly if large silhouette, good transpiring bushes and trees are present.

A typical ET bed system (Fig. 12.3) consists of a 1½ to 3 ft (0.45 to 0.91 m) depth of selected sand over an impermeable plastic liner. A perforated plastic piping system with rock cover is often used to distribute pretreated effluent in the bed. The bed may be square-shaped on relatively flat land, or a series of trenches on slopes. The surface area of the bed must be

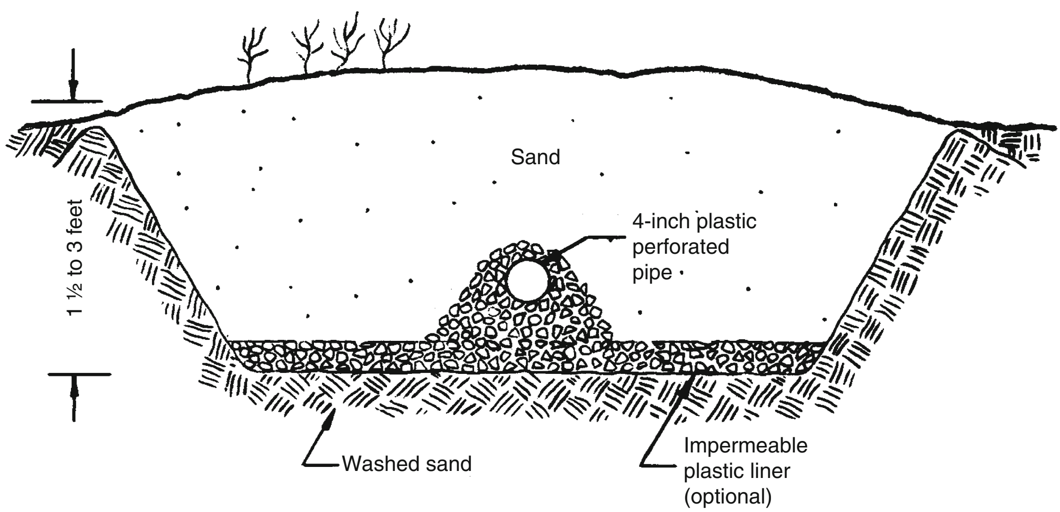

Fig. 12.3. Section through an evapotranspiration bed. (*source:* US EPA). (Conversion factor: 1 inch = 2.54 cm)

large enough for sufficient ET to occur to prevent the water level in the bed from rising to the surface.

Beds are usually preceded by septic tanks or aerobic units to provide the necessary pretreatment. Given the proper subsurface conditions, systems can be constructed to perform as both evapotranspiration and absorption beds. Nearly three-fourth of all the ET beds in operation was designed to use both disposal methods. Mechanical evaporators have been developed, but are not used at full scale.

3.2. Applications

There are approximately 4,000–5,000-year-round evapotranspiration beds estimated to be in operation in the United States, particularly in the semiarid regions of the Southwest.

ET beds are used as an alternative to subsurface disposal in areas where these methods are either undesirable due to groundwater pollution potential or not feasible due to certain geological or physical constraints of land. The ET system can also be designed to supplement soil absorption for sites with slowly permeable soils. The use of ET systems for summer homes extends the range of application, which is otherwise limited by annual ET rates. Since summer evaporation rates are generally higher and plants with high transpiration rates are in an active growing state, many areas of the country can utilize ET beds for this seasonal application.

3.3. Limitations

The use of an evapotranspiration system is limited by climate and its effect on the local ET rate. In practice, lined ET bed systems are generally limited to areas of the country where pan evaporation exceeds annual rainfall by at least 24 in. The decrease of ET in winter at middle end high latitudes greatly limits its use. Snow cover reflects solar radiation, which reduces ET. In addition, when temperatures are below freezing more heat is required to change frozen water to vapor. When vegetation is dormant, both transpiration and evaporation are reduced. An ET system requires a large amount of land in most regions. Salt accumulation may eventually eliminate vegetation and thus, transpiration. Bed liner (where needed) must be kept water-tight to prevent the possibility of groundwater contamination. Therefore, proper construction methods should be employed to keep the liner from being punctured during installation.

3.4. Design Criteria

Design of an evapotranspiration bed is based on the local annual weather cycle. The total expected inflow based on household wastewater generation and rainfall rates is compared with an average design evaporation value established from the annual pattern. It is recommended to use a 10-year-frequency rainfall rate to provide sufficient bed surface area (2). A mass balance is used to establish the storage requirements of the bed. Vegetative cover can substantially increase the ET rate during the summer growing season; but may reduce evaporation during the nongrowing season. Uniform sand in the size range of D_{50} of approximately 0.10 mm is capable of raising water approximately 3 ft to the top of the bed. The polyethylene liner thickness is typically greater than or equal to 10 milllion. Special attention should be paid to storm water drainage to make sure that surface runoff is drained away from the bed proximity by proper lot grading.

3.5. Performance

Performance is a function of climate conditions, volume of wastewater, and physical design of the system. Evapotranspiration is an effective and reliable means of domestic wastewater disposal. An ET system that has been properly designed and constructed is an efficient method for the disposal of pretreated wastewater and requires a minimum of maintenance. Healthy vegetative covers are aesthetically pleasing and the large land requirement, although it limits the land use, it does conserves the open space. Neither energy is required, nor is head loss of any value incurred.

3.6. Costs

The following site-specific costs serve to illustrate the major components of an evapotranspiration bed in Boulder, Colorado with an annual net ET rate in the range of 0.04 gpd/ft^2 (0.0032 m^3/min/ha) (2). A 200-gpd (757 Lpd) household discharge would require a 2-ft (0.6 m) deep bed with an area of approximately 5,000 ft^2 (464.5 m^2). Costs have been adjusted to current value (2009) of US Dollars using the Cost Index for Utilities shown in Appendix A (24).

Construction cost	
Building sewer with 1,000-gal (3,785-L) septic tank, design and permit	$1,700
Excavation and hauling (375 yd^3) (286.71 m^3)	$2,500
Liner (5,200 ft^2) (483.08 m^2)	$1,600
Distribution piping (625 ft) (190.5 m)	$700
Sand (340 yd^3) (260 m^3) and gravel (38 yd^3) (29.05 m^3)	$4,300
Supervision and labor	$1,200
Total	$12,000
Annual operation and maintenance cost:	
Pumping septage from septic tank (every 3–5 years)	$12–48
Total	$12–48

The construction cost for this particular system would be approximately $2.40/ft^2, ($25.83/m^2) which is consistent with a reported national range of $1.80–3.86/ft^2 ($19.37–41.55/m^2). The cost of an evapotranspiration bed is highly dependent on local material and labor costs. As shown, the cost of sand is a significant portion of the cost of the bed. The restrictive sand size requirement makes availability and cost sensitive to location.

If an aerobic pretreatment unit is used instead of the septic tank, add $700–7,000 to the construction cost and an amount of $144–495/year to the annual operation and maintenance cost.

4. LAND TREATMENT: RAPID RATE SYSTEM

The land-based technologies have been in use since the beginning of civilization. Their greater value may be the use of the wastewater for beneficial return (agricultural and recharge) in water-poor areas, as well as nitrogen control benefits. If nitrogen control benefits are desired, some key issues arise concerning the type of plant crop with its growing and harvesting needs and/or the cycling of the water application and restorative oxygenation resting periods. Native soils and climate add the remaining variables.

Generally, the wastewater applications are cyclic in land-based technologies, making some form of storage or land rotation mandatory to ensure the restorative oxygenation derived from the resting period. Surface wastewater applications allow additional beneficial soil aeration (plowing, tilling, and raking), which can become mandatory for the heavily loaded systems after an elapsed season, or number of loading cycles. Actual surface cleaning programs, to remove the plastic, rubber, and other debris found in pretreated municipal wastewaters, also may be necessary, although not at the frequency used for beneficial soil aeration.

In this and the following sections detailed information on the four most common land-based technologies will be provided. Subsurface, slow, and rapid infiltration systems do not discharge to surface waters and conceptually may allow a more relaxed nitrogen control standard in comparison to the overland flow system, depending on local ground-water regulations.

4.1. Description

Rapid rate infiltration was developed approximately 100-years ago and has remained unaltered since then. It has been widely used for municipal and certain industrial wastewaters throughout the world. Wastewater is applied (see Fig. 12.4) to deep and permeable deposits such as sand or sandy loam usually by distributing in basins or infrequently by sprinkling, and is treated as it travels through the soil matrix by filtration, adsorption, ion exchange precipitation, and microbial action (25). Most metals are retained on the soil; many toxic organics are degraded or adsorbed. An underdrainage system consisting of a network of drainage pipe buried below the surface serves to recover the effluent, to control groundwater mounding, or to minimize trespass of wastewater onto adjoining property by horizontal subsurface flow. To recover renovated water for reuse or discharge underdrains are usually intercepted at one end of the field by a ditch. If groundwater is shallow, underdrains are placed at or in the groundwater to remove the appropriate volume of water (2). Thus, the designed soil depth, soil detention time and underground travel distance to achieve the desired water quality can be controlled. Effluent can also be recovered by pumped wells.

Basins or beds are constructed by removing the fine-textured top soil from which shallow banks are constructed. The underlying sandy soil serves as the filtration media. Underdrainage is provided by using plastic, concrete (sulfate resistant if necessary), or clay tile lines. The distribution system applies wastewater at a rate which constantly floods the basin throughout the application period of several hours to a couple of weeks. The waste floods the bed and then drains uniformly away, driving air downward through the soil and drawing fresh air from above. A cycle of flooding and drying maintains the infiltration capacity of the soil material. Infiltration diminishes slowly with time due to clogging. Full infiltration is readily restored by occasional tillage of the surface layer and, when appropriate, removal of several inches from the surface of the basin. Preapplication treatment to remove solids improves distribution system reliability, reduces nuisance conditions, and may reduce clogging rates. Common preapplication treatment practices include the following:

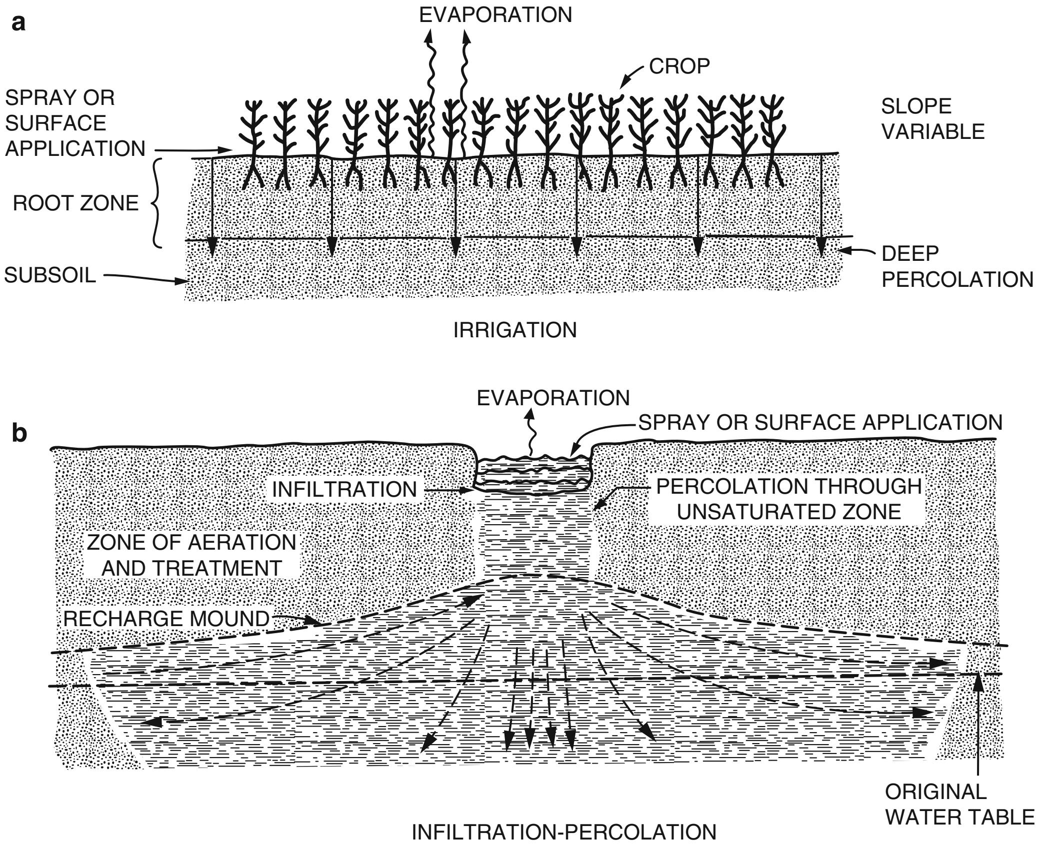

Fig. 12.4. Flow diagram of land treatment using rapid rate system. (a) Irrigation, (b) infilteration–percolation. (*source:* US EPA).

(a) Primary treatment for isolated locations with restricted public access (26)
(b) Biological treatment for urban locations with controlled public access
(c) Storage is sometimes provided for flow equalization and for nonoperating periods.

Nitrogen removals are improved by (17, 27):

(a) Establishing specific operating procedures to maximize denitrification
(b) Adjusting application cycles
(c) Supplying an additional carbon source
(d) Using vegetated basins (at low rates)
(e) Recycling portions of wastewater containing high nitrate concentrations, and
(f) Reducing application rates.

Rapid rate infiltration systems require relatively permeable, sandy-to-loamy soils. Vegetation is typically not used for nitrogen control purposes but may have value for stabilization and maintenance of percolation rates. The application of algae-laden wastewater to rapid infiltration systems is not recommended because of clogging considerations but could be considered with attendant additional tolerance for surface maintenance, drying, and soil aeration needs.

4.2. Applications

Rapid infiltration is a simple wastewater treatment system, that is (2):

(a) Less land intensive than other land application systems and provides a means of controlling groundwater levels and lateral subsurface flow
(b) It provides a means of recovering renovated water for reuse or for discharge to a particular surface water body
(c) It is suitable for small plants where operator expertise is limited
(d) It is applicable for primary and secondary effluent and for many types of industrial wastes, including those from breweries, distilleries, paper mills, and wool scouring plants (26, 28, 29).

In very cold weather the ice layer floats atop the effluent and also protects the soil surface from freezing. Generated residuals may require occasional removals of top layer of soil. The collected material is disposed of onsite.

4.3. Limitations

The rapid infiltration process is limited by (2):

(a) Soil type
(b) Soil depth
(c) The hydraulic capacity of the soil
(d) The underlying geology, and
(e) The slope of the land.

Nitrate and nitrite removals are low unless special management practices are used.

4.4. Design Criteria

The design criteria for rapid rate system can be summarized as follows (2):

(a) Field area: 3–56 acres/MG/d (3.2–59.9 m^2/m^3/d)
(b) Application rate: 20–400 ft/year, 4–92 in./wk (6.1–121.9 m/year; 10.2–233.7 cm/wk)
(c) BOD_5 loading rate: 20–100 lb/acre/d (22.4–112.1 kg/ha/d)
(d) Soil depth: 10–15 ft (3–4.6 m) or more
(e) Soil permeability: 0.6 in/h (1.5 cm/h) or more
(f) Hydraulic loading cycle: 9 h to 2 weeks application period, 15 h to 2 weeks resting period
(g) Soil texture sands, sandy barns
(h) Basin size: 1–10 acres (0.4046–4.046 ha); at least 2 basins/site
(i) Height of dikes: 4 ft (1.22 m); underdrains 6 ft (1.83 m) or more deep
(j) Application techniques: flooding or sprinkling
(k) Preapplication treatment: primary or secondary.

Designs can be developed that foster only nitrification or nitrification and denitrification (17, 27). Nitrification is promoted by low hydraulic loadings and short application periods (1–2 days) followed by long drying periods (10–16 days). Denitrification can vary from 0 to

Table 12.4
Loading cycles for high rate infiltration systems

Loading cycle objective	Applied wastewater	Season	Application period (d[a])	Drying period (d)
Maximize infiltration rates	Primary	Summer	1–2	5–7
		Winter	1–2	7–12
	Secondary	Summer	1–3	4–5
		Winter	1–3	5–10
Maximize nitrogen removal	Primary	Summer	1–2	10–14
		Winter	1–2	12–16
	Secondary	Summer	7–9	10–15
		Winter	9–12	12–16
Maximize nitrification	Primary	Summer	1–2	5–7
		Winter	1–2	7–12
	Secondary	Summer	1–3	4–5
		Winter	1–3	5–10

Source: US EPA (25).
[a]Regardless of season or cycle objective, application periods for primary effluent should be limited to 1–2 days to prevent excessive soil clogging.

80%. For significant denitrification, the application period must be long enough to ensure depletion of the soil (and nitrate nitrogen) oxygen. Higher denitrification values predictably track higher BOD: nitrogen ratios. Enhancement may be promoted by recycling or by adding an external driving substrate (methanol). Nitrogen elimination strategies also may reduce the drying period by about half to yield lower overall nitrogen residuals with higher ammonium-nitrogen concentrations. Suggested loading cycles (25) to maximize infiltration rates, nitrogen removal, and nitrification rates are given in Table 12.4.

4.5. Performance

The effluent quality is generally excellent where sufficient soil depth exists and is not normally dependent on the quality of wastewater applied within limits. Well designed systems provide for high quality effluent that may meet or exceed primary drinking water standards. Percent removals for typical pollution parameters are (2):

(a) BOD_5, 95–99%
(b) TSS, 95–99%
(c) Total N, 25–90%
(d) Total P, 0–90% until flooding exceeds adsorptive capacity (30)
(e) Fecal Coliform, 99.9–99.99 + % (31).

The process is extremely reliable, as long as sufficient resting periods are provided. However, it has a potential for contamination of groundwater by nitrates. Heavy metals could be eliminated by pretreatment techniques as necessary. Monitoring for metals and toxic organics is needed where they are not removed by pretreatment. The process requires long-term commitment of relatively large land areas, although small by comparison to other land treatment systems (32, 33).

4.6. Costs

The construction and operation and maintenance (O & M) costs are shown in Figs. 12.5 and 12.6, respectively (2). The costs are based on 1973 (Utilities Index = 149.36, EPA Index 194.2, ENR Index = 1, 850) figures. To obtain the values in terms of the present (2009) value of the US Dollars, using the Cost Index for Utilities (Appendix A), multiply the costs by a factor of 3.82 (24).

Assumptions applied in preparing the costs given in Figs. 12.5 and 12.6:

(a) Application rate, 182 ft/year. (55.5 m/year)
(b) Construction costs include field preparations (removal of brush and trees) for multiple unit infiltration basins with 4 ft (1.2 m) dike formed from native excavated material, and storage is not assumed necessary.
(c) Drain pipes buried 6–8 ft (1.8–2.4 m) with 400 ft (121.9 m) spacing, interception ditch along length of field, and weir for control of discharge; gravel service roads and 4-ft (1.2 m) stock fence around perimeter.
(d) O & M cost includes inspection and unclogging of drain pipes at outlets; annual tilling of infiltration surface and major repair of dikes after 10 years; high pressure jet cleaning of drain

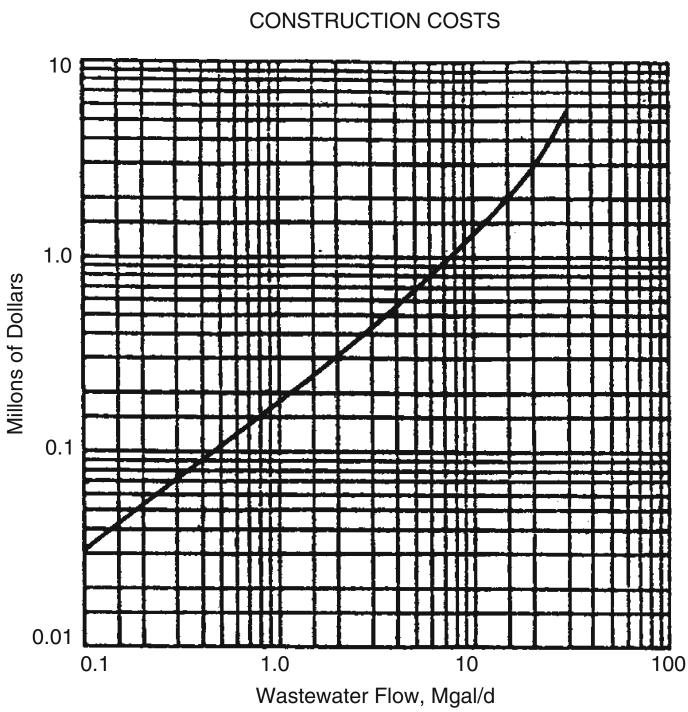

Fig. 12.5. Construction costs for rapid rate system. (*source:* US EPA). 1 Mgal/d = 1 MGD = 3.785 MLD = 43.8 L/s

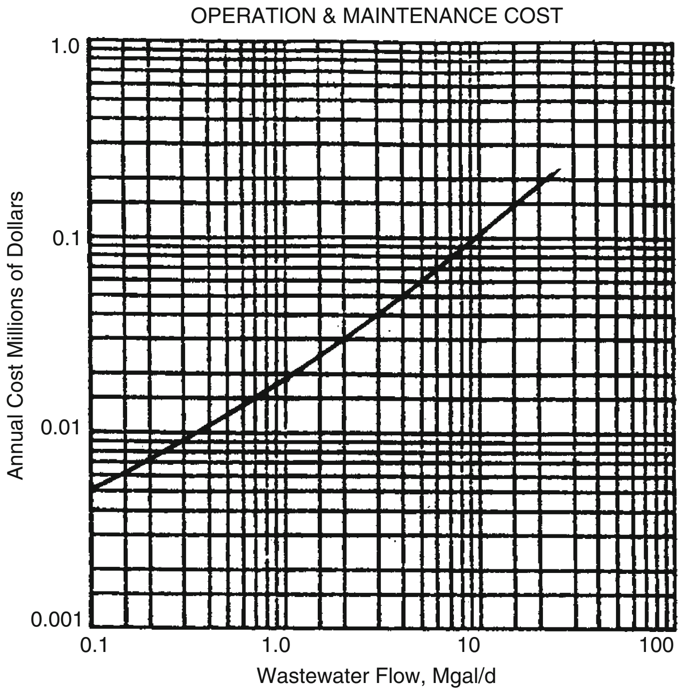

Fig. 12.6. Operation and maintenance costs of rapid rate system. (*source:* US EPA). 1 Mgal/d = 1 MGD = 3.785 MLD = 43.8 L/s

pipes every 5 years, annual cleaning of interceptor ditch, and major repair of ditches, fences and roads after 10 years.

(e) Costs of pretreatment-monitoring wells, land, and transmission to and from pretreatment facility not included.

5. LAND TREATMENT: SLOW RATE SYSTEM

5.1. Description

Slow rate land treatment represents the predominant municipal land treatment practice in the United States. In this process, wastewater is applied to vegetated soils that are slow to moderate in permeability (clay barns to sandy barns) and is treated as it travels through the soil matrix by filtration, adsorption, ion exchange, precipitation, microbial action, and by plant uptake. Wastewater can be applied in various ways including (a) sprinklers, (b) flooding, and (c) ridge and furrow methods as illustrated in Fig. 12.7. An underdrainage system consisting of a network of drainage pipes buried below the surface may be used to recover the effluent, to control groundwater, or to minimize trespass of leachate onto adjoining property by horizontal subsurface flow. To recover renovated water for reuse or discharge, underdrains are usually intercepted at one end of the field by a ditch. Underdrainage for groundwater control is installed as needed to prevent waterlogging of the application site or to recover the renovated water for reuse. Proper crop management also depends on the drainage conditions. Sprinklers

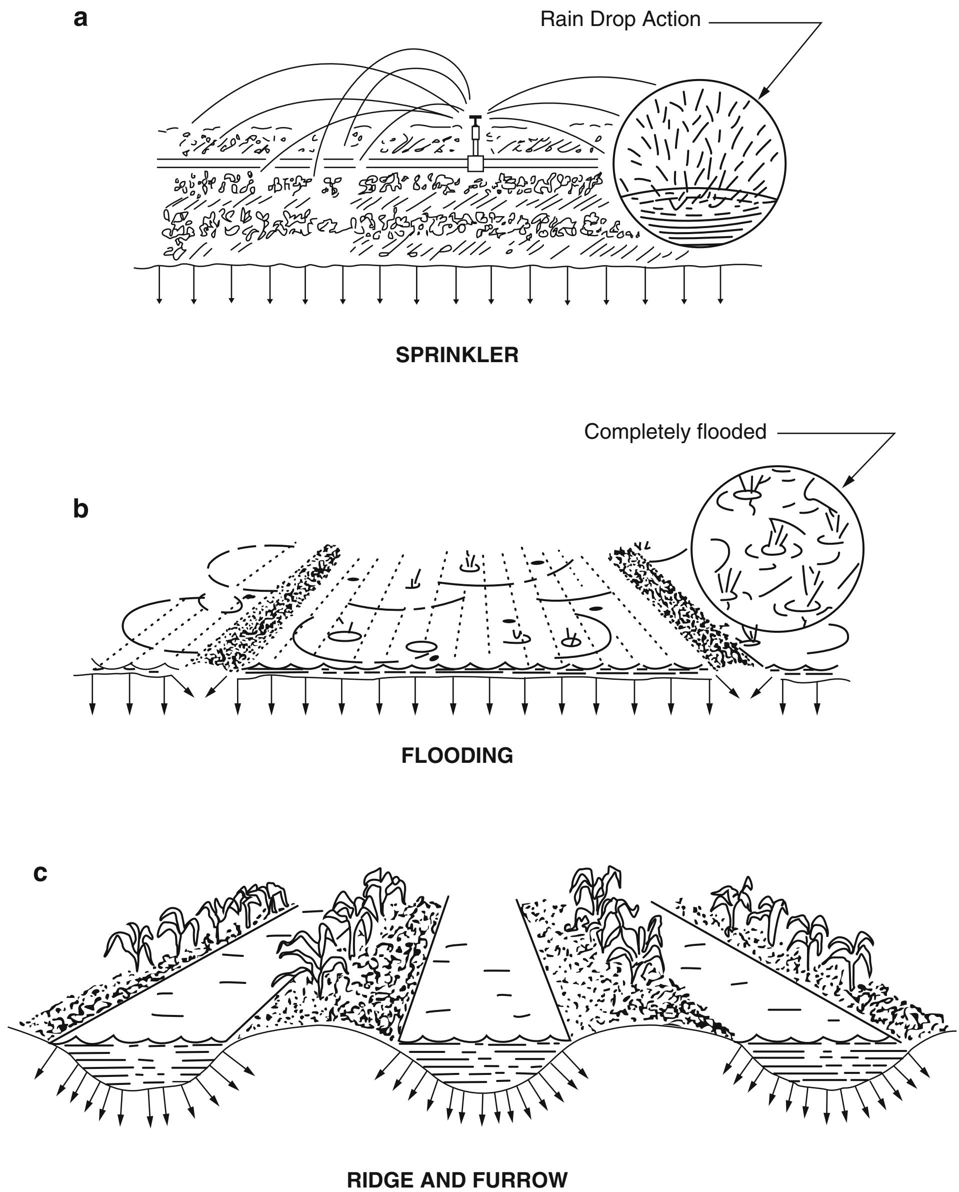

Fig. 12.7. Flow diagram of land treatment using slow rate system. (**a**) Sprinkler distribution, (**b**) flooding, and (**c**) ridge and furrow. (*source:* US EPA).

can be categorized as hand moved, mechanically moved, and permanent set, the selection of which includes the following considerations (2):

(a) Field conditions (shape, slope, vegetation, and soil type)
(b) Climate

(c) Operating conditions, and
(d) Economics.

Vegetation is a vital part of the process and serves to extract nutrients, reduce erosion, and maintain soil permeability. Considerations for crop selection include:

(a) Suitability to local climate and soil conditions
(b) Consumptive water use and water tolerance
(c) Nutrient uptake and sensitivity to wastewater constituents
(d) Economic value and marketability
(e) Length of growing season
(f) Ease of management, and
(g) Public health regulations.

Common preapplication treatment practices include the following:

(a) Primary treatment for isolated locations with restricted public access and when limited to crops not for direct human consumption
(b) Biological treatment plus control of coliform to 1,000 MPN/100 mL for agricultural irrigation, except for human food crops to be eaten raw
(c) Secondary treatment plus disinfection to 200 MPN/100 mL fecal coliform for public access areas (parks).

Wastewaters high in metal content should be pretreated to avoid plant and soil contamination. Table 12.5 shows the wastewater constituents that have potential adverse effects on crops (25). Forestland irrigation is more suited to cold weather operation, since soil temperatures are generally higher, but nutrient removal capabilities are less than for most field crops.

5.2. Applications

Slow rate systems produce the best results of all the land treatment systems. Advantages of sprinkler application over gravity methods include (34):

(a) More uniform distribution of water and greater flexibility in range of application rates
(b) Applicability to most crops
(c) Less susceptibility to topographic constraints, and
(d) Reduced operator skill and experience requirements.

Underdrainage provides a means of recovering renovated water for reuse or for discharge to a particular surface water body when dictated by senior water rights and a means of controlling groundwater. The system also provides the following benefits:

(a) An economic return from the use of water and nutrients to produce marketable crops for forage, and
(b) Water and nutrient conservation when utilized for irrigating landscaped areas.

5.3. Limitations

The slow rate process is limited by (2):

(a) Soil type and depth
(b) Topography

Table 12.5
Potential adverse effects of wastewater constituents on crops

Problem and related constituent	Constituent level			Crops affected
	No problem	Increasing problems	Severe problems	
Salinity (EC_w) (mmho/cm)	<0.75	0.75–3.0	>3.0	Crops in arid climates only
Specific ion toxicity from root absorption				
Boron (mg/L)	<0.5	0.5–2	2.0–10.0	Fruit and citrus trees – 0.5–1.0 mg/L; field crops – 1.0–2.0 mg/L; grasses – 2.0–10.0 mg/L
Sodium (adj–SAR[a])	<3	3.0–9.0	>9.0	Tree crops
Chloride (mg/L)	<142	142–355	>355	Tree crops
Specific ion toxicity from foliar absorption				
Sodium (mg/L)	<69	>69	–	Field and vegetable crops under sprinkler
Chloride (mg/L)	<106	>106	–	application
Miscellaneous				
NH_4-N + NO_3-N (mg/L)	<5	5–30	30	Sugarbeets, potatoes, cotton, grains
HCO_3 (mg/L)	<90	90–520	>520	Fruit
pH (units)	6.5–8.4	4.2–5.5	<4.2 and >8.5	Most crops

Source: US EPA (25).
[a] Adjusted sodium adsorption ratio.

(c) Underlying geology
(d) Climate
(e) Surface and groundwater hydrology and quality
(f) Crop selection, and
(g) Land availability.

Crop water tolerances, nutrient requirements, and the nitrogen removal capacity of the soil–vegetation complex limit hydraulic loading rate (35). Climate affects growing season and will dictate the period of application and the storage requirements. Application ceases during period of frozen soil conditions. Once in operation, infiltration rates can be reduced by sealing of the soil. Limitations to sprinkling include adverse wind conditions and clogging of nozzles.

Slopes should be less than 15% to minimize runoff and erosion. Pretreatment for removal of solids and oil and grease serves to maintain reliability of sprinklers and to reduce clogging. Many states have regulations regarding preapplication disinfection, minimum buffer areas, and control of public access for sprinkler systems.

The process requires long-term commitment of large land area; i.e., largest land requirement of all land treatment processes (36). Concerns with aerosol carriage of pathogens, potential vector problems, and crop contamination have been identified, but are generally controllable by proper design and management.

5.4. Design Criteria

The design criteria for slow rate system can be summarized as follows (2):

(a) Field area: 56–560 acres/MG/d (59.9–598.8 m^2/m^3/d)
(b) Application rate: 2–20 ft/year, 0.5–4 in./wk (0.61–6.1 m/year, 1.27–10.16 cm/wk)
(c) BOD_5 loading rate: 0.2–5 lb/acre/d (0.2–5.6 kg/ha/d)
(d) Soil depth: 2–5 ft (0.6–1.5 m) or more
(e) Soil permeability: 0.06–2.0 in./h (0.15–5.08 cm/h)
(f) Minimum preapplication treatment: primary
(g) Lower temperature limit: 25°F (−3.9 °C)
(h) Particle size of solids: less than one-third of the sprinkler nozzle diameter
(i) Underdrains: 4–8-inch (10.1–20.3 cm) diameter, 4–10-ft (1.2–3.0 m) deep, 50–500-ft (15.2–152.4 m) apart; pipe material: plastic, concrete (sulfate-resistant, if necessary), or clay.

5.5. Performance

Effluent quality is generally excellent and consistent regardless of the quality of wastewater applied (37). Percent removals for typical pollution parameters when wastewater is applied through more than 5 ft (1.5 m) of unsaturated soil are:

(a) BOD_5: 90–99 + %
(b) TSS: 90–99 + %
(c) Total N: 50–95% depending on N uptake of vegetation
(d) Total P: 80–99%, until adsorptive capacity is exceeded (38)
(e) Fecal Coliform: 99.99 + % when applied levels are more than 10 MPN/100 mL.

This treatment is capable of achieving the highest degree of nitrogen removal. Typically, nitrogen losses due to denitrification (15–25%), ammonia volatilization (0–10%) and soil immobilization (0–25%) supplement the primary nitrogen removal mechanism by the crop (17). The balance of the nitrogen passes to the percolate. Typical design standards require preservation of controlling depths to ground water and establishing nitrogen limits in either the percolate or ground water as it leaves the property site. Nitrogen loading to the ground water is often the controlling consideration in the design. For further detailed information on slow rate infiltration systems the reader is referred to refs. (39–44).

5.6. Costs

The construction and O & M costs are shown in Figs. 12.8 and 12.9, respectively (2). The costs are based on 1973 (Utilities Index = 149.36, EPA Index 194.2, ENR Index = 1, 850)

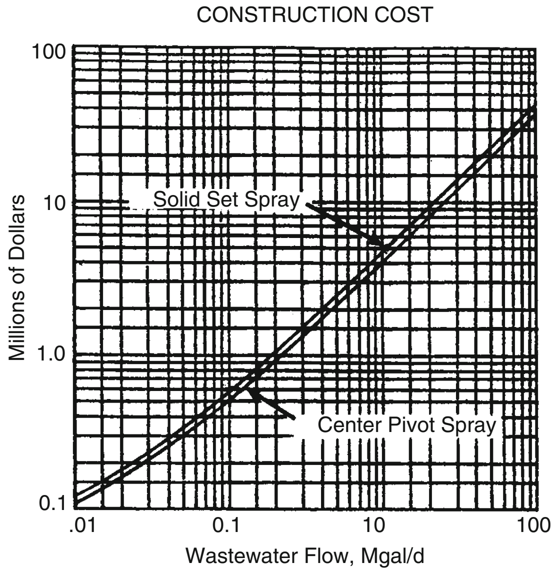

Fig. 12.8. Construction cost of slow rate system. (*source:* US EPA). 1 Mgal/d = 1 MGD = 3.785 MLD = 43.8 L/s

figures. To obtain the values in terms of the present value (2009) of the US Dollars, using the Cost Index for Utilities (Appendix A), multiply the costs by a factor of 3.82 (24).

Assumptions applied in preparing the costs given in Figs. 12.8 and 12.9: (Here 1 in = 2.54 cm; 1 ft = 0.3048 m; 1 acre = 0.4046 ha; 1 MG = 3.785 ML; 1 psi = 6.8948 kPa; 1 gpm = 3.785 Lpm)

(a) Yearly average application rate: 0.33 in./d
(b) Energy requirements: Solid set spray distribution requires 2,100 kwh/year/ft of TDH/MG/d capacity. Center pivot spraying requires an additional 0.84×10^6 kwh/year/acre (based on 3.5 d/wk operation) for 1 MG/d or larger facilities (below 1 MG/d, additional power = $0.84–1.35 \times 10^6$ kwh/year/acre)
(c) Clearing costs are for brush with few trees using bulldozer-type equipment
(d) Solid set spraying construction costs include: lateral spacing, 100 ft; sprinkler spacing, 80 ft along laterals; 5.4 sprinklers/acre; application rate, 0.20 in./h; 16.5 gpm flow to sprinklers at 70 psi; flow to laterals controlled by hydraulically operated automatic valves; laterals buried 18 in.; mainlines buried 36 in.; all pipe 4-in diameter and smaller is PVC; all larger pipe is asbestos cement (Total dynamic head = 150 ft).
(e) Center pivot spraying construction costs include: heavy-duty center pivot rig with electric drive; multiple units for field areas over 40 acres; maximum area per unit, 132 acres; distribution pipe is buried 3 ft deep
(f) Underdrains are spaced 250 ft (76.2 m) between drain pipes. Drain pipes are buried 6–8-ft (1.8–2.4 m) deep with interception ditch along length of field and weir for control of discharge.
(g) Distribution pumping construction costs include: structure built into dike of storage reservoir; continuously cleaned water screens; pumping equipment with normal standby facilities; piping and valves within structure; controls and electrical work

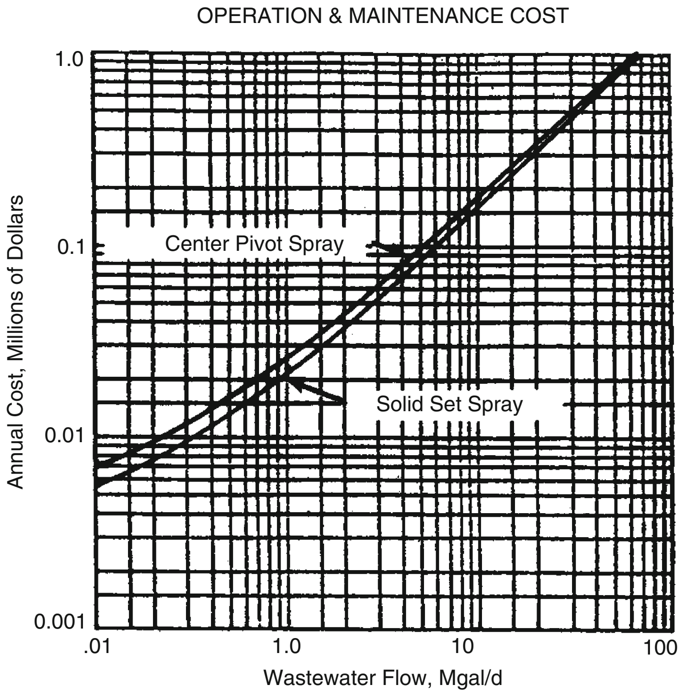

Fig. 12.9. Operation and maintenance cost of slow rate system. (*source:* US EPA). 1 Mgal/d = 1 MGD = 3.785 MLD = 43.8 L/s

(h) Labor costs include inspection and unclogging of drain pipes at outlets and dike maintenance
(i) Materials costs include for solid set spraying: replacement of sprinklers and air compressors for valve controls after 10 years; for center pivot spraying, minor repair parts and major overhaul of center pivot rigs after 10 years; high pressure jet cleaning of drain pipes every 5 years, annual cleaning of interceptor ditch, and major repair of ditches after 10 years; distribution pumping repair work performed by outside contractor and replacement parts; scraping and patching of storage receiver liner every 10 years
(j) Storage for 75 days is included; 15-ft or 4.5 m dikes (12-ft or 3.66 m wide at crest) are formed from native materials (inside slope 3:1, outside 2:1); rectangular shape on level ground; 12-ft or 3.66 m water depth; multiple cells for more than 50 acre or 20.2 ha size; asphaltic lining; 9-in. or 22.9 cm riprap on inside slope of dikes
(k) Cost of pretreatment, monitoring wells, land, and transmission to and from land treatment facility not included.

6. LAND TREATMENT: OVERLAND FLOW SYSTEM

6.1. Description

Wastewater treatment using the overland flow system is relatively new. It is now extensively used in the food-processing industry. Very few municipal plants are in operation and most are in warm, dry areas. Wastewater is applied over the upper reaches of sloped terraces and is

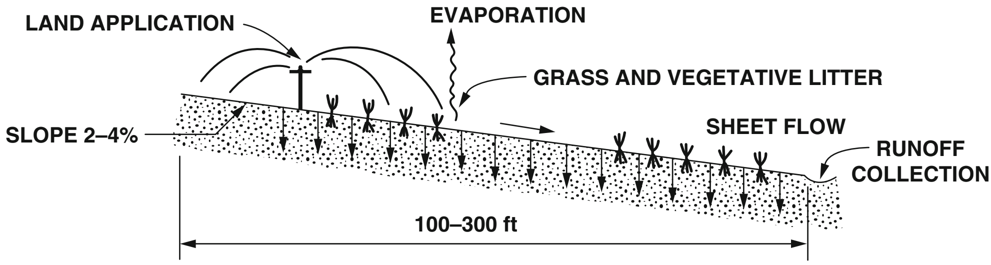

Fig. 12.10. Land treatment using overland flow system. (*source:* US EPA). 1 ft = 0.3048 m

treated as it flows across the vegetated surface to runoff collection ditches (see Fig. 12.10). The wastewater is renovated by physical, chemical, and biological means as it flows in a thin film down the relatively impermeable slope.

A secondary objective of the system is for crop production. Perennial grasses (Reed Canary, Bermuda, Red Top, tall fescue, and Italian Rye) with long growing seasons, high moisture tolerance, and extensive root formation are best suited to overland flow. Harvested grass is suitable for cattle feed. Biological oxidation, sedimentation and grass filtration are the primary removal mechanisms for organics and suspended solids. Nitrogen removal is attributed primarily to nitrification/denitrification and plant uptake. Loading rates and cycles are designed to maintain active microorganism growth on the soil surface. The operating principles are similar to a conventional trickling filter with intermittent dosing. The rate and length of application is controlled to minimize severe anaerobic conditions that result from overstressing the system. The resting period should be long enough to prevent surface ponding, yet short enough to keep the microorganisms in an active state. Surface methods of distribution include the use of gated pipe or bubbling orifice. Gated surface pipe, which is attached to aluminum hydrants, is aluminum pipe with multiple outlets. Control of flow is accomplished with slide gates or screw adjustable orifices at each outlet. Bubbling orifices are small diameter outlets from laterals used to introduce flow. Gravel may be necessary to dissipate energy and ensure uniform distribution of water from these surface methods. Slopes must be steep enough to prevent ponding of the runoff, yet mild enough to prevent erosion and provide sufficient detention time for the wastewater on the slopes. Slopes must have a uniform cross slope and be free from gullies to prevent channeling and allow uniform distribution over the surface. The network of slopes and terraces that make up an overland system may be adapted to natural rolling terrain. The use of this type of terrain will minimize land preparation costs. Storage must be provided for nonoperating periods. Runoff is collected in open ditches. When unstable soil conditions are encountered or flow velocities are erosive, gravity pipe collection systems may be required. Common preapplication practices include the following: screening or comminution for isolated sites with no public access; screening or comminution plus aeration to control odors during storage or application for urban locations with no public access (45, 46). Wastewaters high in metal content should be pretreated to avoid soil and plant contamination.

A common method of distribution is with sprinklers. Recirculation of collected effluent is sometimes provided and/or required. Secondary treatment before overland flow permits reduced (as much as 2/3 reduction) land requirements. Effluent disinfection is required where stringent fecal coliform criteria exist.

6.2. Application

Because overland flow is basically a surface phenomenon, soil clogging is not a problem. High BOD_5 and suspended solids removals have been achieved with the application of raw comminuted municipal wastewater. Thus, preapplication treatment is not a prerequisite where other limitations are not operative. Depth to groundwater is less critical than with other land systems. It also provides the following benefits: an economic return from the reuse of water and nutrients to produce marketable crops or forage; and a means of recovering renovated water for reuse or discharge. This type of applications is preferred for gently sloping terrain with impermeable soils.

6.3. Limitations

The process is limited by soil type, crop water tolerances, climate, and slope of the land. Steep slopes reduce travel time over the treatment area and thus, treatment efficiency. Flat land may require extensive earthwork to create slopes. Ideally, slope should be 2–8%. High flotation tires are required for equipment. Cost and impact of the earthwork required to obtain terraced slopes can be major constraints. Application is restricted during rainy periods and stopped during very cold weather (47). Many states have regulations regarding preapplication disinfection, minimum buffer zones and control of public access.

6.4. Design Criteria

The design criteria for overland Flow system can be summarized as follows (2):

(a) Field area required: 35–100 acres/MG/d (37.4–106.9 m^2/m^3/d)
(b) Terraced slopes: 2–8%
(c) Application rate; 11–32 ft/year, 2.5–16 in./wk (3.3–9.8 m/year, 6.4–40.6 cm/wk)
(d) BOD_5 loading rate: 5–50 lb/acre/d (5.6–56 kg/ha/d)
(e) Soil depth, sufficient to form slopes that are uniform and to maintain a vegetahve cover
(f) Soil permeability: 0.2 in/h (0.5 cm/h) or less
(g) Hydraulic loading cycle: 6–8-h application period, 16–181-week resting period
(h) Operating period: 5–6 d/wk
(i) Soil texture: clay and clay loams.

Below are representative application rates for 2–8% sloped terraces:

in./wk	Pretreatment	Terrace length (ft)
2.5–8	Untreated or primary	150
6–16	Lagoon or secondary	120

Here: 1 ft = 0.3048 m; 1 in/wk = 2.54 cm/wk

Table 12.6
Design loadings for overland flow systems

Preapplication treatment	Application rate ($m^3/h \cdot m$)	Hydraulic loading rate (cm/d)
Screening/primary	0.07–0.12[a]	2.0–7.0[b]
Aerated cell (1-day detention)	0.08–0.14	2.0–8.5
Wastewater treatment pond[c]	0.09–0.15	2.5–9.0
Secondary[d]	0.11–0.17	3.0–10.0

Source: US EPA (48).
[a] $m^3/h \cdot m \times 80.5 = gal/h \cdot ft$.
[b] $cm/d \times 0.394 = in./d$.
[c] Does not include removal of algae.
[d] Recommended only for upgrading existing secondary treatment.

Generally, 40–80% of applied wastewater reaches collection structures, lower percent in summer and higher in winter (southwest data). Table 12.6 shows the required pretreatment and allowed application and hydraulic rates (48)

6.5. *Performance*

Percent removals for comminuted or screened municipal wastewater over approximately 150 ft of 2–6% slope:

(a) BOD_5: 80–95%
(b) Suspended solids: 80–95%
(c) Total N: 75–90%
(d) Total P: 30–60%,
(e) Fecal coliform:90–99.9%.

The addition of alum $Al_2(SO_4)_3$, ferric chloride $FeC1_3$, or calcium carbonate $CaCO_3$ before application will increase phosphorus removals.

Little attempt has been made to design optimized overland flow systems with a specific objective of nitrogen control. Their performance depends on the same fundamental issues: nitrification–denitrification, ammonia volatilization, and harvesting of crops. When measured, overland flow systems designed for secondary treatment often reveal less than 10 mg/L total nitrogen (49). For further detailed information on overland flow systems the reader is referred to references (50–53).

6.6. *Costs*

The construction and O & M costs are shown in Figs. 12.11 and 12.12, respectively (2). The costs are based on 1973 (Utilities Index = 149.36, EPA Index 194.2, ENR Index = 1, 850) figures. To obtain the values in terms of the present value (2009) of the US Dollars, using the Cost Index for Utilities (Appendix A), multiply the costs by a factor of 3.82 (24).

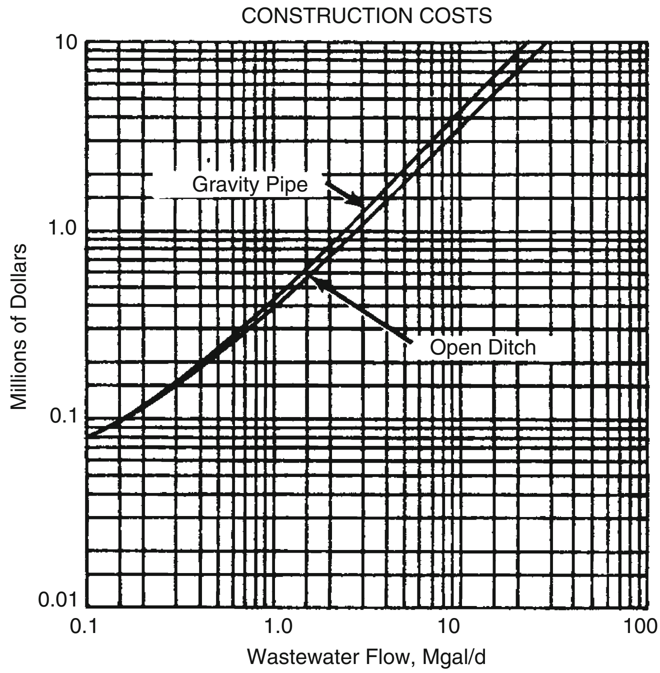

Fig. 12.11. Construction cost of overland flow treatment system. (*source:* US EPA). 1 Mgal/d = 1 MGD = 3.785 MLD = 43.8 L/s

Assumptions applied in preparing the costs given in Figs. 12.11 and 12.12: (Here 1 in = 2.54 cm; 1 ft = 0.3048 m; 1 acre = 0.4046 ha; 1 yd = 0.9144 m; 1 psi = 6.8948 kPa; 1 gpm = 3.785 Lpm)

(a) Storage for 75 days included.
(b) Site cleared of brush and trees using bulldozer-type equipment; terrace construction: 175–250-ft wide with 2.5% slope (1,400 yd/acre of cut). Costs include surveying, earthmoving, finish grading, ripping two ways, disking, land-planning, and equipment mobilization.
(c) Distribution system: application rate, 0.064 in./h; yearly average rate of 3 in./wk (8 h/d; 6 d/wk); flow to sprinklers, 13 gpm at 50 psi; laterals 70 ft from top of terrace, buried 18 in.; flow to laterals controlled by hydraulically operated automatic valves; mainlines buried 36 in.; all pipes, 4 in. diameter and smaller are made of PVC: all larger pipes are made of asbestos cement.
(d) Open Ditch Collection: network of unlined interception ditches sized for a 2 in/h storm; culverts under service roads; concrete drop structures at 1,000 ft intervals.
(e) Gravity Pipe Collection: network of gravity pipe interceptors with inlet/manholes every 250 ft along sub-mains; storm runoff is allowed to pond at inlets; each inlet/manhole serves 1,000 ft of collection ditch; manholes every 500 ft or 152.4 m along interceptor mains.
(f) O & M cost includes replacement of sprinklers and air compressors for valve controls after 10 years and either biannual cleaning of open ditches with major repair after 10 years or the periodic cleaning of inlets and normal maintenance of gravity pipe. Also includes dike maintenance and scraping and patching of storage basin liner every 10 years.

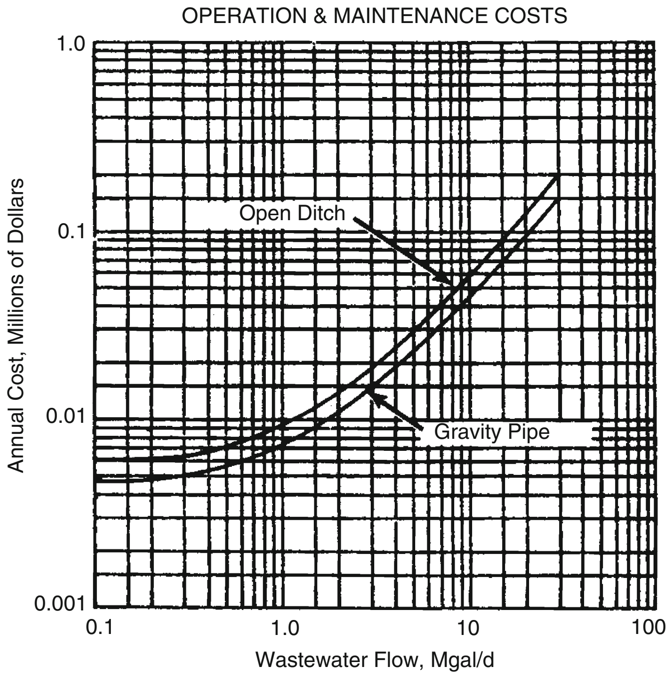

Fig. 12.12. Operation and maintenance cost of overland flow treatment system. (*source:* US EPA). 1 Mgal/d = 1 MGD = 3.785 MLD = 43.8 L/s

(g) Costs for pretreatment, land, transmission to site, disinfection, and service roads and fencing not included.

7. SUBSURFACE INFILTRATION

Subsurface infiltration systems are capable of producing a high degree of treatment; with proper design, they can provide a nitrified effluent, and denitrification can be achieved under certain circumstances. Keys to their success are the adequacy of the initial gravel infiltration zone for solids capture and the following unsaturated zone of native or foreign soils. Failure to provide an oxygenated environment by either resting or conservative loadings can lead to failure. Denitrification under gravity loading is likely to be small, but may be improved through pressure/gravity dosing concepts of liquid application to the trenches (54).

Subsurface infiltration wastewater management practices are embodied in the horizontal leach fields that routinely serve almost one-third of the United States population that use more than 20 million septic tanks in their individual nonsewered establishments and homes (2). In recent years, they have also been advanced for collective service in small isolated communities.

7.1. Description

A septic tank followed by a soil absorption field is the traditional on-site system for the treatment and disposal of domestic wastewater from individual households or establishments. The system consists of a buried tank where wastewater is collected and scum, grease, and settleable solids are removed by gravity separation, and a sub-surface drainage system where clarified effluent percolates into the soil. Precast concrete tanks with a capacity of 1,000 gallons (3785 L) are commonly used for house systems. Solids are collected and stored in the tank, forming sludge and scum 1ayers. Anaerobic digestion occurs in these layers, reducing the overall volume. Effluent is discharged from the tank to one of three basic types of subsurface systems, absorption field (54), seepage bed (54, 55), or seepage pits (56). Sizes are usually determined by percolation rates, soil characteristics, and site size and location. Distribution pipes are laid in a field of absorption trenches to leach tank effluent over a large area (Fig. 12.13). Required absorption areas are dictated by state and local codes. Trench depth is commonly about 24 in. or 60.96 cm to provide minimum gravel depth and earth cover. Clean, graded gravel or similar aggregate, varying in size from $^1/_2$ to $2^1/_2$ in. (1.27–6.35 cm), should surround the distribution pipe and extend at least 2 in. or 5.08 cm above and 6 in. or 15.24 cm below the pipe. The maintenance of at least a 2 ft (0.61 m) separation between the bottom of the trench and the high water table is required to minimize groundwater contamination. Piping typically consists of agricultural drain tile, vitrified clay sewer pipe, or perforated, nonmetallic pipe. Absorption systems having trenches wider than 3 ft are referred to as seepage beds. Given the appropriate soil conditions (sandy soils), a wide bed makes more efficient use of available land than a series of long, narrow trenches.

Many different designs may be used in laying out a subsurface disposal field. In sloping areas, serial distribution can be employed with absorption trenches by arranging the system so that each trench is utilized to its capacity before liquid flows into the succeeding trench. A dosing tank can be used to obtain proper wastewater distribution throughout the disposal area and give the absorption field a chance to rest or dry out between dosings. Providing two separate alternating beds is another method used to restore the infiltrative capacity of a system. Aerobic units may be substituted for septic tanks with no changes in soil absorption system requirements.

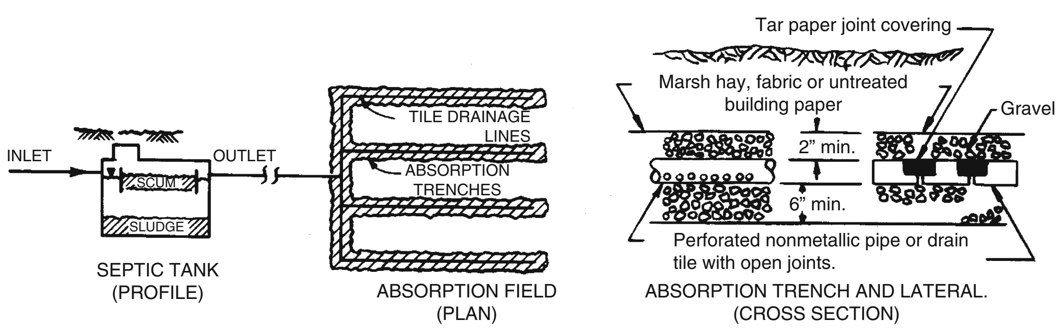

Fig. 12.13. Septic tank absorption field. (*source:* US EPA). 1″ = 1 inch = 2.54 cm

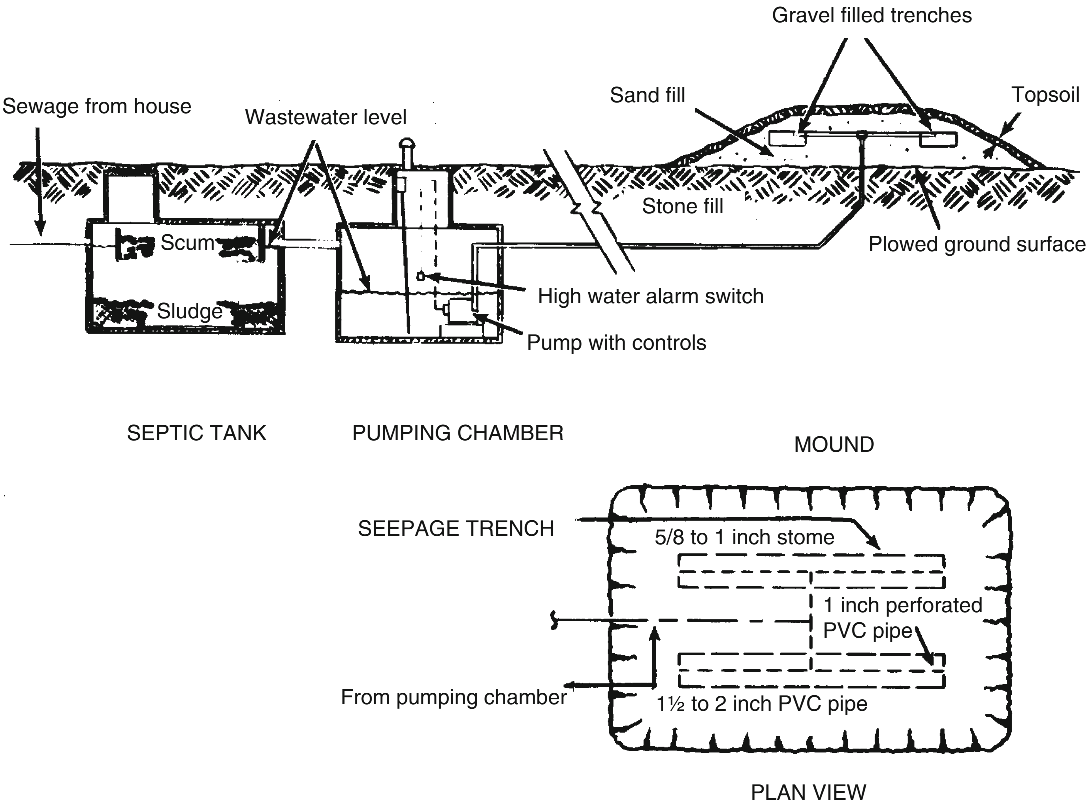

Fig. 12.14. Septic tank mound absorption field. (*source:* US EPA). 1 inch = 2.54 cm

In areas where problem soil conditions preclude the use of subsurface trenches or seepage beds, mounds can be installed (Fig. 12.14) to raise the absorption field above ground, provide treatment, and distribute the wastewater to the underlying soil over a wide area in a uniform manner (2, 57, 58). A pressure distribution network should be used for uniform application of clarified tank effluent to the mound. A subsurface chamber can be installed with a pump and high water alarm to dose the mound through a series of perforated pipes. Where sufficient head is available, a dosing siphon may be used. The mound must provide an adequate amount of unsaturated soil and spread septic tank effluent over a wide enough area so that distribution and purification can be effected before the water table is reached.

The mound system requires more space and periodic maintenance than conventional subsurface disposal system, along with higher construction costs. System cannot be installed on steep slopes, nor over highly (120 mm/in.) impermeable subsurface. Seasonal high groundwater must be deeper than 2 ft (0.61 m) to prevent surfacing at the edge of the mound (2). An alternative to the mound system is a new combined distribution and pretreatment unit to precede the wastewater application to the subsurface infiltration systems (59). The new system is based on pumping of septic tank effluent to one or more units filled with lightweight clay aggregates. The wastewater is distributed evenly over the 2.3 m^2 surface of the pretreatment filter. The filter(s) effluent is then applied to the subsurface infiltration system.

7.2. Applications

Subsurface infiltration systems for the disposal of septic tanks effluents are used primarily in rural and suburban areas where economics are favorable. Properly designed and installed systems require a minimum of maintenance and can operate in all climates.

7.3. Limitations

The use of subsurface effluent disposal fields is dependent on the following factors and conditions (2):

(a) Soil and site conditions
(b) The ability of the soil to absorb liquid
(c) Depth to groundwater
(d) Nature of and depth to bedrock
(e) Seasonal flooding, and
(f) Distance to well or surface water.

A percolation rate of 60 mm/in. is often used as the lower limit of permeability. The limiting value for seasonal high groundwater should be 2 ft below the bottom of the absorption field. When a soil system loses its capacity to absorb septic tank effluent, there is a potential for effluent surfacing, which often results in odors and, possibly, health hazards.

7.4. Design Criteria

Absorption area requirements for individual residences are given in Table 12.7. The area required per bedroom is a function of the percolation rate, the higher the rate the smaller is the required area (2).

Design criteria for the mound system is as follows (2, 57, 58): Design flow 75 gal/person/d; 150 gal/bedroom/d. Basal area based on percolation rates up to 120 mm/in. Mound height at center is approximately 3.5–5 ft. Pump (centrifugal) must accommodate approximately 30 gpm at required TDH.

Properly designed, constructed, and operated septic tank systems have demonstrated an efficient and economical alternative to public sewer systems, particularly in rural and sparsely developed areas. System life for properly sited, designed, installed and maintained systems may equal or exceed 20 years.

7.5. Performance

Performance is a function of the following factors (2):

(a) Design of the system components
(b) Construction techniques employed
(c) Rate of hydraulic loading

Table 12.7
Required areas of subsurface infiltration absorption fields

Percolation rate (mm/in.)	Required area per bedroom (ft^2)
1 or less	70
3	100
5	125
10	165
15	190
30	250
45	300
60	330

Source: US EPA (2). 1 in. = 2.54 cm; 1 ft^2 = 0.0929 m^2

(d) Geology and topography of the area
(e) Physical and chemical composition of the soil mantle, and
(f) Care given to periodic maintenance.

Pollutants are removed from the effluent by natural adsorption and biological processes in the soil zone adjacent to the field. BOD, SS, bacteria, and viruses, along with heavy metals and complex organic compounds, are adsorbed by soil under proper conditions. However, chlorides and nitrates may readily penetrate coarser, aerated soils to groundwater.

Leachate can contaminate groundwater when pollutants are not effectively removed by the soil system. In many well-aerated soils, significant densities of homes with septic tank-soil absorption systems have resulted in increasing nitrate content of the ground water. Soil clogging may result in surface ponding with potential aesthetic and public health problems. The sludge and scum layers accumulated in a septic tank must be removed every 3–5 years. For further detailed information on subsurface infiltration systems the reader is referred to references (60–65).

8. FACULTATIVE LAGOONS AND ALGAL HARVESTING

Simple regression-type ammonium and nitrogen removal models of facultative lagoons have been developed and reported with some suggestion of validation (66, 67). These identify pH to be of primary importance, based on an ammonia-stripping assumption. A pH rise occurs in the pond because carbon dioxide (CO_2) is the carbon source for the algae, which photosynthetically produce biomass and oxygen. The CO_2 source is largely from the aerobic (surface layers) and anaerobic stabilization (bottom layers and deposits) in the lagoon. With insufficient CO_2, the bicarbonate alkalinity will serve as the CO_2 source, and a significant pH rise can be experienced. Significant ammonia stripping does occur at a pH of greater than 8.5 (17).

The reported dependency of ammonia removal on pH could also be a surrogate parameter for an active algal biomass, and the actual ammonium and total nitrogen removals could reflect natural nitrification (using the photosynthetically produced oxygen), denitrification (bacterial use of the dormant algal biomass as the driving substrate during the nighttime hours), and algal synthesis during the daylight hours.

Facultative ponds should be designed to embrace and enhance the anaerobic reactions that produce CO_2 and, most important, methane (CH4), occurring in the bottom of the pond. Failure to do so will likely result in problems and, inevitably, the progressive buildup of solids and pass-through to the plant effluent. Many past problems with this biotechnology were associated with this consideration. The designer would be well-served by consulting the more fundamental publications regarding this technology (68–71).

Facultative ponds have the potential to achieve nitrogen oxidation down to the most stringent levels; their natural daytime to nighttime cycling of photosynthetic activity and aerobic to anoxic bacterial response provides a possible mechanism of nitrogen removal (72). Their liability: what to do with the algal biomass once generated. Procedures start with submerged drawoff outlet designs and consideration of chemical coagulation and/or filtration for tertiary algae removal (73). Regulatory standards may allow for a higher effluent SS. Pumped or submerged outlet removal and the sloped sidewalls of the lagoon allow for considerable flow equalization.

Facilities with an algal harvest approach (maximizing nitrogen removal by synthesis) can be designed to incorporate a number of concepts. The large lagoons at Sunnyvale and Stockton, California, return the subsequently removed algae to lagoons with adequate depth to ensure anaerobic activity. The systems have operated since the late 1970s with no residual removal. Alternatively, the pond design could be as shallow as is reasonable and well mixed, with the objective of maximizing light penetration. Algae-removal concepts abound (73–75) but are often unused on a sustained basis because of the uncertainty (and now a liability) concerning use or disposal of the harvested algae.

9. VEGETATIVE FILTER SYSTEMS

The intent of this section is to present design and maintenance criteria for runoff field application systems (commonly called vegetative filter systems). These relatively inexpensive systems can be effectively utilized to prevent feedlot runoff generated by small livestock management facilities from polluting streams, rivers, and other waters. Small livestock management operations typically do not have the economic resource, necessary to control their feedlot runoff with expensive lagoon-type zero-discharge systems. The vast majority of livestock management operations are relatively small and therefore, this system helps in preventing water pollution from livestock management facilities.

Runoff field application systems need attentive maintenance to function properly. Consistent failure on the part of the operator to maintain a runoff field application system in good operational condition could result in violations of regulations under the National Pollutant Discharge Elimination System (NPDES).

Designing an acceptable runoff field application system involves the following:

1. Meeting the conditions for system utilization.
2. Evaluating the planning considerations.
3. Meeting the component design criteria.
4. Meeting the specifications for vegetation establishment.
5. Providing the operator with operation and maintenance criteria.

9.1. Conditions for System Utilization

Runoff field application systems that are to be constructed and operated at a livestock management facility need to satisfy the following conditions:

1. The livestock management facility confines a maximum of 300 animal units
2. No NPDES permit is required for the facility
3. Sufficient land area with characteristics capable of meeting the design and maintenance criteria for runoff field application systems
4. The runoff field application system is maintained in good operational condition.

9.2. Planning Considerations

The following characteristics need to be addressed in planning a runoff field application system:

1. Slopes and soil material, vegetative species, and time of year for proper establishment of vegetation. Irrigation of the field application area, visual aspects, and other special needs should also be considered.
2. Location of settling basin.
3. Adequate drainage to insure satisfactory performance.
4. Provisions for preventing or designing for continuous or daily discharge of liquid waste to the field application area (e.g., provide temporary storage tanks for milking parlor wastewaters or provide alternate field application areas).
5. Provisions to allow harvesting activities without causing vegetative damage.
6. Provisions for excluding roof water and unpolluted surface water from the settling basin.
7. The need to mechanically distribute the flow uniformly across the top of the field application area.
8. Runoff field application systems designed to be located on soils with infiltration rates outside the range of 1.0–6.0 in./h (2.54–15.24 cm/h), are considered innovative designs.

9.3. Component Design Criteria

9.3.1. Settling Basin

1. Basin volume is obtained based on 4.5 $ft^3/100\,ft^2$ (0.12735 m^3/9.29 m^2) of runoff area plus an additional 10% volume safety factor.
2. Ramp slope should not be steeper than 12:1 (H:V), with 15:1 being preferred.
3. Basin depth ranges from 2 to 4 ft. (0.61–1.22 m)
4. Settling basins located where groundwater tables rise to within 2 ft (0.61 m) of the surface should be provided with foundation drainage.
5. The settling basin riser pipe should be 1.5–2 ft (0.46–0.61 m) in diameter with vertical slots 1 in by 4 in (2.54 cm by 10.16 cm) high spaced at 120° intervals around the pipe. There should be 6

slots/ft of height with the bottom row of slots even with the settling basin floor. To avoid excess clogging, offset or locate the riser pipe as far as practicable from the inlet of the settling basin and attach a 3/3-in. mesh expanded metal screen cover over the top of the riser pipe. Provide a 3/3-in. mesh expanded metal screen ahead of the riser pipe so that all runoff entering the riser pipe must first cross this screen. Refer to diagram in Appendix J.

6. The settling basin ramp, floor, end-wall, and side-walls should be designed, constructed, and maintained to withstand normal operation practices involving power machinery.

9.3.2. *Effluent Transport System*

1. Pressurized effluent transport systems are designed by normal engineering hydraulic considerations including but not limited to static head, friction losses, flow velocity, and pipe diameter.
2. Gravity flow effluent transport systems may be designed as pipes flowing full or as open channels. The design velocity is 2 ft/s (0.61 m/s) or greaser to prevent solids deposition. Minimum pipe capacity is based on the design flow rate (Q_f) over the field application area. The design feedlot runoff volume (VR) is calculated as shown in Appendix B. Design flow rate (Q_f) can be obtained from the graph in Appendix G.
3. Closed pipes used for effluent transport systems are to be provided with some means of cleaning by rodding or flushing.

9.3.3. *Junction Box*

1. A junction box needs to be provided at the intersection of the effluent transport system and distribution manifold to dissipate the energy of the anticipated hydraulic jump from the effluent transport system discharge and to proportionally split the flow to the distribution manifold(s).
2. The recommended junction box design specifications are provided in Appendix I.
3. The junction box should be provided with a removable cover to allow entry for maintenance and prevent entry of objects that would interfere with the operation of the runoff field application system.

9.3.4. *Distribution Manifold*

1. Pressurized distribution manifolds shall be designed by normal engineering considerations including but not limited to static head, friction losses, flow velocity and pipe diameter.
2. Gravity flow distribution manifolds should be less than 50-ft (15.24 m) long each and at least 2 ft (0.61 m) shorter than the width of the field application area.
3. The following must be considered in the distribution manifold design: construction material, length, capacity, Slope (level), solids removal and cleaning and location of junction box.
4. Recommended design of distribution manifolds is provided in Appendix H.
5. Distribution manifolds must be anchored securely while in operation.

9.3.5. *Runoff Field Application Area*

1. The runoff field application area is to be located on gently sloping soils of moderate permeability supporting a heavy stand of grass vegetation and designed to operate by overland flow.
2. Slopes are shaped to cause applied runoff to flow uniformly across the design width for the entire length of the field application area.
3. The uniform sheet flow should move downslope through the field application area flow length at a velocity that will provide a minimum contact time of 2 h. Appendix E, gives minimum flow lengths needed to provide a contact time of 2 h at various slopes.
4. Field application areas should have a minimum width of 20 ft (6.1 m) and a maximum width of 100 ft (30.48 m).

5. The range of soil infiltration rates specified in the planning considerations (1.0–6.0 in./h) (2.54–15.24 cm/h) insures that the infiltration capacity of the field application area will equal or exceed the volume of feedlot runoff to be infiltrated for the 1 year – 2-h design rainstorm event. The following equation is used for designing the field application area:

$$\mathrm{FAA} = \frac{\mathrm{VR}(12)}{(2\,\mathrm{h})\mathrm{SI} - 1.69} \quad \text{when: } l \leq \mathrm{I} \leq 6.0\,\mathrm{in/h} \leq 15.24\mathrm{cm/h}$$

   where:
   FAA = field application area, ft^2
   VR = volume of runoff, ft^3
   SI = soil infiltration rate, in./h
6. The procedure for determining VR and test to determine SI are provided in Appendixes B and C, respectively. Here $1\,ft^2 = 0.0929\,m^2$; $1\,ft^3 = 0.0283\,m^3$; 1 in/h = 2.54 cm/h.

9.4. Specifications for Vegetation Establishment

The following specifications apply to all runoff field application systems:

1. All trees, stumps, brush, rocks, and similar materials that can interfere with installing the field application area should be removed. The materials are disposed of in a manner that is consistent with standards for maintaining and improving the quality of the environment and with proper functioning of the field application area.
2. All areas disturbed during construction have to be vegetated.
3. To aid in the establishment of vegetation, feedlot runoff should be prevented from entering the field application area through the use of temporary diversions until vegetation is established to a minimum height of 4 in. and 90% ground cover.
4. Immediately before seedbed preparation, the following minimum amounts of starter fertilizer should be applied:
   - Nitrogen (N) – 120 lb/acre (134.52 kg/ha) of actual nitrogen
   - Phosphorus (P) – 120 lb/acre (134.52 kg/ha) of P_2O_5
   - Potassium (K) – 120 lb/acre (134.52 kg/ha) of K_2O.
5. Apply limestone, if necessary, for the species to be grown.
6. Incorporate the required lime and fertilizer and prepare a firm seedbed to a depth of 3 in. The seedbed should be free from clods, stones, or other debris that might hamper proper seeding.
7. Select one of the following mixtures and seed according to the rate shown:
   - Reed canarygrass – 25 lb/acre. (28 kg/ha)
   - Mixture reed canarygrass and tall fescue – 15 lb/acre (16.8 kg/ha) of each species.
   - Use of species other than reed canarygrass or tall fescue is considered an innovative design.
8. Apply seed uniformly at a depth of 1/4 to 1/2 in. (0.64 to 1.27 cm) with a drill (band seed) or cultipacker type seeder or broadcast seed uniformly and cover to a depth of 1/4 to 1/2 in. (0.64 to 1.27 cm) with a cultipacker or harrow. If a drill or cultipacker seeder is used, seed across the slope or cut channel.
9. Seeding dates shall be either
   - Early spring to May 15.
   - May 15 to August 1, provided sufficient water is provided for germination and vigorous growth.
   - August 1 to September 10.

10. Mulch with clean straw using 2 tons of mulch per acre (4.48 metric tons of mulch per hectare). The mulch must be uniformly spread over the seeded area.
11. Anchor the mulch by one of the following methods:
    - Press it into the soil to a 2-in. (5.1 cm) depth by using a serrated straight disk or a dull farm disk set straight. Cross the slope perpendicular to the direction of the flow of water, or
    - Apply netting on top of the mulch and anchor it with staples.

9.5. Operation and Maintenance Criteria

The following operation and maintenance criteria apply as best management practices to all runoff field application systems:

1. Protect the field application area from damage by farm equipment, traffic, and livestock. Livestock must be fenced out of the runoff field application area.
2. Avoid damaging the field application area with herbicides.
3. Fertilize the field application area when necessary to establish growth.
4. Harvest when the forage is at the proper state of maturity for maximum quality feed. No harvesting should occur after September 15. Use the following guide for cutting stages and minimum cutting height for the species seeded:
    - Reed canarygrass – cut at early boot stage to heading – minimum cutting height 6 in (15.24 cm).
    - Reed canarygrass – tall fescue mixture – cut at early boot to heading – minimum cutting height 6 in.
5. Repair damage caused by erosion or equipment immediately so the runoff field application system will continue to perform properly. A shallow furrow on the contour across the field application area can be used to reestablish sheet flow.
6. To prevent excess organic solids from entering the field application area:
    - Scrape feedlot regularly: however, do not scrape waste into settling facilities, but place in separate manure stacking area away from settling basin.
    - Drainage from manure stacking facilities should be directed to settling basin or contained.
    - Remove solids from the settling basin when 2–4 in (5.1–10.2 cm) accumulate.
    - Scrape lot frequently during early spring. At least once each 7 days is recommended.
7. If organic wastes accumulate on the field application area and are damaging vegetation, redistribute wastes,
8. Remove solids that accumulate in the effluent transport system, junction box and distribution manifold regularly.
9. Solids removed from runoff field application system components shall be disposed of pursuant to local regulations
10. Periodic soil testing of the field application area is suggested to determine changes in phosphorus, potassium, and pH levels.
11. Each spring, relevel the distribution manifold and restore the design slope on other pipes.
12. When vegetation of a kind other than reed canarygrass or tall fescue infests 20% or more of the field application area, the infested area should be re vegetated.

9.6. Innovative Designs

It is strongly suggested that any operator contemplating use of runoff field application systems not designed, constructed, or maintained in accordance with the design criteria contained in this section should receive prior approval from the Agency for such system. The Agency will approve innovative designs should the operator present clear, cogent, and convincing proof that the technique has a reasonable and substantial chance for meeting the requirements.

Examples of innovative designs are:

1. Settling basin designed at less than 4.5 $ft^3/100\ ft^2$ (0.12735 m^3/9.29 m^2) of drainage area.
2. Settling channel used instead of settling basin.
3. Use of terraces for field application area.
4. Riser pipe designed differently.
5. Use of vegetation other than tall fescue or reed canarygrass.
6. Greater than 300 animal units on feedlot.
7. Distribution manifold designed for full pipe flow driven by gravity.
8. Not providing a junction box.
9. Application of materials other than feedlot runoff, rainfall, or milking parlor washwaters to the runoff field application system (for example, silage leachate, sewage, pesticides, oil, refuse).
10. Use of field application area smaller than provided in this design or with less than 2-h contact time.
11. Use of soils on runoff field application area with infiltration rates outside the range of 1.0–6.0 in/h (2.54–15.24 cm/h)
12. Use of field application area widths greater than 100 ft. (30.48 m)

9.7. Outline of Design Procedure

1. Collect site-specific data
   Types and areas (ft^2) contributing drainage
   Slope of field application area
   Soil infiltration rate (SI) of field application area
2. Calculate runoff volume and total drainage area from Appendix B
3. Settling basin design
   4.5 $ft^3/100\ ft^2$ (0.12735 m^3/9.29 m^2) of drainage area +10% extra volume
   Dimensions from Appendix J
4. Field application area design

$$\mathrm{FAA} = \frac{\mathrm{VR}(12)}{(2\,\mathrm{h})\mathrm{SI} - 1.69}\ \mathrm{ft}^2.$$

   Dimensions from Appendix E
5. Calculate flow onto field application area
   Flows from Appendix G
   or
   $Q_f = 0.0026$ (FAA) (gpm)
6. Effluent transport system design from Appendix F
7. Junction box design from Appendix I
8. Distribution manifold design from Appendix H.

9.8. Procedure to Estimate Soil Infiltration Rate

Soil infiltration rate for a runoff field application area can be determined by the following modified cylinder infiltrometer method:

1. *Preparing the test site:* Drive a rigid, leak-proof container approximately 6 in (15.24 cm) into the ground taking care to avoid disturbing the soil as much as possible. This container should be approximately 2 ft (0.61 m) long by at least 10 in (25.4 cm) wide and may be of any suitable material. A metal pipe is recommended (see Appendix C).
2. *Saturation and swelling of the soil:* Before conducting the test, saturate the soil for at least 4 h, but preferably 8 h, by refilling the container with clean water as needed.
3. *Testing:* At the time of the test, adjust the water level to 12 in (30.48 cm) above the soil surface. Allow the water level to drop 6 in (15.24 cm) and then commence measuring the drop in water level at 15-min intervals until all the water has infiltrated. Repeat testing.
4. *Recording Results:* Record results of all tests as the total minutes required for the last 6 in (15.24 cm) of water to infiltrate (min/in). Average the two tests at each site.
5. *Soil infiltration rate:* The soil infiltration rate (SI) is calculated at each site:

$$\mathrm{SI} = \frac{36}{\mathrm{min\,/in.}} = \mathrm{in./h.}$$

6. *Average soil infiltration rate:* Average the soil infiltration rates from each testing site to calculate the SI value for the runoff field application area.

These tests must not be made on frozen ground and include a safety factor in Part 5 to compensate for inherent inaccuracies in this procedure.

Obtain the Table of engineering properties – Physical and Chemical Properties for Permeability from a modern USDA–SCS soil survey for the county where the runoff field application system will be installed.

1. Locate the soil name and map symbol for the field application area on the map sheets.
2. On the Physical and Chemical Properties Table locate the surface layer permeability rate.
3. At the surface layer use the average value of the permeability range to obtain SI.

9.9. Procedure to Determine Slopes

The slope must be determined at the site of the runoff field application area to be able to use design Appendix E. Many methods are available to determine slope but all methods are based on the fact:

$$\mathrm{Slope} = \frac{\mathrm{rise}}{\mathrm{run}} = \frac{\Delta y}{\Delta x}.$$

The following procedure can be used to determine slope.

1. Obtain a 40-ft (12.19 m) length of string or wire with a 25 ft (7.62 m) section marked off (if you use nylon, measure the 25 ft (7.62 m) with a steel tape because nylon stretches when pulled taut); carpenter's line level from a hardware store: a stake: a rod about 8 ft (2.43 m) long (an 8 ft. 2 in. × 4 in. or 2.44 m 50.8 mm × 101.6 mm works well); a tape measure; a notebook and an assistant.
2. Set up your notes and refer to Appendix D
3. Stake one end of the string at point 1 and attach the other end to the rod so that there is 25 ft (7.62 m) between the stake and rod, and the string can slide up and down the rod. With the string taut, level the string in the center using the line level and record the rise at point 2 in your notes by measuring the string height at the rod.

4. Repeat step 3 all the way down the field and calculate the slope by:

$$\text{Slope} = \frac{\text{A}(100)}{\text{B}} = \%.$$

5. Use the % slope for Appendix E.

10. DESIGN EXAMPLE

A livestock producer had 300 head of feeder cattle on a concrete feedlot (see Fig. 12.15) and wanted to install a runoff field application system to control feedlot runoff which entered a nearby stream.

Solution:

1. Site specific data
   (a) From Fig. 12.15 and procedure in Appendix B:
   Concrete Feedlot Area $= 20.038\ \text{ft}^2 = 0.46$ acres
   Roof Area $= 4,792\ \text{ft}^2 = 0.11$ acres
   All other drainage is to be diverted from the feedlot and field application area with gutters and curbs.

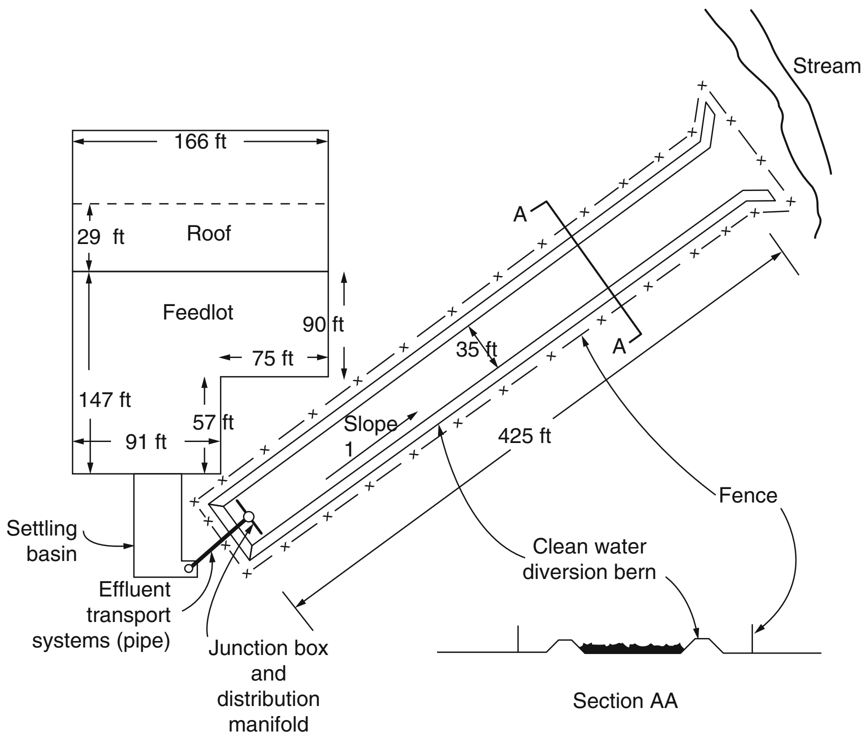

Fig. 12.15. Plan for sample design example (76). 1 ft = 0.3048 m

(b) From the collected slope data and figure in Appendix D, the s1ope of the field application area = 1.0%.
(c) From the soil survey for the county the infiltration rate (SI) of the field application area = 2.0 in./h

2. From Appendix B, Calculate runoff volume and total drainage area.
   Roof $4,785\,ft^2 \times 0.1408 = 674\,ft^3$
   Feedlot $20.037\,ft^2 \times 0.0991 = 1,986\,ft^3$
   Design runoff volume $(VR) = 2,660\,ft^3$
   Total drainage areas $= 20.037 + 4,785 = 24,822\,ft^2$
3. Settling basin design
   The total settling basin volume:
   $24,822\,ft^2 \times 4.5\,ft^3/100\,ft^2 = 1,117\,ft^3$
   $1,117\,ft^3 \times 0.10 = 112\,ft^3$ (Safety factor)
   Total design volume $= 1,229\,ft^3$
   From Appendix J, calculate the settling basin dimensions after choosing 3-ft settling basin height (h), 12 ft width (b) and 15:1 slope.
   $L_1 = 3 \times 15 = 45\,ft$
   $V_1 = (1/2)(12 \times 3 \times 45) = 810\,ft^3$
   $'V_2 = 1,229–810 = 419\,ft^3$
   $L_2 = 419/(12 \times 3) = 11$ ft–8 in. Round-off L_2 to 12 ft
   Foundation drainage tiles are not needed as the soil survey indicated the groundwater table did not rise above 5-ft depth.
   A 24-inch diameter riser pipe is provided and concrete is chosen as the settling basin construction material.
4. Field application area design
   The field application area calculation:

$$\text{FAA} = \frac{2,660 \times 12}{(2 \times 2.0) - 1.69} = \frac{31,920}{231} = 13,818\,\text{ft}^3 \text{ minimum area needed}$$

   Use Table in Appendix E to determine the dimensions of the field application area
   Using the next larger sized area of $14,875\,ft^2$:
   Slope = 1.0%
   Length = 425 ft
   Width = 35 ft
   $FAA = 14,875\,ft^2 = 0.34$ acres.
5. Calculate flow onto field application area
   Use Appendix G to determine the flow onto the field application area: Flow is approximately 40 gpm. A more accurate calculation can be made as follows:
   $Q_f = (0.0026)(FAA)$
   $Q_f = (0.0026)(14,875\,ft^2) = 38.7$ gpm.
6. Effluent Transport System Design
   The pipe to transport the settling basin effluent to the distribution manifold can be chosen using Appendix F. The smallest pipe available to handle 38.7 gpm is a 6-in. PVC pipe:
   Slope = 0.5%
   PVC = nonperforated pipe
   Diameter of pipe = 6 in.

7. Junction box design
   A junction box will be constructed to the specifications provided in Appendix I.
   Adjustable slots are included in the drop boxes to compensate for frost heaving of the junction box.
8. Distribution manifold design
   The distribution manifolds are designed using the 1/2 pipe criteria at 150 gpm as provided in Appendix H.
   Length of each manifold = $\frac{1}{2}(35 - 2\,\text{ft}) = 16.5\,\text{ft}$.
   An 8-in. diameter PVC pipe (17-ft long) would be purchased and cut in half down the pipe length to provide two manifolds each 4-in. deep. Each manifold will have 6 in. removed to provide the required length of 16.5 ft.

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Appendix A us Army Corps of Engineers Civil Works Construction Yearly Average Cost Index for Utilities (24)

Year	Index	Year	Index
1967	100	1989	383.14
1968	104.83	1990	386.75
1969	112.17	1991	392.35
1970	119.75	1992	399.07
1971	131.73	1993	410.63
1972	141.94	1994	424.91
1973	149.36	1995	439.72
1974	170.45	1996	445.58
1975	190.49	1997	454.99
1976	202.61	1998	459.40
1977	215.84	1999	460.16
1978	235.78	2000	468.05
1979	257.20	2001	472.18
1980	277.60	2002	484.41
1981	302.25	2003	495.72
1982	320.13	2004	506.13
1983	330.82	2005	516.75
1984	341.06	2006	528.12
1985	346.12	2007	539.74
1986	347.33	2008	552.16
1987	353.35	2009	570.38
1988	369.45		

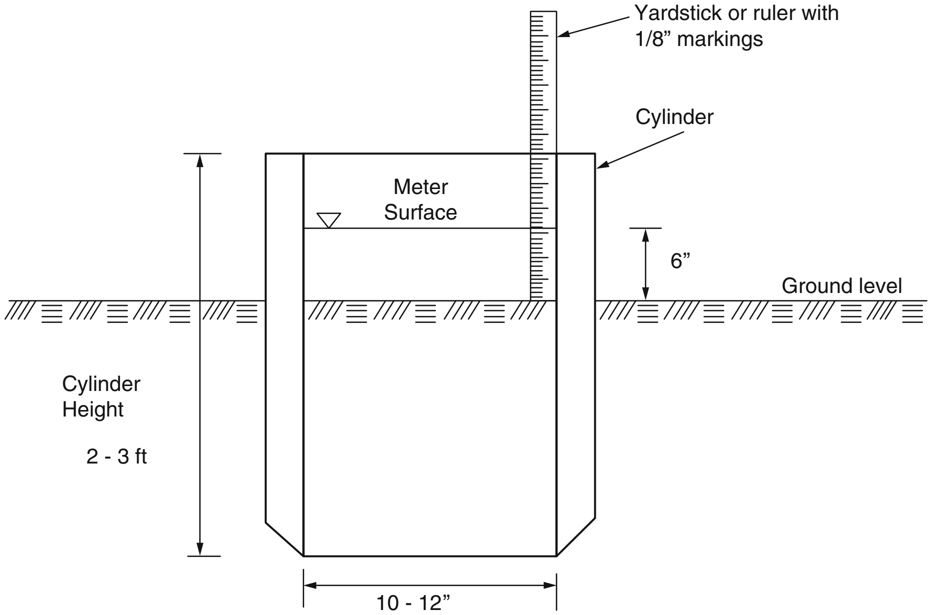
Appendix B Procedure to Estimate Volume of Feedlot Runoff (76) (Conversion factors: 1 ft^2 = 0.0929 m^2; 1 ft^3 = 0.0283 m^3)

	(A)	X	(B)	=	(C)
Type of Drainage Area	Area ft^2		Multiplication* Factor (ft)		Runoff Volume ft^3
Roof			0.1408		
Feedlot					
a. Paved or Concrete			0.0991		
b. Earthen			0.0748		

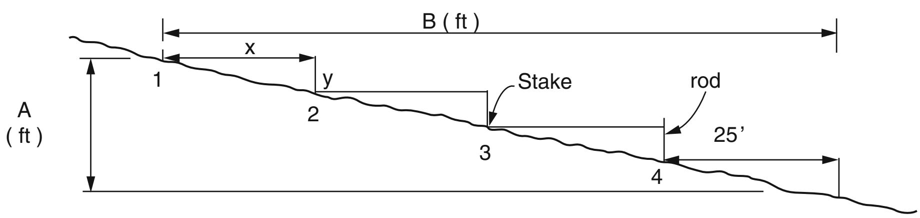
* Multiplication factor corresponds to Q of the U.S.D.A.-S.C.S. runoff equation.
Storm event (I) is 1-year, 2-hour storm of 1.69 inches.
Curve numbers (CN) are 100-roof; 95-paved; 91-earthern.
$S = (1000/CN) - 10$
$Q = (I - 0.2S)^2/(I + 0.8S)$

1. Feedlot Runoff Volume = Total of Column (C) (ft^3).
2. Milking Parlor Washwater = $\frac{\text{gallons}}{\text{day}}$ x .936 (ft^3 per week)
3. Design Runoff Volume (VR) = 1 + 2 (ft^3).
   Use VR (ft^3) for designing field application area.
4. Total area (sum of column A in square feet) divided by 100 is used to design settling basin.
5. To convert Runoff Volume (VR) from units of ft^3 into equivalent units of gallons, multiply ft^3 by 7.481 gallons/ ft^3

Appendix C Cylinder Infiltrometer (76)
(Conversion factors: 1 ft = 0.3048 m; 1″ = 1 in = 2.54 cm)

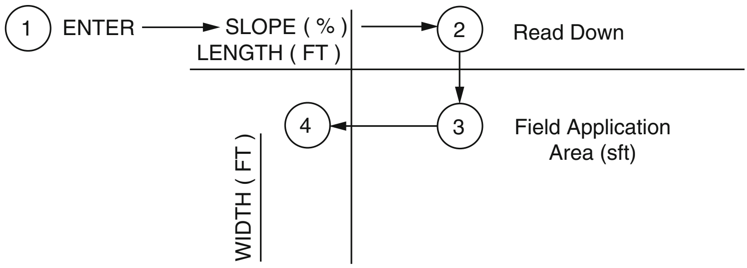


Appendix D Field Set-up for Determining Slope (76)
(Conversion factor : 1 ft = 1′ = 0.3048 m)



Appendix E Determination of Dimensions of Field Application Area (76) (Conversion factors: 1 FT = 1 ft = 0.3048 m; 1 sft = 1 ft^2 = 0.0929 m^2)

How to Use Table E-1



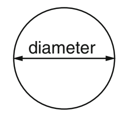
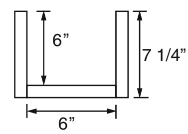
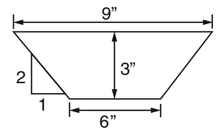
1. Enter at slope of field application area from Appendix D.
2. Read down column and find corresponding length of field application area.
3. Continue down column stopping at area closest to that previously calculated for your site.
4. Read left to find width of field application area.

Table E–1: Runoff Field Application Areas (ft^2)

Slope %	0.5	0.7	1.0	1.5	2.0	3.0	4.0
Length (ft)	300	375	425	525	600	750	800
20	6,000	7,500	8,500	10,500	12,000	15,000	17,000
25	7,500	9.375	10,625	13,125	15,000	18,750	21,250
30	9,000	11,250	12,750	15,750	18,000	22,500	25,500
35	10,500	13,125	14,875	18,375	21,000	26,250	29,750
40	12,000	15,000	17,000	21,000	24,000	30,000	34,000
45	13,500	16,875	19,125	23,625	27,000	33,750	38,250
50	15,000	18,750	21,250	26,350	30,000	37,500	42,500
55	16,500	20,625	32,375	28,875	33,000	41,250	46,750
60	18,000	22,500	25,500	31,500	36,000	45,000	51,000
65	19,500	24,375	27,625	24,125	39,000	48,750	55,250
70	21,000	26,250	29,750	36,750	42,000	52,500	59,500
75	22,500	28,125	31,875	39,375	45,000	56,250	63,750
80	24,000	30,000	34,000	42,000	48,000	60,000	68,000
85	25,500	31,875	36,125	44,625	51,000	63,750	72,250
90	27,000	33,750	38,250	47,250	54,000	67,500	76,500
95	28,500	35,625	40,375	49,875	57,000	71,250	80,750
100	30,000	37,500	42,500	52,500	60,000	75,000	85,000

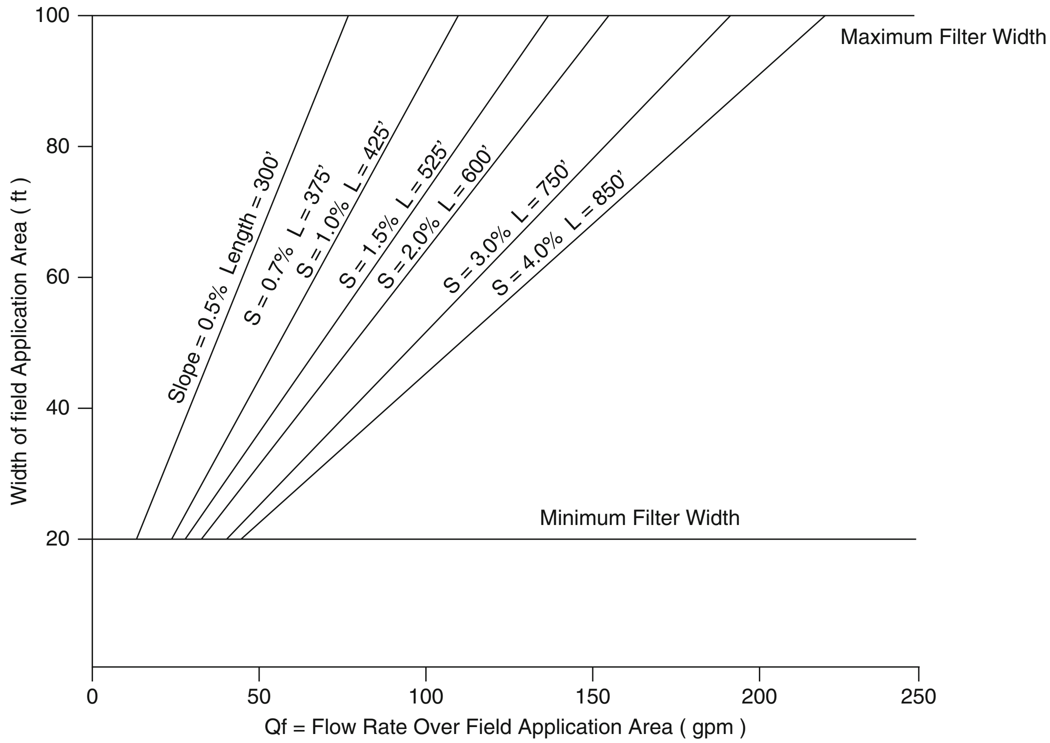
Conversion factors: 1 ft = 0.3048 m; 1 ft^2 = 0.0929 m^2

Appendix F Recommended Effluent Transport Systems Design (76) (Conversion factors: 1 gpm = 3.785 Lpm; 1″ = 1 in = 2.54 cm; 1 ft/s = 0.3048 m/s)

Type	Maximum Flow* Of (gpm)	Minimum Slope (%)	Design Velocity (ft/s)	Materials	Dimensions	Diagrams
Pipe	179	0.5	2	PVC	6” diam	
	332	0.4	2	PVC	8” diam	
Open Channel						
Rectangular	224	0.33	2	Concrete Wood, Asphalt, Aluminum	6” x 6”	
Trapezoidal	224	0.37	2	Concrete Wood, Asphalt, Aluminum	b = 6” s = 2 : 1 d = 3”	

*Mannings Equation with n = 0.013.

Appendix G Graph for Determining Flow Rate Over Field Application Area (76) (Conversion factors: 1 inch = 1″ = 2.54 cm; 1 ft = 0.3048 m; 1 gpm = 3.785 Lpm)



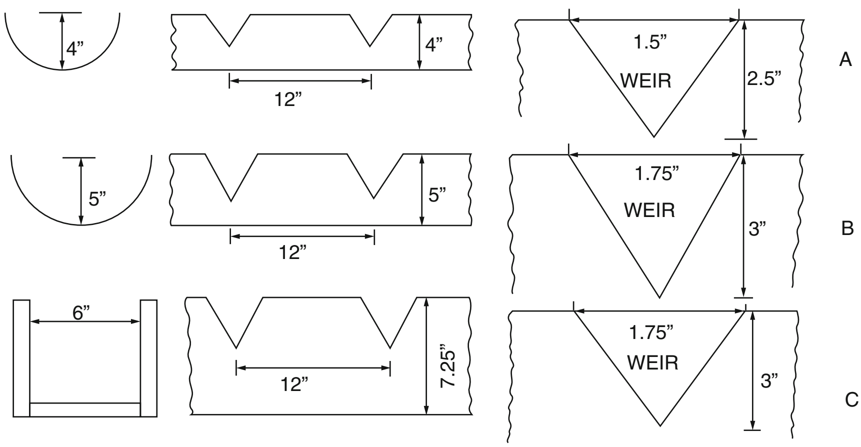
Assumptions : $Q = VA = \frac{(\text{Area x Depth of Flow})}{\text{Time}}$

Depth of Flow = 1/2 Inch = 0.042 ft

Contact Time = 2 hours = 7200 seconds

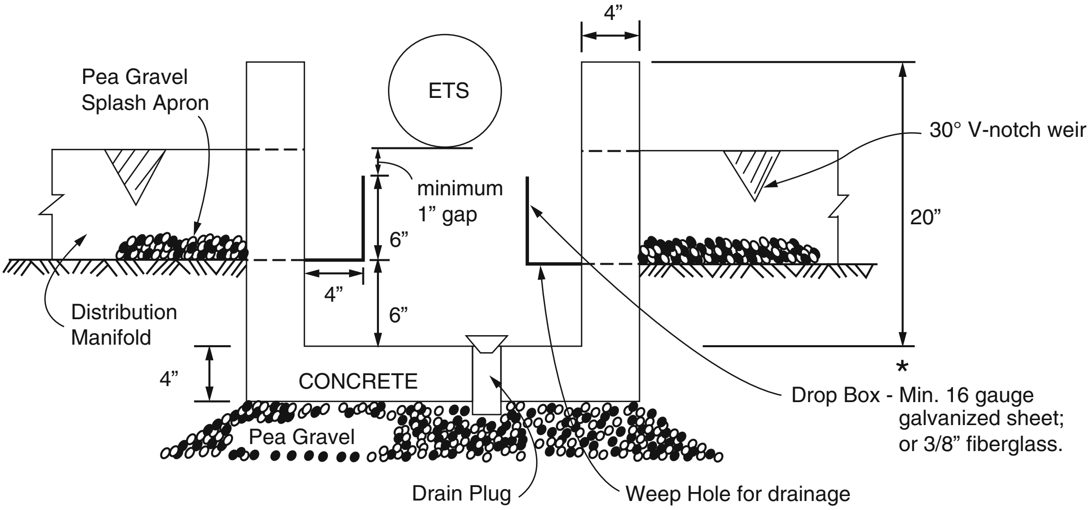
Appendix H Distribution Manifold Design (76)
(Conversion factors: 1 fps = 1 ft/s = 0.3048 m/s; 1 gpm = 3.785 Lpm; 1″ = 1 in = 2.54 cm; 1 feet = 1 ft = 0.3048 m)

Type[1]	Maximum Flow Qf (gpm)	Slope	Initial Velocity (fps)	Dimensions	Materials[2]	Weirs[3]	Diagram
1/2 Pipe	150	level	1.3	8" diam	PVC	30° V–notch	A
	225	level	1.3	10"	PVC	30° V–notch	B
Box Trough	225	level	1.0	6" x 6"	2" x 8" dimension 1umber	30° V–notch	C
Aluminum Guttering	(Size with the Box Trough Criteria Above)						

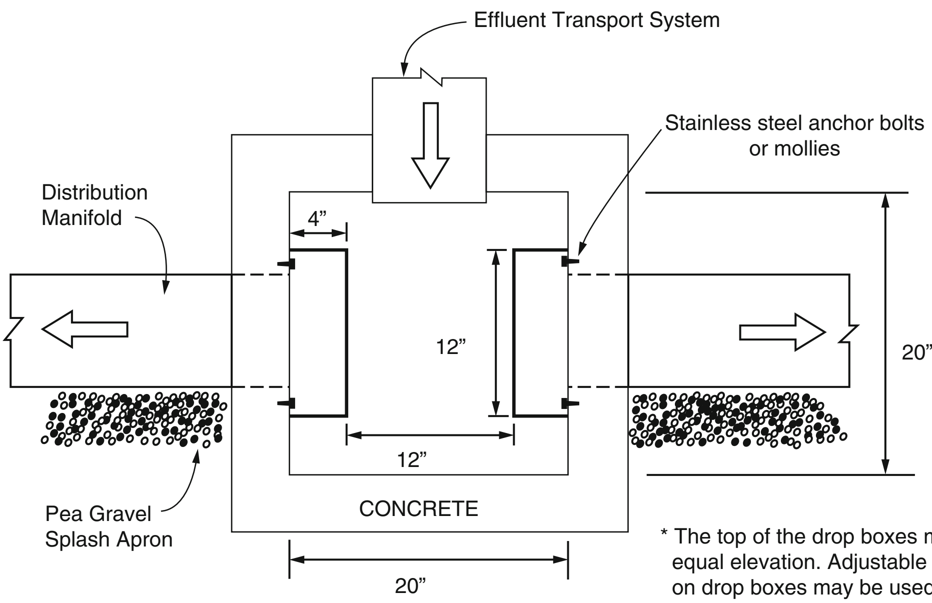


1 Anchor with 1/8" thick wire staples spaced 5 – 8 feet apart.
2 Manning's roughness coefficient n = 0.013.
3 One foot on center spacing; sharp crested weir on pipe, broad crested on box trough.

Appendix I Junction Box Design (76)
(Conversion factor: 1″ = 1 in = 2.54 cm)



CROSS - SECTION VIEW



TOP VIEW

* The top of the drop boxes must be at equal elevation. Adjustable slots on drop boxes may be used to compensate for frost heaving of junction box.

Appendix J Diagram of Settling Basin Components (76)
(Conversion factors: 1″ = 1 inch = 2.54 cm; 1 ft = 0.3048 m; 1 ft^3 = 0.0283 m^3)