CHAPTER 2

SEWAGE TREATMENT

Section I. PURPOSE

2-1. Introduction

a. In the theater of operations the purpose of sewage treatment is twofold.

(1) It safeguards health by eliminating, to the extent required, the disease-producing organisms. The treatment does not purify the sewage.

(2) It stabilizes the sewage so that it will not overload the disposal media, in lake, stream, or drainfield.

b. Treatment may be of two types, primary and secondary.

(1) Primary treatment is the separation of the settleable and floating solids from the liquid and the stabilization of these solids.

(2) Secondary treatment is the stabilization of the finely-divided sewage solids which remain in the liquid after primary treatment.

c. Specific design criteria given in this section should be used where TM 5-302 designs are not adequate. Use of TM 5-302 designs should be possible in most theater of operation situations.

Section II. SEWAGE CHARACTERISTICS

2-2. General

a. Sewage, the used water together with the solids that are mixed with it, can be of four types. These are—

(1) Sanitary sewage (also called domestic sewage)—the sewage which originates in the sanitary conveniences of houses, barracks, shops, and other areas for work or living.

(2) Industrial sewage—the waste from an industrial process such as dyeing, brewing, or papermaking.

(3) Storm sewage-the water (runoff) from rain and snow and the particles carried with it.

(4) Infiltration-the ground water and the particles carried with it which leak into a sewer through joints or breaks.

b. In theater of operations construction, generally only infiltration and sanitary sewage are allowed in the sewerage system. Wastes from gasoline dispensing systems, wash racks, garages, and shop floor drains must be excluded from sanitary sewers because such wastes deter the natural biological processes which occur during the stabilization of sewage. However, the waste from a laundry may be discharged into the theater of operations sewer system. Storm water runoff from ground surface, pavements, and roofs should not be permitted to enter sanitary sewers. It is difficult to obtain flow conditions in combined sewers (sewers that are designed to carry both sanitary and storm sewage) that are adequate during dry weather to prevent the deposition of sewage solids in the sewer and subsequent septic action. A considerably larger pipe would be required for combined sewers than for sanitary sewers; the cost of installing the larger pipe at the greater depth usually required for sanitary sewers often would equal and sometimes exceed the cost of separate sewer systems. However, where sewage treatment is not required and is not likely to be required, combined sewers may be used if their use results in considerable saving in construction effort and if slopes are available to produce the necessary velocities.

2-3. Composition

a. Physically, sewage is composed of 99.8 to 99.9 percent used water. Thus only .1 to .2 percent of sewage is solid matter. Of this solid matter, 40 to 70 percent is organic matter which will putrefy and give off unpleasant odors. The rest is inorganic matter which is usually harmless.

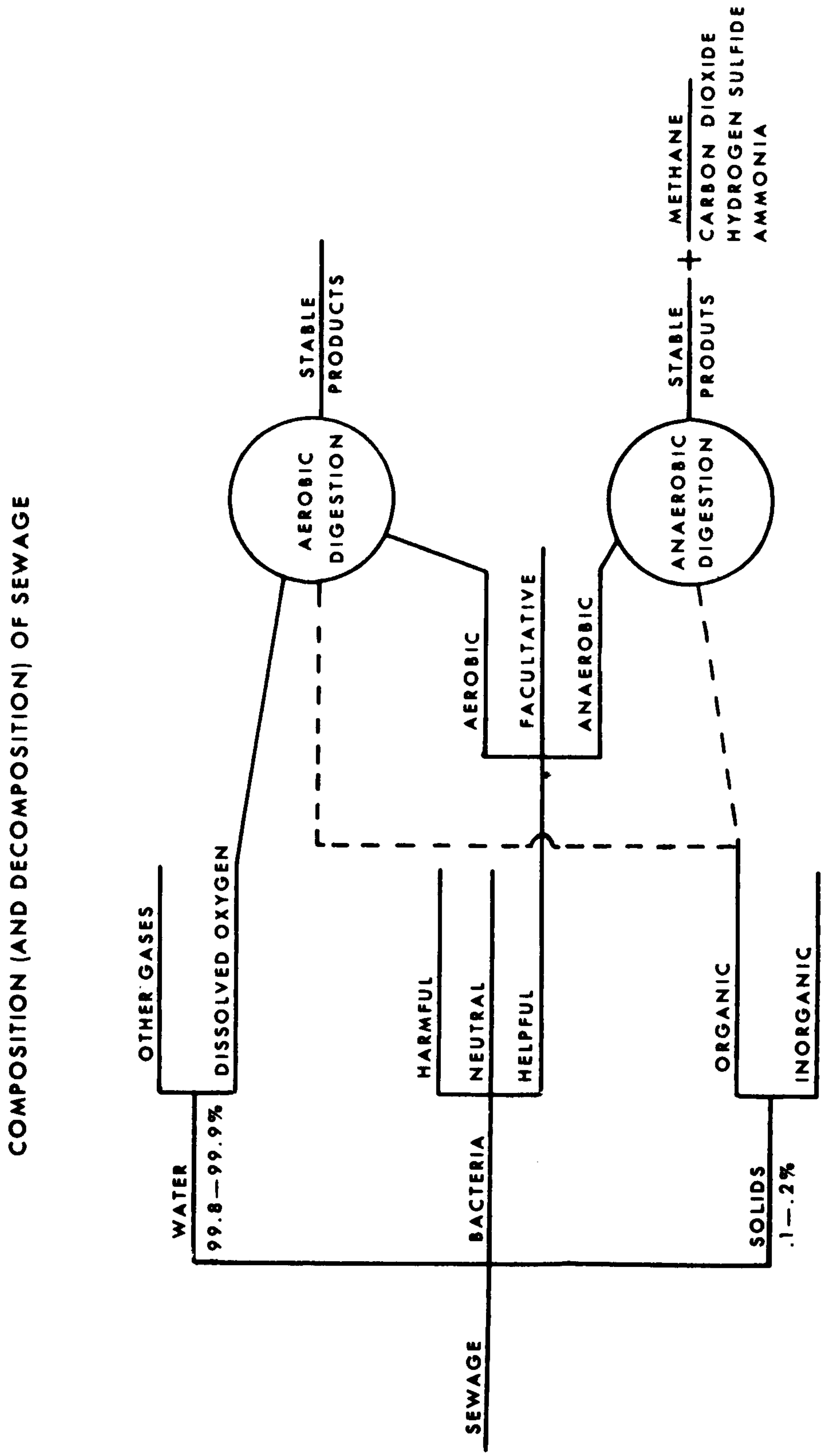


Figure 2–1. Composition and decomposition of sewage.

b. Chemically, sewage contains substances of animal, vegetable, and mineral origin. The first two are called organic matter and are composed largely of the elements carbon, oxygen, hydrogen, and nitrogen.

c. Biologically, sewage contains enormous numbers of living organisms. They are comprised mainly of viruses and phages, bacteria, and other microscopic organisms, listed in order of increasing size. These organisms may be helpful, harmful, or neutral. The harmful ones are those which are pathogenic, that is, disease-producing. The diseases carried in sewage are those normally called "water-borne diseases" such as typhoid fever, cholera, and dysentery. Fortunately, the number of pathogenic organisms decreases rapidly in sewage because they have been removed from the favorable conditions and abundant food supply in the human body. In addition, their ingestion by predatory protozoa, the lack of suitable food in treated sewage, and disinfection by chemicals and by the sun's rays further reduce their number. The helpful organisms are those which are used in the treatment of sewage. Figure 2–1 graphically shows the composition and decomposition of sewage.

2-4. Decomposition

a. Two processes aid the decomposition of sewage: aerobic digestion and anaerobic digestion (fig 2-1).

(1) *Aerobic digestion.* Aerobic digestion requires oxygen and takes place through the combination of dissolved oxygen from the water, aerobic bacteria, and organic solids. This combination results in the formation of a stable product.

(2) *Anaerobic digestion.* Anaerobic digestion does not require oxygen and is a result of the combination of organic solids and anerobic bacteria. From this combination a stable product is found along with some very odorous gases.

b. The final products of aerobic sewage decomposition are compounds formed by oxidation of the original raw sewage components. The amount of oxygen used in the decomposition of a sample of sewage is a measure of the amount of decomposable organic matter present in the sewage, and therefore of its strength. or polluting power.

(1) The biochemical oxygen demand (BOD) is a measure of the polluting power of sewage. BOD is the amount of oxygen required for the biological decomposition of dissolved organic solids to occur under aerobic (dissolved oxygen always present) conditions. The BOD of military sewage is usually taken as 0.20 pounds of oxygen per person per day.

(2) As with any biologically activated process, BOD varies with time and temperature. The standard BOD value is given as oxygen demand per unit (parts per million or pounds per' person) in 5 days at 20 degrees centigrade. This is not meant to say that the biochemical oxygen demand is satisfied in five days, but only that a longer test period becomes impractical. Wherever in this chapter BOD is mentioned with no reference to time or temperature, the standard 5 days at 20°C is to be assumed.

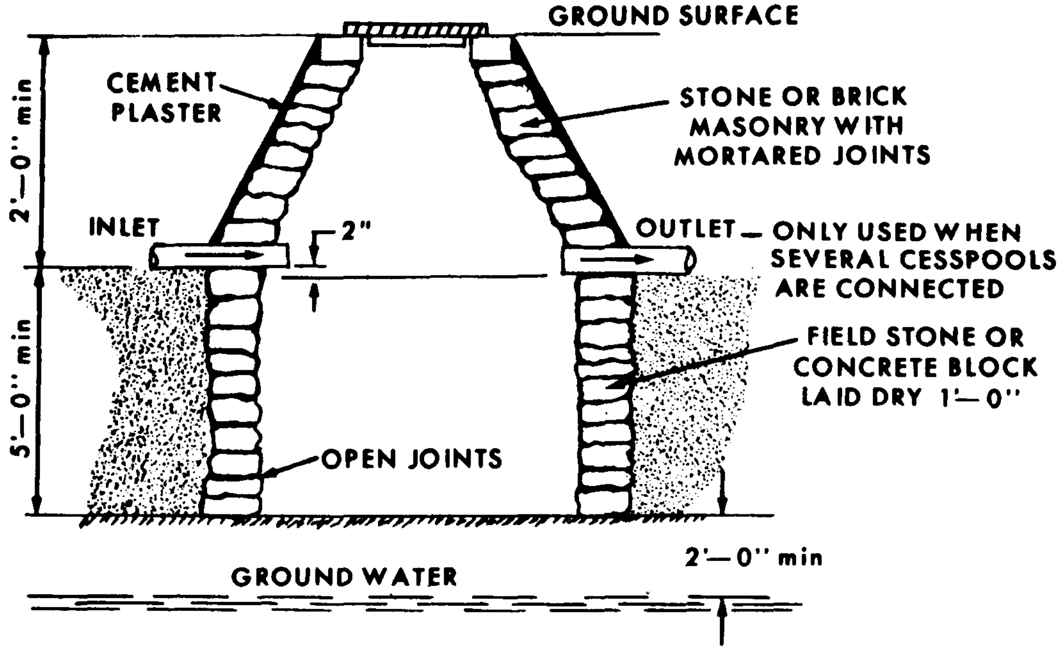
Section III. TREATMENT FACILITIES

2–5. Cesspools

a. Cesspools are usually constructed with open-jointed masonry walls and an unlined bottom through which liquid percolates into the surrounding soil. Solids settle to the bottom and are digested by anaerobic bacteria. The cesspool's ability to function properly ceases when the solids accumulate and clog the soil. When this clogging occurs, a second cesspool should be constructed a minimum of 20 feet away from the existing one and connected to it with an overflow pipe. In this arrangement the first cesspool acts as a settling and digestion pit (septic tank) and the second one acts as a leaching pit.

b. Cesspools may be used where the subsoil is porous to a depth of 8 to 10 feet and where the depth of the cesspool will not pollute or contaminate the ground water. If the bottom of the cesspool is in dry soil at least two feet above the highest ground water table, there is very little danger that it will contaminate the ground water. As a general safety rule the cesspool should be constructed a minimum of 100 meters away and downhill from any water source.

c. The total number and size of cesspools required depends upon the quantity of sewage and the leaching characteristics of the soil. A description of how to conduct a percolation test to determine the leaching characteristics of the soil is given in chapter 3. The allowable application rates and cesspool details are given in figure 2–2. Additional design information is available from TM 5-302.



CESSPOOL — DETAIL

APPLICATION RATES OF SEWAGE FOR CESSPOOLS

TIME IN MINUTES REQUIRED FOR WATER TO FALL ONE INCH IN TEST HOLE	ABSORPTION IN GALLONS PER SQUARE FOOT OF PERCOLATING AREA PER DAY	DIAMETER	DEPTH Below Inlet	AREA IN SQUARE FEET
		TOTAL ABSORPTIVE AREA = AREA OF WALLS (BELOW THE INLET) + AREA OF THE BOTTOM		
		TOTAL ABSORPTIVE AREA = (2 π R) (HEIGHT) + π R²		
1	5.3	5'	5'	99
2	4.3	6'	6'	142
5	3.2	7'	6'	170
10	2.3	8'	6'	201
30	1.1	8'	7'	216
		9'	7'	262
		9'	8'	293
		10'	8'	330
		12'	10'	489

Figure 2–2. Application rates of sewage for cesspools.

2-6. Septic Tanks

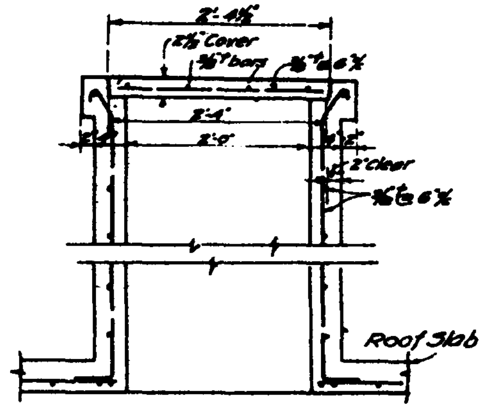
Septic tanks serve small installations where the effluent can be disposed of by dilution, leaching cesspools, leaching trenches, tile fields or artificial subsurface filter systems.

a. The volume of the septic tank should be equal to the peak sewage flow for a period of 16 to 24 hours, plus an additional 25 percent of the total volume for sludge storage. The length of the tank should not be less than two or more than three times the width. Manholes should be provided over the inlet and outlet pipes and over the low points in tanks with hopper-bottoms. These manholes will allow access for inspection and cleaning (fig 2–3). Additional design information may be found in TM 5–302.

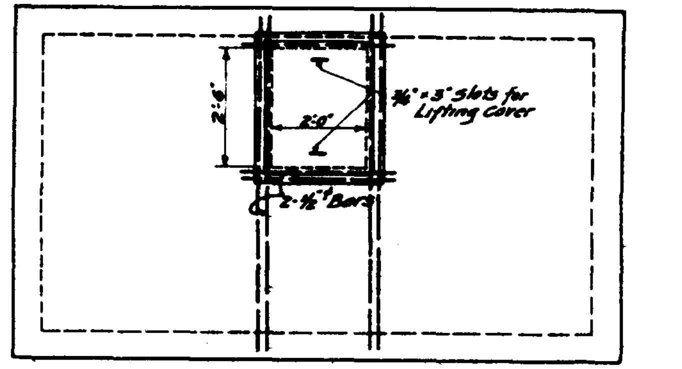
b. Although properly designed septic tanks require little operating attention, they must be inspected periodically, frequency being determined by size of tank and population load. Minimum frequency should be once every 2 months at periods of high flow. The inspection must determine that inlet and outlet are free from clogging, that the

SEPTIC TANK DIMENSIONS & REINF.

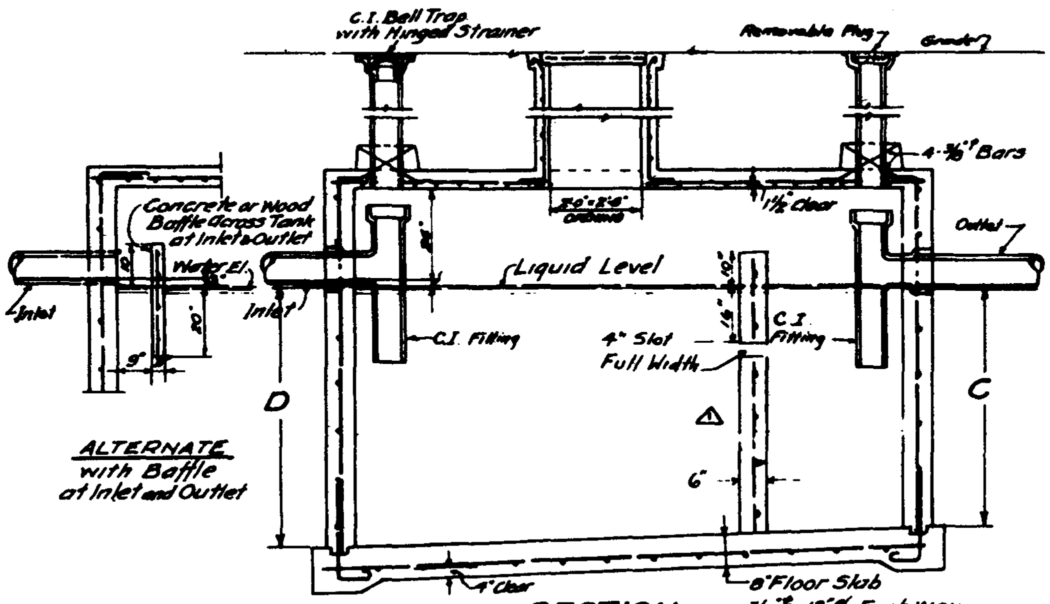
CAPACITY GALL'S	CU. FT.	+25%	A	B	C	D	WALL THICKNESS	WALL REINFORCEMENT For 1/2"φ HORIZ.	WALL REINFORCEMENT For 1/2"φ VERT.	WALL REINFORCEMENT For 3/8"φ HORIZ.	WALL REINFORCEMENT For 3/8"φ VERTICAL	ROOF SLAB THICKNESS	ROOF SLAB REINF. TRANSVERSE	ROOF SLAB REINF. LONGITUDINAL
500	67	83	6'-8"	3'-0"	4'-3"	4'-9"	7" WALL THICKNESS	1/2"φ @ 12" c/c ALL WALLS	1/2"φ @ 12" c/c ALL WALLS	3/8"φ @ 8" c/c	3/8"φ @ 8" c/c, 3/8"φ @ 12" c/c	3½"	3/8"φ @ 4" c/c	3/8"φ @ 12" c/c ALL SLABS
750	100	125	8'-2"	3'-8"	4'-3"	4'-9"						3½"		
1000	133	166	8'-8"	4'-1"	4'-9"	5'-3"					MIDDLE HALF OF WALL 3/8"φ @ 6" c/c, END QUARTERS OF WALL 3/8"φ @ 8" c/c	3½"		
1250	167	208	9'-9"	4'-6"	4'-9"	5'-3"				3/8"φ @ 6" c/c		4"	3/8"φ @ 3½" c/c	
1500	200	250	10'-6"	4'-9"	5'-0"	5'-6"						4"		
1750	233	292	11'-6"	5'-0"	5'-0"	5'-6"						4½"	1/2"φ @ 6" c/c	
2000	266	332	12'-6"	5'-3"	5'-0	5'-6"						4½"		



MANHOLE

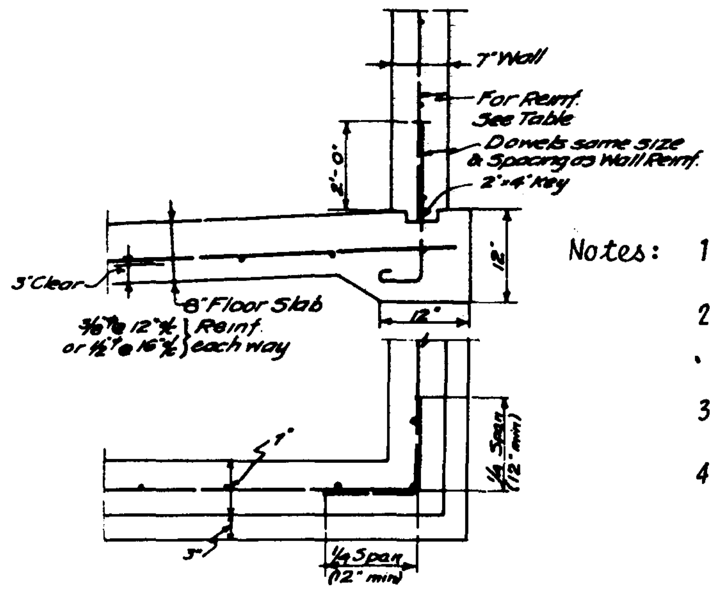


ROOF SLAB PLAN



SECTION

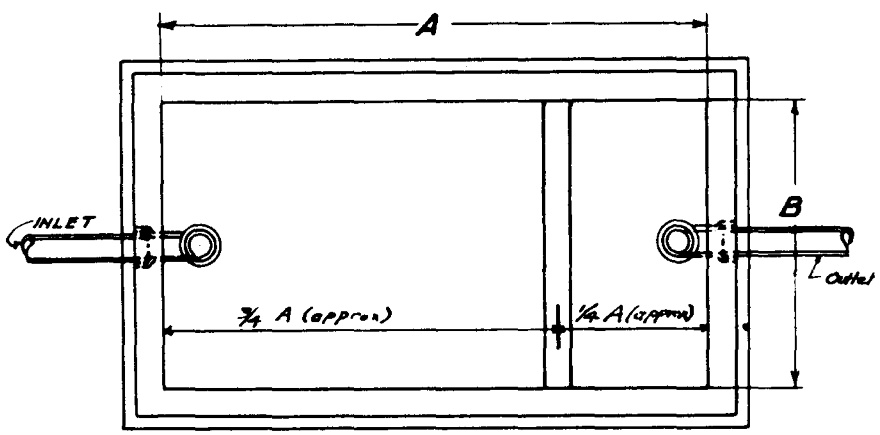
NOTE: For Wall and Roof Slab Reinforcement see Table.



TYPICAL CORNER REINF.

Notes:

1. Other designs may be used to suit local conditions.
2. The capacities indicated are exclusive of 25% allowance for sludge accumulation.
3. Top of tank may be at grade if conditions permit.
4. Tank may be poured in place, precast elsewhere, or may be fabricated or prefabricated of other approved material.



PLAN

BASIS OF STRUCTURAL DESIGN:

1. Roof slab is designed for an earth load of 300 lbs. plus a live load of 100 lbs. per square foot.
2. Walls are designed for the internal liquid pressure or for an external earth pressure equivalent to a fluid pressure of 33 lbs. per foot of depth, whichever load causes the max. stress.
3. Concrete to have a minimum strength of 3000 lbs. per sq. inch in 28 days, with $n = 10$; $f_s = 20000$ lbs. and $f_c = 1350$ lbs. per sq. inch.

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depth of scum and sludge accumulation is not excessive, and that the effluent passing to subsurface disposal is relatively free from suspended solids. A high concentration of suspended solids in the effluent quickly clogs subsurface disposal facilities. Sludge and scum accumulation cannot exceed one-fourth of tank capacity. Statements, which are sometimes made, that septic tanks liquefy all solids, that they never need cleaning, and that the effluent is pure and free from germs are not true. Perhaps 40 to 60 percent of the suspended solids are retained; the rest are discharged in the effluent.

c. Separating sludge and scum from the liquid in septic tanks is difficult; for small tanks they are customarily mixed. The entire contents should not be removed when the tank is cleaned. A small quantity of sludge should be left in the tank to "seed" future biological processes. The material removed contains fresh or partially digested sewage solids which must be disposed of without endangering public health. Disposal through manholes in the nearest sewerage system, as approved by local authorities, or burial in shallow furrows on open land is recommended.

d. The liquid effluent should be disposed of by dilution or irrigation. See Chapter 3, Disposal, for additional information.

2-7. Sewage Treatment Plant

a. Two types of sewage treatment plants may be constructed from the Engineer Functional Component System:

(1) One plant provides only primary treatment, the removal and stabilization of settleable and floating solids (fig 2-4).

(2) The second type of plant provides complete treatment, both primary and secondary. After primary treatment has been completed, solu-

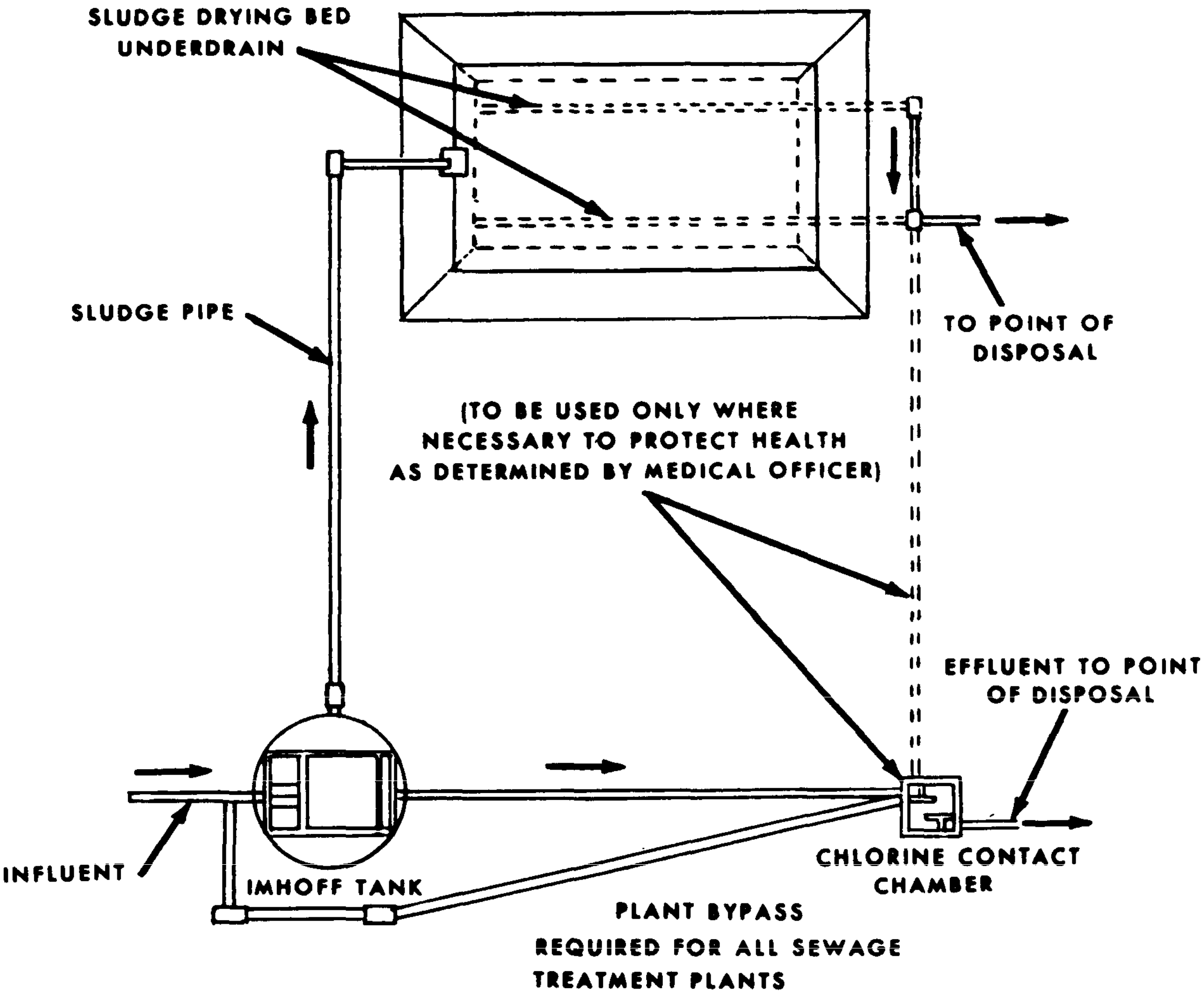


Figure 2-4. Typical primary treatment plant.

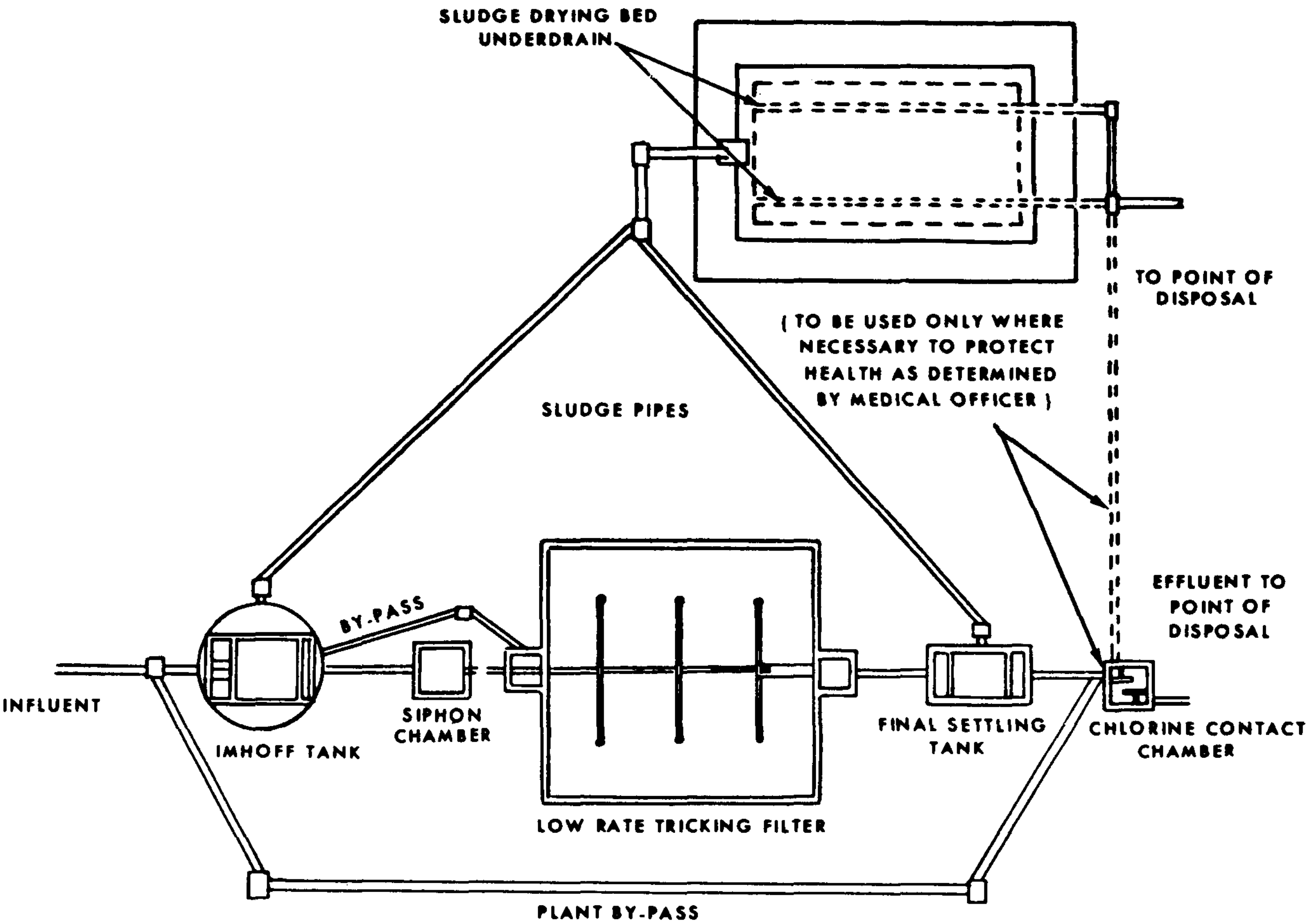


Figure 2–5. Typical primary and secondary treatment plant.

ble or finely divided sewage solids remaining in the liquid are biologically oxidized (fig 2-5).

b. Specific design criteria given in this section are for situations where standard designs from TM 5-302 are not adequate. Standard designs from TM 5-302 should be used whenever possible.

2–8. Facilities for Primary Treatment

a. Bar Screen. A bar screen is used to screen large particles such as rags, rocks and sticks from the sewage. Bar screens are usually required at the inlet to pumping stations and treatment plants. The bar screen is constructed of bars installed longitudinally in a channel, 1 to 1½ inches apart, clear measurement, and should have a slope of about 1:2. One inch screens collect 1 to 3 cubic feet of screenings per million gallons of sewage. The screens should also be constructed with an overflow chamber to prevent stoppages (fig 2-6).

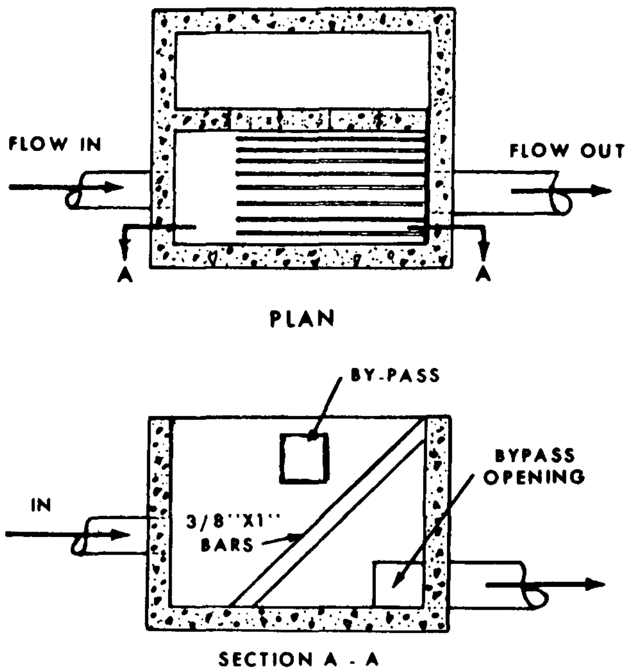


Figure 2–6. Bar screen.

b. Plain Settling Tanks.

(1) The only function of the plain settling tank is to detain the sewage long enough and at a low enough velocity to permit most of the suspended solids to settle out. The settled solids, often

called sludge, are removed from the settling tank daily and transferred to another facility for digestion.

(2) Factors considered in designing settling tanks are the quantity of sewage (average flow), detention time, method of sludge removal, length, width, and depth.

(a) The liquid volume of the tank may be calculated by the formula:

$$V = \frac{2.5}{180} [.7(\text{Des. pop.} \times \text{Ave. Flow}) \quad \text{Inf. All}]$$

where:

v	=	Liquid Volume of the tank in cubic feet
2.5	=	Recommended detention time in hours
180	=	(7.5 cubic ft / gal) (24 hours / day)
Des. Pop.	=	Design population of the installation
Ave. Flow	=	Average water demand in gallons per day per person
Inf. All.	=	Infiltration allowance = (length of sewer in feet) (1440 min / day) (infiltration rate or 2 gpm / 1000')

(b) The length and width may be determined by assuming a depth of 10 to 12 feet and dividing this into the tank volume. The resultant will be the surface area in square feet. Based on the ratio that the length of the tank should be equal to 3 times the width, the rectangular dimensions can then be determined. Additional allowances are necessary to provide freeboard, about 12 inches, and space in the bottom for sludge storage (fig 2-7).

(c) Sludge is removed through a sludge draw-off pipe having its inlet about 1 foot above the tank bottom. For design details see TM 5-302.

c. Separate Sludge Digestion Tanks.

(1) Raw sludge from the settling tank is discharged daily into the sludge digestion tank for septic decomposition by anaerobic bacteria. The simplest type of digestion tank is an uncovered earth basin which receives the settled sludge from the settling tank by gravity flow. Digested sludge is drawn off at the bottom, which should be cone-or hopper-shaped to facilitate the outflow of sludge. Concrete lined tanks are preferred, although brick or stone masonry, gunite, sheet-metal, or wood tanks may be used.

(2) The volume of the digester should be equal to 3 cubic feet per capita. In plants that recycle the sludge from the final settling tank to the plain settling tank or directly to the digester, the volume should be equal to 4.5 cubic feet per capita. The depth of the digester should be between 15 and 25 feet.

(3) This design basis allows for a reasonable depth of sludge which, unless stirred, stratifies into 4 layers as follows:

(a) An upper, relatively inactive scum layer,

(b) A central layer of tank liquor, from which solids have settled,

(c) A lower, relatively active layer of digesting solids, and

(d) A bottom, relatively inactive layer of stable solids.

(4) The rate at which digestion and the resulting change in fluidity takes place depends on the temperature and the alkalinity of the sludge. The optimum temperature range is 90 to 100 degrees and the Ph value should be between 6.8 and 7.3.

(5) A more efficient treatment of the sewage can be accomplished by returning the liquor from the central layer of the sludge digestion tank to the plant influent (in the primary settling tank). The liquor can be withdrawn from the sludge digestion tank by tapping 3 or 4 outlets spaced about 2 feet apart vertically, beginning approximately 3 feet below the maximum liquid level.

(6) The digested solids in the bottom of the digestion may be withdrawn in the same manner as the sludge was withdrawn from the plain settling tank or the Imhoff tank. This stable solid may be transferred to the sludge drying beds.

d. Imhoff Tanks.

(1) An Imhoff tank is a sedimentation tank and digestion tank in one (fig 2-8). It consists of an upper compartment for settling out solids from the slowly flowing sewage and a lower compartment for septic digestion of the sludge. The upper compartment forms a channel with an approximately 8-inch slot in the bottom. Sides of the slot have a 1 horizontal to 1½ vertical slope and are overlapped to prevent gases formed by digesting sludge from escaping into the upper or "flowing-through" compartment. With an average flow, solids settle in the upper compartment in 2 to 2½ hours, pass downward through the slot, and settle to the bottom of the lower compartment where they are digested. Accumulated solids are removed periodically through a sludge draw-off pipe having its inlet about 1 foot above the tank bottom.

(2) Design of the upper or "flowing-through" compartment is based on the retention period. (See plain settling tanks.) The lower or digestion compartment is designed to hold 3 cubic feet per

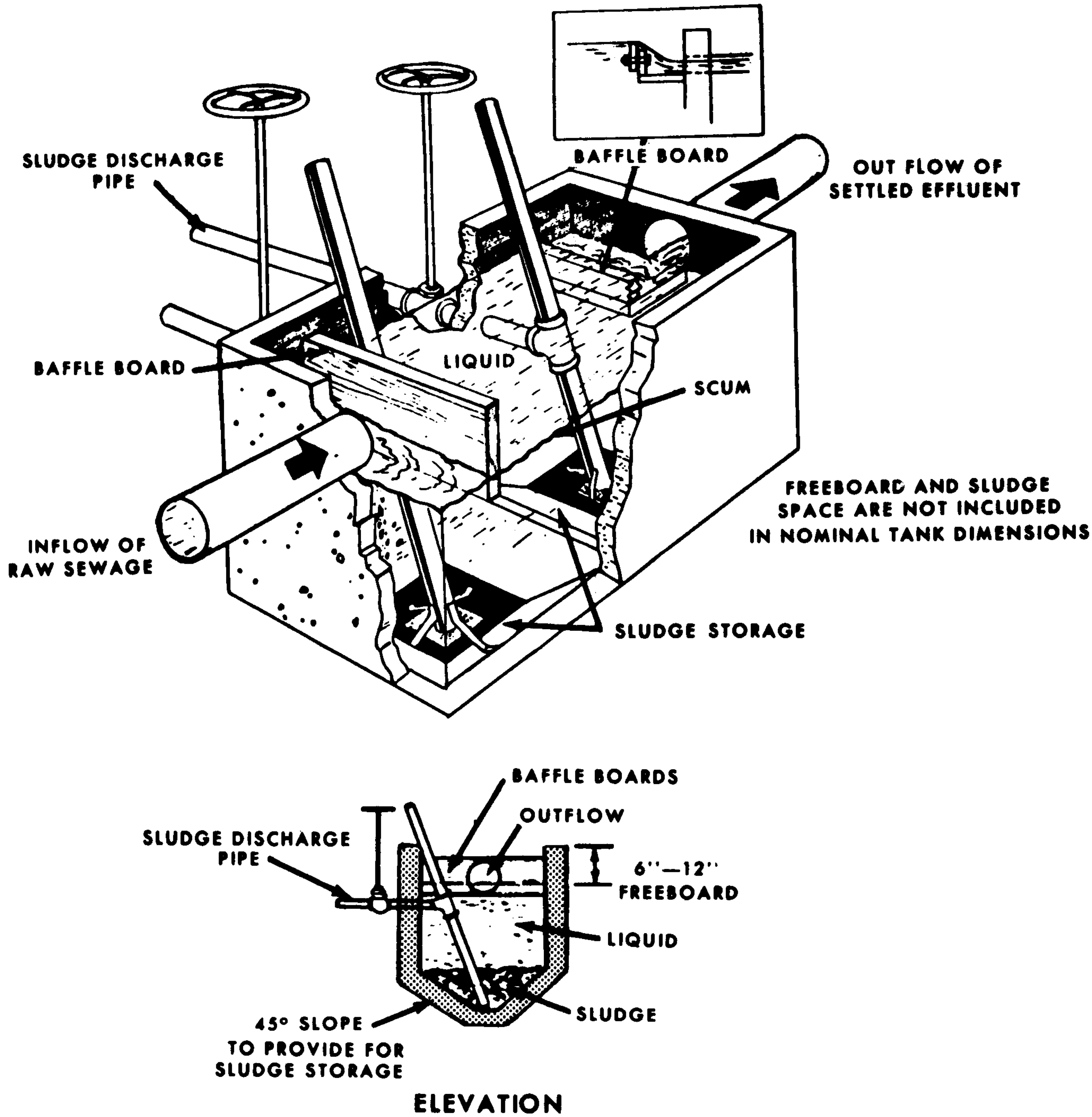


Figure 2–7. Settling tank.

capita below a plane 18 inches beneath the bottom of the slot. If sludge from secondary settling is returned to this compartment for digestion, the capacity of the compartment must be increased to 4½ cubic feet per capita. Construction drawings of Imhoff tanks are given in TM 5–302.

(3) The digested sludge removed from the Imhoff tank should be transferred to the sludge drying beds.

e. Sludge Drying Beds. A common method of preparing digested sludge for disposal is by air drying. There are generally two types of sludge drying beds which can be constructed.

(1) Drying beds without drains: Natural sludge drying beds without underdrains are constructed by building earth dikes. They should provide 3 to 4½ square feet of surface per capita, depending on climate and permeability of the soil. Liquid sludge from the digestion tank is applied about 12 inches deep. When dried, it forms a cake about 4 inches thick. This cake is removed with a fork or shovel and can be used as humus.

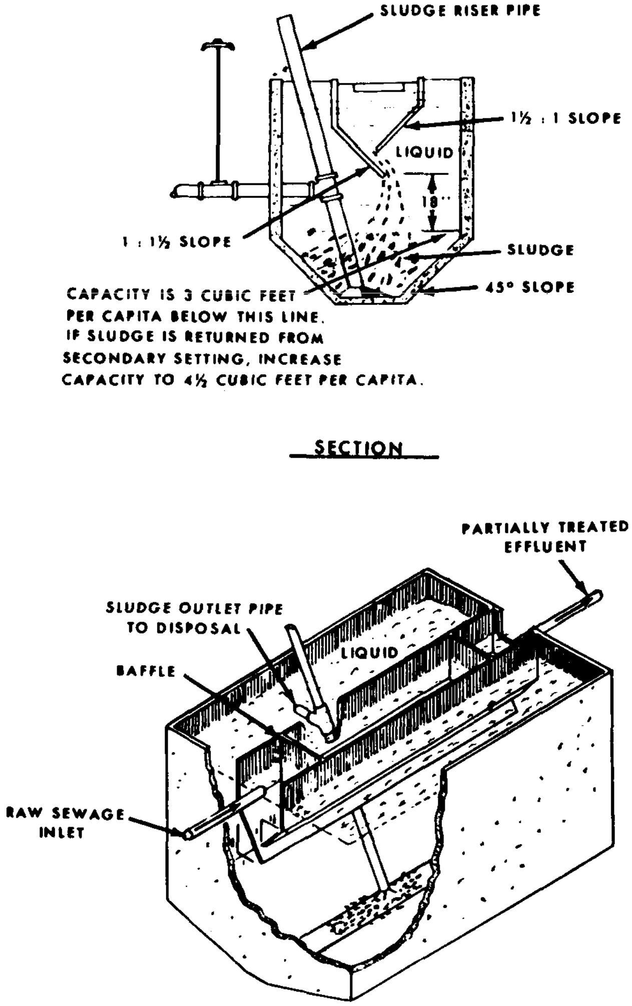


Figure 2–8. Imhoff tank.

(2) Drying beds with drains: Underdrain sludge drying beds consist of a surface layer and sand 6 to 12 inches thick, a 6 to 12 inch layer of gravel below the sand, and underdrains below the gravel layer. The underdrains should be 4 to 6 inch open joint or perforated pipe space 10 to 20 feet apart and should be laid in a V-shaped trench and surrounded with coarse gravel. The required area of a sludge bed is 1 to 1½ square feet per capita; the maximum length is about 100 feet. The bed is subdivided into sections by wood or masonry curbs spaced midway between the drain pipes. Characteristics and handling of sludge are the same as for natural beds. Drying requires 2 to 4 weeks, depending on humidity and rainfall. Sand removed with the sludge must be replaced when

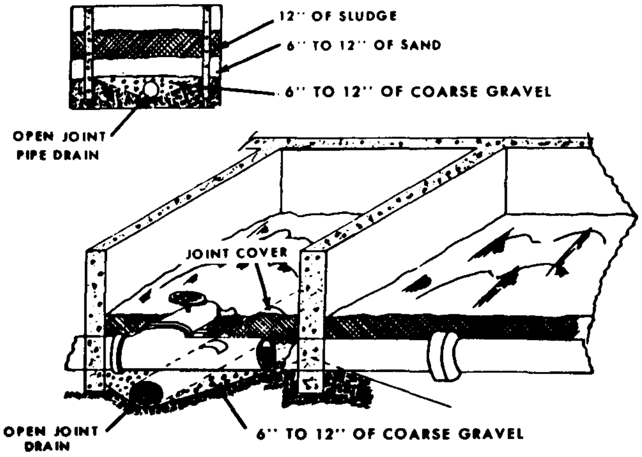


Figure 2–9. Sludge drying bed.

the thickness of the sand layer is reduced to 4 inches (fig 2-9).

2-9. Secondary Treatment

a. Dosing Tank.

(1) In a conventional treatment plant the dosing tank is a control mechanism which performs two functions, the first of which is to discharge the effluent from the primary treatment facility, at intervals, over a filter media. Its second function is to provide sufficient hydraulic head to distribute the effluent evenly over the filter. Figure 2–10 shows a typical dosing tank. The dosing chamber volume is equal to 15 minutes full flow from the primary treatment unit.

(2) The siphon operates as follows: When the water is cut off at the low water line the liquid will be standing in the discharge pipe at the level A. As the liquid rises in the tank and covers the siphon vent, air is trapped under the dome. As the liquid level approaches the high water level the air under the dome is compressed; the liquid in the discharge pipe is forced down to level B; and the liquid level under the dome is near the upper end of the discharge pipe. Discharge will occur when a slight increase in head causes the water level at B to be depressed so that the compressed air will escape through the vent and overflow pipe. This sudden release of air will allow the water to rush into the discharge pipe and start the siphon action. The siphon action continues until the water level in the tank falls below the air vent, breaking the siphon action.

b. Trickling filters.

(1) Trickling filters, often called sprinkling filters, are beds of crushed rock, crushed slag, or

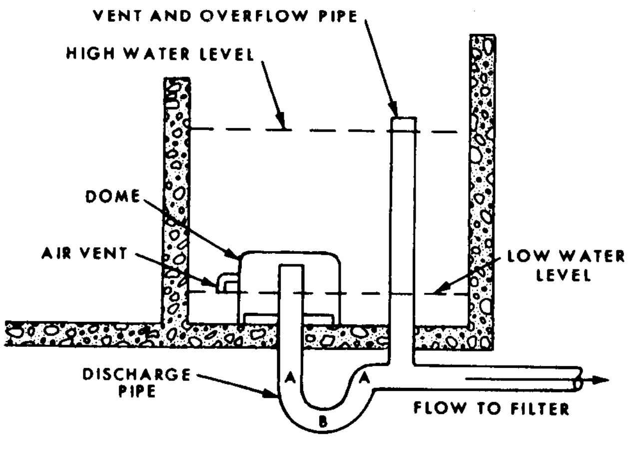


Figure 2–10. Dosing tank.

gravel, to the surface of which primarily treated sewage is applied through rotary distributors or stationary sprays. The sewage then trickles in a thin film over the stones to a system of underdrains (figs 2-11 and 2-12). These beds are not actually filters in the usual sense, but accomplish their function in the treatment of sewage mainly through oxidizing action by aerobic bacteria. The effect is that dissolved and suspended organic matter in the sewage is absorbed by bacterial growth on the stones and converted to more stable compounds. Some of these compounds coagulate and settle in the final settling tank. Others are soluble and pass on with the final effluent sewage. There are two main types of trickling filters,

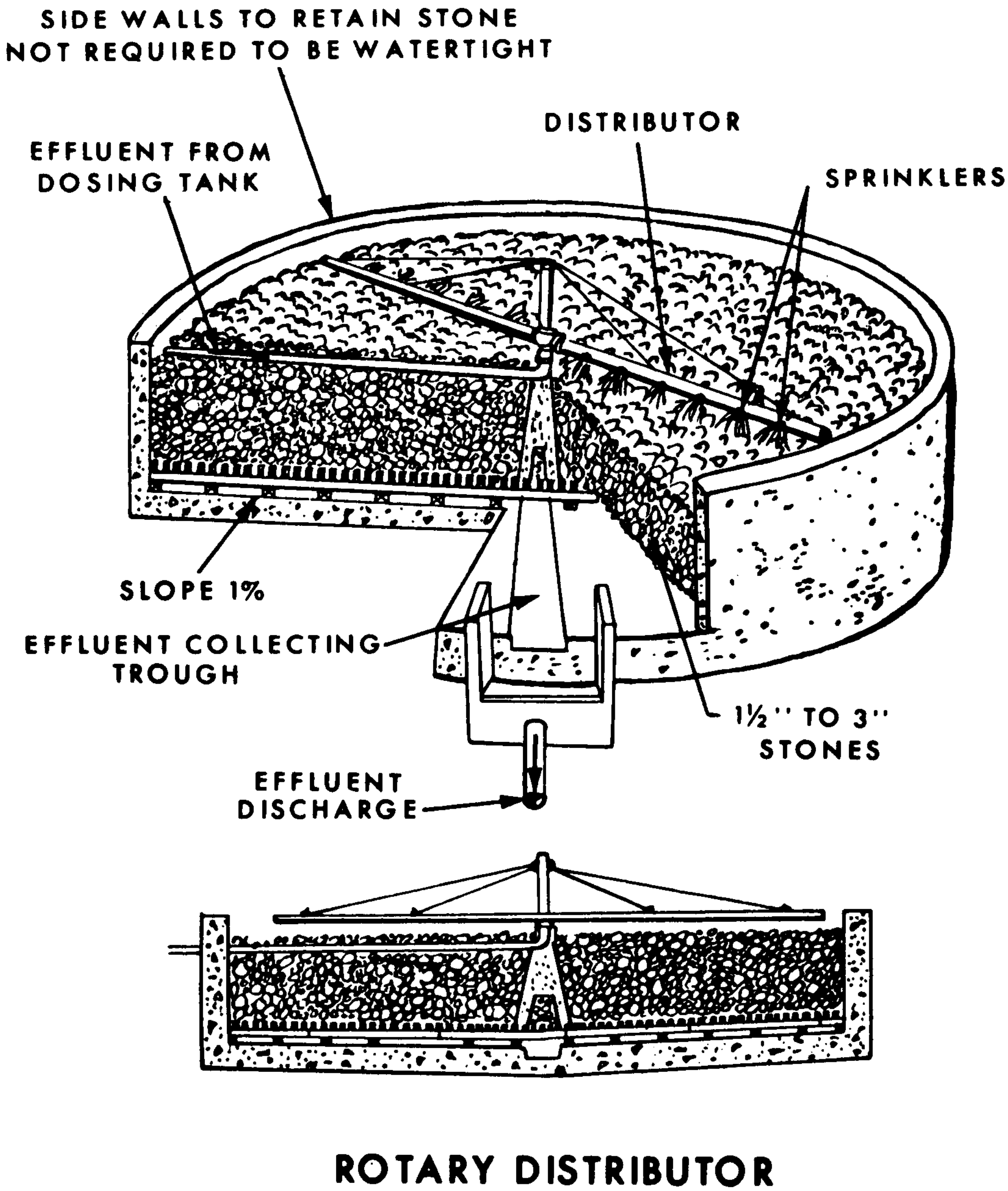
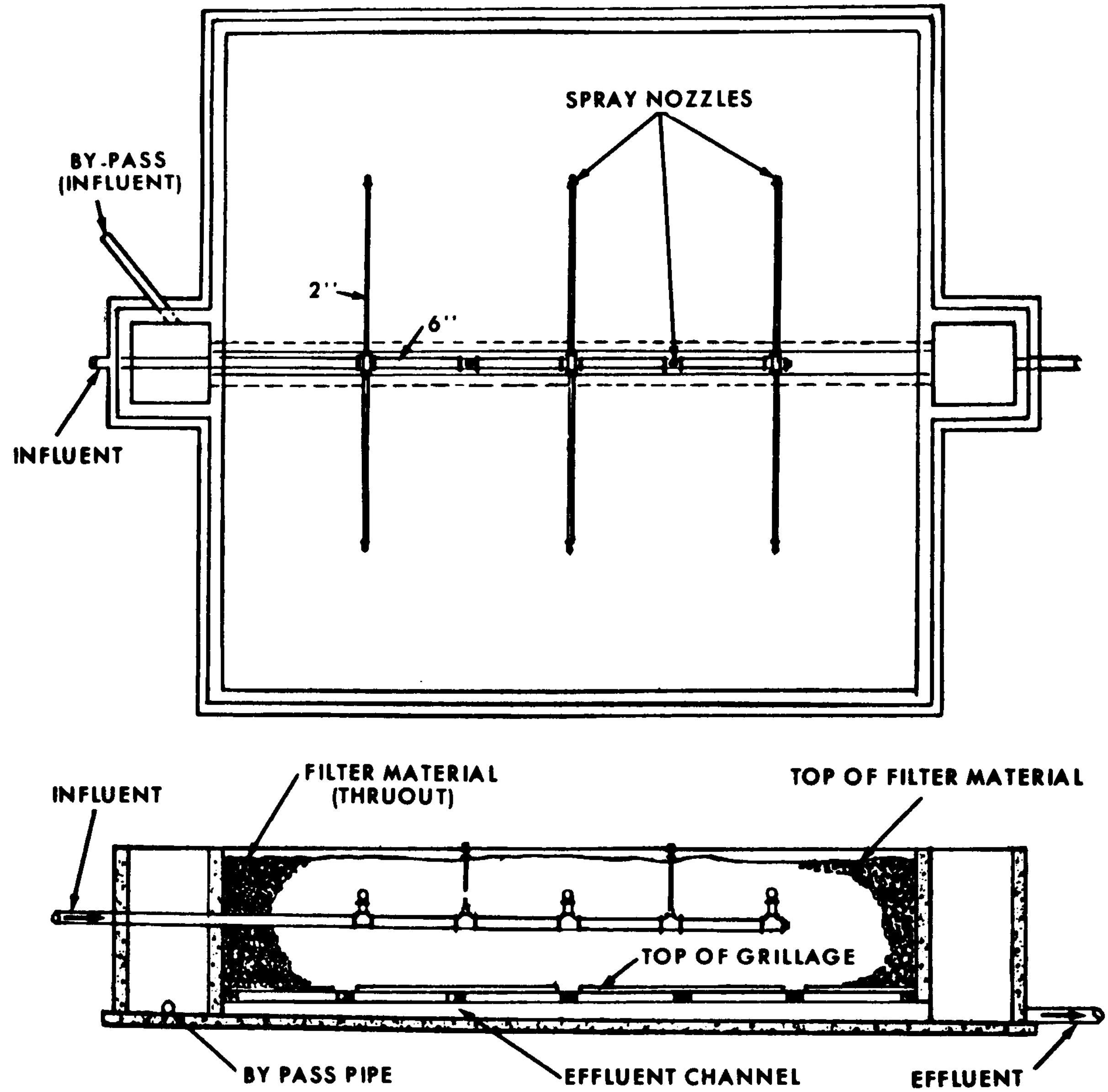


Figure 2–11. Rotary distributor.



FILTER MATERIAL SPECIFICATIONS

MATERIAL FOR FILTER MEDIA SHOULD BE SOUND HARD PIECES, CLEAN AND FREE FROM DUST, SCREENINGS, AND OTHER FINE MATERIAL. IT SHOULD BE AS NEARLY UNIFORM IN SIZE AS POSSIBLE. THE MATERIAL SHOULD NOT DISINTEGRATE UNDER SERVICE CONDITION, EITHER BY BREAKING INTO SMALLER PIECES OR BY CRUMBLING INTO FINE MATERIAL. THE USE OF FLAT ELONGATED OR GLASSY PIECES SHOULD BE AVOIDED. MATERIAL MAY BE GRAVEL, BROKEN STONE, SLAG, OR OTHER HARD DURABLE SUBSTANCE. THE MATERIAL SHALL BE OF A SIZE THAT WILL PASS A 3 – INCH SCREEN AND BE RETAINED ON A 1 1/2–INCH ROUND SCREEN. THE SODIUM SULPHATE SOUNDNESS TEST MAY BE USED TO DETERMINE DURABILITY OF STONE.

Figure 2–12. Sprinkler-nozzle system.

standard or low rate and high rate. The application of sewage at higher rates and the recirculation of a portion of the effluent constitute the principal difference between the operation of a high rate filter and that of a standard rate filter. The design procedure is as follows: The size of the filter bed is determined on the basis of about 0.35 cubic yard of stone per capita. Desirable hydraulic head between the lowest liquid level in the dosing chamber and the center of the rotary distributor arm is 10 to 12 inches (fig 2-11). If sprinkler nozzles are used, a 6- to 10-foot head from the high-water level in the dozing tank to the sprinkler-nozzle outlet is required (fig 2-12).

(2) Crushed stone is the best filter material, but gravel, coke, clinker, broken brick, or slag can be used. To permit maximum voids for passage of sewage, and air for ventilation, filter material should be reasonably uniform in size—1½- to 3-inch stone is best. The filter layer should be 5 to 8 feet deep.

(3) Underdrains maybe either whole or half tile laid with open joints, or a grillage of 2- by 4-inch timber laid on edge. The underdrain system must be constructed so all parts of the filter bed are ventilated.

(4) See TM 5-302 for standard plans.

c. Final Settling Tanks. The effluent from trickling filters should be passed through final settling tanks to remove the bacterial gel which forms on the filter stone and peels off into the effluent. Sludge obtained from final settling tanks is about one-half the volume obtained from primary settling tanks. It can be run directly to drying bads or preferably returned to the digestion tank. Final settling tanks should be large enough to provide a 2 to 2½ hour detention period at the average rate of flow. The sludge should be removed daily to prevent septic action. The slope of the hopper bottom is 1 to 1 or steeper. Side water depth of final settling tanks should not be more than 10 feet. Other details of construction are the same as for plain settling tanks. See TM 5-302 for construction drawings.

d. Oxidation Ponds.

(1) Oxidation ponds are sometimes used instead of a trickling filter for secondary treatment. This facility is a relatively large shallow pond into which the effluent, from the primary treatment is discharged. Secondary treatment is accomplished here by natural purification under the influence of sunlight and air. Site considerations should include locating the facility far enough from habitation (preferable one-half mile or more) so that odors from the decomposition of organic matter are not objectionable. Ponds should not be constructed in areas where freezes last longer than 10 days.

(2) Capacity of the pond is based on a 30-day storage period. Only the volume of the pond above a 2-foot depth is considered when the total ponding area is 5 acres or less; when the pending area is larger, only the volume above 3-foot depth is considered. For best results, three or more ponds should be used in series. They may be separated by narrow dikes or may be more widely spaced, depending on the terrain and economy of construction. Where it is possible to construct the ponds at different elevations, the flow from one to another should be over a wide, shallow weir to permit maximum aeration and oxidation of the sewage. Where topography permits, a series of weirs, usually called a cascade, is used to insure maximum aeration (fig 2–13).

2-10. Chemical Treatment

a. Disinfectants, such as liquid chlorine or calcium hypochlorite, may be added to sewage in emergencies to safeguard health and prevent odor and fly nuisances. They are sometimes used during periods of low stream flow when there is not enough stream water for proper dilution. They also may be used when a part of a plant is bypassed during cleaning or a breakdown.

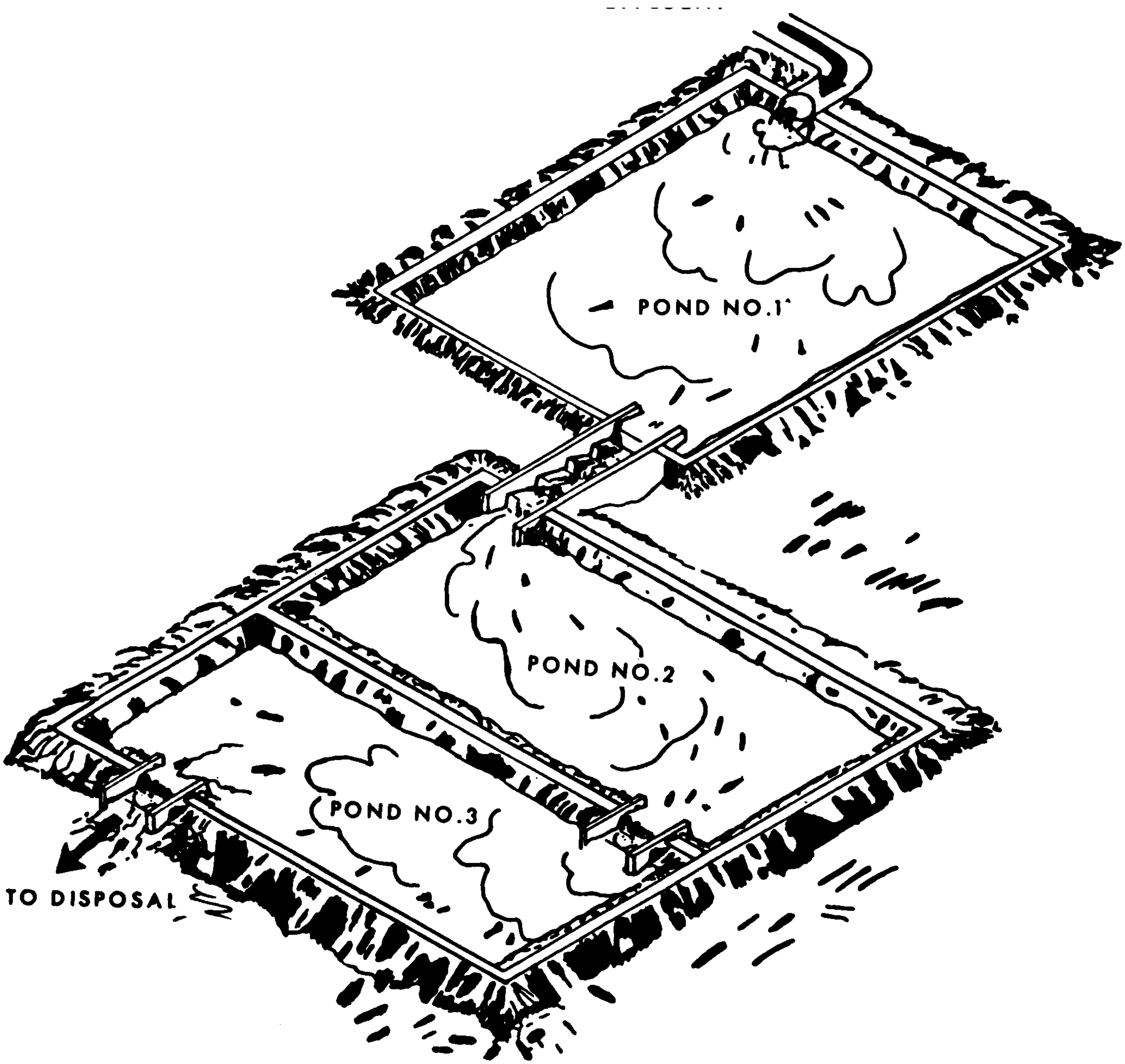
b. Since chlorine kills bacteria, it will greatly decrease the decomposition rate of the sewage therefore delaying reduction of the BOD. It sometimes is used to delay the oxygen demand until the sewage reaches a body of water large enough to provide the oxygen required. It is also effective in killing disease-producing organisms if the contact period and the chlorine concentration are sufficient and if all particles are finely enough divided to permit chlorine contact.

c. Should conditions be such that through failure of power or equipment there is a possibility of contaminating a water supply with raw sewage, provisions should be made for chlorinating at a rate of 200 pounds per million gallons at the 4-hour peak rate of sewage flow. In other cases where chlorination is required, provisions should be made for chlorination at a rate of 125 pounds per million gallons at the 4-hour peak rate of sewage flow. The 4-hour peak rate is considered to be 175 percent of the average daily rate of flow. Chlorine can be applied by mechanical chlorinators or by an improvised drum chlorinator.

d. Construction drawings for a chlorine contact chamber may be found in TM 5-302.

2-11. Sewage Lagoons

a. General. Most of the treatment facilities mentioned previously require a considerable amount of engineer effort to construct. Theater of operation situations require that engineer works be constructed to accomplish their mission with the least possible utilization of time, manpower, equipment and material. The sewage lagoon, ap-



OXIDATION PONDS
Figure 2-13. Oxidation ponds.

plicable in all but extreme arctic regions, provides an ideal solution to the sewage treatment problem as it gives excellent primary and secondary sewage treatment with an absolute minimum of construction effort.

(1) Primary treatment is accomplished by settling and anaerobic digestion. Secondary treatment is accomplish by aerobic digestion.

(2) Sludge accumulates at a very slow rate allowing many years of efficient service from the lagoon without an appreciable reduction in capacity. Sewage lagoon effluent, as is the case with the effluent from conventional sewage treatment plants, is not necessarily free of pathogenic organisms and may require additional treatment. It should be disposed of by one of the methods described in chapter 3.

b. Lagoon Design Formulus.

(1) The science of lagoon design is not exact. Early designs required a total pond area of one acre for every 100 to 200 persons while later developments and experience led to much higher loadings. In Africa, lagoons are operating satisfactorily today with total pond areas of 1 acre for every

600 to 1,000 persons. However, such rules of thumb can be misleading or even dangerous. So many variables enter the picture that each case should be investigated individually.

(2) In designing a lagoon, it is necessary to establish the capacity which is the area of the lagoon times the depth. To arrive at these figures, the following basic information must be obtained.

(a) The maximum volume of liquid entering the lagoon is the sum of the basic liquid waste-water production of the installation which the lagoon serves, plus liquid entering the system through infiltration, and rainfall.

1. The waste water production of the installation is equal to 70% of the average water demand in gallons per day multiplied by the design population [waste-water (sewage) = .7 (ave. water demand x design population)].

2. Infiltration of water into systems, resulting from poorly constructed and maintained pipes, leaking manholes, etc., may be substantial, and requires an increase in design capacity.
In temperate regions, an infiltration rate of 2 gal/min for each 1,000 feet of sewer line should be assumed. In tropical areas, where annual rainy seasons occur, a much higher rate must be assumed to allow for an increase in design. capacity.

(b) Minimum volume of liquid to be retained in the lagoon, which is the basic liquid waste water production minus the loss of liquid from the lagoon from seepage and evaporation.

1. The problem of liquid loss by seepage into the soil is twofold. First, there is the danger of polluting nearby water sources if the lagoon bottom is below or too near the water table at any season. Secondly, under severe conditions, the loss of liquid may be great enough to drop the volume of the water retained to a point below that necessary for efficient aerobic operation. Some loss of liquid is to be expected through percolation in any soil, though the volume of such liquid loss depends upon the soil encountered. A percolation test must be made to allow an accurate estimate of the initial liquid loss, and the relative danger of polluting any nearby water source. The test procedure and a table of relative absorption rates are given in section II of chapter 3. The table also includes a classification of soil types which can be used as a supplement to the percolation test in determining the suitability of a site for lagoon construction. Sludge deposits slowly seal the lagoon bottom, reducing the losses to a negligible point in relatively impervious soils, and drastically reducing percolation in even the worst cases. For example, experience indicates that an initial loss as high as 6 inches per day may gradually decline to as little as ¼ inch to ¾ inch per day. If the percolation test indicates the soil will absorb too much liquid, the bottom of the lagoon should be sealed. The simplest and least costly method of sealing the bottom is to compact the existing soil or add a layer of compacted clay, 6 to 10 inches deep. The use of asphalt cutback or emulsions may also be used.

2. The amount of evaporation at a given moment depends on the temperature, humidity, and wind velocity. As a result, it is difficult to predict with any accuracy the evaporation rate for any short period of time. Fortunately, such losses are only critical on a seasonal basis, for which reasonably accurate averages are known for most regions of the world. Lacking any kind of data, evaporation rates may be roughly estimated using a table such as the one below.

Table 2–1. Evaporation Rates

Climate	Evaporation in inches by month												Total annual evaporation
Above equator	Jan.	Feb.	March	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
Below equator	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	
Hot	4.0	5.0	6.5	8.0	10.0	12.0	13.0	13.0	11.0	8.5	6.5	5.0	113.0
Moderate	1.0	1.4	2.0	3.0	4.8	6.5	8.5	8.0	6.5	4.6	2.6	1.1	50.0
Cold	0.6	0.7	0.8	1.0	1.3	1.6	2.0	1.9	1.8	1.6	1.1	0.7	15.0
	(lowest)						(highest)						

3. A design bell curve could be developed from the above, assuming single rainy and dry seasons. Where two rainy and dry seasons must be reckoned with, a double bell curve would result and the above sequence of figures would be of little use. In any case there is no substitute for local knowledge. Where no experts are available, local farmers are usually good consultant in outlining seasonal character, though seldom in terms of quantitative figures.

4. To obtain accurate local figures, field tests are made over at least one complete annual cycle, and preferably several. Though these cannot meet immediate needs, they will both facilitate future lagoon design for the region in question and sufficient modifications to allow more efficient operation of the original system. Field measurement of evaporation can be done by the use of a metal pan, 4 feet in diameter and 10 inches deep. This unit is filled to within 2 inches of its rim and is supported to place the water surface a foot or more above ground level. The drop in water level is measured periodically and the unit is refilled from time to time to the original level. The recorded results are multiplied by 70 percent to arrive at a theoretical reservoir evaporation rate. The volume of evaporation for any given time (day, week or month) can be determined by the following formula:

$E = 485\, E_1 A_5$ where:

E = volume of evaporation in gallons

E_1 = estimated evaporation in inches

A_5 = lagoon area in acres

(c) The strength of the sewage in terms of BOD per person per day and the loading of the pond in pounds of BOD per acre per day. For military installations a BOD value of 0.17 to 0.20 lb should be used for design computations. The surface area required for lagoon construction may be determined from the formula:

$$A_s = \frac{\text{(Des. Pop) (BOD Load)}}{20}$$

where:

A_s = Surface area in acres.

Des. Pop = Design Population of the installation.

BOD Load= Normal BOD Loading (0.17 to 0.20 lb) per person per day.

20 = Design BOD loading of 20 lb per acre per day.

(d) For reasons of economy and efficient operation, the depth of the liquids in lagoons should normally range somewhere between 2 and 6 feet; with minimum depth of 2 to 2½ feet, vegetation is not likely to grow at the bottom of the pond: Shallower ponds (2 to 5 feet) are best in cool climates in order to allow for maximum penetration of sunlight. Because of the higher angle of the sun in tropical climates, deeper sunlight penetration permits deeper ponds (3 to 6 feet). Experience in various parts of Africa indicates that a depth of 4 feet is usually satisfactory.

(e) With the minimum and maximum desired depths established, and using the surface figures calculated above, the volume of the lagoon can be found with the formulas:

Min LC = (A_s) (min. dep.) (43,560) and

Max LC = (A_s) (max. dep.) (43,560)

where:

Min LC = minimum lagoon capacity in cubic feet

Max LC = maximum lagoon capacity in cubic feet

A_s = surface area in acres (see paragraph 2–116(2) (c))

Min. dep = minimum depth of lagoon in feet

Max. dep = maximum depth of lagoon in feet

43,560 = conversion factor to obtain number of square feet in acre.

Because the efficient operation of lagoons depends on maintaining optimum maximum and minimum liquid depths, these must be taken into account in the design of a lagoon.

This will require a careful study of local annual temperature and rainfall data. For example, provision must be made to accommodate the maximum infiltration which generally occurs in the rainy season when usually minimum infiltration and maximum evaporation occur during the same period.

(f) A minimum retention period must be determined in order to induce the reduction of biochemical oxygen demand to a point allowing discharge of effluent into a normal waterway or irrigation system. In the US, lagoons of the flow-through type, receiving raw sewage, normally employ 60 to 90 days retention. In tropical countries this is likely to be reduced but should not be less than 20 to 25 days. A practical retention time is based on the rate of flow balanced against an efficient minimum and economically maximum pond size. If the volume of influent is roughly equal to the volume of liquid remaining after percolation and evaporation losses to keep the lagoon level within acceptable minimum and maximum limits, no effluent will result and the system can be termed balanced. As a balanced lagoon system is sometimes desirable, the lagoon size can be planned within reasonably flexible limits to achieve this end. Operating a lagoon as a closed or balanced system during the dry season, and allowing for effluent at a rate within the desired retention time during the rainy season is one of the several means of operating lagoons in a tropical climate. Both maximum and minimum hydraulic retention times can be determined by the formulas:

$$T\ max = \frac{7.48\ (C\ max)}{G_m}$$

$$\text{and } T\ min = \frac{7.48\ (C\ min)}{G_m}$$

Where:

T max = maximum retention time in days.
T min = minimum retention time in days.
C max = maximum capacity in cubic feet.
C min = minimum capacity in cubic feet.
G_m = gallons per day influent.
7.48 = gallons per cubic foot.

The optimum retention time will depend upon organic loading, as well as hydraulic loading. The lower the loading in pounds of 5 day BOD per acre per day, the greater the volume of liquid. This permits a longer retention period and a correspondingly greater reduction of BOD.

(g) The Army Medical Service is responsible for inspecting waste disposal facilities and operations and recommending changes to protect the health and welfare of the troops. Consequently, the Army Medical Service should be contacted to resolve questions as to whether single or multiple sewage lagoons will be required, retention times required, and other technical advice required.

(h) Though availability of land is a controlling factor, sites at lower elevations than the collection system are economically preferable in order to eliminate the need for costly lift stations. The lagoon layout should always be planned so that the direction of the prevailing wind is never along the line of flow thus short circuiting sewage from inlet to outlet or retarding the normal flow. Obstructions which restrict air movement should be avoided. Wind induces wave action and subsurface currents needed to stimulate oxidation. However, winds in excess of 30 miles per hour may create wave action which may cause erosion along the edges of the lagoon. (US experience indicates that erosion will not be a serious problem unless lagoons reach an area of 30 acres or larger.) To assure a clear sweep for winds, seasonal changes in direction and relative speeds should be known. Again, farmers, fishermen, or others who work outdoors year around are usually excellent sources of general climatic data if local figures are not available. As with evaporation, however, long term observations should be made to broaden background data for future designs and improvements in primary systems. Because local wind conditions are affected by a number of factors, including temperature, obstructions, etc., a generalization concerning clear distances in the immediate vicinity of the lagoon is difficult to make. In the average case, one might allow a clear distance of 5 to 8 times the height of any groups of trees or bushes from the lagoon. In the case of isolated buildings, a clear sweep equal to the height or width of the structure, whichever is greater, is generally sufficient. In any case, a minimum clear sweep of 300 feet free of all but isolated obstructions should provide adequate wave action.