University Curriculum Development for Decentralized Wastewater Management

Septic Tanks

by

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Table of Contents

SEPTIC TANKS

Introduction

Although relatively inconspicuous, and much maligned, the septic tank is the essential component of the small scale decentralized wastewater management option utilized by approximately 25% of the US population. The wastewaters generated in the residence or from small commercial and institutional activities are collected and transported by the plumbing system drain pipes directly from the building into a unit called the septic tank. The septic tank is a single or multi-chambered watertight vault which provides the first and very important pretreatment in the typical small scale onsite wastewater treatment system. As the wastewater enters the tank the velocity of flow is reduced providing relatively quiescent conditions, which allows portions of the suspended solids to settle to the bottom, permits grease and other floatables to rise to the surface and be retained, and provides storage space for the very complex physical, chemical, and biological processes to occur. The septic tank is probably the single most important treatment unit in the small scale decentralized wastewater management system concept, and accomplishes approximately 50% of the ultimate treatment within the tank. Without this treatment, the discharge of residential wastewater to the soil-absorption system would most certainly lead to premature or excessive clogging of the drainfield. A typical household septic tank system is shown in Figure 1a.

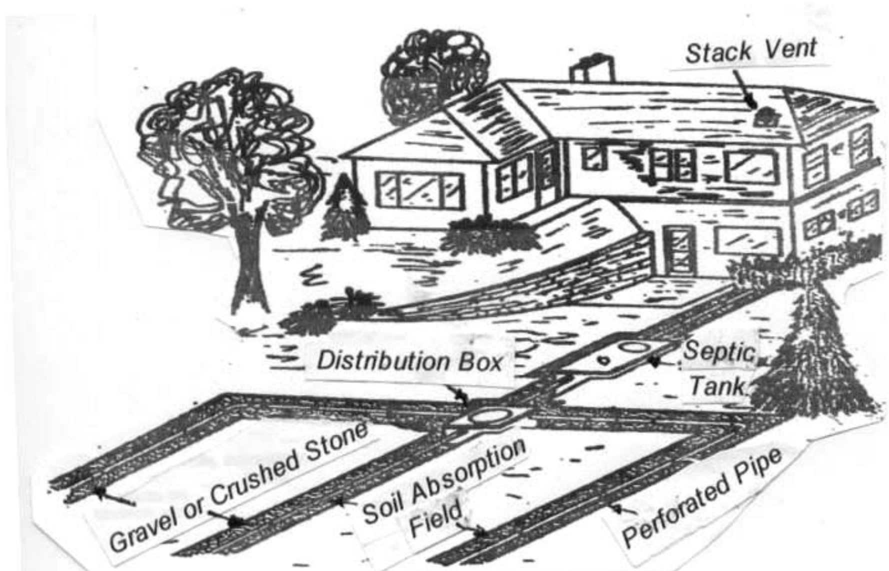


Figure 1a. A typical household septic tank soil absorption system.
University of Wisconsin (1975)

History

M. Mouras of France is generally credited with developing the modern septic tank and in 1881 obtained a patent on a device he named the "Mouras Automatic Scavenger". An excerpt from Mouras' overly optimistic patent description follows:

> *Mouras Automatic Scavenger*
> *"A mysterious contrivance consisting of a vault hermetically closed by a hydraulic seal. By a mysterious operation, and one which reveals an entirely novel principle, it rapidly transforms all the excrementitious matters it receives into a homogeneous fluid, only slightly turbid, and holding all the solid matter in suspension in the form of scarcely visible filaments. The vault is self emptying and continuous in its workings."* (Dunbar, 1908)

The last sentence in the Mouras patent, "the vault is self emptying and continuous in its workings," was very misleading and may have led to many later failures. However, it probably was not used as it is today. It may have been a storage receptacle which was emptied periodically into a local sewer.

In 1895 Donald Cameron, of Great Britain, more correctly described the septic actions and processes within the vault and named it the septic tank.(Crites and Tchobanoglous, 1997) Subsequently, a variety of tank configurations have developed although the fundamental concept remains the same, basically to provide a place for physical, chemical, and biological pre-treatment of the wastewater.

The use of septic tanks for primary treatment of household wastewater first started in the United States in the late 1880s, but surprisingly it would take another 60 years or so for subsurface dispersal of the effluent to become common practice. (Kreissl, 2003)

In 1950 the Housing and Home Finance Agency recognized that the suburban trend of development was extending beyond the limits of existing sewer mains, and that a majority of new homes to be built would be forced to rely on individual onsite sewage treatment systems. (Shuman and McGhan, 1950) Until this time sanitary engineers had recognized the septic tank, followed by soil absorption, as the safest and most dependable method of rural wastewater management, but with a sparsity of real performance data to justify the position. As a consequence, in 1950 the Housing and Home Finance Agency in collaboration with the U.S. Public Health Service sponsored a comprehensive testing program to obtain basic information to improve the design and operational criteria for septic tanks. (Shuman and McGhan, 1950)

Following this, the states began to adopt laws upgrading onsite sewage system design and installation practices to ensure proper functioning and to control the threat posed by waterborne pathogens. (Kreissl, 1982)

In 1996 the U.S. Congress requested the Environmental Protection Agency to report on the potential benefits of onsite/decentralized wastewater treatment and management systems. One year later the report concluded that onsite/decentralized wastewater treatment systems could protect the public health and environment and could lower capital and maintenance costs in low density developments, and provide long term manageable solutions. (US EPA, 2002)

The 1996 EPA Response to Congress on decentralized wastewater treatment systems also concluded that onsite/decentralized systems were especially advantageous in ecologically and environmentally sensitive areas, particularly those where on-lot water reuse and ground water recharge was needed. In the report the adaptability to varying site conditions and the ability to combine technologies/processes were touted as additional benefits in ensuring cost effective and environmentally sound wastewater treatment solutions.

Design Considerations

Materials of Construction

For residential installation, septic tanks are typically made of precast reinforced concrete, fiberglass, and polyethylene, and if less than 6,000 gallons, are typically premanufactured. Formerly, mainly due to the lack of proper materials, wood was of necessity used, but it is generally no longer acceptable. According to Bounds (Bounds, 1997), reinforced concrete is usually the material of choice due to its cost-effectiveness, structural integrity, corrosion resistance, watertightness, and buoyancy resistance. The structural integrity of polyethylene is less than concrete and fiberglass tanks (Crites and Tchobanoglous, 1997), and thus such tanks are typically restricted to unsaturated sites with reduced structural requirements. Cross-section views of typical single and multiple compartment ribbed fiberglass septic tanks are shown in Figures 1b, 2, and 3. The polyethylene and fiberglass tanks are reputed to be non-permeable and have excellent watertight integrity; they are lightweight, more resistant to corrosion, and easy to transport and set in place without cranes. Installation, backfilling, and addressing buoyancy, however, tends to require a bit more effort and time. Plastic tanks are typically fabricated with a rib design sufficiently compatible with the plastic's strength and modulus of elasticity (stress to strain ratio) to ensure its structural strength and integrity under common and long-term loading conditions. Although polyethylene and fiberglass are typically referred to as lightweight "plastic" tanks, fiberglass has much greater structural strength characteristics which are more similar to those of steel. Modulus of elasticity is also much greater in fiberglass than polyethylene; therefore, fiberglass is capable of holding its shape under greater loading conditions (especially long-term loads). Some older fiberglass and polyethylene tanks were prone to deflection and splitting. Field repairs on polyethylene tanks require sophisticated thermal welding techniques. Field repairs on fiberglass tanks can be done with appropriate fiberglass products or epoxies. Newer model tanks are usually constructed with ribs to provide structural stability, and manufacturers generally provide specific recommendations for backfill material and processes to maintain tank integrity. These tanks are lighter than concrete tanks, easier to transport, and easier to handle during installation. However, they are more prone to float out of the ground in areas of high water tables. In such locations they must be kept full of water or anchored to prevent such movement.

Structural Soundness

Septic tanks must be properly designed, reinforced, and constructed of the correct mix of materials, in order to support anticipated loads without cracking, deforming, or collapsing. They must be able to withstand handling and transport after manufacturing, be capable of supporting a 2,500 lb. wheel load in addition to soil loads, and withstand both internal and external hydraulic pressures. Two compartment tanks have the added benefit of the dividing wall providing reinforcing support for the long wall axis. The concrete mixture must be carefully controlled so that the final product meets the 28 day compressive strength of 4,000 psi. Concrete tank walls are usually about four inches thick with No. 5 reinforcing bars spaced at 8 inch centers. Tanks constructed of fiberglass reinforced polyester (FRP) are usually about ¼ inch in thickness. It should be noted that shapes will vary depending upon the type of material, concrete, fiberglass or polyethylene.

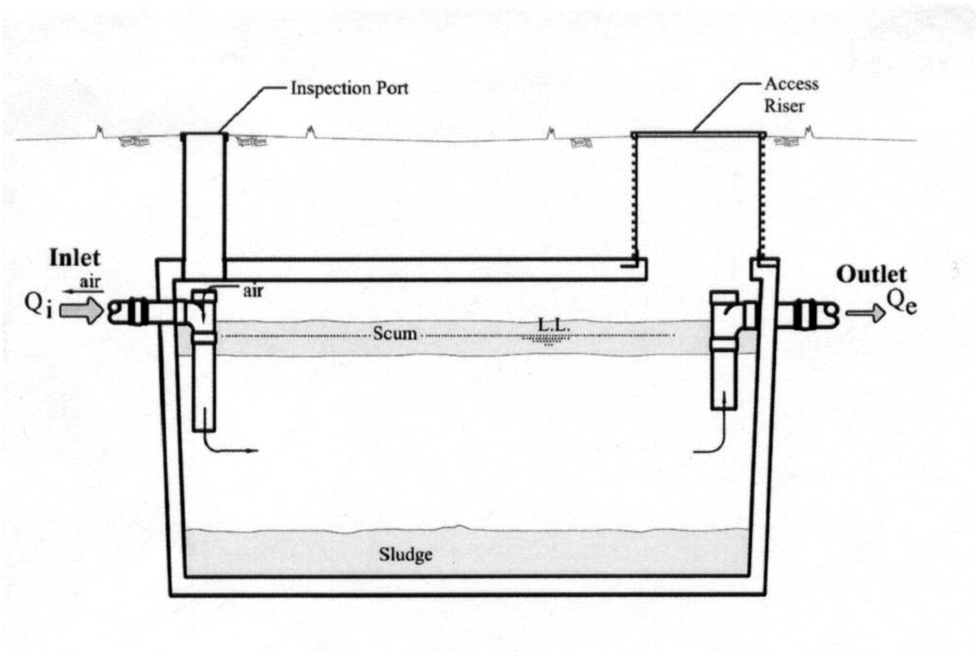


Figure 1b. Section view of single compartment concrete tank, 1,000 gallon

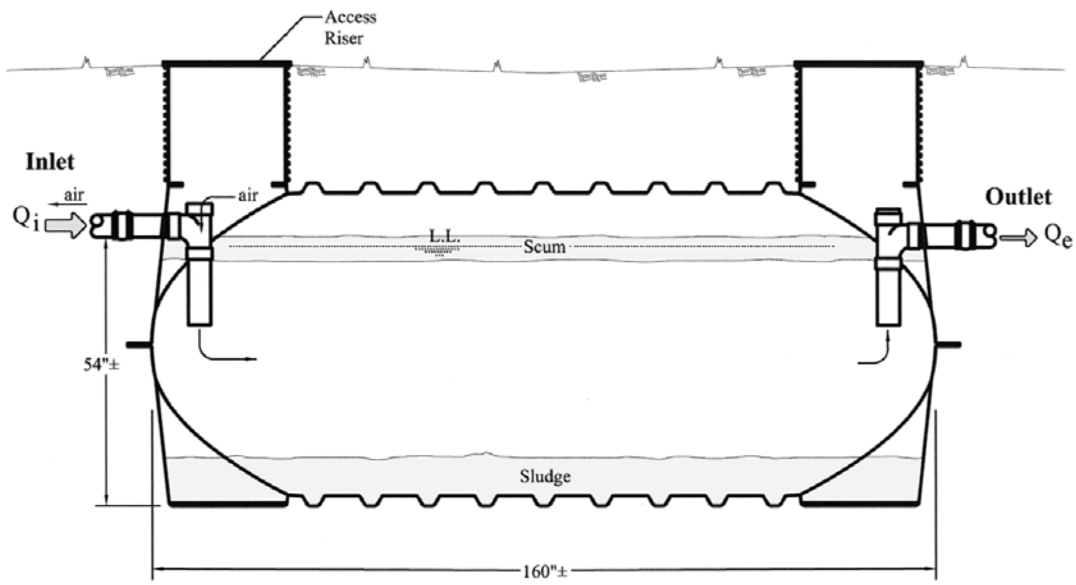


Figure 2. Section view of single compartment tank, fiberglass 1,000 gallon

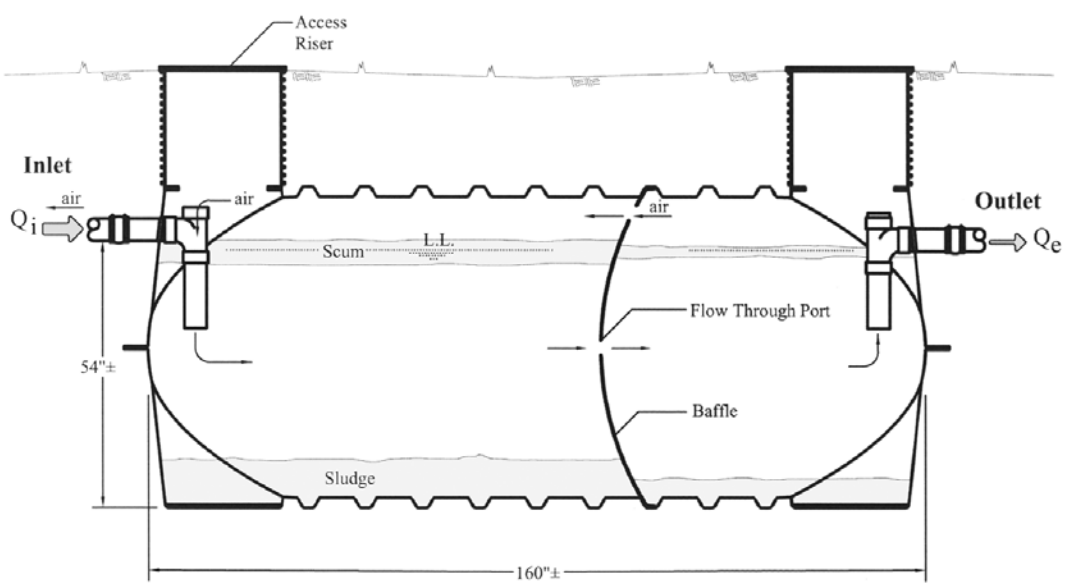


Figure 3. Two compartment fiberglass tank with flow-through ports and shared liquid levels

Sizing

Generally, for the typical single-family residential septic tank system the septic tank is a prefabricated off-the-shelf item from manufacturers. Important factors considered in the original design are volume, surface area, compartmentation, and inlet and outlet arrangements. The septic tank should be sized to provide the best attainable removal of suspended solids and BOD.

Volume

The required size for the septic tank is based upon empirical relationships that have developed through the years, and is directly related to the number of bedrooms in the residence. Generally, the local health department specifies the minimum size of a tank, by promulgating expected average daily waste flows per person which should provide a minimum of 48 hr retention time, before any sludge or scum accumulation. Other design criteria state the tank should provide a minimum of 24 hour retention time at maximum sludge depth and scum accumulation. With the passage of the Energy Policy Act in 1992 the U.S. Congress for the first time established maximum water use standards for toilets, urinals, shower heads and faucets. These standards which applied to plumbing fixtures manufactured after 1994 are shown in Table 1. (Qureshi, 1995)

Table 1. **Plumbing Standards Set by Energy Policy Act of 1992**

Product	Maximum Water Use
Shower heads	2.5 gpm
Faucets	2.5 gpm
Water Closets	1.6 gpf (gallons per flush)
Urinals	1.0 gpf (gallons per flush)

From Qureshi, 1995

As these changes for plumbing fixtures are phased in, the trend toward increasing water demands experienced in the past are beginning to be reversed. As an example, the Seattle, Washington Public Utility District customer base represents about 85 percent of the water service in King County. During the period 1990 to 2000, the population within the service area grew 10 percent, while the water consumption declined 8 percent, and is expected to decrease 4 percent more by 2010. (The Seattle Times, 2003) Table 2 illustrates daily water use per household in the past, pre 1980, and what it might have been if the changes were implemented. Clearly these reductions in water use with the subsequent lessening of wastewater flow will influence future small scale wastewater planning and design. Although experience has shown that even with these low flow fixtures, people will rinse off longer while showering, run faucets longer to fill basins, tubs are bigger, and toilets are often flushed twice, so the low flush and flow fixtures aren't quite as conservative as the numbers represent. However, while this anticipated decrease in per capita water consumption with a concomitant lessening in wastewater generation will decrease the hydraulic loading on treatment systems, it does not reduce the pollutant mass loading, which amounts to 0.18 to 0.22 lbs/day/cap BOD, and 0.20 to 0.25 lbs/day/cap TSS. As previously stated, the local code usually promulgates the average daily per capita wastewater flows. Then by assuming two persons per bedroom, the expected average daily wastewater can be determined.

Table 2. **Daily Water Consumption per Capita**

	Pre 1980	Post 1994
Toilet		
Gallons/flush	5.0	1.6
Water use (gal) (4 flush/day)	20.0	6.4
Shower		
Flow rate (gal/min)	4.0	2.5
Water use (gal) (5 min. shower)	20.0	12.5
Faucet		
Flow rate (gal/min)	3.0	2.5
Water use (gal) (4 min)	12.0	10.0
Total per capital Water use (gal)	52.0	28.9*

Adapted from Qureshi, 1995

*These hypothetical values represent the total daily water use per capita if the 1992 standards were implemented.

1.) Residential Size Tanks

Crites and Tchobanoglous (Crites and Tchobanoglous, 1997) suggested the following tank sizes which should generally achieve effective performance. The values are nominal and refer to the volume occupied by the tank contents not including the reserve space above the outlet invert, and thus, the total volume may be 10 to 20 percent larger. (See Table 3) A hydraulic retention time of 48 hours is recommended based on a sludge and scum free tank.

Table 3. **Common Septic Tank Volumes**

One or two bedrooms	1,000 gal.
Three bedrooms	1,500 gal.
Four bedrooms	2,000 gal.

From Crites and Tchobanoglous

2.) Commercial Size Tanks

For situations such as cluster homes, apartments, small commercial establishments, and shopping malls, the expected wastewater flow cannot be computed by simply knowing the number of bedrooms, but rather must be calculated from empirical equations, or relative fixture flows. It is possible that actual metered flow data from comparable existing facilities may be available and, if so, should be used. It's also important to keep in mind that the relative flow data for "like" facilities with similar floor plans (such as McDonalds, B-Kings, etc.) may not be representative in all locations. Foot traffic, store location, and popularity can cause flow characteristics between like facilities, with common floor areas, to vary by as much as a factor of 10, which could lead to premature overloading. When flow data and growth information are not readily available, plans for easy expansion should be incorporated into the design layout. It is more cost effective to initially install larger primary tankage that will address unexpected usage and growth issues, and also plumb the system for easy expansion of the secondary processes.

For non-residential and commercial/institutional applications the wastewater flow is subject to wide fluctuations with time. The range of typical daily flows from a variety of commercial, institutional, and recreational categories are shown in Tables 4, 5, and 6. Clearly estimating non-residential wastewater flows is a very complex task, considering that there may be a large number of diverse establishments within a given category. (US EPA, 1980) In addition many intangible influences, such as location, popularity, and price, may produce substantial variations among otherwise similar establishments. (US EPA, 1980) In the absence of actual flow data but with personal knowledge of the situation at hand, the designer is allowed some discretion by selecting the typical value or a flow value within the range. The design should provide long enough residence time in the septic tank for proper suspended solids and oil/grease removal by sedimentation and floatation. Clearly the actual residence times in septic tanks may vary significantly, because of the accumulation of sludge and scum, and thus the volume of the tank will vary as well.

To size the septic tank for systems other than residential homes, the rule of thumb often used is to use two to three times the estimated design flow. (US EPA, 2002) This conservative rule is intended to maintain a 24 hour minimum hydraulic retention time when the tank is ready for pumping with the tank one-half to two-thirds full of sludge and scum. (US EPA, 2002) With these larger wastewater flows it may require a concrete septic tank so large it has to be cast in place in the field. Cast in place tanks must be designed structurally and volumetrically according to site and loading conditions. Prefabricated fiberglass tanks are also available and capable of handling some larger flows.

Table 4. **Typical Wastewater Flow Rates from Commercial Sources**

Facility	Unit	Flow, gallon/unit/day Range	Flow, gallon/unit/day Typical
Airport	Passenger	2-4	3
Apartment house	Person	40-80	50
Automobile service station	Vehicle served	8-15	12
	Employee	9-15	13
Bar	Customer	1-5	3
	Employee	10-16	13
Boarding house	Person	25-60	40
Department store	Toilet room	400-600	500
	Employee	8-15	10
Hotel	Guest	40-60	50
	Employee	8-13	10
Industrial building (sanitary waste only)	Employee	7-16	13

Table 4 (continued)

Facility	Unit	Flow, gallons/unit/day Range	Typical
Laundry (self-service)	Machine	450-650	550
	Wash	45-55	50
Office	Employee	7-16	13
Public lavatory	User	3-6	5
Restaurant (with toilet)	Meal	2-4	3
Conventional	Customer	8-10	9
Short order	Customer	3-8	6
Bar/cocktail lounge	Customer	2-4	3
Shopping Center	Employee	7-13	10
	Parking Space	1-3	2
Theater	Seat	2-4	3

Adapted in part from Tchobanoglous, G. and F.L. Burton (1991) Wastewater Engineering, Treatment, Disposal, Reuse. 3rd Ed., McGraw-Hill, New York

Table 5. **Typical Wastewater Flow Rates from Institutional Sources**

Facility	Unit	Flow, gallons/unit/day Range	Typical
Assembly hall	Seat	2-4	3
Hospital, medical	Bed	125-240	165
	Employee	5-15	10
Hospital, mental	Bed	75-140	100
	Employee	5-15	10
Prison	Inmate	80-150	120
	Employee	5-15	10
Rest home	Resident	50-120	90
	Employee	5-15	10
School, day-only:			
With cafeteria, gym, showers	Student	15-30	25
With cafeteria only	Student	10-20	15
Without cafeteria, gym, showers	Student	5-17	11
School, boarding	Student	50-100	75

Adapted in part from Tchobanoglous, G. and F.L. Burton (1991) Wastewater Engineering, Treatment, Disposal, Reuse. 3rd Ed., McGraw-Hill, New York

Table 6. **Typical Wastewater Flow Rates from Recreational Facilities**

		Flow, gallons/unit/day	
Facility	Unit	Range	Typical
Apartment, resort	Person	50-70	60
Bowling alley	Alley	150-250	200
Cabin, resort	Person	8-50	40
Cafeteria	Customer	1-3	2
	Employee	8-12	10
Camps			
Pioneer type	Person	15-30	25
Children's, with central toilet/bath	Person	35-50	45
Day, with meals	Person	10-20	15
Day without meals	Person	10-15	13
Luxury, private bath	Person	75-100	90
Trailer camp	Trailer	75-150	125
Campground – developed	Person	20-40	30
Cocktail Lounge	Seat	12-25	20
Coffee Shop	Customer	4-8	6
	Employee	8-12	10
Country Club	Guests onsite	60-130	100
	Employee	10-15	13
Dining hall	Meal Served	4-10	7
Dormitory, bunkhouse	Person	20-50	40
Fairground	Visitor	1-2	2
Hotel, resort	Person	40-60	50
Picnic park, flush toilets	Visitor	5-10	8
Store, resort	Customer	1-4	3
	Employee	8-12	10
Swimming Pool	Customer	5-12	10
	Employee	8-12	10
Theater	Seat	2-4	3
Visitor center	Visitor	4-8	5

Adapted in part from Tchobanoglous, G. and F.L. Burton (1991) Wastewater Engineering, Treatment, Disposal, Reuse. 3rd Ed., McGraw-Hill, New York

Septic Tank Effluent Pumps (Dosing Tank)

In septic tanks equipped with discharge pumps their internal capacity is divided into distinctive horizontal zones. As indicated below, the tank's total volume is equal to the sum of the volumes of each zone.

$$V_T = V_R + V_{OA} + V_{CZ} + V_{SC} + V_{SL}$$

A cross section of a 1,000 gallon concrete septic tank equipped with an effluent pump is shown in Figure 4. The designation of 1,000 gallon tank is nominal and refers to the volume normally occupied by the tank contents, not including the reserve space. Therefore, the total volume is usually about 15 to 20 percent larger. Referring to Figure 4:

- The reserve space V_R is the volume from the top of the scum layer to the soffit. This space allows for ventilation of gases back through the household plumbing stack vent.
- The operating zone V_{OA} is that portion of the tank between the "off" level and "high water alarm level." It should be sufficient to modulate surge peak flows without causing nuisance alarms or excessive hydraulic gradients.
- The clear zone V_{CZ} varies and lies between the bottom of the scum and the top of the sludge layer.
- The scum layer V_{SC} is that portion of the septic tank contents that floats. Generally one-quarter of the scum layer is assumed to float above the liquid level, while three-quarters is submerged.
- The sludge layer V_{SL} is the accumulation of solids that settle on the bottom of the tank. Keeping the operating zone small has the advantage of maximizing volumes of sludge and scum that can be stored. Limiting the liquid level range to 6 to 12 inches or approximately 10% of the total volume promotes stratification and discourages suspension of solids in the tank.

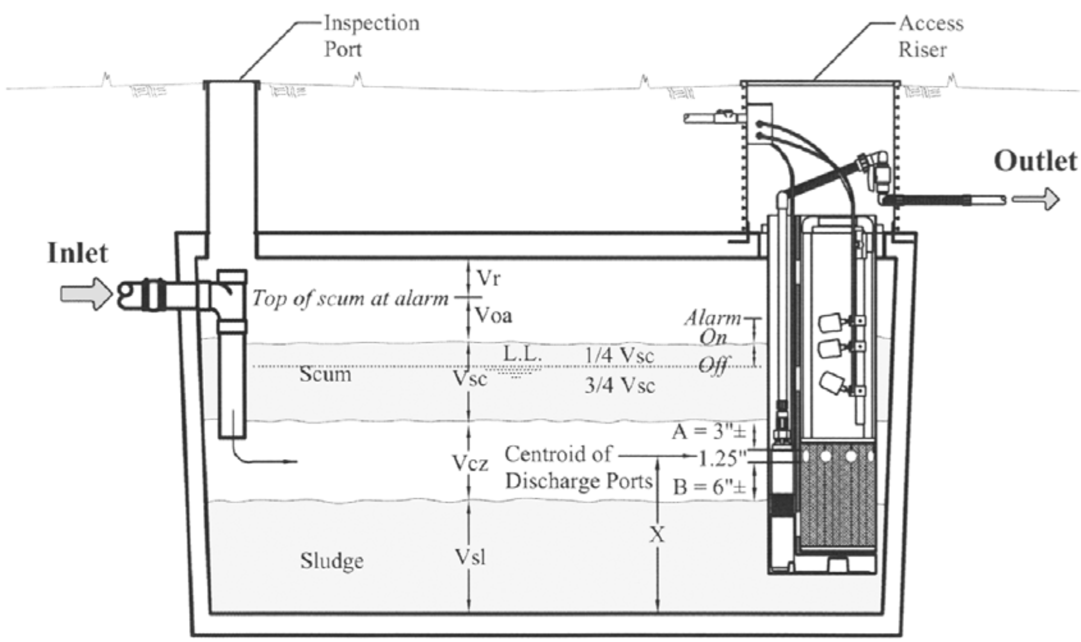


Figure 4. Typical 1,000 gallon concrete design septic tank with a pump vault
From Bounds, 1997

Processes within the Septic Tank

While generally thought of as a very simple concept, the septic tank is actually a very complex physical, chemical and biological processing unit. The septic tank provides for the separation, storage, and digestion of suspended solids as well as for the growth, reproduction and death of large numbers of anaerobic organisms. BOD removals of 50 to 60 percent and total suspended solids removals between 60 to 80 percent are easily accomplished. See Table 11.

Settling, Flotation and Liquid/Solids Separation

Settling is one of the most widely used unit processes in wastewater treatment, which involves the separation of suspended particles that are heavier than water by gravitational settling. The septic tank is a gravitational settling device that provides a space for sedimentation and floatation to take place. This primary clarification improves the wastewater quality prior to further treatment in the downstream treatment units, such as the soil absorption field and many other secondary treatment processes. Thus the primary purpose of the septic tank is to provide relatively quiescent conditions to allow settleable solids to sink to the bottom and accumulate and floatable solids to rise to the top and accumulate. This segregation and stratification that occurs is essential to the overall performance of the septic tank, and involves both ascending and descending matter. Gas ebullition is typically sporadic, but does affect the resuspension of settled material and the movement of anaerobic microbes between zones. In addition there are also periods when parts of the submerged scum settles back.

In general, four types of settling phenomena have been defined:

Type 1) Discrete particle

Type 2) Flocculant

Type 3) Hindered (also called zone)

Type 4) Compression

With such heterogeneous wastewaters and variable flows during the settling process in a septic tank it is possible that all four types of settling may occur. The four types of settling are described in Table 7, and shown graphically in Figure 5.

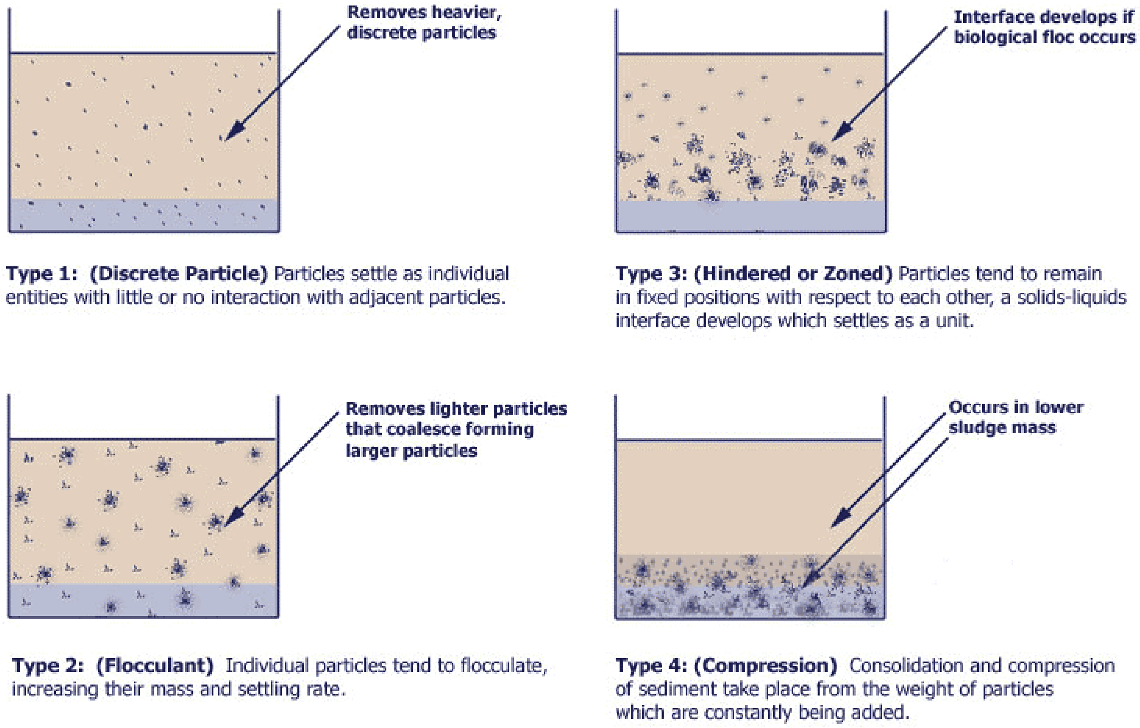


Figure 5. Types of settling phenomena

Table 7

Types of Settling Phenomena Involved in a Septic Tank
(Adapted from Hazen, 1904)

Type of Settling Phenomena	Description	Occurrence in Septic Tank
(Type 1) Discrete Particle	Settling of particles in a suspension of low solids concentration, particles settle as individual entities, with little or no interaction with adjacent particles.	Removes heavier discrete irregular particles.
(Type 2) Flocculant	Individual particles tend to coalesce, or flocculate, increasing their mass and settling rate.	Removes lighter particles that flocculate into heavier particles.
(Type 3) Hindered (Zone)	The particles tend to remain in fixed positions with respect to each other, a solids-liquid interface develops at the top of the settling mass, which settles as a unit.	Occurs if biological floc develops.
(Type 4) Compression	Consolidation and compression of sediment takes place from the weight of the particles which are constantly being added. Further settling can occur only by compression of the structure.	Occurs in the lower sludge mass.

Analysis of Discrete Particle Settling

A discrete particle is one that does not alter its size, shape, and weight during the settling process. While the residential wastewater entering the septic tank contains irregular particles and, therefore, does not fit the strict definition of a suspension of discrete particles, the analysis of the settling of discrete particles yields some very important results. The classic laws of settling by Newton and Stokes state that a discrete particle settling in a quiescent fluid will accelerate to a terminal vertical velocity at which time the frictional resistance, or drag, equals the gravitational force. (See Figure 6.) The frictional drag force is a function of the particle velocity, fluid density, fluid viscosity, particle diameter and drag coefficient. The gravitational force depends upon the density of the particle and the fluid, the acceleration of gravity and the volume of the particle (Metcalf and Eddy, 1979). Hazen (Hazen, 1904) and Camp (Camp, 1946) presented excellent treatises on settling theory. They analyzed the settling of discrete particles in a so-called “ideal basin”, based upon the following three assumptions: a.) the direction of flow is horizontal with a uniform velocity; b.) the concentration of suspended particles of each size is uniform over the depth at the inlet end; and c.) the particles reaching the bottom remain there.

Based upon a plug flow analysis, where Q in equals Q out, in order for a discrete particle to settle out the actual settling velocity v_s must be equal or greater than v_o where v_o is the velocity of a particle that falls through h in time t. See Figure 7. Due to inlet and outlet influences, plug flow conditions as strictly defined are only approximated in a septic tank.

Since $v_o = \frac{h}{t}$ and $t = \frac{C}{Q}$ and $C = hA$ and $h = \frac{C}{A}$ therefore $v_o = \frac{\frac{C}{A}}{\frac{C}{Q}} = \frac{Q}{A}$ which is called the surface overflow rate (SOR) or surface loading rate (SLR). Similarly, particles with $v_s < v_o$ will be removed in the ratio $X_R = \frac{v_s}{v_o}$. Thus, for Type I settling in an "ideal basin" it is independent of depth and detention time but is directly related to the surface overflow rate. Neither the depth nor the residence time in the septic tank influences particle removal efficiency, the relationship is entirely between flow and surface area. However, practical results are influenced by turbulence, eddy and thermal currents, design of inlet and outlet collectors and wastewater characteristics.

Particulate setting in a septic tank is mainly discrete or flocculant settling. Both processes rely on the properties of particle size, specific gravity, shape, and fluid specific gravity and viscosity. Discrete settling implies that the particles settle independently and is not influenced by other particles, and the terminal settling velocity may be estimated by Newton's law. On the other hand, flocculant settling cannot be so easily determined, but it can be postulated that it increases with time as particles collide increasing their density.

It can be shown that suspended solids removal is not a function of depth by considering a septic tank exactly the same as that of Figure 7, with the same Q, but half full of sludge as shown in Figure 8. The actual settling velocity v_s would remain unchanged with the same wastewater but since the detention time and depth are half that in the previous example, the same ratio of particle removal, $X_R = \frac{v_s}{v_o}$ would be accomplished.

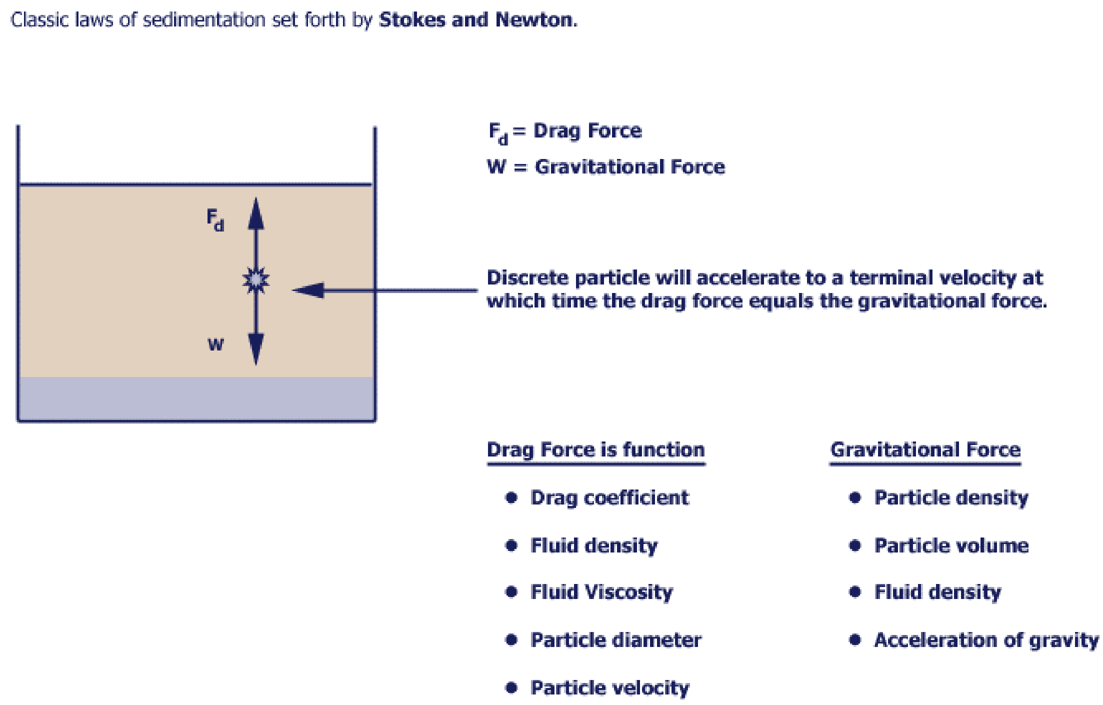


Figure 6. Analysis of discrete particle settling.

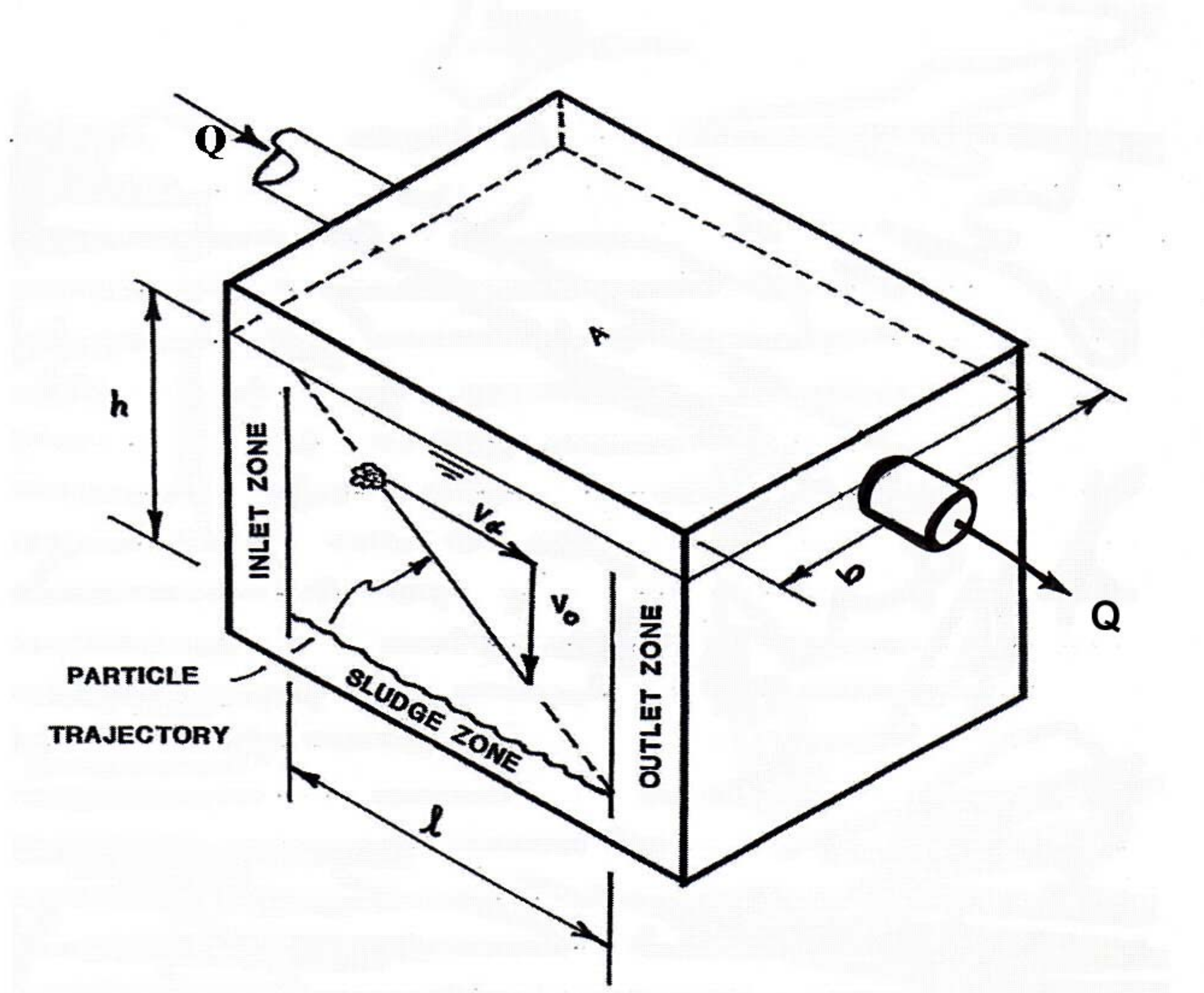


Figure 7. Ideal settling in a septic tank (Seabloom et al., 1982)

Q = Quantity of flow

C = Volume of tank

A = Surface area of settling zone

h = depth of liquid

t = detention time

l = length

V_s = actual settling velocity

V_o = velocity of particle that falls through h in time t

V_x = horizontal velocity

b = width

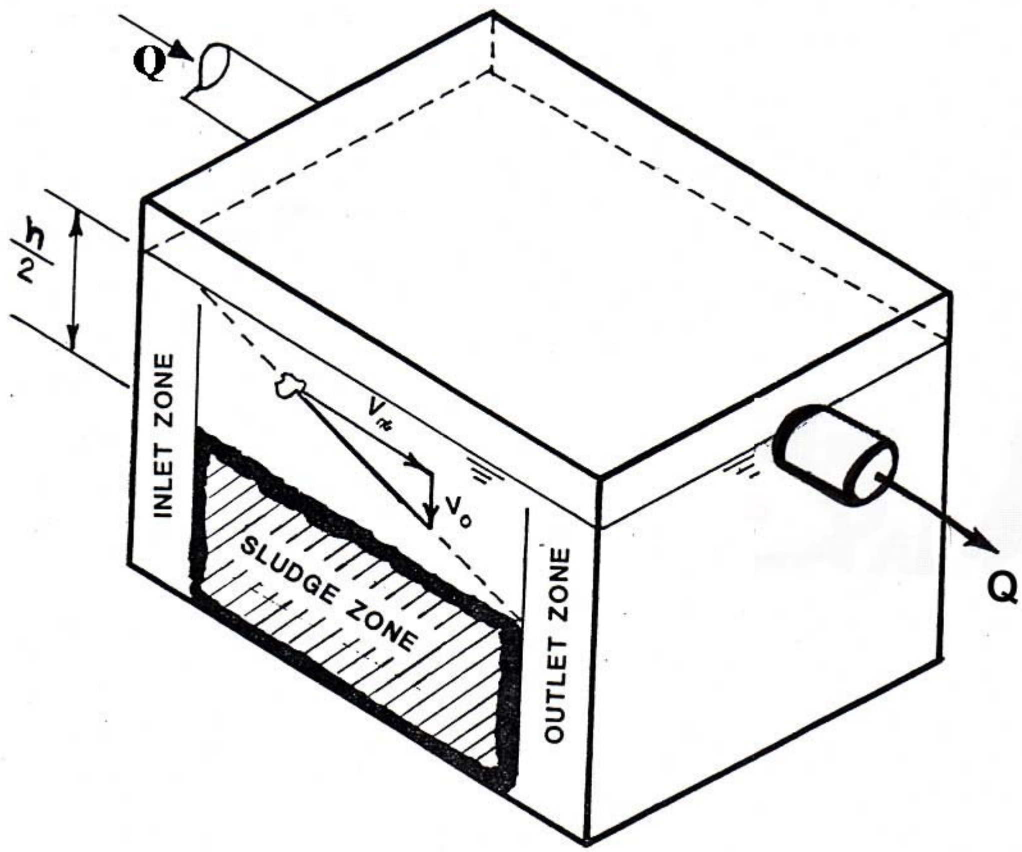
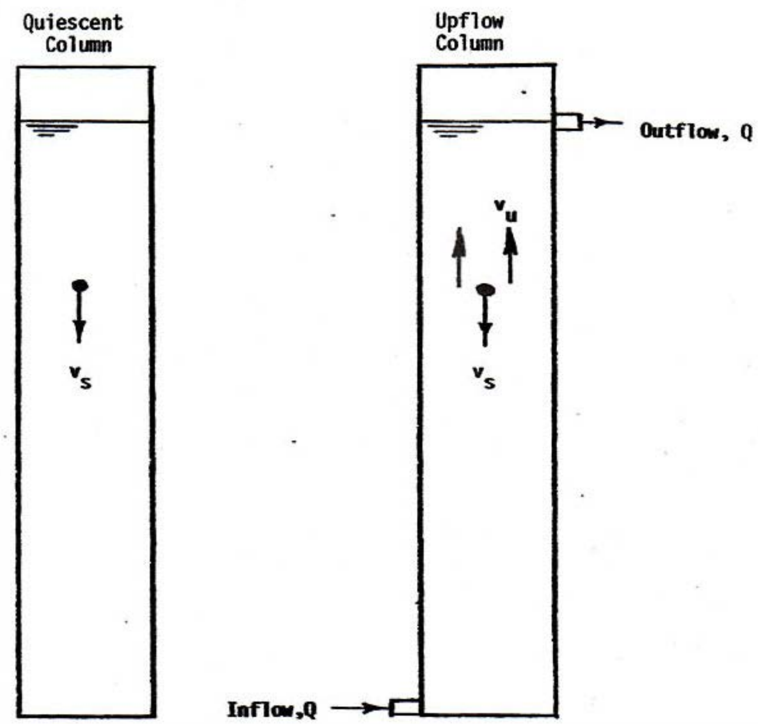


Figure 8. Ideal settling in a septic tank half full of sludge (Seabloom et al., 1982)



a b

V_S = Terminal Settling Velocity

V_U = Upflow Velocity

Figure 9. The Upflow Water Column Analogy (Benedict, 1975)

The concept of the surface overflow rate can also be demonstrated by the upflow water column analogy. In Figure 9a a quiescent column of water with a uniform distribution of suspended solids is shown. Consider a single discrete suspended particle that under the influence of gravity accelerates downward to reach a terminal velocity V_S. The second identical column shown in Figure 9b has the same distribution of suspended solids, but also has an inflow Q at the base. By the continuity theorem, this would produce an upward flow of water $Q = AV_U$ where A is the cross-sectional area of the column and V_U is the upward velocity. Also it can be seen that $V_U = \frac{Q}{A}$ is the surface overflow rate, and if $V_S > V_U$ the particles will settle downward, but if $V_S < V_U$ the particles will be carried upward and out.

As previously stated, in actual practice the effects of inlet and outlet turbulence, thermal currents, short circuiting, hydraulic surges, and resuspension of settled solids by biological decomposition will influence the performance of the tank.

Despite the clear theoretical relationship of the SOR to solids removal efficiency, the theory may not necessarily be extrapolated to conditions in the septic tank. This is particularly true at the inlets and outlets where turbulence, eddy currents, thermal effects, solids resuspension, scouring and wide flow variations drastically complicate the problem. However, clearly a septic tank with greater surface area would tend to be more efficient than one with equivalent volume and a smaller area (i.e., equivalent inflows would result in smaller liquid rises in the larger surface tank; thus reducing the discharge driving head and gravity out-fall rate). Systems with discharge pump assemblies could also result in similar improved settling characteristics by forcing longer quiescent times between discharge occurrences and keeping discharge rates less than 5 gpm. Discharge rates of 5 gpm and more are larger than most discharges from a properly designed residential tank. It is important to note that limiting the pump volume in each dose will help to limit turbulence and resuspension of solids during the pumping event. If the pump discharge occurs during a significant inflow event, solids carry-over may occur.

Flotation

The removal of suspended solids by settling in a septic tank is only a part of its overall capability. Separation of suspended solids by floatation also occurs in the tank. The process takes place during quiescence and may in principle be compared to settling in reverse. Also the floatation process is enhanced by the presence of oil and grease in the wastewater, which congeals on the small discrete particle surfaces, making them more buoyant. The accumulation of scum by floatation is a significant factor relative to the efficient removal of grease, oil, and floating solids. The rate of scum accumulation by floatation will be discussed in more detail in a later section.

Flow Modulation

The maximum daily household water use standards set by Congress are shown in Table 1, and the hypothetical total daily water consumption per capita is listed in Table 2. The rate at which water is used over a twenty-four hour period is quite variable, as shown in Figure 10. There are two distinct peak uses, mid morning and mid evening. However, the rate at which water is used in the house is not the rate at which it enters and exits the septic tank. Because of the so-called storage effect, some household water using devices store some of the water before allowing it to be discharged as wastewater; a bath tub is an example. This results in a certain amount of modulation of the subsequent wastewater flow. In addition the time of flow in the sewer pipe to the septic tank further controls the peak discharge. It is common practice to set the invert of the septic tank inlet 2 to 3 inches above that of the invert of the outlet pipe. Thus, for water to leave the septic tank the wastewater level must rise above the level of the outlet invert. The rise of the wastewater level provides additional storage and is equal to the surface area of the tank times the rise in elevation, which also provides the necessary head for the discharge of the wastewater to a downstream treatment unit. Obviously, the more the water surface area, the less rise in water level and lower the discharge rate. If the surface overflow rate was reduced, the modulation would be even greater, which would be a benefit for solids removals and flow equalization for

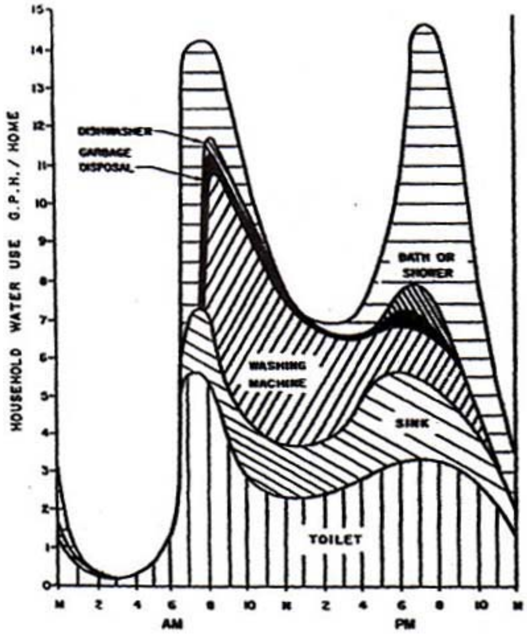


Figure 10. Daily variation in household water use. Bennett, E., and D. Linstedt, 1970, Colorado State University.

downstream processes. Shallow tanks (for a given volume) and effluent screens with flow modulating orifices are two ways that the modulation could be increased (Otis, 2004).

In addition the flows from schools, churches, restaurants, residential clusters, offices, hospitals, parks and food processors are characterized with peak and surge flows. The flow from these sources may be modulated through the use of pumps and adjustable timer controls to ensure that the wastewater collection, conveyance and treatment system remain efficient and affordable. For example the secondary and final treatment processes may be based upon the modulated flow rather than peak conditions. The reserve space and operating zone in septic tanks can be sufficiently designed to take the surge out of peak loads. A hypothetical flow modulated diagram is shown in Figure 11.

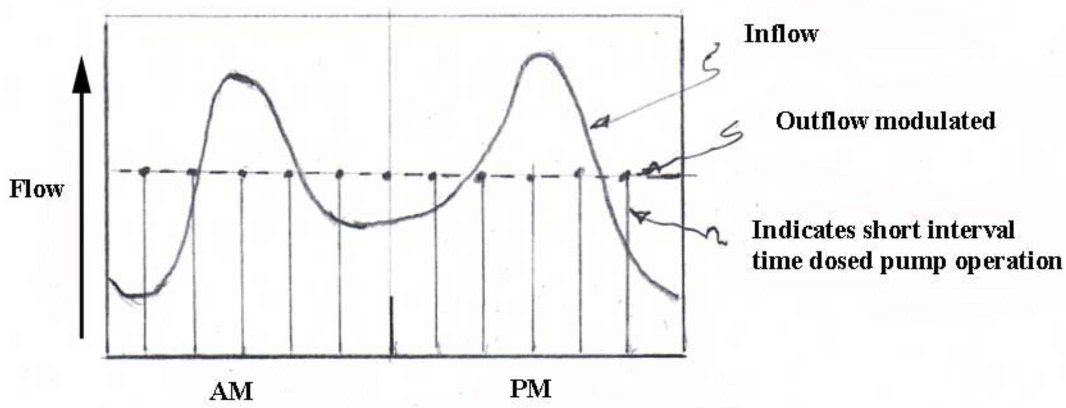


Figure 11. Peak discharge vs. modulated discharge

Compartmentation

There are conflicting findings about whether compartmentation of septic tanks is beneficial or not. Some investigators have stated the benefit of dividing a septic tank into compartments is insignificant, while others report that a two-compartmented tank is better than a single-compartment tank of equal capacity. Some experimental studies dating back to 1922 at the University of Illinois by Lehmann, Kelleher, and Buswell (Lehmann et al., 1928), at Victoria, Australia in 1933 and 1936 by Hepurn (Hepburn, 1933), 1949 by Weibel, Straub, and Thoman (Weibel et al., 1949), and in 1950 by Shuman and McGhan (Shuman and McGhan, 1950) indicated some advantage to compartmentation. The Manual of Septic Tank Practice (Public Health Service, 1969); the EPA Design Manual – Onsite Wastewater Treatment and Disposal Systems (US EPA, 1980); the EPA Onsite Wastewater Treatment Systems Manual (US EPA, 2002); and Studies on Household Sewage Disposal Systems, Part III, Housing and Home Finance Agency and the Public Health Service (1951) state that while the single compartment tank would give acceptable performance, a two compartment tank would provide better suspended solids removal. There is some evidence that outlet screens in two compartment tanks have longer times between cleaning than single compartment tanks (Kreissl, 2003). This is presumably due to the trapping action of the second compartment which allows settling of particles scoured out of the first compartment (Kiker). Recalling basic settling theory, the compartmentation of a septic tank actually results in two smaller tanks connected in series if an overflow tee is installed in the baffle wall and, thus, reduces the surface area and increases the surface overflow rate. Theoretically, particles, other than those resuspended by scouring or gasification, or floculated will not settle out in the final compartment if they did not do so in the first and larger compartment. Compartmentation may also be accomplished by placing flow-through ports in the baffle between the expected sludge and scum layers. This hydraulically links the liquid surface of both compartments, and thus the liquid level rise and flow through rates would be equivalent and dependent on the outlet configuration (shared liquid levels and equivalent surface area). However, the flow to the outlet of the first compartment would increase the flow velocity and would impart turbulence to the second compartment.

Winneberger (Winneberger, 1984) explains the effect that velocities and turbulences have on the migration path of particles as they travel through septic tanks. He concluded that slow velocities through long tanks yield the highest effluent quality.

Based upon some work at the Glide, Oregon, pressure sewer system, Bowne (Bowne, 1982) reported in 1982 that single compartment tanks were satisfactory but inferior to multiple compartment tanks in terms of suspended solids retention. Bowne subsequently modified his stand to reflect later information (Bowne, 1982). Bowne pointed out the questionable economics of increasing the cost of a septic tank just to provide compartmentation. Bowne also stated compartmentation adds complexity to an otherwise simple tank, the need for which is minimal when compared with the need for a watertight tank. Other investigators have stated that the benefit of compartmentation is insignificant (Malan, 1964; University of Wisconsin, 1978).

Although there is little significant or measurable difference in effluent quality, operators and service providers tend to be more comfortable with servicing systems when the solids are baffled away from the discharge assemblies and thus generally prefer compartmented tanks. More recent viewpoints also suggest that compartmented tanks with flow-through ports do not add significant complexity since additional risers and clean-outs are not necessary (see Figures 14 and 15). Larger tanks provide better solids segregation, solids storage capacity, lower overflow rates, greater surge capacity, and greater overall retention times. The cost difference between 1000 and 1500 gallon tanks is typically less than 20%, yet yields a 50% increase in capacity. And, over the life of the system, pump out frequencies can be reduced such as to make up the little extra initial cost many times over. Consequently, recent design preferences lean towards larger and baffled tanks with flow-through ports as shown in Figure 3.

Since the question of compartmentation suffered from a lack of definitive data concerning its benefit, or lack of benefit, a study was conducted by the National Sanitation Foundation (NSF) for the University of Washington in 1982 (Seabloom et al., 1982). The purpose of the study was to determine the treatment efficiency of a single-chamber 1,000-gallon septic tank and a double-chambered 1,000-gallon septic tank when operated under parallel conditions, using comminuted raw sewage from the City of Ann Arbor, Michigan. Thus some of the values represent numbers that were measured as wastewater treatment plant influent after long conveyance times in collection systems, and comminution prior to entering the test septic tanks. These values also represent annual averages including winter inflows & infiltration.

With reference to Table 8, the superior settling capability and BOD reduction of the single chamber tank over the two-compartment tank was demonstrated. To minimize the controversy about the condition of the wastewater (raw or comminuted) a full scale testing program was carried out at the University of Maine (Boyer and Rock, 1992; Rock and Boyer, 1995). The wastewater from college dormitories was pumped to the tanks under study. Thus its consistency was probably not unlike comminuted municipal wastewater. Nevertheless, from the results of their study shown in Table 8, it was concluded in general that the two-compartment tank gave the best performance with respect to BOD and TSS removal. (Boyer and Rock, 1992; Rock and Boyer, 1995) These results directly contradicted the data from reference (Seabloom et al., 1982), thus there clearly is a need for further research on the question of compartmentation. It is quite possible that less emphasis should be devoted to the study of compartmentation and rather, more study of long shallow tanks, discussed later in the tank geometry section.

Table 8. **<u>Comparison of Effluent from Single and Compartmented Septic Tanks</u>**

National Sanitation Foundation Study (Seabloom et al., 1982)

Characteristic		Single Chamber Influent	Single Chamber Effluent	Single Chamber Percent Removal	Double Chamber Influent	Double Chamber Effluent	Double Chamber Percent Removal
BOD	mg/L	184	85	54%	184	99	46%
Suspended Solids	mg/L	234	44	81%	234	123	48%
Settleable Solids	mL/L	16.9	0.2	98.8%	16.9	0.6	96.6%

University of Maine Study (Boyer and Rock, 1992)

Characteristic		Single Chamber Influent	Single Chamber Effluent	Single Chamber Percent Removal	Double Chamber Influent	Double Chamber Effluent	Double Chamber Percent Removal
BOD	mg/L	288	195	32.3%	267	184	31.1%
Suspended Solids	mg/L	310	64	79.5%	306	57	81.5%
Settleable Solids	mL/L*	--	--	--	--	--	--

*Not available. Effluent values represent values from tanks without screens or effluent filters.

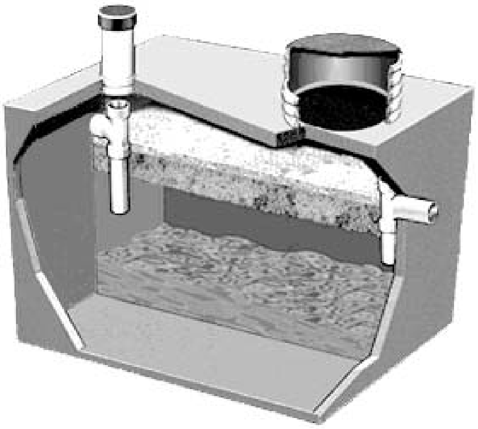


Figure 12. Typical Gravity Septic Tank
(Single Compartment)

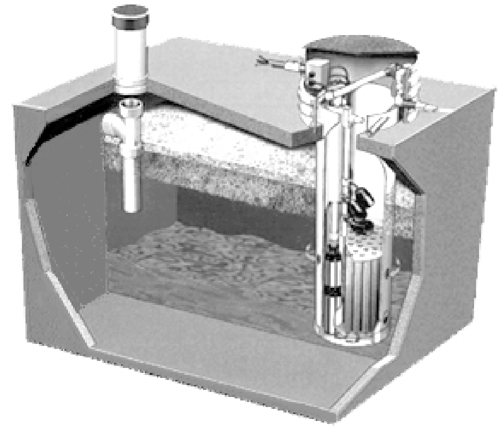


Figure 13. Dosing Septic Tank*
(Single Compartment)
*Installation may vary with centrifugal pump set on tank bottom.

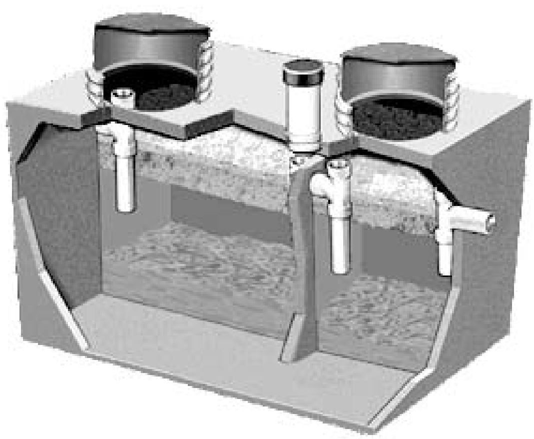


Figure 14. Typical Gravity Septic Tank
(Two Compartment)

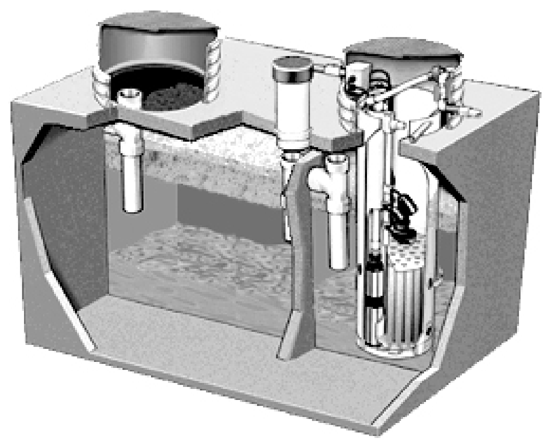


Figure 15. Dosing Septic Tank*
(Two Compartment)
*Installation may vary with centrifugal pump set on tank bottom.

A later report to the Washington State Board of Health presented numerous arguments for requiring two-compartment tanks in the State (WA State DSHS, 1976). It was pointed out that, based upon the observations of experienced persons in the septic tank industry, the two-compartment tank gave better service than the single-compartment tank, and provided a safety factor by preventing solids from being carried over into the soil absorption system when the first compartment had filled with solids and scum. Of course, as previously stated, by discrete particle settling theory this should not happen. Typical single compartment gravity and dosing septic tanks are shown in Figures 12 and 13, respectively. Typical two compartment dosing septic tanks are shown in Figures 14 and 15, respectively.

Biological Decomposition

There are two types of biological decomposition depending upon the presence or absence of oxygen, namely aerobic and anaerobic. The septic tank is, in effect, a horizontal flow reactor in which aerobic, facultative, and anaerobic organisms perform complex biochemical processes.

Aerobic decomposition. The organic matter is decomposed in the presence of oxygen and the process is called "aerobic." It is a very complicated biological conversion of the carbonaceous organic matter into new cell tissue (biomass) and the conversion of various solid organic components into gaseous end products. See Figure 16. The process encourages the growth of myriads of living organisms whose respiratory requirements quickly diminish the dissolved oxygen, and it generally creates no odor problems. Even though the environment in the septic tank would generally be anoxic or anaerobic, it is quite possible that due to an unusually large flow of relatively clean wastewater containing considerable dissolved oxygen, aerobic conditions might briefly prevail in the clear zone between the top of the settled sludge and the bottom of the scum layer. This condition would certainly be short-lived because the microbial population would rapidly deplete the dissolved oxygen.

Anaerobic decomposition. Anaerobic decomposition is a complex two-stage process that takes place in the absence of oxygen. An idealized illustration of the process is shown in Figure 17.

Acid or non-methanogenic phase. In this first stage the acid forming bacteria hydrolyze complex organic molecules to simple soluble compounds. The starches are hydrolyzed to simple sugars and the proteins are broken down into amino acids, while the fats remain essentially intact. Continued metabolism leads to the formation of organic acids which depress the pH and retard further bacterial decomposition. (See Figure 17.)

Figure 16. Aerobic decomposition

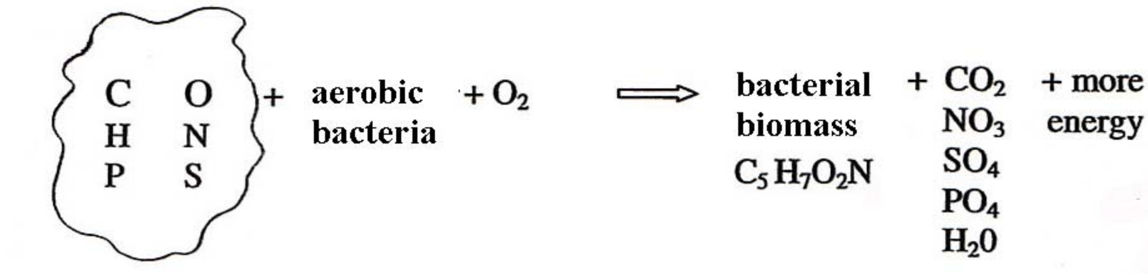
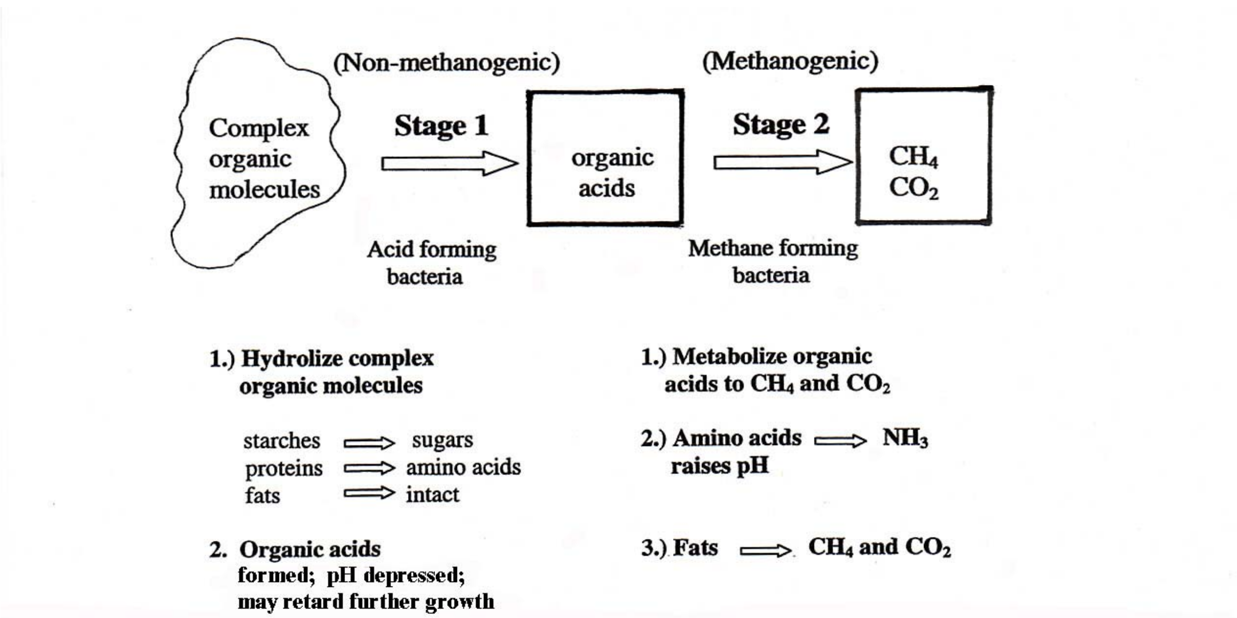


Figure 17. Two stages in anaerobic decomposition



Methanogenic (methane producing) phase. In a continuous process a second group of organisms known as the methane-forming bacteria, utilize the organic acids as substrate and metabolize the acids to CO_2 and CH_4. The amino acids are now broken down resulting in the formation of ammonia, which tends to neutralize some of the acids and raises the pH to a more favorable level for methane bacteria, which now also attack the fats. The fatty acids are decomposed into simpler compounds which can now be metabolized to CH_4 and CO_2.

Large numbers of intestinal organisms die in the adverse environment of the tank. Many other facultative and anaerobic bacteria grow, reproduce, and die in the tank. Many of these organisms are carried up by rising gas bubbles so as to seed the liquid contents and enhance the anaerobic decomposition of the remaining organic material.

The reduction of organic matter during anaerobic decomposition is accompanied by the generation of H_2S and other foul smelling gases such as the mercaptans. These gases escape the septic tank by flowing back through the household plumbing vent, usually exiting through the residence roof, or through the septic tank risers, or out through the soil absorption system.

Anaerobic decomposition of the organic sludge and scum takes place, first forming volatile acids which are then eventually converted mostly to water, carbon dioxide and methane. Soluble organic matter is also stabilized by anaerobic bacteria by a similar process. The result is a significant reduction of sludge volume (Baumann et al., 1978).

Under long-term quiescent conditions, as the digestion proceeds the contents of the tank stratify into three zones: the settled solids form an anaerobic zone on the bottom; the floating solids form another anaerobic zones on the surface; and in between the two an anaerobic zone of relatively clear liquid results. The flow in the clear zone tends to move in small increments. Data from numerous studies shown in Table 9 and 10, indicates the septic tank influent is dramatically improved after flowing through the tank. Table 9 portrays the BOD, TSS, and grease in the wastewater as it enters into the septic tank. After exiting the tank the dramatic improvement in the quality of the wastewater is evidenced by a reduction in BOD to 122 mg/L, TSS to 72 mg/L, and grease to 21 mg/L as shown in Table 10. Finally, the average percentage removal of these parameters are shown in Table 11, namely an 60% reduction in BOD, a 77% removal of TSS, and 79% diminishment of grease.

Table 9. Characteristics of Raw Residential Wastewater

Source	BOD_5 mg/L	TSS mg/L	Oil and Grease mg/L
Housing and Home Finance Agency (Long, 1997)	370	348	100
Bounds (Bounds, 1997)	304	226	42
Seabloom (Seabloom et al., 1982)	184	234	--
Otis et al. (Otis et al., 1973)	233	269	--
Crites et al. (Crites and Tchobanoglous, 1997)	450	503	164
Average	308	316	102

Table 10. Characteristics of Septic Tank Effluent

Source	BOD_5 mg/L	TSS mg/L	Oil and Grease mg/L
Housing and Home Finance Agency (Long, 1997)	93	118	18
Bounds (Bounds, 1997)	118	52	16
Seabloom (Seabloom et al., 1982)	85	44	--
Otis et al. (Otis et al., 1973)	125	60	--
Crites et al.[a] (Crites and Tchobanoglous, 1997)	190	85	30
Average	122	72	21

[a]Without filter and kitchen wastes

Table 11. Average Removal of BOD, TSS and Grease in Septic Tank

Parameter	Average Raw Sewage Influent	Average Septic Tank Effluent	% Removal
BOD mg/L	308	122	60
Total Suspended Solids mg/L	316	72	77
Grease mg/L	102	21	79

Adapted from Tables 9 and 10

Most municipal primary wastewater treatment plants would be hard pressed to meet such a level of treatment. Clearly, the energy-free septic tank is a most cost-effective method of primary treatment for residential wastewater. However, as noted in Table 11, septic tank effluent still has a relatively high BOD, has considerable suspended solids and grease, and also contains large populations of enteric coliform organisms as well as possible presence of pathogens and must receive further treatment, such as though a subsurface soil absorption system before being discharged into the environment. Also it should be remembered the nitrogen in the raw wastewater entering the septic tank is in the complex organic molecular form from the proteinaceous matter in feces and the urea from the urine. The decomposition by anaerobic bacteria known as ammonification readily changes a portion of both to ammonia, which then exits the tank. Although not the main purpose of the septic tank, there is, however, some removal of nitrogen resulting from the settling of solids and floatation of scum, amounting to 10-30% N. (Oakley, 2003; Lenning, 2003)

Solids Accumulation Rate

It is important to estimate the scum and solids accumulation rates in the septic tank in order to predict the septage (sludge + scum) removal intervals. The two most accepted empirical relationships for predicting the sludge and scum accumulations in a septic tank were suggested in 1988 by Bounds (Bounds, 1988) and in 1955 by Weibel (US PHS), et al. (Weibel et al., 1955).

These sludge and scum accumulation rates have a statistical confidence level of 95%, and predict the gallons-per-person accumulated after any time given in years; thus, they may be used to calculate the pumping interval for any sized tank. The two equations are as follows and are shown graphically in Figure 18, where it can be seen the Bounds equation would give slightly larger quantities of solids and scum.

$N_{Sl+Sc} = 47t^{0.675}$ (Bounds)
where N_{Sl+Sc} = volume of sludge and scum, in gallons per capita after time t in years — Equation No. 1

$N_{Sc} = 5.24t + 12.04$ (Weibel et al) — Equation No. 2
$N_{Sl} = 8.15t + 38.82$ — Equation No. 3
$N_{Sl+Sc} = 13.39t + 50.86$ — Equation No. 4
where N_{Sc} = volume of scum, in gallons per capita after time in years
where N_{Sl} = volume of sludge, in gallons per capita after time in years
where N_{Sc+Sl} = volume of sludge + scum, in gallons per capita after time in years

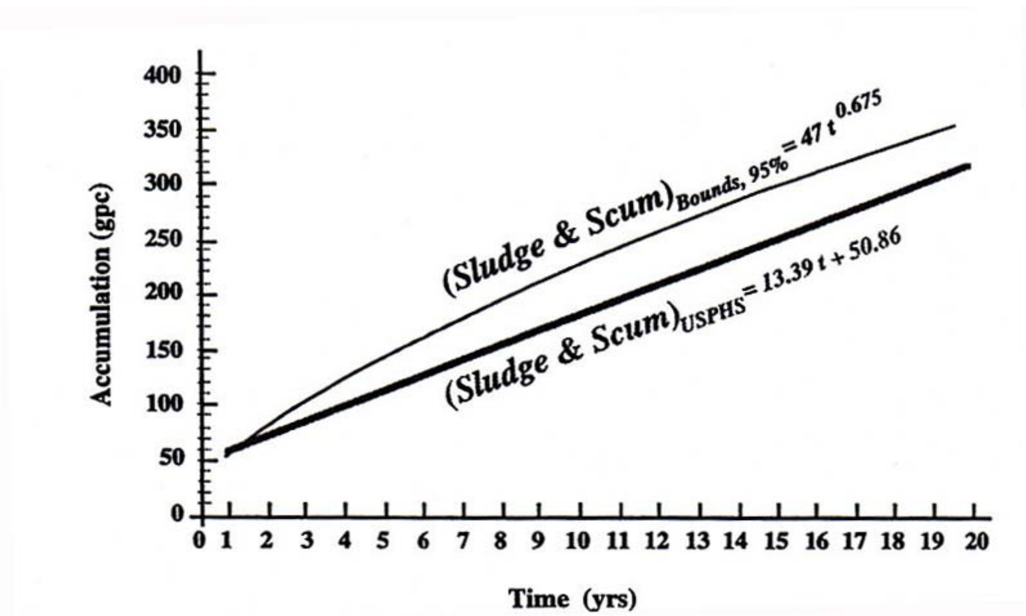


Figure 18. Average rates of septage (sludge + scum) accumulation. (Bounds, 1997)

Using these equations, at 95% confidence levels, the amount of sludge and scum can be calculated with a reasonable degree of conservativeness and, knowing the dimensions of the tank and the desired clear space between the scum and sludge, the pumping interval may be determined. Generally it is estimated that about one-quarter of the scum is expected to float above the liquid level, with the remaining three-fourths submerged.

Periodic pumping of septic tanks is recommended to ensure proper system performance and reduce the risk of hydraulic failure. (US EPA, 2002) Solids are removed from septic tanks using vacuum tanker trucks. Generally the tank should be pumped when sludge and scum accumulations exceed 30 percent of the tank volume or are encroaching on the inlet and outlet baffles. (US EPA, 2002) In 1980 and again in 2002, the USEPA recommended that if the systems are not regularly inspected, the septic tank should be pumped every 3 to 5 years, depending on the size of the tank, the number of building occupants, and household appliances. (US EPA, 1980)(US EPA, 2002) On the other hand, Bounds (Bounds, 1995) concluded such pump-out intervals were just not supported by scientific evidence, and suggested much longer intervals as shown in Table 12. Thus it can be seen that for a family of 3 with a 1,000 gallon septic tank an 11-year pump out interval is suggested, which is significantly longer than that encouraged by most regulatory agencies.

Table 12. Septage Pumping Interval (95% level of confidence) (Bounds 1997)

Glide Effluent Sewer 1987

1000 Gallon Tank				
Number of Occupants	2	3	4	5
Pump-out Interval, yrs	22	11	7	4

1500 Gallon Tank				
Number of Occupants	5	6	7	8
Pump-out Interval, yrs	9	7	5	4

Recalling that in 1980, the majority of individual onsite systems were not managed nor monitored it was reasonable that the rule of thumb to pump out tanks every 3 to 5 yrs± evolved into a general rule for regulating authorities to promote. Albeit, it was recognized as being ultra conservative with a clear intent to provide the highest degree of safety and protection to the subsurface soil infiltration system from excessive solids carry-over. However, as decentralized effluent sewers and management districts evolved, the feasibility of efficient management required efficient process control. Additionally, an excessively high estimation for pump out frequencies was a strong decentralized system deterrent, when the pump out costs were amortized as part of the feasibility study (in Oregon, pump out costs ranged from $160 to $400 per occurrence). Clearly the disparity of views regarding the proper septic tank pump out frequency is a quandary to the entire small scale decentralized wastewater management industry and to its millions of users. It cannot and will not be solved until some real science is brought to bear on the problem. Until then it is hard to make a categorical statement as to the proper frequency of pump outs. After reviewing all the variables in a given situation, any pump out frequency that fell within the limits of 3 to 5 and 7 to 11 years would be prudent and reasonable.

The organic material that settles to the bottom of the tank undergoes facultative and anaerobic decomposition and generates gases such as carbon dioxide (CO_2), methane (CH_4), hydrogen sulfide (H_2S) and foul-smelling gases called mercaptans. The gases that are released into the atmosphere are quickly drafted out of the tank back through the building sewer and plumbing vents. The results of studies and testimonies by the Public Health Services, the EPA, and other experts that have accumulated to date are convincing and conclusive that generally methane concentrations generated in the septic tank with respect to the available oxygen are also not explosive. The National Fire Protection Association NFPA (in 1992) found the atmosphere to be non-explosive, the effluent was non-volatile and the gas vapors did not normally exist in volatile mixtures or quantities. Consequently, the National Electric Code (NEC) through NFPA 820 recognized that passively vented residential septic tanks are non-explosive unclassified environments. However, the septic tank is an extremely hazardous confined space with insufficient oxygen and toxic gases and should never be entered. (US EPA, 2002)

Buoyancy

In areas with high ground water, precautions must be taken during septage pumping to prevent the tank from floating, causing damage to piping and landscape. This is particularly true with light weight plastic and fiberglass tanks. Precautions might include:

- Where high ground water is suspected, provide sufficient soil cover to prevent floatation.
- Pour additional concrete over tank to prevent floatation.
- Provide flanges extending horizontal from tank.
- Provide anchored straps.
- Clearly outline correct pumping procedure to pumper personnel.

The heavy weight of concrete tanks can equate to less concerns and cost related to anti-buoyancy measures (although buoyancy issues, even with concrete tanks and vaults, still need to be addressed).

Tank Geometry

Length to Width Ratio

It has been previously stated that sedimentation in a tank is largely independent of depth and detention time, but rather is a function of the surface overflow rate. Studies have also shown that the performance of many settling tanks is impaired by short circuiting which is primarily due to inlet and outlet conditions and tank geometry (Dunbar, 1908; Crites and Tchobanoglous, 1997; Hazen, 1904). These studies stated such short circuiting could be minimized by the use of long, shallow, narrow, rectangular, horizontal flow tanks (Dunbar, 1908; Crites and Tchobanoglous, 1997; Hazen, 1904). This recommendation should not be taken to an unreasonable extreme where a long, narrow, and shallow tank could approach the performance of the pipe itself, which would not allow any settling. Thus the length to width ratio (L/W) is a very important characteristic of a septic tank, but unfortunately the prefabricated tank dimensions are often limited for ease of loading and transporting on trucks. Typical length to width ratios for 1,000 gal tanks are on the order of 1½ to 1 and 1,500 gal tanks are 2 to 1. Elongated tanks with length-to-width ratios of 3 to 1 and greater have been shown to reduce short-circuiting and improve suspended removal. (Ludwig, 1950) It follows that a particle in suspension in a long shallow tank has a shorter settling path and, therefore, is more likely to sink and be captured in the sludge blanket.

Four Zones of Settling in Large Tanks

In large rectangular sedimentation tanks at large water and wastewater treatment plants, it has been demonstrated there is a loss of effective settling area due to entrance and exit turbulence. To illustrate this, consider the rectangular tank shown in Figure 19 that is divided into four zones which affect settling. It should be noted Zones 2 and 3 occur together in the same space.

1. The inlet zone which distributes the suspension of solids over the cross sectional area of the basin

2. The settling zone where settling occurs

3. The sludge zone for storage of settled solids

4. The outlet zone where the effluent is collected

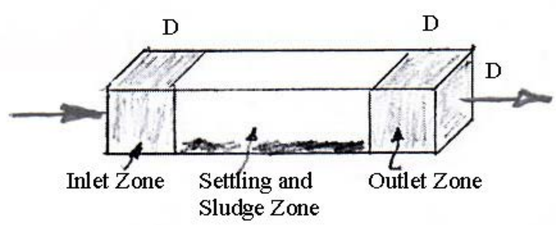


Figure 19. Four zones of settling in large tanks

In large tanks Camp (Camp, 1946) reported that due to turbulence and eddy currents in the inlet and outlet zones, they cannot be counted upon for settling. Furthermore, it was stated the length of these zones was approximately equal to the depth in the tank (Camp, 1946). Therefore, it can be assumed that all settling must take place in the settling zone. Consequently, to increase the length of the settling zone, it can best be accomplished by decreasing the depth of the tank. Extending this analogy to a septic tank, the inlet tee effectively creates the inlet zone, and the outlet tee forms the outlet zone, with the sludge and settling zones in between (Figure 20). To continue the analogy, it can be seen the length of the settling zone may be enhanced by decreasing the depth of the septic tank, assuming the volume remains constant.

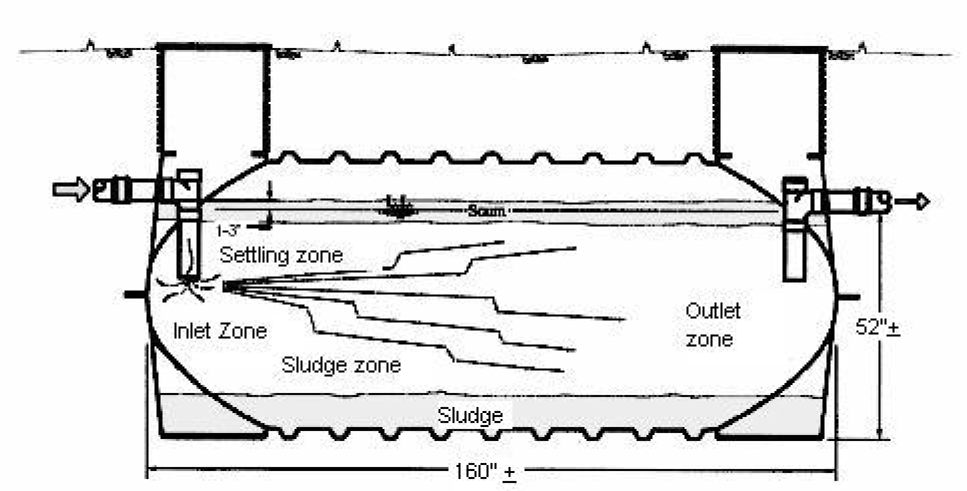


Figure 20. Zones of Settling in a Septic Tank

Prefabricated horizontal plastic and fiberglass tanks with oval cross sections should have similar flow characteristics to rectangular cross section tanks.

Vertical Cylindrical Tanks

Although less common than rectangular septic tanks, vertical cylindrical tanks have been used. Vertical cylindrical tanks are used extensively in large water treatment works. Recalling the sedimentation theory, it is easy to see that they are less effective in removing suspended solids. Referring to Figure 21a, a plan and section view of a center feed circular tank with circumferential outlets is shown. It can be seen that there is no theoretical effective settling zone.

In the peripheral-feed design vertical circular tank shown in Figure 21b, after the inlet tee a baffle deflects the incoming wastewater and induces the flow into a tangential direction. The water then flows around the tank in a circular motion and is discharged through an outlet tee. Grease and scum are confined to the area around the outlet tee. In Figure 21c the plan and elevation views of a circular septic tank are shown. It can be seen that the settling and sludge zones tend to merge into the same space which reduces the settling capacity. Circular tanks have had limited use as septic tanks.

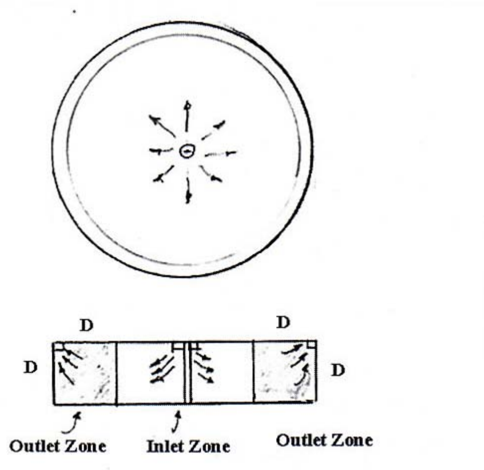


Figure a. Circular Tank Center Feed
Plan and Elevation Views

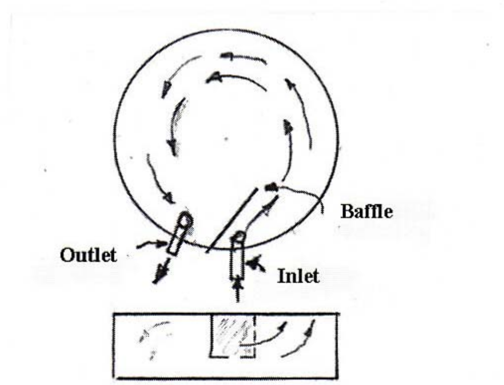


Figure b. Circular Tank Peripheral Feed
Plan and Elevation Views

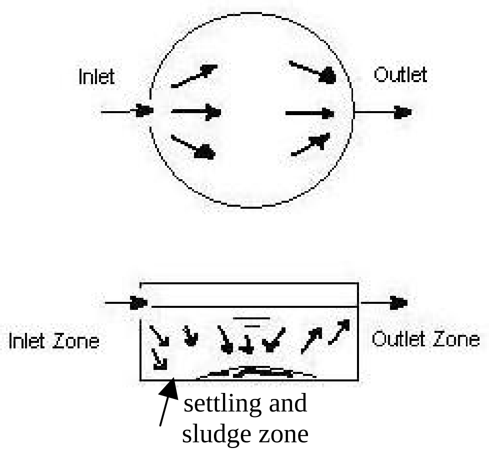


Figure c. Circular Tank Conventional Feed
Plan and Elevation View

Figure 21. Circular tanks

Meander Tanks

The so-called meander tank is generally found in large community systems, and the concept is also becoming more popular in onsite applications. A meander tank is a rectangular tank with one or more baffle walls arranged parallel longitudinally within the tank, as shown in Figure 22. The flow enters the tank and flows parallel to the wall and then reverses direction 180° and returns toward the inlet end of the tank where it again reverses direction and flows to the outlet.

Configuring parallel chambers into a single tank is a way to reduce the cross section area, increase the length-to-width ratio, reduce short circuiting, reduce inlet and outlet turbulent zones, and improve the overall tank effectiveness. The serpentine flow path through the meander tank causes many changes in directions of flow velocities (zero velocity vectors) which also enhances settling characteristics.

Based upon theory alone, in the opinion of the writers the meandering tank appears to be more effective in removing solids and retaining scum than a tank without the partitions, and as such, it may be a harbinger of the future of septic tank design. However, from a practical standpoint it would be more difficult to build and may present real problems in effective removal of sludge (Otis, 2004).

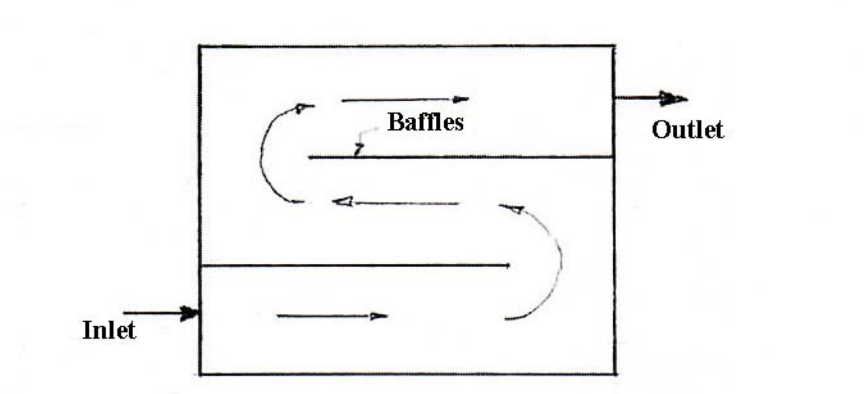


Figure 22. Meander septic tank
Plan View

An isometric view of a two chamber meandering septic tank with pump discharge is shown in Figure 23. Notice how the longitudinal baffle effectively reduces the cross sectional area and extends the length of flow.

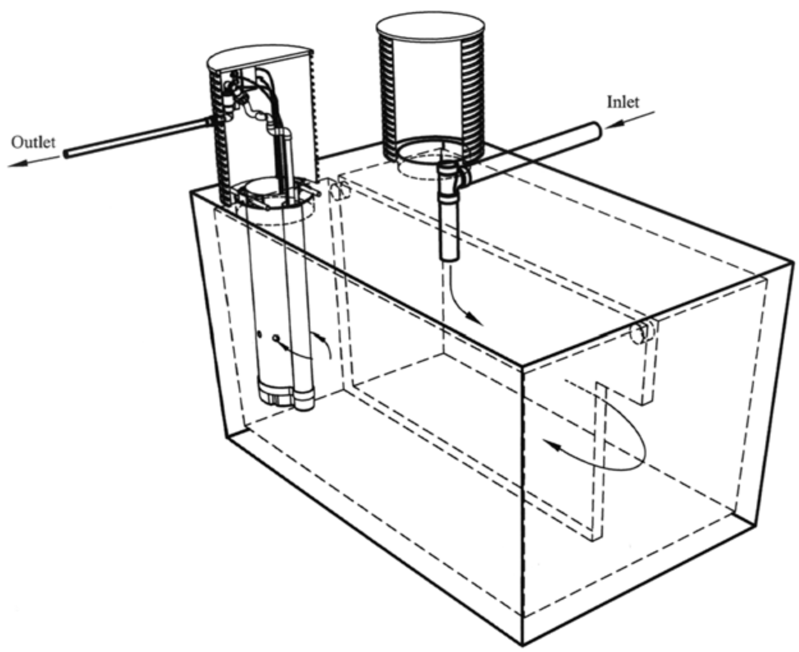


Figure 23. Isometric view of two chamber meandering septic tank

Watertightness

It is critical that in addition to being structurally sound, the septic tank must be watertight. Water tightness is critical regardless of the construction material (reinforced concrete, fiberglass, or polyethylene). Quality assurance during the manufacturing process and proper precasting or manufacturing procedures should be implemented to ensure water tightness of all tanks.

Formerly, the standard construction procedure for reinforced concrete septic tanks called for cold seams at the bottom, or mid-seam, and at the top where the lid was placed on the tank. With the exception of the seam around the top, leaks at these joints allow untreated liquid to flow out at the bottom and depending upon the water table elevation relative to the leak in the tank, permit ground water to infiltrate and hydraulically overload the system. While not true in all states, the problem of leaking concrete tanks has generally been lessened by using monolithic bottom and wall pours with strict construction controls and watertight testing by the manufacturer and installer. Parenthetically, it should be noted, monolith bottom and wall pours for concrete septic tanks have been required in the State of Wisconsin since 1962 (Otis, 2004).

Hydrostatic Testing

The watertightness of tanks, including risers, inspection ports, and inlet and outlet joints, may be tested in the field, and regulatory trends are to require field testing of all tanks just prior to backfilling. The procedure is to fill the tank with water two to three inches in the riser, let it soak for 24 hours (provision for concrete, since concrete will absorb some water), refill the tank and check the water level again after 24 hours. If the tank loses more than one gallon, it should be rejected. Care should be taken so that the risers and accesses are sealed at tank openings and at the ground surface. The disadvantage of this test is that it creates outward forces, rather than inward forces and the volume of water needed may not be available.

Vacuum Testing

Vacuum testing of tanks requires less time than hydrostatic testing. In this test all pipe penetrations, manholes and risers are sealed air-tight, and a special insert is sealed on one of the tank manholes. Air is evacuated by a pump through this insert to a standard vacuum level, and the reading on a vacuum gage is recorded. Local codes or American Society for Testing and Materials (ASTM) standard C-1224 or the National Precast Concrete Association (NPCA) standard can be used to determine the target vacuum for the size, shape and tank material being used. In order to pass the test, the required vacuum must be maintained for a brief (under 10 minutes) period of time. Loss of vacuum beyond the allowable limit, excessive deformation, or any cracking of the tank indicates that the tank has not passed the vacuum test.

The materials industry, represented by ASTM (a voluntary standards development organization) and the NPCA (a trade association which is a voluntary association made up of precast concrete producers), have developed testing criteria and procedures for the two testing methods, as presented in Table 13.”

Table 13. Watertightness Testing Procedure/Criteria for Precast Concrete Tanks

Standard	Hydrostatic Test		Vacuum Test	
	Preparation	Pass/Fail Criterion	Preparation	Pass/Fail Criterion
C1227, ASTM (1993)	Seal tank, fill with water, and let stand for 24 hours. Refill tank.	Approved if water level is held for 1 hour.	Seal tank and apply a vacuum of 2 in. Hg.	Approved if 90% of vacuum is held for 2 minutes.
NPCA (1998)	Seal tank, fill with water, and let stand for 8 to 10 hours. Refill tank and let stand for another 8 to 10 hours.	Approved if no further measurable water level drop occurs.	Seal tank and apply a vacuum of 4 in. Hg. Hold vacuum for 5 minutes. Bring vacuum back to 4 in. Hg.	Approved if vacuum can be held for 5 minutes without a loss of vacuum.

From US EPA, 2002

Checking Watertightness of Existing Tank

Testing the watertight integrity of an existing septic tank is considered impracticable because it would require stopping the inflow and sealing off inlet and outlet pipes. Instead much more can be discerned by a thorough visual inspection of the tank before and after it is pumped. If the ground around the tank is saturated, the tank could be pumped out and observations made over the next few hours to detect leakage into the tank around pipe penetrations, seams, or through breaks in the tank. A note of caution, if the soil is saturated around the tank and all the water is removed, the buoyancy of the tank may be of concern. If possible, pump outs should be limited to dry weather, but if it is necessary to pump a tank down during wet weather or saturated conditions, only part of the volume should be removed and that should be restricted to surface and settled solids. In other cases, it may be necessary to excavate completely around the tank to visually look for leaks. However, if visual inspection is not enough, and it is absolutely necessary to test an existing septic tank, then the method of choice would be the vacuum test, since it does not require pumping the tank first (Otis, R.J., 2004). If there is any doubt about the integrity of the existing tank, it should be replaced.

Appurtenances

Risers and Inspection Ports

Access to the septic tank is necessary for pumping septage, for inspection and maintenance of the inlet and outlet baffles or tees, and to allow servicing the effluent screen. To accomplish this, both risers and inspection ports are used. Risers are large, 18 to 24 inch square or round openings extending from the top of the septic tank to the ground surface. See Figures 1, 2, and 3. Inspection ports are usually about 8 inches in diameter or larger located over all openings not served by a riser. Risers and inspection ports should have watertight lids and be sealed to the tank. See Figure 2.

Joints and Connections

All joints and connections are potential leak points and should be sealed for watertightness. Risers should be sealed to the tank with a watertight seal or gasket, and they should have watertight lids. Inlet and outlet pipe penetrations are a common point of leakage, particularly if the tank or piping settles or shifts after installation. These connections should be sealed to the tank so that they are watertight and flexible. Although bituminous seal, mastic, or concrete grout have been used in many areas, newer flexible gasket and boot fittings are available that can be cast in place at the time of tank manufacture and can provide a much more reliable seal. Rubber boot seals are particularly desirable because they are flexible and can retain a seal during backfilling and settling. In all instances it is important that all the manufacturer's directions and recommendations are followed.

Tees and Baffles

The importance of inlets and outlets in septic tanks cannot be overemphasized. If they are not properly designed, sized and placed, they may cause excessive flow velocities in parts of the tank. This may cause turbulence, short circuiting, and channeling which reduces the settling efficiency. Invariably, the flow comes to the septic tank in a pipe with a much smaller cross section than that of the tank. This means as the inflow enters the larger cross section in the septic tank, the combination of the inertia of the wastewater and the rapid divergence of the streamlines, forms eddy currents and turbulence. (Ingersoll et al., 1955) A streamline is a continuous line drawn through the fluid so that it has the direction of the velocity vector at every point. (Streeter and Wylie, 1975) The effects of this zone of turbulence may extend for a considerable distance into the tank which usually approximates the depth of the tank. On the other hand, the updraft effect of the outlet causes the streamlines to converge which affects the flow for a much shorter distance. (Streeter and Wylie, 1975) Thus, in general the inlets are more critical than outlets in controlling turbulence and short circuiting. (Ingersoll et al., 1955) However, some field studies since 1970 on sedimentation suggest just the opposite: that the outlet is by far the most important influence on turbulence. The use of baffles and tees has been the customary attempt to minimize these effects. Baffles are simply partial walls that extend across the short dimension of the tank near the inlet or outlet pipe, but do not extend all the way to the top or bottom of the tank. Baffles may be made of various materials or the same as the tank. However, due to the tendency of some materials to deteriorate rapidly, most are now made of PVC material. T-shaped pipes attached to the inlet or outlet pipe, open at the top with the lower part submerged form what is called an inlet or outlet tee. See Figure 1. The purpose of the inlet tee and/or the baffle is to direct the incoming wastewater flow downward to the level of the clear zone and aid in the dissipation of the kinetic energy in the fluid and to minimize turbulence and discourage short circuiting. The openings at the top allow the free flow of air which allows gases to exit the tank out the inflow pipe and up the house plumbing vent.

Baffles and tees on the outlet should extend far enough above the wastewater surface and deep enough into the clear zone to keep the scum layer from entering the outlet port. The elevation of the outlet port is usually 2-3 inches below the elevation of the inlet port to allow some accumulation of scum and prevent backwater from interfering with free flow of solids into the tank during brief rises in the tank's liquid level as wastewater enters.

Gas bubbles produced by anaerobic digestion can carry solids upward, resuspending them and possibly carrying them into the absorption field. Gas deflection baffles below the outlet device deflect the rising solids carried by bubbles away from the outlet and keep them from leaving the tank. See Figure 26. These devices have been found to be of limited value, and are seldom if ever used (Otis, R.J., 2004).

Effluent Screens

Effluent screens are designed to help keep solids in the tank. They are intended to trap suspended solids that either are buoyant or have been resuspended from the scum or sludge layers. See Figures 24 and 25. Mesh, slotted screens and stacked plates with openings from 1/64 to 1/8 inch are available. Usually, the screens can be fitted into the existing outlet tee or retrofitted directly into the outlet. An access port directly above the outlet is required so the screen can be removed for inspection and cleaning. In most cases, effluent screens are cleaned when the tank is pumped, but they should be inspected annually and if possible have an alarm to monitor the liquid level in the tank. Factors that can increase the frequency of maintenance include:

- High content of fats, greases and oils
- Presence of hair or laundry lint
- Backwash from water softening units plumbed into the sewer system
- High water usage and peak flows which may disturb and disrupt settled solids

Clogging of screens is not usually an indication of a problem with the screen unit. The purpose of a screen is to catch suspended solids. Rather, premature clogging may be an indicator of other problems such as:

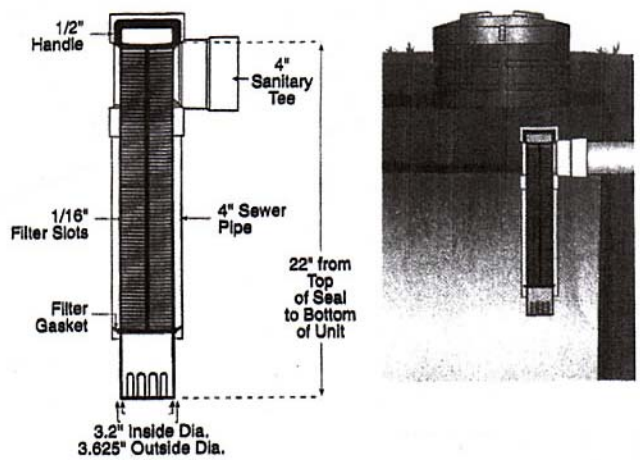
- The lack of adequate biological digestion in the tank
- Excessive flows that cause turbulence
- Neglecting to pump out the septic tank as needed
- Disturbances within the tank

In choosing the appropriate effluent screen device, the following factors should be considered:

- Effluent screens are designed to reduce solids discharge, not necessarily BOD discharge.
- The screen case should act as an outlet tee.
- Screens should allow solids of no greater than 1/8 inch to pass through the cartridge.
- The screen should be secured in place and should not allow bypass of unfiltered solids if the screen openings become clogged.
- The effluent filter housing should be sized and placed so that it does not interfere with normal pumping of the tank.
- Effluent screen should be snug to wall surface to prevent shortening the length of flow of the settling zone.

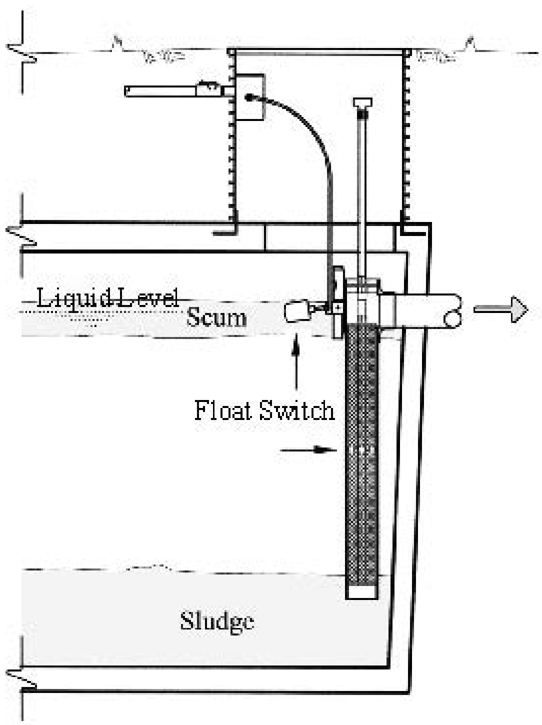
- The surface area of the effluent filter should be matched to the projected wastewater flow and waste characteristics from the facility. As the design flow increases, more surface area must be provided.

Figure 24. Outlet screen



Zabel Industries Inc.

Figure 25. Outlet screen



Surge Tanks

Due to topography, it may be necessary to pump the wastewater from the residence to the septic tank. Also, there are situations where grinder pumps or solids handling pumps may precede the septic tank. If these relatively high velocity outputs are allowed to enter the septic tank, it will result in excessive turbulence and disruption of the quiescent conditions, which will prevent proper settling and may cause high suspended solids in the effluent. To overcome this operational problem, a flow equalization basin, which might be an additional small septic tank, could be plumbed into the open channel flow gravity house sewer as far upstream as possible, which would tend to attenuate the velocity by the time it reaches the septic tank. These tanks need to be monitored for solids accumulation.

Garbage Grinders

Garbage grinders or garbage disposals are a fact of life in today's modern homes. It is time rural home owners have the same appliances as urban dwellers, including garbage disposals, thus the wastewater system should be designed accordingly. They are usually installed under the kitchen sink and are basically motorized grinders, shredders or macerators designed to shred food scraps, vegetable peelings and cuttings, bones and other food wastes to allow them to flow freely through the household plumbing into some type of wastewater treatment system. Disposing of food waste in this manner eliminates the nuisance of having to store decaying food wastes in a trash can and await the weekly pickup. Clearly this will increase the organic strength of the wastewater which may have an impact on the performance of the septic tank and any subsequent downstream wastewater treatment facilities. In the past the USEPA generally discouraged the use of garbage grinders due to the more rapid buildup of scum and sludge layers which might increase the risk of clogging the soil adsorption field. (US EPA, 1980) The increase in pollutant loading caused by the use of garbage grinders is shown in Table 14. Interestingly enough, as shown in Figure 26, later data has shown that the use of in-sink garbage disposal devices increased the scum accumulation significantly, up by approximately 34 percent, while the increase in sludge was found to be only 2 percent. (Bounds, 1986-87) Thus at this time it is not clear whether it is necessary to increase the size of the septic tank to accommodate garbage grinders, and until more definitive data are available the question will remain unanswered.

Table 14. Increase in Pollutant Loading Caused by Addition of Garbage Disposal

Parameter	**Increase in Pollutant Loading (%)**
Suspended solids	40-90
Biochemical oxygen demand	20-65
Total nitrogen	3-10
Total phosphorus	2-3
Fats, oils, and grease	70-150

Reference: Hazeltine, 1951; Rawn, 1951; University of Wisconsin, 1978

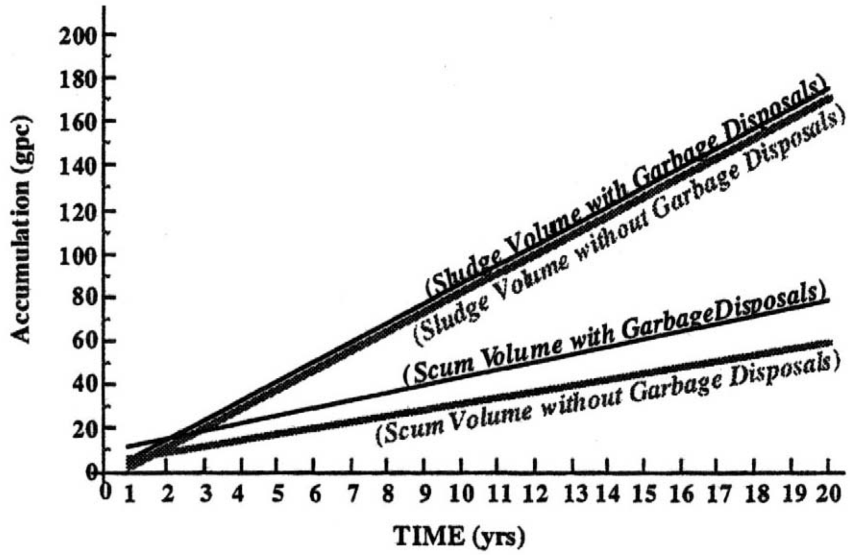


Figure 26. Accumulation rates for systems with garbage disposals and those without. (Bounds 1986-87)

Septage

Septage is the highly variable odoriferous residual material in the septic tank, namely the scum, sludge and the partially clarified liquid that lies between them. It typically has a widely varying total solids content of around 3 to 10 percent and contains high levels of grit, hair, nutrients, pathogenic organisms, oil, and grease. (US EPA, 2002) It may also harbor potentially toxic levels of metals and chemicals, and also has the widely varying chemical and physical characteristics as depicted in Table 15. (US EPA, 2002) The federal government by passage of 40 CFR (Code of Federal Regulations) Chapter I, Part 503 established standards, general requirements, pollutant limits, management practices and general operational standards for the final use or disposal of sewage sludge. These are commonly known as the 503 requirements.

Septage Management

Also, states and municipalities typically establish rules and regulations for septage management, which includes procedures to protect the public health and environment. Key components of a septage management program includes pumping, handling, transport, treatment, and reuse of the material. The accumulated sludge and scum stored in the septic tank should be removed using a vacuum septic tank hauler truck, operated by a certified, licensed, and trained service provider. (US EPA, 2002) The ultimate fate of septage generally falls into three basic categories: land application, treatment at a wastewater treatment plant or at a special septage treatment facility. (US EPA, 2002)

Table 15. Chemical and Physical Characteristics of Domestic Septage

Parameter	Concentration (mg/L)	
	Average	Range
Total solids	34,106	1,132-130,475
Total volatile solids	23,100	353-71,402
Total suspended solids	12,862	310-93,378
Volatile suspended solids	9,027	95-51,500
Biochemical oxygen demand	6,480	440-78,600
Chemical oxygen demand	31,900	1,500-703,000
Total Kjeldahl nitrogen	588	66-1,060
Ammonia nitrogen	97	3-116
Total phosphorus	210	20-760
Alkalinity	970	522-4,190
Grease	5,600	208-23,368
pH	--	1.5-12.6

From US EPA, 2002

Land Application

This is the most common method for septage management in the United States. (US EPA, 2002) Simple and cost effective, it uses minimal energy and recycles the organic material and nutrients back to the land. When septage is disposed of in this way, it is necessary to provide adequate buffers and setbacks from streams, lakes, and agricultural areas. If directly applied to agricultural producing sites, the products must not be directly consumed by humans. (US EPA, 2002) Land application categories may include the following:

1.) Spreading by Hauler Truck or Farm Equipment

The septage hauler truck, after pumping the septage, takes it to the disposal site and directly applies it to the soil. Alternatively, the septage may be transferred to a wagon spreader or into a holding faculty for later spreading.

2.) Spray Irrigation

In this method the pretreated septage is pumped at high pressure (80 to 100 psi) through nozzles and sprayed directly onto the soil. (US EPA, 2002) If some of the spraying is into the air rather than directly into the ground, aerosols may be of concern.

3.) Ridge and Furrow

On relatively level land the pretreated septage is directly applied into furrows or row crops.

4.) Subsurface Incorporation

This approach directly places untreated septage just below the surface of the soil, which reduces odor problems and health risks, while still fertilizing and conditioning the soil. There are three methods of subsurface application.

a.) Plow and Furrow Irrigation

With this method the plow creates a narrow furrow 6 to 8 inches deep, and the liquid septage is discharged directly into the furrow and covered.

b.) Subsurface Injection

Similar to plow and furrow. A tillage tool creates a narrow cavity 4 to 8 inches deep, and then the liquid septage is injected into the cavity and covered.

c.) Co-disposal in Sanitary Landfill

When allowed by jurisdiction, the septage or sludge is deposited directly in a landfill and immediately covered to control odors and vectors. (US EPA, 2002)

Disposal at Wastewater Treatment Plant

This is often the most convenient and cost effective option for septage management. (US EPA, 2002) Due to the fact that the liquid septage is so much more concentrated than the normal wastewater influent to the treatment plant, it is absolutely necessary to consult with the plant operator before any septage is fed into the plant. The input points to the wastewater treatment plant include the following:

1.) Upstream Manhole

The septage is fed in with the normal influent at a receiving station equipped with an access manhole upstream from the plant inlet.

2.) Treatment Plant Headworks

Typically, as shown in Figure 27, the septage tank hauler truck may discharge into a septage storage tank where it can be pumped by grinder type transfer pumps into the treatment plant. This option should only be used after a thorough analysis indicates the treatment plant has the capacity to accept and treat the wastes. Again the treatment plant operator must be notified ahead of time.

3.) Special Sludge Handling Process

In this option, bypassing the plant inlet, the septage is fed directly into a specially designed sludge handling process. Again the impact on the sludge treating facilities at the plant must be carefully analyzed to ensure it does not disrupt the process.

4.) Special Septage Handling and Treatment Plant

These facilities vary from simple lagoons to very sophisticated treatment works using mechanical and/or chemical processes, which might include lime stabilization, chlorine oxidation, aerobic and anaerobic digestion, composting, and dewatering using pressure or vacuum filtration or centrifugation. (US EPA, 2002) It is the most expensive option and should be considered only as a last resort. (US EPA, 2002)

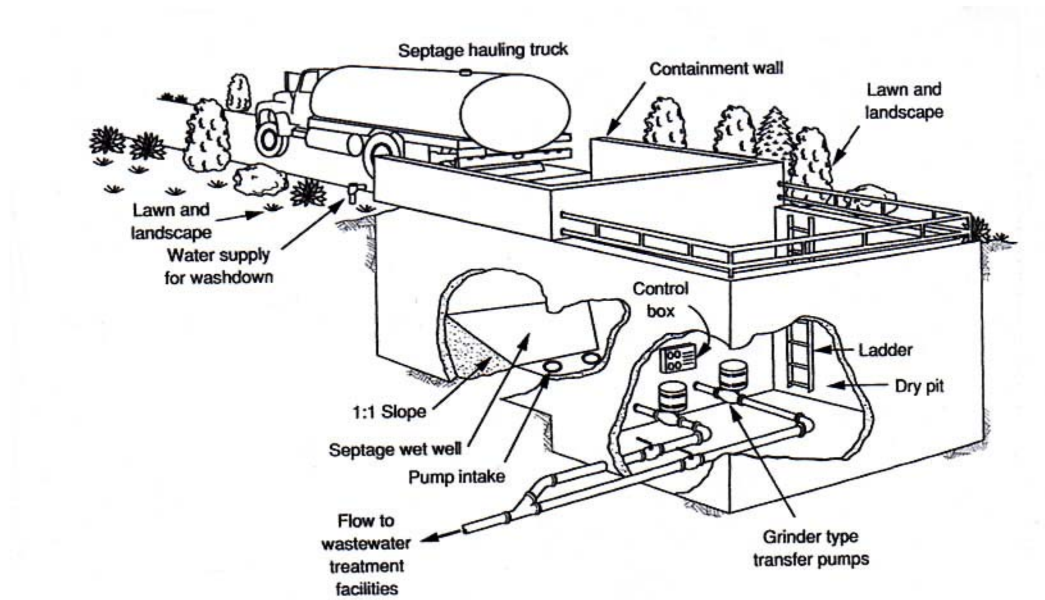


Figure 27. Typical septage receiving station located at a wastewater treatment plant. From Reference (Metcalf and Eddy, 1979)

Septic Tank Additives

There are many proprietary septic tank additives on the market that purport to improve the performance or aesthetics of the septic tank. These products are frequently advertised to remedy failed drainfields, reduce sludge depth and scum thickness, counteract the effects of laundry bleach and detergents, clear pipe deposits, reduce odor, and minimize the need for pumping the septic tank (Long, 1997; Clark, 1999). The benefits of consumer products sold as septic system cleaners, degraders, decomposers, deodorizers, organic digesters, or enhancers are not significant or have not been demonstrated conclusively, depending on the product. Some of these products can actually interfere with treatment processes, affect biological decomposition of wastes, contribute to system clogging, and contaminate ground water. (US EPA, 2002) It is estimated there may be over 100 additives on the market, and yet there never has been any authoritative testing by manufacturers of the myriad of additives, some of which are known to be detrimental to biological processes. (Church and Dwight Co, 1976) There are three general types of commonly marketed septic tank additives.

Types of Additives

1.) *Inorganic compounds*, usually strong acids or alkalis, are promoted for their ability to open clogged drains. Product ingredients (e.g., sulfuric acid, lye) are similar to those used in popular commercial drain cleaners. These products can adversely affect biological decomposition processes in the treatment system and cause structural damage to pipes, septic tanks, and other treatment system components. Hydrogen peroxide, once promoted as an infiltration field reconditioner, has been found to actually degrade soil structure and compromise long-term viability of soil treatment potential. Its use to unclog failed infiltration fields is no longer recommended. (US EPA, 2002)

2.) *Organic solvents*, often chlorinated hydrocarbons (e.g., methylene chloride, trichloroethylene) commonly used as degreasers and marketed for their ability to break down oils and grease. Organic solvents represent significant risks to ground water and wastewater treatment processes. These products can destroy resident populations of decomposer and other helpful microorganisms in the treatment system. Use of products containing organic solvents in onsite treatment systems is banned in many states. Introduction of organic solvents into onsite systems located in states that ban the use of these products may trigger liability issues if ground water becomes contaminated. (US EPA, 2002)

3.) *Biological additives*, like bacteria and extracellular enzymes mixed with surfactants or nutrient solutions which mirror, but do not appear to significantly enhance normal biological decomposition processes in the septic tank. Some biological additives have been found to degrade or dissipate septic tank scum and sludge. However, whether this relatively minor benefit is derived without compromising long-term viability of the soil infiltration system has not been demonstrated conclusively. Some studies suggest that material degraded by additives in the tank contributes to increased loadings of BOD, TSS, and other contaminants in the otherwise clarified septic tank effluent. (US EPA, 2002)

Other products containing formaldehyde, paraformaldehyde, quaternary ammonia, and zinc sulfate are advertised to control septic odors by killing bacteria. This objective, however, runs counter to the purpose and function of septic tanks (promoting anaerobic bacterial growth). Another variety of consumer products is marketed for their ability to remove phosphorus from wastewater. These products are targeted at watershed residents who are experiencing eutrophication problems in nearby lakes and streams. Aluminum (as alum, sodium aluminate, aluminum chloride, and activated alumna), ferric iron (as ferric chloride and ferric sulfate), ferrous iron (as ferrous sulfate and ferrous chloride), and calcium (as lime) have been proven to be effective in stripping phosphorus from effluent and settling it to the bottom on the tank. An important side effect of this form of treatment, however, can be destruction of the microbial population in the septic tank due to loss of buffering capacity and a subsequent drop in pH. Treatment processes can be severely compromised under this scenario.

In a study at North Carolina State University, it was found that the use of three bacterial additives did not reduce sludge accumulation, had no effects on TSS removal, had inconclusive evidence on reducing scum thickness, and had a very limited transitory treatment on BOD removal. (Clark, 1999) It was concluded that the study did not demonstrate any practical value from the use of bacterial additives, but did admit that more research was necessary before definite conclusions could be drawn regarding the use of bacterial additives in septic tanks. (Clark, 1999) Finally, a study in the State of Washington, after reviewing the ingredients in additives submitted for approval, concluded it was unlikely the ingredients would cause harm to public health and water quality, but was silent on whether the additives improved performance. (Long, 1997) Based upon the lack of any credible evidence of positive benefits to septic tank performance, the Washington State Health Department does not recommend the use of additives. (Long, 1997)

Water Softeners

Hardness in water is mainly caused by the ions of calcium and magnesium. Generally, the hardness in water is objectionable because it diminishes the ability of soap to form suds, and as a result much more soap is required for washing and laundering, etc. Also, hardness tends to form an objectionable scale on the inside surfaces of pipes, boilers, plumbing fixtures, and similar equipment.

Hardness in water can be removed by an ion exchange process in a household device called a water softener. The incoming hard water is passed through the water softener which contains high capacity ion exchange resins supersaturated with sodium ions. As the hard water passes through the exchange resin, the calcium and magnesium ions in the water are exchanged for sodium ions which are then released into the water. With time the ion exchange sites become saturated with calcium and magnesium ions, and thus no longer have the capacity to retain such ions. When this occurs, the softener must be recharged by flushing with a strong solution of salt brine. The sodium ions in the brine solution reclaim their positions on the resin beads, while the calcium and magnesium ions are released into the backwash water and exit the residence into the wastewater treatment system.

Consequently, there are two concerns: One, will the high concentrations of salts, calcium, and magnesium ions have a deleterious impact on the septic tank, and secondly, will it be harmful to the soil absorption field?

The concentration of salts and brines added to septic tanks from water softener backwash wastes may theoretically be argued beneficial as it might reduce the stress on the bacteria if discharges are controlled and diluted to the right concentration. If the dilution is not properly controlled, it may produce concentrations that are deliterious. However, ions specific effects on bacteria must also be considered. High calcium and magnesium levels can retard metabolic activity by tying up the reactive points of the enzymes that microbes use for digestion. Also, the backwash brine will often increase the chloride level in septic tanks from 70-100 mg/L to 1500-2000 mg/L.

These high concentrations may be toxic to essential septic tank microbes. The result may be an increase in sludge accumulation along with an increase in the solids remaining in suspension, which can lead to more solids carryover to the disposal field. Little research has been done to determine the toxicity of sodium on the bacteria in the tank, or the affect on solids dispersion and degradation in settling and floating characteristics. However anecdotal reports of premature clogging of effluent filters have been noted when water softener backwash has been discharged to septic tanks. (Konsler, 2003) Whether this is due to dispersal from the chlorides or regeneration cycles has not yet been established, yet it seems the unique effluent quality is likely due to more than high flows (Konsler, 2003).

Another concern with water softeners is that the regeneration wastes are denser than typical residential wastewaters. As a result of testing and monitoring sodium dispersion/stratification, it was reported that distinct stratification occurred in the tanks that received water softener regeneration wastes. (Winneberger, 1984) Also, that water softener brine settled to the bottom of the tank causing the normal wastewater flows to floats or sheet above it. The incoming flow tended to only mix with the wastewater above the brine, unless it was colder or denser, and thus the detention volume was reduced in the space above the brine. This also suggested that discrete settling characteristics will change and will need to be based on more dense viscous fluids (i.e., density, Reynolds' number, drag forces, etc.).

The following adverse affects have been found in tanks and other advanced treatment systems receiving softener discharge (Bounds, 2003):

- There was little or no scum development after four years of operation, when the expected scum measurement should be four inches.
- The solids and grease carryover to disposal fields was greater, indicating that more particulates were discharged from the septic tanks.
- The clear zone was less distinguishable, indicating that solids seemed to remain suspended, and high concentration of chlorides (1800 mg/L) in tanks that required extra maintenance.
- In advanced treatment systems, the nitrification process is retarded.

It seems the issue of water softener discharge on septic tanks and soil absorption is quite ambiguous. The USEPA Manual (US EPA, 2002) states that home water softeners, which periodically generate a backwash that is high in sodium, magnesium, and calcium concentrations, can affect wastewater treatment processes and the composition and structure of the infiltration field biomat and the underlying soil. However, attempts to predict whether impacts will occur and to estimate their severity are difficult and often inconclusive.

Then in the same EPA Manual (US EPA, 2002) it was reported that studies conducted by soil scientists at the University of Wisconsin and the National Sanitation Foundation concluded that the wastewater effluent generated from properly operating and maintained water softeners would not harm onsite systems that were designed, operated, and maintained appropriately. Specifically, the studies conclude the following: (US EPA, 2002)

- High concentrations of calcium and magnesium in the softener backwash water have no deleterious effect on the biological functions occurring in the septic tank and may theoretically be argued as beneficial.

- The additional volume of wastewater generated (typically about 50 gallons per recharge cycle) is added slowly to the wastewater stream and does not cause any hydraulic overload problems.
- Soil structure in the soil absorption field is positively affected by the calcium and magnesium ions in water softener effluent. (Corey et al., 1997)

Consequently, there is a real need for more research to correctly define the impact water softener regeneration waste has on the septic tank and soil absorption field. In light of the overuse of water softener regenerant and from the problems it causes in the septic tank and on the effluent screens, it is suggested the regenerant brines be discharged separately until the reasons for the problems are determined. (Kreissl, 2003)

Reverse Osmosis

Osmosis can be defined as the movement of a solvent through a semi-permeable membrane which is impermeable to the solute (the dissolved substance) with the direction of flow from the more dilute to the more concentrated. As the name implies, in the process of reverse osmosis, the liquid is caused to flow in reverse through a semi-permeable membrane, that is it flows from the more concentrated to the more dilute. This is accomplished by exerting high pressure on the concentrated solution, causing the semi-permeable membrane to function like a filter to retain the ions and particles in solution on the concentrated side. The technology has progressed to where economically acceptable reverse osmosis (RO) units are now available for household use to provide potable water from unsatisfactory sources. They are purported to remove salts, dissolved minerals, viruses, bacteria, color and tastes from water sources, and in so doing a large percentage of the influent flow is rejected. Since impurities removed by reverse osmosis are constituents in a relatively clean water source and would be in the normal flow if RO was not used, they may be returned to the wastewater flow.

Oils and Grease

In typical households the wastewater contains a certain amount of substances previously known collectively as fats, oils and grease (FOG). The term FOG, as previously used in the literature, has now been replaced simply by the term oil and grease (Crites and Tchobanoglous, 1997). Commonly, the oils and grease that do not congeal at room temperature are vegetable oils, while those that do congreal are known as animal oils. Oil and grease are quite similar chemically, since both compounds are esters (formed by the reactions of acids and alcohols) (Crites and Tchobanoglous, 1997). Those that are liquid at ordinary temperatures are called oils, and those that are solid are called grease, and both have low specific gravities, which causes them to quickly rise to the surface of a liquid. Thus during quiescence the principle of separating these lighter particles from a liquid by floatation may be compared in the reverse to removing heavier particles by settling. Even though it is true the longer the detention time, the greater the opportunity for oil and grease particles to ascend to the surface, it is the surface area of the tank relative to the amount of wastewater to be treated that determines the degree of attainable separation (Imhoff and Fair, 1940). In addition if not periodically removed, the scum layer that builds up and partially sinks below the liquid level may reduce the clear space between the bottom of the scum and the top of the sludge layer. This might result in the undesirable carry-over of solids in the effluent. The discharge of oil and grease in septic tank effluent is particularly troublesome where additional downstream treatment of the effluent is to be accomplished by media filters. Once retained in the scum layer, the biological degradation of the oil and grease progresses by either aerobic or anaerobic means depending upon the availability of oxygen. Therefore, it generally will follow anaerobic decomposition as idealized in Figure 17. As shown, the first stage is hydrolysis with the production of organic acids and ends in the conversion into methane and carbon dioxide. The relative insolubility of the compounds restricts the rate of the process.

For domestic strength wastewater, the septic tank is a very effective oil and grease interceptor. This fact is demonstrated in Tables 9 and 10, where respectively the values of oil and grease in the raw sewage averaged 102 mg/L, and after flowing through the septic tank it had been reduced to an average of 21 mg/L for a removal rate of 79%. Thus the septic tank may be relied upon to retain most of the concentrations of oil and grease in the wastewater from the average private home.

However, largely from restaurants, service stations, schools, hospitals, camps, motels and small businesses, the wastewater may contain oil and grease in such quantities if allowed to enter a septic tank soil absorption system, will cause clogging and drainfield failure. For example it has been shown that the oil and grease content in the wastewater of seven food service businesses, using on-site wastewater treatment systems, ranged from a low of 152 mg/L to a high of 14,958 mg/L (Stuth and Guichard, 1989). Clearly, these values are much greater than those previously mentioned for residential wastewater. In these cases it will be necessary to separate the wastewater carrying the grease and oil, and direct it into a specially designed tank called a grease interceptor. The grease interceptor is a small floatation device, generally smaller but not unlike a septic tank, which allows the grease and oil to cool and float and be retained, while the cleaner water underneath is discharged. See Figure 28. In general the three things that are necessary for effective grease removal are time, temperature and pH. The interceptor should be plumbed to receive grease wastes only (no black water) and located as close to the building as possible to prevent excessive cooling and congealing in the side sewer, as well as being easily accessible for maintenance and cleaning, the frequency of which can best be determined by observation of the unit over time. The units are usually off the shelf items made of precast concrete with both submerged inlet and outlet pipes. Similar to settling basins, the larger length to width ratios provide more effective grease removal. The effluent from the interceptor should be connected to the influent pipe of the septic tank.

The premature failure of soil absorption systems can be attributed among other things to the presence of excessive amounts of oil and grease in the wastewater. A study made in the State of Washington found that at least half of the restaurants using onsite sewage treatment systems had experienced major problems (Stuth and Guichard, 1989). In another survey of 42 restaurants it was found that 14 of the 42 systems were failing (Siegrist et al., 1984).

The importance of identifying and controlling complications caused by oil and grease has led to the promulgation of regulations to limit concentrations in the septic tank inflow and minimizing the grease concentration in the effluent. It is particularly critical to the life of the drainfield and to any filtering process.

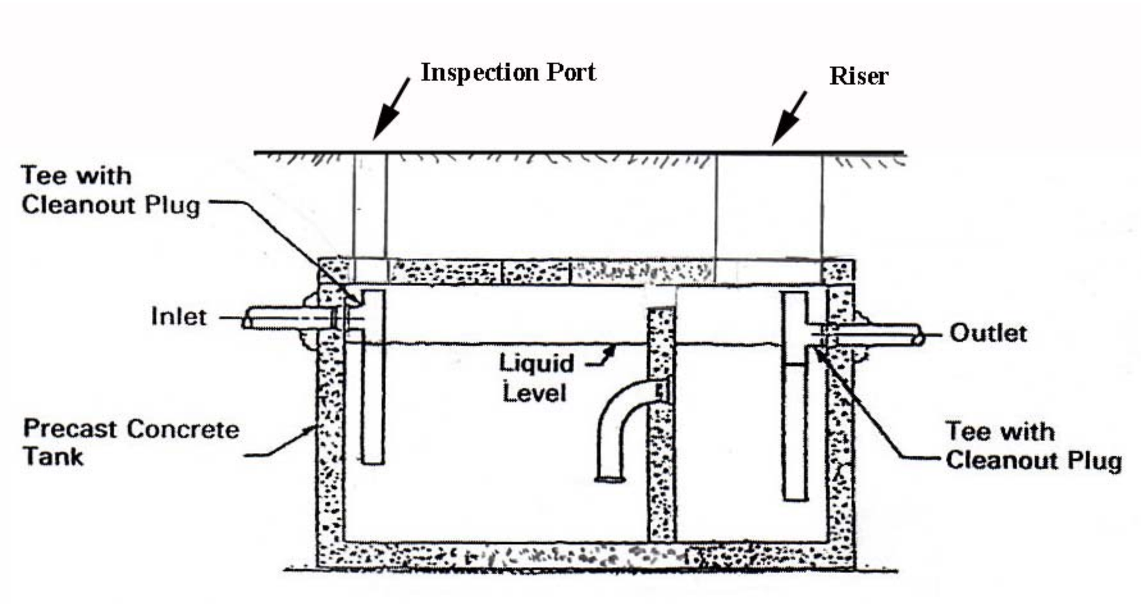


Figure 28. Double-compartment grease interceptor
Adapted from US EPA, 1980.

Septic Tank, Location and Construction Considerations

The first step is to walk the site and consider the tank location with respect to soil conditions for bedding and backfilling, ascertain if there may be floatation (tank buoyancy) problems, and make sure all surface water sources are routed away from the proposed site.

Location

The tank should be located so as to maintain minimum horizontal setbacks from buildings, property boundaries, wells and waterlines. Care should be taken to avoid large trees, rock outcroppings, and drainage swales or depressions where water may collect. The tank location should provide easy access for both construction and septage removal trucks. If possible, check the building stub-out elevation and determine if it looks reasonable to provide 1 to 2 percent slope for the building sewer.

Bedding and Backfill

The tank should be located on underlying soils capable of bearing the weight of the tank and its content. Soils with high organic content or with large boulders and sharp edges should be avoided. It is important that the hole for the tank not be over excavated so that the tank can be set on undisturbed soil. If over excavation occurs, the bottom of the hole should be bedded with granular material (gravel or coarse sand) of uniform depth. In areas where rock or uneven excavations are encountered, it is necessary to place several inches of granular material across the bottom of the excavation to fully support the bottom of the tank and distribute the weight of the tank evenly. Just the slightest irregularity or smallest protrusion or rock in the tank excavation can fracture the tank once it is fully loaded. The tank must be set level to provide the proper drop from inlet to outlet. All pipe penetrations must also be watertight initially and after backfill. Risers must be sealed to the tank to produce a watertight joint and lids must also be watertight. Backfill must be placed according to tank manufacturer's recommendations to avoid uneven or excessive pressures on the tank walls during the installation process. It is particularly important that the backfill recommendations be carefully followed when setting fiberglass and plastic tanks. However, backfilling should not proceed until the sealant setting time has been completed and a watertightness test has been performed.

Operation and Maintenance

(From US EPA Design Manual "Onsite Wastewater Treatment and Disposal Systems 1980")

One of the major advantages of the septic tank is that it has no moving parts and, therefore, needs very little routine maintenance. A well designed, constructed, installed, and maintained concrete, fiberglass, or plastic tank should last for 50 years. Because of corrosion problems, steel tanks can be expected to last no more than 10 years. One cause of septic tank problems involves a failure to pump out the sludge and scum solids when required. As the sludge and scum depth increases, the effective liquid volume and detention time decrease. As this occurs, scum and sludge scouring increases, treatment efficiency falls off, and more solids escape through the outlet. The only way to prevent this is by periodic pumping of the tank.

Tanks should be inspected at intervals of no more than every 2 to 3 years to determine the rates of scum and sludge accumulation and to inspect the effluent filter. If inspection programs are not carried out, a pump-out frequency of once every 3 to 5 years is reasonable. Once the characteristic sludge accumulation rate is known, inspection frequency can be adjusted accordingly. The inlet and outlet structures and key joints should be inspected for damage after each tank pump-out.

Actual inspection of sludge and scum accumulations is the only way to determine definitely when a given tank needs to be pumped. When a tank is inspected, the depth of sludge and scum should be measured in the vicinity of the outlet baffle. The tank should be cleaned whenever: (Dunbar, 1908) the bottom of the scum layer is within 3 in. of the bottom of the outlet device, or (Crites and Tchobanoglous, 1997) the sludge top level is within 6 to 12 in. of the bottom of the outlet device. The efficiency of suspended solids removal may start to decrease before these conditions are reached.

Scum can be measured with a stick to which a weighted flap has been hinged, or with any device that can be used to feel the bottom of the scum mat. The stick is forced through the mat, the hinged flap falls into a horizontal position, and the stick is raised until resistance from the bottom of the scum is felt. With the same tool, the distance to the bottom of the outlet device can be determined. Presently there are proprietary devices available to determine sludge and scum accumulations periodically or on a continuous basis.

Following is a list of considerations pertaining to septic tank operation and maintenance:

1. Climbing into septic tanks is very dangerous and should not be attempted.

2. The manhole, not the inspection pipe, should be used for pumping so as to minimize the risk of harm to the inlet and outlet baffles.

3. Leaving solids in the septic tank to aid in starting the system is not necessary.

4. It is not necessary to remove all solids after pumping.

5. Special additives are not needed to start, improve or assist tank operation once it is under way. No chemical additives are needed to "clean" septic tanks. Such compounds may cause sludge bulking and decreased sludge digestion. However, ordinary amounts of bleaches, lyes, caustics, soaps, detergents, and drain cleaners do not harm the system. Other preparations, some of which claim to eliminate the need for septic tank pumping, are not necessary for proper operation and are of questionable value.

6. Materials not readily decomposed (e.g., sanitary napkins, coffee grounds, cooking fats, bones, wet-strength towels, disposable diapers, facial tissues, disposable cleaning wipes, cigarette butts, cat litter) should never be flushed into a septic tank. They will not degrade in the tank, and can clog inlets, outlets, and the disposal system. Newer biodegradable products should not be disposed in the tank, even though they may claim to be septic tank safe.

Regulations

Through the years onsite decentralized wastewater treatment and dispersal systems have evolved from simple pit privies to indoor plumbing systems utilizing septic tanks for primary treatment with subsequent subsurface discharge to the soil. In addition to improving the public health by breaking the fecal-oral route of infection these systems did much to minimize the aesthetic insult so common to the old fashioned privies. The septic tank which has the capability to equalize hydraulic flows, remove settleable solids, retain oils and grease, and provide some anaerobic digestion of retained organic matter played a major role in this transformation.

State and local public health departments were charged with enforcing, and in some cases promulgating, the rules and regulations defining the technology. Unfortunately, many of the codes relied upon the soil percolation test to establish design criteria, but did not consider the complex interrelationships between soil conditions, wastewater characteristics, topography and climate. (Kreissl, 1982) Often these regulations were passed from one jurisdiction to another in spite of vastly different climate and soil conditions. (Kreissl, 1982) To compound the problem, the laws frequently depended upon minimally trained personnel to oversee the design, permitting and installation of the systems by largely unregulated installers. (Kreissl, 1982; Plews, 1977)

This led to a hodge-podge of local rules and regulations, and to "prescriptive designs" which required the site and soil conditions to fit the design rather than having the design fit site and soil conditions. In the 1950s the states adopted laws to upgrade onsite system design and installation practices to improve the functioning so as to control the threat of waterborne disease. (Kreissl, 1982)

By the late 1970s based upon local experience and new research, there was a gradual increase in sizes of septic tank and soil absorption fields. (Plews, 1977) Other improvements in state codes included separation distances between infiltration trench bottom and seasonal ground water tables, minimum trench widths, horizontal setbacks to potable water sources, and minimum allowable land slopes. (Kreissl, 1982) Regulations set the size of the septic tanks, materials of construction, structural soundness, watertightness and the frequency of maintenance.

While lawmakers continue to revise onsite system codes, most revisions still fail to address the fundamental issue of system performance. The codes still emphasize prescriptive standards. In the future any cost effective regime for protecting public health and the environment will require increased focus on system performance, pollutant transport fate and the resulting environmental impacts.

Summary

The septic tank is a single or multi-chambered watertight vault which provides the first and very important pretreatment in the typical small scale onsite wastewater treatment system. As the wastewater enters the tank, the velocity of flow is reduced providing relatively quiescent conditions, which allows portions of the suspended solids to settle to the bottom, permits grease and other floatables to rise to the surface and be retained, and provides storage space for the very complex physical, chemical, and biological processes to occur. It is probably the single most important treatment unit in the small scale decentralized wastewater management system concept, and accomplishes approximately 50% of the ultimate treatment within the tank. Without this treatment the discharge of residential wastewater to the soil-absorption system would most certainly lead to premature or excessive clogging of the drainfield.

M. Mouras of France is generally credited with developing the modern septic tank and in 1881 obtained a patent on a device he named the "Mouras Automatic Scavenger." In 1895 Donald Cameron of Great Britain correctly described the septic actions and processes within the vault and named it the septic tank. The use of septic tanks for primary treatment of household wastewater first started in the United States in the late 1880s, but surprisingly it would take another 60 years or so for subsurface dispersal of the effluent to become common practice.

For residential installation septic tanks are typically premanufactured and made of precast reinforced concrete, fiberglass, or polyethylene. The required size for the septic tank is based upon empirical relationships that have developed through the years and is directly related to the number of bedrooms in the residence. Generally, the local health department specifies the minimum size, usually 1000 gallons. For non-residential, commercial and institutional applications the size of the tank is based upon the expected wastewater flow. There are conflicting findings about whether compartmentation of septic tanks is beneficial or not, and there clearly is a need for further research on this question.

After exiting the tank there is a dramatic improvement in the quality of the wastewater, as evidenced by average percent reductions of 60% BOD, 79% TSS, and 79% grease. However, septic tank effluent still has a relatively high BOD and considerable suspended solids and grease, and also contains large populations of enteric coliform organisms, as well as the possible presence of pathogens, and must receive further treatment, such as through a subsurface soil absorption system before being discharged into the environment.

It is important to have periodic pumping of the scum and solids accumulation in the septic tank to insure proper system performance. Presently, there is a disparity of views regarding the proper septic tank pump out frequency. Generally, frequencies of 3 to 11 years have been suggested as prudent and reasonable. Excessively short pump out frequencies may act as strong deterrents to decentralize wastewater systems when the pump out costs are amortized as part of the project.

Studies of tank geometry have received more attention with indications that long, shallow, narrow tanks may improve performance and there may be a future for meandering tanks. In conclusion the septic tank is the heart of a passive, energy free, wastewater treatment system that requires minimal operational attention that provides a cost efficient primary treatment of wastewater.

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List of Figures

List of Tables

Appendix

Do's and Don'ts
Best Practice and Preventive Maintenance for Wastewater Treatment Systems

There are a number of **do's** and **don'ts** that will help ensure a long life and minimal maintenance for onsite systems. As a general rule, nothing should be disposed into any wastewater system that hasn't first been ingested, other than toilet tissue, mild detergents and wash water. Here are some additional guidelines:

Inside the House

Don't flush dangerous and damaging substances into the septic tank. Specifically, do not flush:

- Flammable or toxic products
- Household cleaners, especially floor wax and rug cleaners
- Chlorine, chlorides, and pool or spa products
- Paint

Don't flush substances that cause maintenance problems and/or increase the need for septage pumping, such as:

- Kitty litter, coffee grounds, tea bags, egg shells, cigarette butts
- Paper towels, newspapers, sanitary napkins, diapers
- Cooking grease, bath or body oils
- Rags, large amounts of hair
- Water softener backwash

Don't use garbage disposals excessively. They increase the amount of solids entering your tank. Compost scraps or dispose with your trash. Collect grease in a container and dispose with your trash.

Don't use special additives that are touted to enhance the performance of your tank or system. Additives can cause major damage to your drainfield and other areas in the collection system. The natural microorganisms that grow in your system generate their own enzymes that are sufficient for breaking down and digesting nutrients in the wastewater.

Don't use excessive amounts of water (*typical is about 50 gallons per person per day*).

Don't leave interior faucets on to protect water lines during cold spells. A running faucet can easily increase your wastewater flow by 1,000 to 3,000 gallons per day and hydraulically overload your drainfield. Instead, properly insulate or heat your faucets and plumbing.

Do repair leaky plumbing fixtures. *(A leaky toilet can waste up to 2,000 gallons of water in a single day – that's 10-20 times more water than a household typically uses in a day!)*

Do conserve water:

- Take shorter showers or baths with a partially filled tub.
- Don't let water run unnecessarily while washing hands, food, teeth, dishes, etc.
- Wash dishes and clothes when you have a full load.
- When possible avoid doing several loads in one day.
- Use water saving devices on faucets and showerheads.
- When replacing old toilets, buy a low-flush model.

Do keep lint out of your septic system by cleaning the lint filters on your washing machine before every load.

Outside the House

Do familiarize yourself with the location of your septic system and electrical control panel.

Do keep the tank access lid secure to the riser at all times.

Do make arrangements with a reliable service person or provide regular monitoring and maintenance.

Do keep accurate records of maintenance and service calls.

Do keep an "as built" system diagram in a safe place for reference.

Don't dig without knowing the location of your septic system.

Don't drive over your tank or any buried components in your system, unless it's been equipped with a special traffic lid.

Don't dump RV waste into your septic tank. It will increase the frequency of required septage pumping, and the stabilizing chemical additives may kill the beneficial biological activity in the septic tank.

Don't enter your tank. Any work to the tank should be done from the outside. Gases that can be generated in the tank and/or oxygen depletion can be fatal.

Don't ever connect rain gutters or storm drains to the sewer or allow surface water to drain into it. The additional water will increase costs, reduce the capacity of the collection and treatment systems, and flood the drainfield.