Chapter 2
Application of Natural Processes for Environmental Protection

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Contents

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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 land treatment system, slow rate land treatment system, overland flow land treatment system, and subsurface infiltration have also been applied. This chapter describes the above applications and explains their practice, limitations, design criteria, performance, and costs.

Keywords Natural processes • Aquatic organisms • Aquaculture • Water hyacinth system • Wetland • Subsurface Infiltration • Overland flow land treatment system • Evapotranspiration • Elevated sand mound design • Performance • Costs

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. 2.1), 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

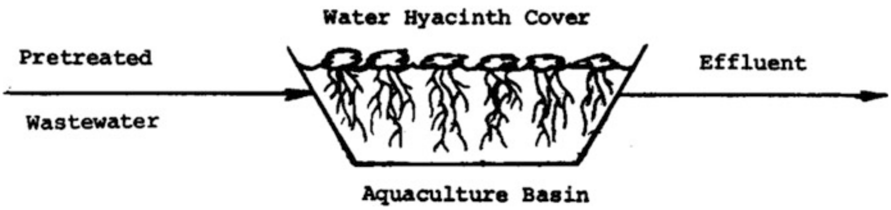

Fig. 2.1 Aquaculture treatment: water hyacinth system (Source: US EPA [2])

agricultural products. Other organisms and methods with wider climatological applicability are being studied. The ability of hyacinths to remove nitrogen during active 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
(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 seven 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 2.1 shows the design criteria for water hyacinth systems [4]. The following ranges refer to hyacinth treatment as a tertiary process on secondary effluent [2]:

Table 2.1 Design criteria for water hyacinth systems

Factor	Aerobic non-aerated	Aerobic non-aerated	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	500–1000
Harvest schedule	Annually	Twice per month	Monthly

Source: US EPA [4]

(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 2–15 acres/MG/day.

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 coworkers [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 1000–10,000 lb/day/acre. 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 (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 bypassing 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. 2.2). 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
(c) Digested to produce methane

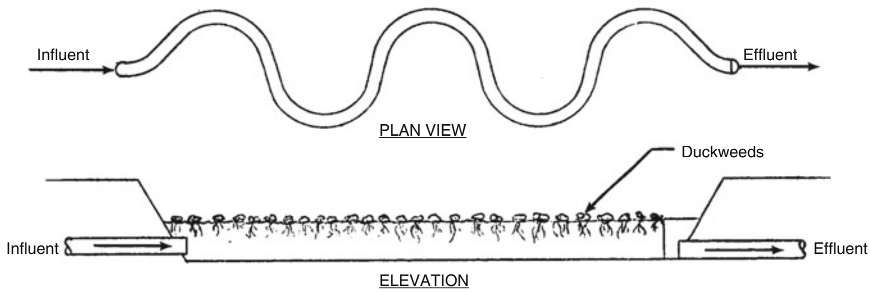

Fig. 2.2 Aquaculture treatment: wetland system (Source: US EPA [2])

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 plant 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 occur 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 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, lakes 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 windscreens 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/day.
(c) Depth may vary with type of system, generally 1–5 ft.

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.

Tables 2.2 and 2.3 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]:

(a) BOD_5, 80–95 %
(b) TSS, 29–87 %
(c) COD, 43–87 %

Table 2.2 Nutrient removal from natural wetlands

Project	Flow, m^3/day	Wetland type	Percent reduction			
			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	2309	Marsh	47	58	20	–
Bellaire, MI	1,136[d]	Peatland	88	–	–	84
Cootes 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 to November only

Table 2.3 Nutrient removal from constructed wetlands

Project	Flow, m^3/day	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]	–	SFS[b]	118	30	57	5.5	75	90	–
Sydney, 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 [4]
[a]Free water surface system
[b]Subsurface flow system

(d) Nitrogen, 42–94 % depending upon vegetative uptake and frequency of harvesting
(e) Total P, 0–94 % (high levels possible with warm climates and harvesting)
(f) Coliforms, 86–99%
(g) 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 upon type of system and whether or not harvesting is employed. Duckweed, for example, yields 50–60 lb/acre/day (dry weight) 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].

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. 2.3) consists of a 1½–3-ft 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 flatland or a series of trenches on slopes. The surface area of the bed must be 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-fourths of all the ET beds in operation were designed to use both disposal methods. Mechanical evaporators have been developed, but are not used at full scale.

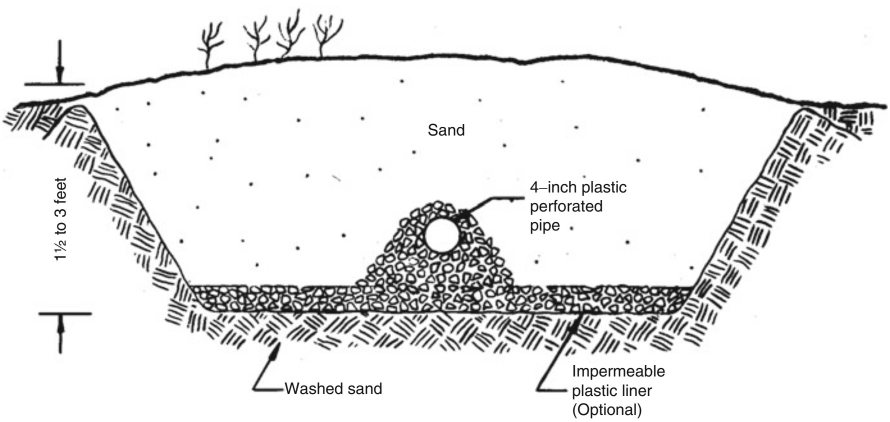

Fig. 2.3 Section through an evapotranspiration bed (Source: US EPA [2])

3.2 Applications

There are estimated to be 4,000–5,000 year-round evapotranspiration beds in operation in the USA, 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 and high latitudes greatly limits its use. Snow cover reflects solar radiation, which reduces EF. 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 watertight 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 non-growing season. Uniform sand in the size range of D_{50} of approximately 0.10 mm is capable of raising water about 3 ft to the top of the bed. The polyethylene liner thickness is typically greater than or equal to 10 mil. 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, does conserve 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 [2]. A 200-gpd household discharge would require a 2-ft deep bed with an area of approximately 5000 ft^2. All costs have been adjusted to 2016 US dollars (USD) using the Cost Index for Utilities [24].

Construction cost in 2016 USD:

Building sewer with 1,000-gal septic tank, design, and permit	2,020
Excavation and hauling (375 yd^3)	2,900
Liner (5,200 ft^2)	1,900
Distribution piping (625 ft)	850
Sand (340 yd^3) and gravel (38 yd^3)	5.060
Supervision and labor	1,390
Total	14,120 USD

Annual operation and maintenance cost:

Pumping septage from septic tank (every 3–5 years)	13.5–57
Total	13.5–57 USD

The construction cost for this particular system would be approximately USD 2.83/ft^2, which is consistent with a reported national range of USD 2.07 to USD 4.52/ft^2. The cost of an evapotranspiration bed is highly dependent upon 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 USD 756–7,560 to the construction cost and an amount of USD 166–580/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 groundwater 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 to deep and permeable deposits, such as sand or sandy loam usually by distributing in basins (Fig. 2.4) 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,

Fig. 2.4 Flow diagram of land treatment using rapid rate system (Source: US EPA [2])

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 topsoil 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:

(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
(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) It is 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 on-site.

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
(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/day
(b) Application rate 20–400 ft/year, 4–92 in./week
(c) BOD_5 loading rate 20–100 lb/acre/day
(d) Soil depth 10–15 ft or more
(e) Soil permeability 0.6 in./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, at least two basins/site

Table 2.4 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

(i) Height of dikes 4 ft, underdrains 6 or more ft 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 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 2.4.

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 costs are shown in Figs. 2.5 and 2.6, respectively [2]. The costs are based on 1973 (Utilities Index = 149.36, EPA Index 194.2, ENR Index = 1850) figures. To obtain the values in terms of the present 2016 USD, using the Cost Index for Utilities [24], multiply the costs by a factor of 5.50.

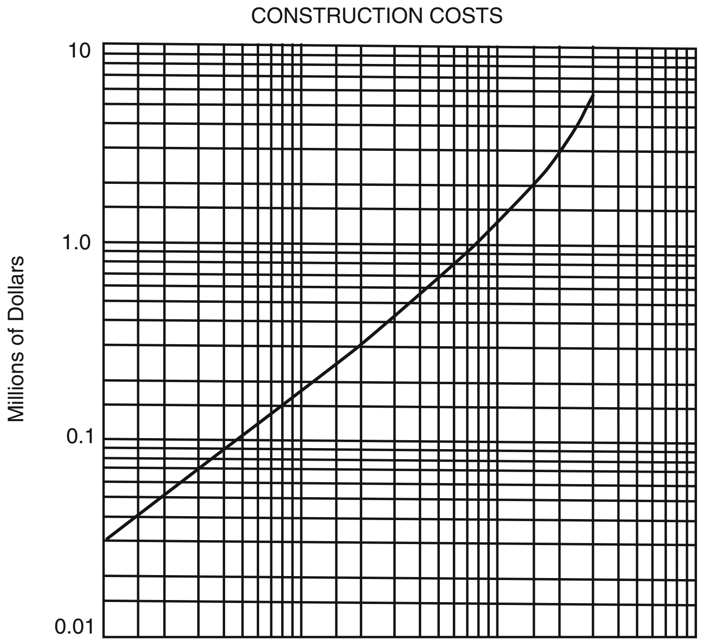

Fig. 2.5 Construction costs for rapid rate system (Source: US EPA [2]). (To elevate costs to 2016 multiply by a factor of 5.50)

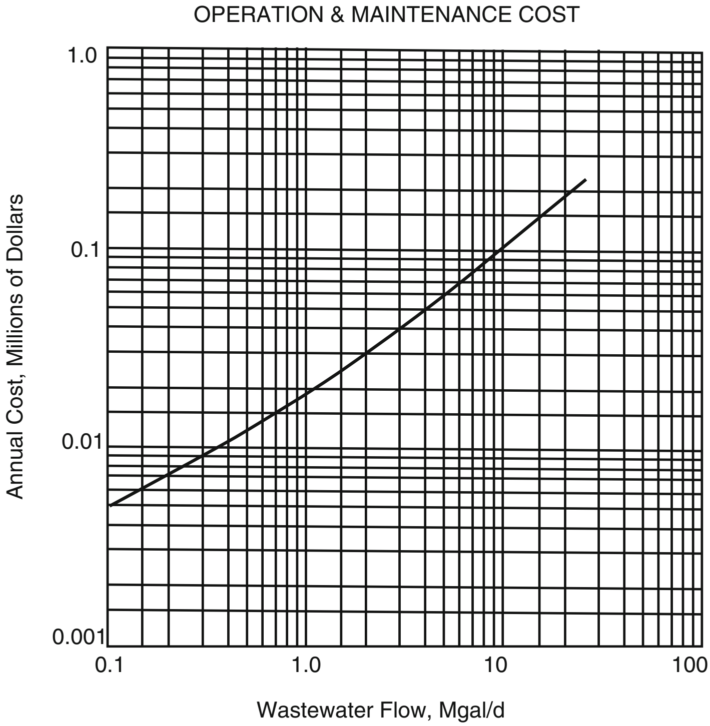

Fig. 2.6 Operation and maintenance costs of rapid rate system (Source: US EPA [2]). (To elevate costs to 2016 multiply by a factor of 5.50)

Assumptions applied in preparing the costs given in Figs. 2.5 and 2.6:

(a) Application rate 182 ft/year.
(b) Construction costs include field preparations (removal of brush and trees) for multiple unit infiltration basins with 4-ft dike formed from native excavated material, and storage is not assumed necessary.
(c) Drain pipes buried 6–8 ft with 400-ft spacing, interception ditch along length of field, and weir for control of discharge; gravel service roads and 4-ft 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 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 USA. In this process, wastewater is applied by sprinkling 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 plant uptake (Fig. 2.7). An underdrainage system consisting of a network of drainage pipe buried below the surface serves 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 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
(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
(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

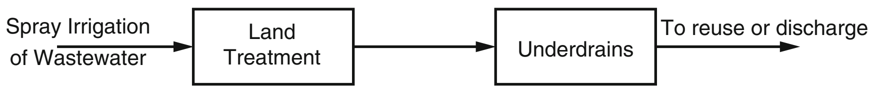

Fig. 2.7 Flow diagram of land treatment using slow rate system (Source: US EPA [2])

Table 2.5 Potential adverse effects of wastewater constituents on crops

Constituent level				
Problem and related constituent	No problem	Increasing problems	Severe problems	Crops affected
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
Specification 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	Sugar beets, 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) 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 2.5 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
(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
(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
(c) Underlying geology
(d) Climate
(e) Surface and groundwater hydrology and quality
(f) Crop selection
(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/day
(b) Application rate 2–20 ft/year, 0.5–4 in./week
(c) BOD_5 loading rate 0.2–5 lb/acre/day
(d) Soil depth 2–5 ft or more
(e) Soil permeability 0.06–2.0 in./h
(f) Minimum preapplication treatment primary
(g) Lower temperature limit 25 °F
(h) Particle size of solids less than one-third of the sprinkler nozzle diameter
(i) Underdrains 4–8 in. diameter, 4–10 ft deep, and 50–500 ft apart and 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 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 groundwater and establishing nitrogen limits in either the percolate or groundwater as it leaves the property site. Nitrogen loading to the groundwater is often the controlling consideration in the design. For further detailed information on slow rate infiltration systems, the reader is referred to references [39–44].

5.6 Costs

The construction and operation and maintenance costs are shown in Figs. 2.8 and 2.9, respectively [2]. The costs are based on 1973 (Utilities Index = 149.36, EPA Index 194.2, ENR Index = 1850) figures. To obtain the values in terms of the present 2016 USD, using the Cost Index for Utilities [24], multiply the costs by a factor of 5.50.

Assumptions applied in preparing the costs given in Figs. 2.8 and 2.9:

(a) Yearly average application rate: 0.33 in./day.
(b) Energy requirements: solid set spray distribution requires 2100 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 days/week operation) for 1 MG/d or larger facilities (below 1 MG/day, additional power = 0.84 to 1.35×110^6 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 that is PVC; and all larger pipe that is asbestos cement (total dynamic head = 150 ft).

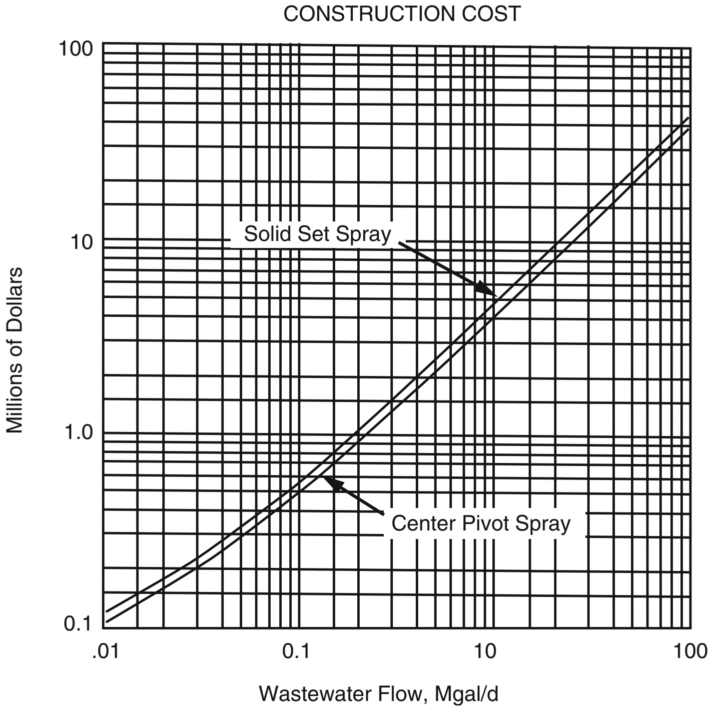

Fig. 2.8 Construction cost of slow rate system (Source: US EPA [2]). (To elevate costs to 2016 multiply by a factor of 5.5)

(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; and distribution pipe that is buried 3-ft deep

(f) Underdrains are spaced 250 ft between drain pipes. Drain pipes are buried 6–8-ft 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, and controls and electrical work.

(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; and scraping and patching of storage receiver liner every 10 years.

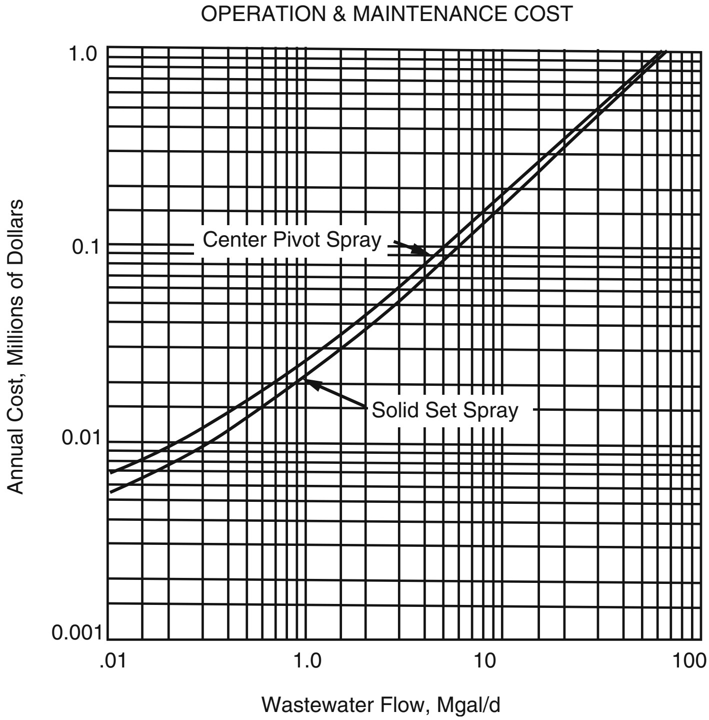

Fig. 2.9 Operation and maintenance cost of slow rate system (Source: US EPA [2]). (To elevate costs to 2016 multiply by a factor of 5.50)

(j) Storage for 75 days is included; 15-ft dikes (12-ft wide at crest) are formed from native materials (inside slope 3:1, outside 2:1); rectangular shape on level ground; 12-ft water depth; multiple cells for more than 50-acre size; asphaltic lining; 9-in. 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. A flow diagram of the system is shown in Fig. 2.10. Wastewater is applied over the upper reaches of sloped terraces and is

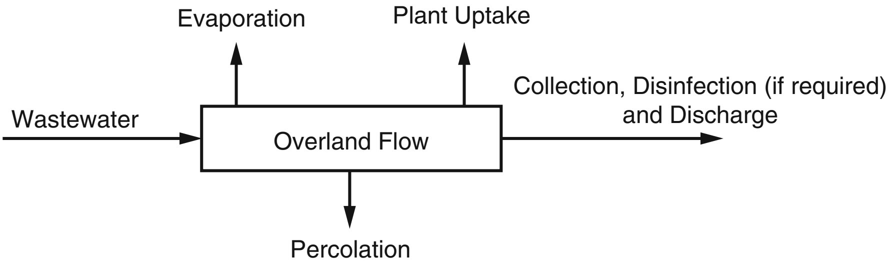

Fig. 2.10 Flow diagram of land treatment using overland flow system (Source: US EPA [2])

treated as it flows across the vegetated surface to runoff collection ditches. 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, redtop, 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 are 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 and 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 prior to overland flow permits reduced (as much as two-third 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. Flatland 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/day
(b) Terraced slopes 2–8 %
(c) Application rate, 11–32 ft/year, 2.5–16 in./week
(d) BOD_5 loading rate, 5–50 lb/acre/day
(e) Soil depth, sufficient to form slopes that are uniform and to maintain a vegetative cover
(f) Soil permeability, 0.2 in./h or less

Table 2.6 Design loadings for overland flow systems

Preapplication treatment	Application rate m^3/h m	Hydraulic loading rate cm/day
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 m × 80.5 = gal/h ft
[b]cm/d × 0.394 = in./day
[c]Does not include removal of algae
[d]Recommended only for upgrading existing secondary treatment

(g) Hydraulic loading cycle, 6–8-h application period, 16–181week resting period
(h) Operating period, 5–6 days/week
(i) Soil texture clay and clay loams

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

In./week	Pretreatment	Terrace length, ft
2.5–8	Untreated or primary	150
6–16	Lagoon or secondary	120

Generally, 40–80% of applied wastewater reaches collection structures, lower percent in summer and higher in winter (southwest data). Table 2.6 shows the required pretreatment and allowed application and hydraulic rates [48].

6.5 *Performance*

Percent removals for comminuted or screened municipal wastewater over about 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 [$CaCO_3$] prior to 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 [12, 50–52].

6.6 Costs

The construction and operation and maintenance costs are shown in Figs. 2.11 and 2.12, respectively [2]. The costs are based on 1973 (Utilities Index = 149.36, EPA Index 194.2, ENR Index = 1850) figures. To obtain the values in terms of the present 2016 USD, using the Cost Index for Utilities [24], multiply the costs by a factor of 5.50.

Assumptions applied in preparing the costs given in Figs. 2.11 and 2.12:

(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 (1400 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./week (8 h/day, 6 days/week); 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 pipe 4 in. diameter and smaller is PVC; and all larger pipe is asbestos cement.

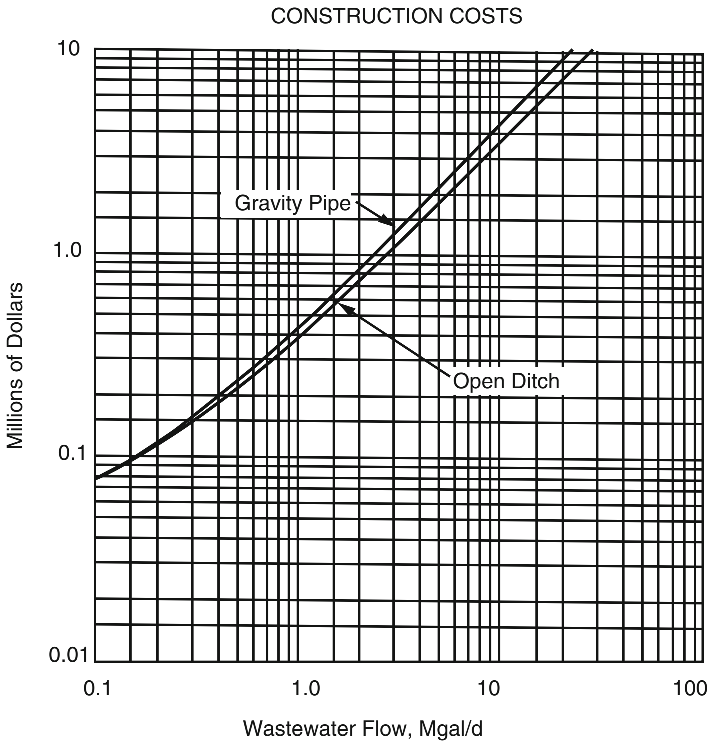

Fig. 2.11 Construction cost of overland flow treatment system (Source: US EPA [2]). (To elevate costs to 2016 multiply by a factor of 5.50)

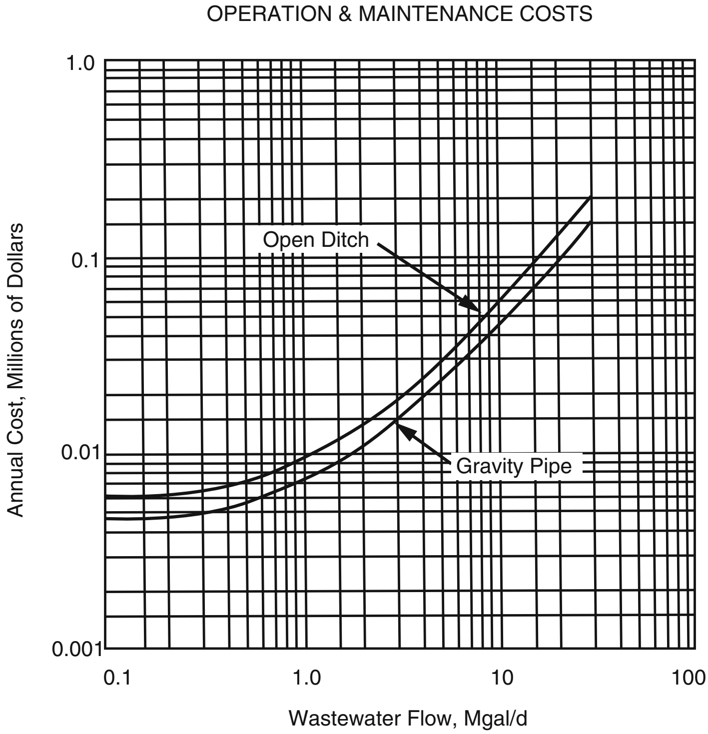

Fig. 2.12 Operation and maintenance cost of overland flow treatment system (Source: US EPA [2]) (To elevate costs to 2016 multiply by a factor of 5.50)

(d) Open ditch collection: network of unlined interception ditches sized for a 2 in./h storm; culverts under service roads; and concrete drop structures at 1,000-ft intervals.
(e) Gravity pipe collection: network of gravity pipe interceptors with inlet/manholes every 250 ft along submains; storm runoff that is allowed to pond at inlets; each inlet/manhole that serves 1,000 ft of collection ditch; and manholes every 500 ft 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 and also includes dike maintenance and scraping and patching of storage basin liner every 10 years.
(g) Costs for pretreatment, land, transmission to site, disinfection, 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 solid 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 [53].

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 non-sewered 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 subsurface drainage system where clarified effluent percolates into the soil. Precast concrete tanks with a capacity of 1,000 gallons are commonly used for house systems. Solids are collected and stored in the tank, forming sludge and scum layers. 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 [53], seepage bed [53, 54], or seepage pits [55]. 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. 2.13). Required absorption areas are dictated by state

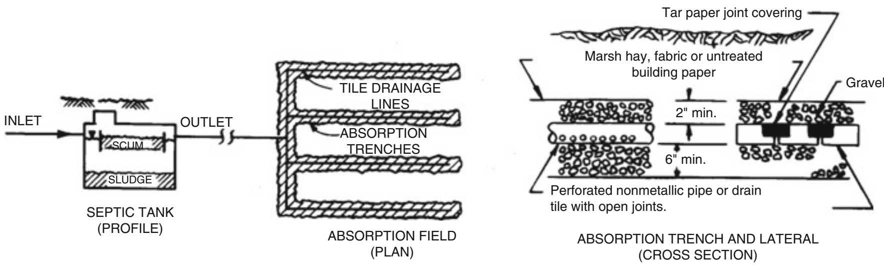

Fig. 2.13 Septic tank absorption field (Source: US EPA [2])

and local codes. Trench depth is commonly about 24 in. to provide minimum gravel depth and earth cover. Clean, graded gravel or similar aggregate, varying in size from one-half to 2½ inches, should surround the distribution pipe and extend at least two inches above and six inches below the pipe. The maintenance of at least a 2-ft 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.

In areas where problem soil conditions preclude the use of subsurface trenches or seepage beds, mounds can be installed (Fig. 2.14) to raise the absorption field above ground, provide treatment, and distribute the wastewater to the underlying soil over

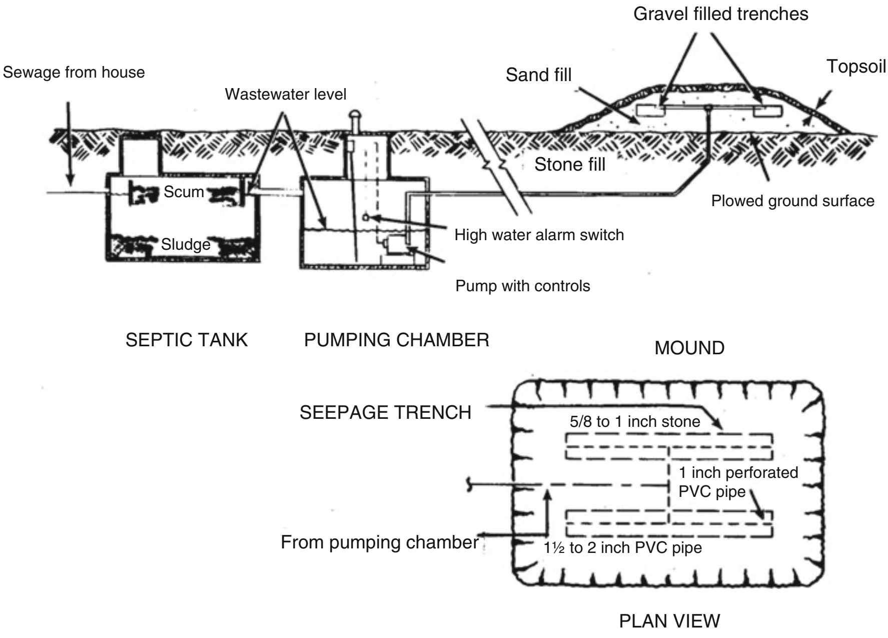

Fig. 2.14 Septic tank mound absorption field (Source: US EPA [2])

a wide area in a uniform manner [2, 56, 57]. 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 min/in.) impermeable subsurface. Seasonal high groundwater must be deeper than two feet 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 [58]. 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 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
(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.

Table 2.7 Required areas of subsurface infiltration absorption fields

Percolation rate, min/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]

7.4 Design Criteria

Absorption area requirements for individual residences are given in Table 2.7. 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 are as follows [2, 56, 57, 59]: design flow 75 gal/person/day, 150 gal/bedroom/day, basal area based on percolation rates up to 120 min/in., mound height at center approximately 3.5–5 ft, and pump (centrifugal) that must accommodate approximately 30 gpm at required TDH. The design standards for a mound are shown in Table 2.8. It includes four steps as illustrated in the following two examples. The steps are [59]:

1. Flow estimation
2. Design of the absorption trenches
3. Dimensioning the mound
4. Checking for limiting conditions

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
(d) Area geology and topography
(e) Physical and chemical composition of the soil mantle
(f) Care given to periodic maintenance

Table 2.8 Standards for elevated sand mounds

1. Elevated sand mounds shall utilize absorption trench distribution design, and shall not be installed on land with a slope greater than twelve (12) percent. The trenches shall be installed with the long dimension of the trench parallel to the land contour. The minimum spacing between trenches shall be four feet (1.2 m), a maximum trench width of four feet (1.2 m) shall be permitted. No more than three (3) parallel trenches may be installed within a mound.

2. A minimum total trench length of forty (40) feet (12 m) shall be provided in each trench in mounds constructed in soils with percolation rates of 60 to 120 minutes per inch when two or more trenches are used.

3. The required bottom area of the trench or trenches shall be based upon a flow of 150 gallons (570 L) per bedroom per day with a application rate of 1.2 gallons/day/square foot (49 L/d/m^2).

4. The effective basal area of the mound for soils with a percolation rate of 61 to 120 minutes per inch is to be calculated on a maximum application rate of 0.24 gallons/day/square foot (10 L/d/m^2).

5. The area of sand fill shall be sufficient to extend three feet (0.9 m) beyond the edge of the required absorption (or stone) area before the sides are shaped to a 4:1 slope.

6. The effective basal area of the mound for soils with a percolation rate of 61 to 120 minutes per inch is to be calculated on a maximum application rate of 0.24 gallons/day/square foot (10 L/d/m^2).

7. The effective basal area of the mound for soils with a percolation rate of 5 to 60 minutes per inch is to be calculated on an application rate of 0.74 gallons/day/square foot (29 L/d/m^2).

Source: [59]

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 groundwater. Soil clogging may result in surface ponding with potential esthetic 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].

Additional technical information on natural biological treatment processes and terminologies can be found from the literature [66–79].

7.6 Design Example 1: Elevated Sand Mound at a Crested Site

Given

A three-bedroom home, a percolation rate of 80 min/in. at a depth of 24 in. below ground surface, a crested site with a land slope of 2 %, high groundwater is 36 in. below ground surface, and all other site factors that are satisfactory [59].

Design

1. Estimate daily flow in gpd = Q

   $Q = \text{number of bedrooms} \times 150 \text{ gpd/bedroom}$ (see Sect. 7.4 Design Criteria)

   $= 3 \times 150 = 450$ gpd.

2. Absorption trench system

   Application rate in sand fill in gpd/ft^2 = 1.2 gpd/ft^2 (from Table 2.8)

$$\begin{aligned}\text{Trench bottom area} &= \text{daily flow in gpd/application rate in sand fill in gpd/ft}^2\\ &= 450\,\text{gpd}/1.2\,\text{gpd/ft}^2\\ &= 375\,\text{ft}^2\end{aligned}$$

   L_1 = total length of trench = (trench bottom area)/trench width

   Using a trench width $= a = 3$ ft (see Fig. 2.15)

   $= 375\ \text{ft}^2/3\ \text{ft}$

   $= 125$ ft

   Using two trenches, length per trench = 125 ft/2 = 62.5 ft

   Use two trenches, 3-ft wide and 65-ft long

   At least 4 ft must be provided between trenches (b). For crested sites it is desirable to provide at least 10 ft between trenches. This design will use a spacing, b = 10 ft.

3. Dimensioning the sand fill portion of the mound

   The length of the mound is computed by adding the length of the top (horizontal extent) of the sand fill (l + 2c) and the horizontal distances on each end of the top needed to provide a side slope of one vertical to four horizontal. Note that 12 in. of fill must exist below the trench and a trench is 9-in. deep. Thus:

$$L = \text{mound length} = L_1 + 2c + [(2 \text{ sides} \times 4 \text{ vertical} \times \text{vertical thickness of fill, in.})/(1 \text{ horizontal} \times 12 \text{ in./ft})]$$
$$L = 65 + (2 \times 3) + [(2 \times 4 (9 \text{ in.} + 12 \text{ in.}) / (12 \text{ in./ft})]$$
$$L = 65 + 6 + 14$$
$$\mathbf{L = 85 \text{ ft the length of the mound at the crest of this site}}$$

The width of the mound (W) is computed in a similar manner using the width of the trenches (a) and number of trenches and trench spacing (b). Thus:

$$W = 2a + b + 2c + [(2 \text{ sides} \times 4 \text{ vertical} \times \text{vertical thickness of fill, in.})/(1 \text{ horizontal} \times 12 \text{ in./ft})]$$
$$W = (2 \times 3) + 10 + 6 + 14$$
$$W = 36 \text{ ft}, \ 0\,\% \text{ slope}$$

For a 2 % slope, the vertical fall is about 2 % × 36 ft = 0.36 ft in a horizontal distance of 18 ft. The approximate additional width of the mound on a crested site with 2 % slopes is 0.36 × 4 × 2 = 2.9 ft. ≈ 3 ft. Thus:

$$\mathbf{W = total\ mound\ width = 36 + 3 = 39\ ft}.$$

The mound length, L, at the downslope base of the sand fill will be 88 ft. Note that additional land area is needed for the mound for placement of the topsoil over the sand fill portion of the mound.

4. Checking for limiting conditions
The effective basal area of the sand fill (shaded area in plan view of Fig. 2.15) in the mound below and downslope of the trenches must be large enough to absorb the estimated daily waste flow. In calculating this basal area, exclude the portions of the mound on each side of the end the trench or trenches and their extension downslope.
In this calculation:

A = effective basal area of mound, ft^2 = shaded area in plan view,
Q = estimated daily flow, gpd,
R = natural soil infiltration rate, gpd/ft^2.
Thus, $R = Q/A$, expressed in gpd/ft^2.

In this case, a crested site is used and the trench length, L_1 by the sum of the trench width, a, the horizontal extent of fill beyond the trench, c, and the horizontal distance needed to provide the side slope (one-half of the correction used for total mound width).

$$A = L_1(a + c + 7 + 1.5)$$
$$A = 65\,(3 + 3 + 7 + 1.5)$$
$$A = 942 \text{ ft}^2$$

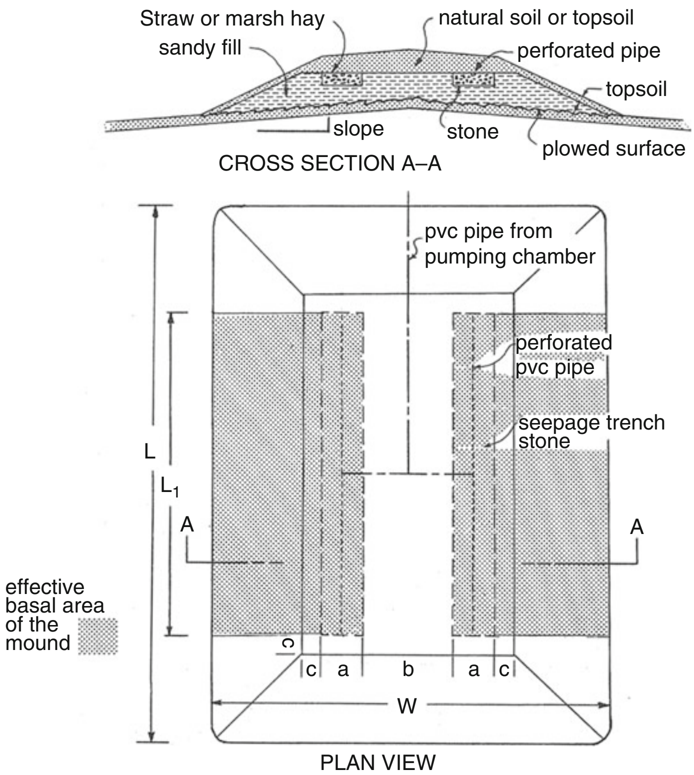

Fig. 2.15 Mound system on a crested site (Source: [59])

$$Q = 450/2 = 225 \text{ gpd per trench}$$
$$R = Q/A = 225/942 = 0.24 \text{ gpd/ft}^2$$

From Table 2.8, R must not exceed 0.24 gpd/ft^2

This design is satisfactory. If calculated R exceeds the maximum, increase the size of the mound downslope or trench length to provide a satisfactory value of R.

7.7 Design Example 2: Elevated Sand Mound at a Sloping Site

Given

A four-bedroom home, a percolation rate of 45 min/in. at a depth of 24 in. below ground surface, land slope is 4 %, high groundwater is 36 in. below ground surface, and all other site factors that are satisfactory [59].

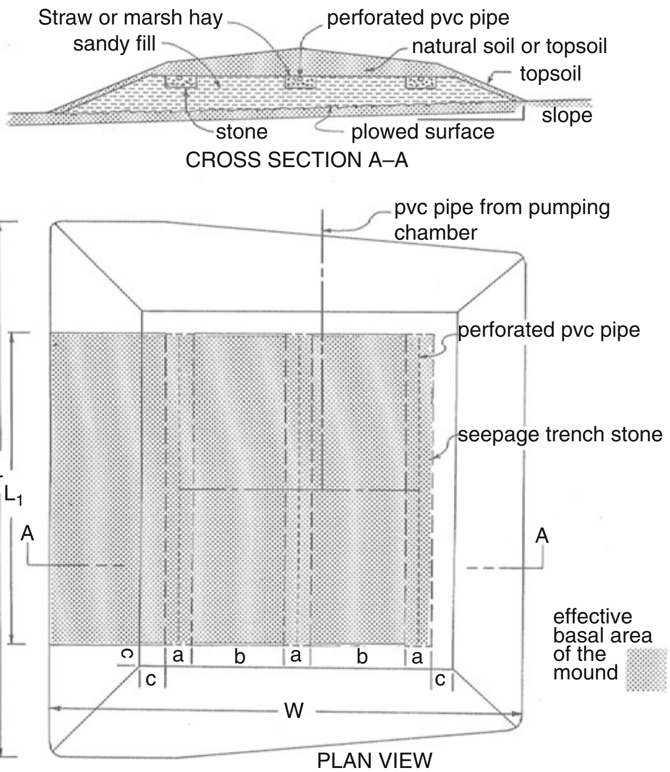

Fig. 2.16 Mound system on a level or sloping site (Source: [59])

Design

1. Estimate daily flow in gpd = Q

   Q = number of bedrooms × 150 gpd/bedroom (see Sect. 7.4 Design Criteria)

   = 4 × 150 = 600 gpd

2. Absorption trench system

   Application rate in sand fill in gpd/ft^2 = 1.2 gpd/ft^2 (from Table 2.8)

$$\begin{aligned}\text{Trench bottom area} &= \text{daily flow in gpd/application rate in sand fill in gpd/ft}^2\\ &= 600\ \text{gpd}/1.2\ \text{gpd/ft}^2\\ &= 500\ \text{ft}^2\end{aligned}$$

L_1 = total length of trench = (trench bottom area)/trench width

Using a trench width = a = 4 ft (see Fig. 2.16)

$$= 500\ \text{ft}^2/4\ \text{ft}$$
$$= 125\ \text{ft}$$

Where the natural soil percolation rate is faster than 60 min/in., it is desirable to limit trench length to 50 ft for ease in designing the pressure distribution system. Generally it is best to design a mound with long trenches.

Number of trenches = 125/50 = 2.5; use three trenches.

Using three trenches, length per trench = 125 ft/3 = 41.67 ft; use a trench length of 42 ft

Use three trenches, 4-ft wide and 42-ft long.

At least 4 ft must be provided between trenches (b). Use a spacing, b = 4 ft.

3. Dimensioning the sand fill portion of the mound

   The length of the mound is computed by adding the length of the top (horizontal extent) of the sand fill (l + 2c) and the horizontal distances on each end of the top needed to provide a side slope of one vertical to four horizontal. Note that 12 in. of fill must exist below the trench and a trench is 9-in. deep. Thus:

$$\mathrm{L = mound\ length} = \mathrm{L_1 + 2c + [(2\ sides \times 4\ vertical \times vertical\ thickness\ of\ fill,\ in.)/}$$
$$\mathrm{(1\ horizontal\ \times 12\ in./ft)]}$$
$$\mathrm{L = mound\ length\ at\ the\ trench} = 42 + (2 \times 3) + \left[(2 \times 4(9\ \mathrm{in.} + 12\ \mathrm{in.})/(12\ \mathrm{in./ft})\right]$$
$$\mathrm{L} = 42 + 6 + 14 = 62\ \mathrm{ft}$$

L = 62 ft the length of the mound at the upslope base of the fill.

The width of the mound (W) is computed in a similar manner using the width of the trenches (a) and number of trenches and trench spacing (b). Thus:

$$\mathrm{W = 3a + 2b + 2c + [(2\ sides \times 4\ vertical \times\ vertical\ thickness\ of\ fill,\ in.)]/}$$
$$\mathrm{(1\ horizontal\ \times\ 12\ in./ft)]}$$
$$\mathrm{W} = (3 \times 4) +\ 2 \times 4 + 6 + 14$$
$$\mathrm{W} = 40\ \mathrm{ft},\ 0\ \%\ \mathrm{slope}$$

The approximate additional downslope width of the mound at a sloping site with a 4 % slope is:

$$\mathrm{(4\ vertical\ 1\ horizontal)(3a\ +\ 2b\ +\ c\ +\ 14/2)\ (4\ \%/100)}$$
$$4\,[(3\ \times\ 4)\ +\ (2\ \times\ 4)\ +\ 3\ +\ 7]\ (0.04)\ =\ 4.8\ \mathrm{ft;\ use\ 5\ ft.}$$

W = total mound width = 40 + 5 = 45 ft

The mound width correction upslope is negligible. Thus the mound width of the sand fill portion measured from the center of the mound will be 20-ft upslope and 25-ft downslope. The mound length, L, at the downslope base of the sand fill will be 72 ft. Note that additional land area is needed for the mound for placement of the topsoil over the sand fill portion of the mound.

4. Checking for limiting conditions

   The effective basal area of the sand fill (shaded area in plan view of Fig. 2.16) in the mound below and downslope of the trenches must be large enough to absorb the estimated daily waste flow. In calculating this basal area, exclude the portions of the mound upslope from the trenches and the portion of the mound on each side of the ends of the trenches and their extension downslope.

In this calculation:

A = effective basal area of mound, ft^2 = shaded area in plan view
Q = estimated daily flow, gpd
R = natural soil infiltration rate, gpd/ft^2.
Thus, R = Q/A, expressed in gpd/ft^2.

A is computed by multiplying the trench length, L_1, by the sum of the trench widths, the spaces between trenches, the horizontal extent of fill beyond the last trench, and the horizontal distance needed to provide the side slope (including the correction for total mound width).

$$A = L_1(3a + 2b + c + 7 + 5)$$
$$A = 42[(4 \times 3) + (2 \times 4) + 3 + 7 + 5)$$
$$A = 1470\ ft^2$$

$$Q = 600\ gpd$$
$$R = Q/A = 600/1470 = 0.41\ gpd/ft^2$$

From Table 2.8, R must not exceed 0.74 gpd/ft^2

This design is satisfactory. If calculated R exceeds the maximum, increase the size of the mound by increasing spacing between trenches or by increasing trench length to provide a satisfactory value of R.

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