AN INTRODUCTION TO ADVANCED WASTEWATER TREATMENT

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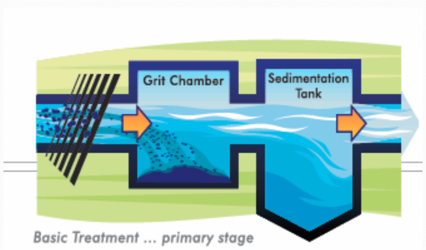
1. SEQUENCE OF PROCESSES.

1. SEQUENCE OF PROCESSES. The sequence of treatment processes through which wastewater passes is usually characterized as:

1. Preliminary treatment
2. Primary treatment
3. Secondary treatment
4. Tertiary (advanced) treatment

This discussion is an introduction to advanced treatment methods and processes. Advanced treatment is primarily a tertiary treatment.

1. SEQUENCE OF PROCESSES.



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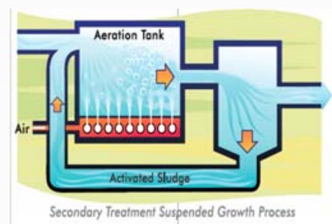

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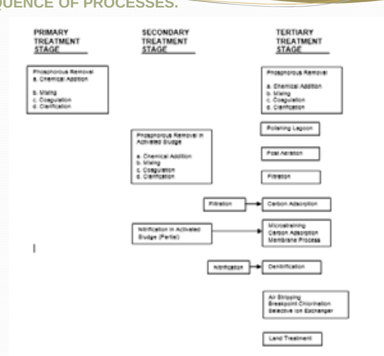


1. SEQUENCE OF PROCESSES.

Description	Type Wastewater Treated*	SS	BOD	COD	NH_3	ORG N	NO_3	PO_4	TDS	Waste for Ultimate Disposal
Physical Unit Operations										
Air Stripping of Ammonia	EBT	--	--	--	85-98	--	--	--	--	None
Filtration:										
Multimedium	EBT	80-90	50-70	40-60	--	20-60	--	--	--	Liquid & Sludge
Diatomite Bed	EBT	95-99	--	--	--	--	--	--	--	Sludge
Microstrainers	EBT	50-80	40-70	30-60	--	20-40	--	--	--	Sludge
Distillation	EBT nitrified + filtration	99	98-99	95-98	--	90-98	99	99	95-99	Liquid
Flotation	EPT, EBT	60-80	--	--	--	20-30	--	--	--	Sludge
Foam Fractionation	EBT	75-90	70	60-70	--	--	--	--	--	Liquid
Freezing	EBT+ filtration	95-98	95-99	90-99	--	90-99	99	99	95-99	Liquid
Gasphase Separation	EBT	--	--	--	50-70	--	--	--	--	None
Land Application	EPT, EBT	95-90	90-95	80-90	60-80	80-95	5-15	60-90	--	None
Reverse Osmosis	EBT+ filtration	95-98	95-99	90-95	95-99	95-99	95-99	95-99	95-99	Liquid
Sorption	EBT	--	50	40	--	--	--	99	10	Liquid & Sludge
Chemical Unit Processes										
Carbon Adsorption	EPT, EBT	80-90	70-90	60-75	--	50-90	--	--	--	Liquid
Chemical Precipitation	EBT	60-80	75-90	60-70	5-15	30-50	--	90-95	20	Sludge
Chemical Precipitation in Activated Sludge	EPT	80-95	90-95	85-90	30-40	30-40	30-40	30-40	10	Sludge
Ion Exchange	EBT+filtration	--	40-60	30-50	85-98	80-95	80-90	85-98	+	Liquid
Electrochemical Treatment	Raw	80-90	50-60	40-50	80-85	80-85	--	80-85	--	Liquid & Sludge
Electrodialysis	EBT+filtration+ carbon adsorption	--	--	--	30-50	--	30-50	30-50	40	Liquid
Oxidation (chlorine)	EBT	--	80-90	65-70	50-80	--	--	--	--	None
Reduction	EBT	--	--	--	--	--	NO_3NH_3	--	--	None
Biological Unit Processes										
Bacterial Assimilation	EPT	80-95	75-95	60-80	30-40	30-40	30-40	10-20	--	Sludge
Denitrification	Agricultural return water	--	--	--	--	--	60-95	--	--	None
Harvesting of Algae	EBT	--	50-75	40-60	50-90	50-90	50-90	50	--	Algae
Nitrification-Denitrification	EPT, EBT	--	--	--	--	--	60-95	--	--	None

*EPT is effluent from preliminary treatment and EBT is effluent biological treatment.
+Varies with type of resin.

2. POLISHING POND.

2. POLISHING PONDS. Wastewater treatment ponds may be used as a practical and economical method for upgrading existing secondary treatment facilities to obtain improved organic and suspended solids removal. Both aerobic and aerobic-anaerobic ponds can be used for this purpose. Ponds used for polishing purposes are subject to the same operating characteristics as those used for primary or secondary treatment, and the same precautionary design considerations must be applied.

J. Paul Guyer 2014 7

2. POLISHING POND.

J. Paul Guyer 2014 8

J. Paul Guyer 2014 9

3. POST-AERATION.

3. POST-AERATION. This can be accomplished by either diffused, cascade, U-tube or mechanical aeration. Diffused aeration is carried out in tanks 9 to 15 feet deep and 10 to 50 feet wide (depth-to-width ratio is maintained at less than 2), with detention time of about 20 minutes. The maximum air requirement is approximately 0.15 cubic feet per gallon of wastewater treated. Mechanically aerated basins are 8 feet deep and require 15 to 50 square feet per aerator. Surface aeration is the most efficient mechanical aeration in terms of required horsepower (0.1 horsepower per 1,000 gallons of effluent). The drop required for cascade aeration in a stepped-weir structure or in a rapidly sloping channel filled with large rocks or concrete blocks will depend on the desired oxygen uptake: 2 feet of drop will be provided for each milligram per liter of dissolved oxygen increase required.

J. Paul Guyer 2014 10

4. MICROSTRAINING.

4. MICROSTRAINING.

4.1 DESCRIPTION OF PROCESS. A microstrainer consists of a rotating drum supporting a very fine, stainless steel or plastic screen. Wastewater is fed into the inside of the drum and filters radially outward through the screen, with the mat of solids accumulating on the screen inside the drum. The solids are flushed into a removal trough at the top of the drum by a pressurized backwash system. From this trough, the solids are returned to the head of the system. Process effluent wastewater can be used for the backwash. Table 2 provides performance data for several microscreen installations.

J. Paul Guyer 2014 11

4. MICROSTRAINING.

Parameter	Typical Value
Hydraulic Loading	
(23-micron fabric)	600 gal/sq ft/hr
(35-micron fabric)	800 gal/sq ft/hr
Backwash Water Required	3-6 percent of average flow
Backwash Pressure	15-50 psi
Drum Speed	0.7-4.3 rpm
Allowable Head Loss	12-18 in. water
Optimum Hydraulic Loss Through Screen	6 in.
Optimum Solids Loading	0.88 lb/day/sq ft at 6.6 gpm/sq ft

Table 2

Performance parameters of microstrainers

J. Paul Guyer 2014 12

4. MICROSTRAINING.

4.2 DESIGN FACTORS. Microstrainers will be designed on the basis of not exceeding 10.0 gallons per minute per square foot of submerged screen area at design maximum flow. Multiple units will be provided and all units will be protected against freezing. Typical opening sizes for microstraining fabrics are, 23, 35 and 60 microns (respective number of openings per square inch being 165,000, 80,000 and 60,000). With the 23- micron screen fabric, the microstrainer can be credited for 75 percent solids removal; 60 percent removal is achievable using the 35-micron fabric. Maximum solids loading for microstraining of activated sludge effluent is 0.88 pounds per day per square foot at a hydraulic loading of 6.6 gallons per minute per square foot.

4. MICROSTRAINING.

4.3 ADVANTAGE AND EFFICIENCY. An advantage of microstraining is the relatively low head loss (between 12 and 18 inches, with a 6-inch limit across a single screen). The efficiency of a microstrainer is determined by the hydraulic and solids loadings as well as by the filtering characteristics of the influent. Microstrainers will not remove colloidal material or small (micron size) algae. Microstrainers are also adversely affected by fluctuations in influent composition and quality.

4. MICROSTRAINING.

4.4 HYDRAULIC CONTROL. Hydraulic control of microscreening units is effected by varying the drum speed in proportion to the differential head across the screen. The controller is commonly set to give a peripheral drum speed of 15 feet per minute at 3 inches differential and 125 to 150 feet per minute at 6 inches. In addition, backwash flow rate and pressure may be increased when the differential reaches a given level. The operating drum submergence is related to the effluent water level and head loss through the fabric. The minimum drum submergence value for a given installation is the level of liquid inside the drum when there is no flow over the effluent weir. The maximum drum submergence is fixed by a bypass weir, which permits flows in excess of unit capacity to be bypassed; at maximum submergence, the maximum drum differential should never exceed 15 inches. Effluent and bypass weirs should be designed as follows:

- Select drum submergence level (70 to 75 percent of drum diameter) for no flow over the effluent weir;
- Locate top of effluent weir at selected submergence level;
- Determine maximum flow rate;
- Size effluent weir to limit liquid depth in effluent chamber above the weir to 3 inches at the maximum flow rate;
- Position the bypass weir 9 to 11 inches above effluent weir (3 inch head on effluent weir maximum flow plus 6 to 8 inch differential on drum at maximum drum speed and maximum flow);
- Size bypass weir length to prevent the level above effluent wire flow exceeding 12 to 18 inches at peak maximum flow or overflowing the top of the backwash collection hopper.

4. MICROSTRAINING.

4.5 BACKWASHING. Backwash jets are directed against the outside of the microscreen drum as it passes the highest point in its rotation. About half the flow penetrates the fabric, dislodging the mat of solids formed on the inside. A hopper inside the drum receives the flushed-off solids. The hopper is positioned to compensate for the trajectory that the solids follow at normal drum peripheral velocities. Microscreen effluent is usually used for Backwashing. Straining is required to avoid clogging of backwash nozzles. The inline strainers used for this purpose will require periodic cleaning; the frequency of cleaning will be determined by the quality of the backwash water.

4. MICROSTRAINING.

4.5.1 SYSTEMS. The backwash system used by Zurn employs two header pipes; one operates continuously at 20 pounds per square inch, while the other operates at 40-55 pounds per square inch. Under normal operating conditions, these jets operate at 35 pounds per square inch. Once a day they are operated at 50 pounds per square inch for ½ hour to keep the jets free of slime buildup. Should this procedure fail to keep the jets clean, the pressure is raised to 55 pounds per square inch. At this pressure the spring-loaded jet mouth widens to allow for more effective cleaning.

4. MICROSTRAINING.

4.5.2 HIGH PRESSURE. Backwash pressure can be increased to compensate for heavy solids loadings which require higher pressure for thorough cleaning. The superiority of the higher-pressure system is manifested by the following:

- Operation at 50 pounds per square inch, as opposed to 15 pounds per square inch, increases the process flow capacity 30 percent.
- Suspended solids concentration in the backwash can increase from 260 milligrams per liter at 15 pounds per square inch to 425 milligrams per liter at 50 pounds per square inch.
- Water consumption of the jets as a percent of process effluent decreases from 5 percent at 15 pounds per square inch to 2 percent at 50 pounds per square inch. In general, backwash systems are operated at as low a pressure as possible consistent with successful cleaning. High-pressure operation incurs added system maintenance, particularly jet replacement, and is used only as needed.

4.6 SUPPLEMENTAL CLEANING. Over a period of time, screen fabrics may become clogged with algal and slime growths, oil, and grease. To prevent clogging, cleaning methods in addition to Backwashing are necessary.

4.6.1 ULTRAVIOLET LAMPS. They reduce clogging from algal and slime growth, the use of ultraviolet lamps placed in close proximity to the screening fabric and monthly removal of units from service to permit screen cleaning with a mild chlorine solution is recommended. While most literature sources say ultraviolet lamps are of value, one authority feels these lamps are uneconomical because they require frequent replacement.

4.6.2 HOT WATER. Where oil and grease are present, hot water and/or steam treatment can be used to remove these materials from the microscreens. Plastic screens with grease problems are cleaned monthly with hot water at 1200 Fahrenheit to prevent damage to the screen material. Downtime for cleaning may be up to 8 hours.

4.7 OPERATION. In starting a microscreening unit, care should be taken to limit differential water levels across the fabric to normal design ranges of 2 to 3 inches. For example, while the drum is being filled, it should be kept rotating and the backwash water should be turned on as soon as possible. This is done to limit the formation of excessive differential heads across the screen which would stress the fabric during tank fillup. Leaving the drum standing in dirty water should be avoided because suspended matter on the inside screen face which is above the water level may dry and prove difficult to remove. For this reason, introducing unscreened waters, such as plant overloads, into the microscreen effluent compartment should also be avoided. If the unit is to be left standing for any length of time, the tank should be drained and the fabriccleaned to prevent clogging from drying solids.

5. FILTRATION.

5.1 BASIC DESIGN PARAMETERS. The basic parameters to consider are the following:

- Type and size of filter media;
- Depth of filter;
- Rate, duration and timing of backwash;
- Filter run duration;
- Filtration rate; and
- Type of chemical pretreatment dosage requirement.

5.2 COARSE-MEDIA FILTRATION.

5.2.1 GENERAL DESIGN CONSIDERATION. Filter media size will influence filter performance; smaller media will achieve better suspended solids removal, but will involve increased pressure drop and head loss buildup. Therefore, a balance between removal efficiency and hydraulic loading rate must be attained. For sewage applications, coarser media, higher flow rates and longer filter runs will be used. Chemical treatment of the feed water may be necessary to improve effluent quality.

5.2.2 MEDIA SIZES AND FILTRATION RATE. Coarse media particles must have an effective size of approximately 1.3 millimeters with a uniformity coefficient of approximately 1. Sand or anthracite coal may be used, with coal giving a poorer solids removal but producing less pressure drop. Refer to the EPA *Process Design Manual for Suspended Solids Removal* for additional information regarding media specification.
The design application rate for coarse-media filters will be 5 gallons per minute per square foot at design maximum flow.

5.2.3 EFFECTIVENESS. Single-media, coarse sand filters will be credited with 60 percent removal of suspended solids when the sand media size is no greater than 1.0 millimeters and the flow rate is no greater than 4 gallons per minute per square foot. Biochemical oxygen demand removal efficiencies will be dependent on the biochemical oxygen demand fraction of the suspended solids that is removed since dissolved organic materials generally pass through the filter.

5. FILTRATION.

5.3 MULTI-MEDIA FILTRATION. Multi-media filtration, as compared to single-media filtration, will provide better suspended solids removal with longer filter runs at higher flow rates. A 75 percent suspended solids removal efficiency with multi-media filtration will be an acceptable design allowance for a design application rate of 5 gallons per minute per square foot. Filter aids such as alum can be used to increase removal efficiency. An application rate of 6 gallons per minute per square foot at maximum design flow will be utilized for design. Typical design parameters for multi-media filtration processes are given in tables 3 and 4.

5. FILTRATION.

		Coal		Sand		Garnet	
		Size Mesh	Depth inches	Size Mesh	Depth inches	Size Mesh	Depth inches
Dual	1	9×24	18	16×35	6	-	-
Media	2	10×16	12	14×16	8	-	-
	3	10×20	22	20×40	12	40×80	8
Mixed	4	10×16	15	10×20	12	20×40	3
Media	5	10×20	8	20×40	9	40×80	3

Table 3

Typical Multi-media designs

5. FILTRATION.

Process Elements	Design Criteria
Hydraulic loading	4 gpm/sq ft
Pretreatment required	Removal of settleable solids
Depth of filter media	30–36 in
Length of run	10–15 hr
Terminal head loss	6–8 ft of water
Backwash rate	15 gpm/sq ft

Table 4

Performance parameters for multi-media filtration

5. FILTRATION.

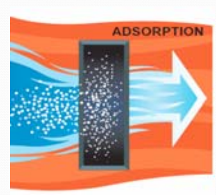
5.4 UPFLOW FILTRATION. Upflow filtration utilizes a pressurized wastewater feed with flows in the upward direction. Upward flow overcomes the fine-to-coarse particle-size distribution disadvantage of single-media filters. The media used is sand on top of gravel, with some models containing a grate on top of the sand layer to keep it compacted during filtration. This type of filter will achieve an average suspended-solids removal of 85 percent and is capable of higher solids loading than conventional filters. The maximum design filtration rate will be 8 gallons per minute per square foot. Continuous upflow, air wash filters are also available.

5. FILTRATION.

5.5 FILTER WASHING. All filters, with the exception of the upflow type, will require a reverse flow or backwash rate of 15 gallons per minute per square foot. An increased application or forward wash rate of 25 gallons per minute per square foot will be used for upflow filters. The required design duration of the wash cycle will be 8 minutes. The source of wash water in sewage filtration applications will be filter effluent or chemically coagulated and settled effluent rather than secondary effluent to ensure that the filter wash supply will always be free of large quantities of suspended solids. A filter wash flow indicator should be included so that the operator can be sure that the desired wash rate is being maintained at all times. The wasted wash water must be reprocessed. Storage facilities will be provided with filter wash wastewater returning to process at a controlled rate not to exceed 15 percent of the inflow. Provisions must be made to store the incoming flow during the filter wash cycle or, if there are no parallel units, to increase the rate on the other filters during the washing cycle. Either mechanical surface wash equipment or air scouring facilities will be provided as part of the backwashing design considerations.

6. ACTIVATED CARBON ADSORPTION.

6. ACTIVATED CARBON ADSORPTION. Use of activated carbon adsorption will be based on carbon column studies performed on the waste with the type of carbon that is to be used in the operating process at the site proposed.



6. ACTIVATED CARBON ADSORPTION.

6.1 PROCESS CONFIGURATIONS.

6.1.1 DOWNFLOW. When used in a downflow configuration, carbon adsorption beds will accomplish filtration as well as adsorption. This generally is an inefficient use of the activated carbon and will require frequent backwashing. When the feedwater suspended solids concentration is greater than 50 to 65 milligrams per liter, solids removal pretreatment must be provided. Downflow carbon adsorption processes operate at hydraulic loadings of 2 to 10 gallons per minute per square foot of column cross-section area. The columns must be maintained in an aerobic condition to prevent sulfide formation; this will be accomplished by maintaining dissolved oxygen levels in feed and backwashing waters.

J. Paul Guyer 2014 31

6. ACTIVATED CARBON ADSORPTION.

6.1.2 UPFLOW. Upflow carbon adsorption can be operated in three different modes. At hydraulic loadings less than 2 gallons per minute per square foot, the carbon bed remains packed at the bottom of the column, providing filtration as well as adsorption. (This filtration can cause backwashing problems.) At hydraulic loadings of 4 to 7 gallons per minute per square foot, the carbon is partially expanded and suspended solids pass through the bed. At loadings greater than 7 gallons per minute per square foot, the carbon bed is lifted. Upflow carbon beds are usually operated in the expanded-bed or partially expanded-bed mode and normally require no backwashing. However, periodic backwashing is helpful in removing carbon fines. Post-filtration will be provided to remove suspended solids from the effluent.

J. Paul Guyer 2014 32

6. ACTIVATED CARBON ADSORPTION.

6.1.3 PULSED BED. A "pulsed bed" is defined as an upflow carbon adsorption system where a layer of exhausted carbon is withdrawn from the bottom of the carbon bed, with a regenerated layer being added to the top of the bed. This technique approximates countercurrent operation and is a nearly-continuous process.

6.1.4 GRAVITY AND PRESSURIZED FLOW. Gravity-flow systems have the advantage of eliminating the need for pumps and pressure vessels. The restricting factor in gravity flow is head loss. For this reason, pretreatment for suspended solids removal is required. Gravity-flow systems can either downflow or upflow. The upflow, expanded-bed configuration will facilitate maintenance of a constant head loss. Pressurized-flow systems will offer more flexibility in process design by operating at higher flow rates and over wider ranges of pressure drop.

J. Paul Guyer 2014 33

6. ACTIVATED CARBON ADSORPTION.

6.1.5 SERIES AND PARALLEL ARRANGEMENT. Carbon contacting beds can be arranged as single stages, independently operated; or as multi-stages, either in series or in parallel. Series configurations achieve more complete organic removal and will be used when carbon adsorption is required to remove 90 percent of the total plant organics. Economic studies indicate that two-stage series operation is least expensive in terms of operating costs. For lower levels of treatment, single-stage, parallel contactors staggered in their status of operation or degree of exhaustion can produce the desired product by blending of individual effluent.

J. Paul Guyer 2014 34

6. ACTIVATED CARBON ADSORPTION.

6.1.6 REGENERATION. Activated carbon is regenerated in a step heating process; refer to the *EPA Process Design Manual for Carbon Adsorption* for design details. Carbon regeneration systems include preliminary dewatering of the carbon slurry to a moisture content of 40 to 50 percent, heating in a multiple-hearth furnace to 1,500-1,700 degrees Fahrenheit, quenching of regenerated carbon, and recycle to contactors. The regeneration process requires 3,200 British thermal units for burning off the impurities and 1 pound steam per pound of regenerated carbon. Air pollution control equipment is required, usually an afterburner and a wet scrubber or bag filter.

J. Paul Guyer 2014 35

6. ACTIVATED CARBON ADSORPTION.

6.1.7 CARBON TRANSPORT. The carbon is usually transported within the system as a slurry at velocities between 2.5 and 10 feet per second. Lower velocities make the system vulnerable to solids deposition and higher velocities cause abrasion in pipes. Velocities of 3 to 4 feet per second, with 4 pounds water per pound of carbon (0.5 gallon water per pound carbon), are recommended. The carbon slurry can be stored before and after regeneration, or it can be transported directly to and from the contactors. The latter arrangement requires at least two spare contactors and is a significant cost factor in pressurized systems.

J. Paul Guyer 2014 36

6. ACTIVATED CARBON ADSORPTION.

6.1.8 BACKWASHING. Backwashing frequency is determined by head loss buildup, with lower flow rates usually allowing less frequent backwash. Backwashing is supplemented by surface washing and air scouring, and the complete operation lasts 15 to 45 minutes. Backwashing should provide 30 to 50 percent bed expansion while consuming no more than 5 percent of normal feed rate (i.e., 15 to 20 gallons per minute per square foot). Effluent can be used for backwash and then returned to the primary treatment stage.

6. ACTIVATED CARBON ADSORPTION.

6.2 PROCESS DESIGN PARAMETERS. Where practical, carbon column studies should be conducted on the waste to be treated to determine the process design parameters. These studies should use the type of activated carbon that will be used in operating the full-scale plant.

6.2.1 PRETREATMENT. Pretreatment will be provided as necessary to keep the suspended solids concentrations below 50 milligrams per liter unless the carbon bed is to be used as a filter also.

6.2.2 CARBON SIZE. The carbon will be 8x30 mesh, granular carbon unless carbon column studies show a different size to be more effective.

6. ACTIVATED CARBON ADSORPTION.

6.2.3 CONTACT TIME. Contact time is the most important design factor affecting organics removal and should be determined empirically for the particular situation. Typical values range from 18 to 36 minutes.

6.2.4 HYDRAULIC LOADINGS. Hydraulic loadings between 2 and 10 gallons per minute per square foot are acceptable; there appears to be little effect on organics removal in this range. The main consideration is with head loss buildup. Gravity-flow systems are limited to hydraulic loadings less than 4 gallons per minute per square foot.

6.2.5 CARBON QUANTITIES AND ADSORPTION CAPACITY. Carbon requirements range from 250 pounds to 350 pounds of carbon per million gallons treated; 300 pounds per million gallons is the preferred value. The adsorption capacity of carbon is affected by several factors and should be determined experimentally for each particular wastewater to be treated. Factors which influence adsorption include surface area, nature of the material to be adsorbed (adsorbate), pH, temperature, nature of carbon (adsorbent), and complexity of material to be adsorbed. The adsorption capacity of carbon per cycle usually ranges from 0.25 to 0.87 pounds COD removed per pound of carbon applied. To obtain guidance regarding the selection of the type oactivated carbon to be used in bench-scale or pilot-scale studies, refer to chapter 4 of the *EPA Process Design Manual for Carbon Adsorption.*

6. ACTIVATED CARBON ADSORPTION.

6.3 EQUIPMENT. The effluent quality requirement will determine the required contact time and this in turn will set the approximate total carbon volume. The hydraulic loading will determine the total cross-sectional area and total carbon bed depth. The total bed depth can be divided between beds in series, and the total cross-sectional area can be divided into separate carbon beds in parallel. Vessel heights should provide for bed expansion of 50 percent. Contact tanks should have length-to-diameter ratio of between 0.75 and 2.0, with carbon depth usually greater than 10 feet. The tanks should be constructed of concrete or lined carbon steel. Typical coating materials range from a painted, coal tar epoxy to laminated rubber linings. The carbon transport system must be designed to resist the abrasiveness of carbon slurry. More specific design details can be obtained from the EPA Process Design Manual for Carbon Adsorption and from equipment manufacturers.

7. PHOSPHOROUS REMOVAL.

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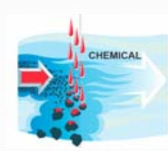

7.1 GENERAL APPROACHES. Mineral addition and lime addition are the principal methods for in-plant removal of phosphorus from wastewater. The most commonly used of these metal salts are: alum, a hydrated aluminum sulfate ($Al_2SO_4)_3.18\ H_2O$; sodium aluminate ($Na_2O.Al_2O_3$); ferric sulfate ($Fe_2(SO_4)_3$); ferrous sulfate ($FeSO_4$); ferric chloride ($FeCl_3$); and ferrous chloride ($FeCl_2$). Mineral addition is usually followed by anionic polymer addition, which aids flocculation; the pH may require adjustment depending on the particular process. In lime addition, phosphorus removal is attained through the chemical precipitation of hydroxyapatite ($Ca_5OH(PO_4)_3$). When designing the phosphorus removal system, consideration must be given to the phosphorus levels in the system effluent suspended solids. Additional information may be found in the *EPA Process Design Manual for Phosphorous Removal*.

7. PHOSPHOROUS REMOVAL.

7.2 MINERAL ADDITION USING ALUMINUM.

7.2.1 ALUMINUM REQUIREMENTS. The theoretical requirement for aluminum (Al) in the precipitation process is a mole ratio of aluminum to phosphorus of 1:1. Actual case histories have indicated considerably higher (2:1) than stoichiometric quantities of aluminum are needed to meet phosphorus removal objectives. Alum ($Al_2(SO_4)_3.18H_20$) is the aluminum additive most frequently used, with sodium aluminate being substituted when alum addition would force the pH too low for other treatment processes. The theoretical weight ratio of alum to aluminum is 11:1 and in practice alum weight ratios in the range of 13:1 to 22:1 (depending on the degree of removal desired) have been needed. For higher removal efficiencies, the Al:P ratio must be increased. Table 5 lists the Al:P (and Fe:P) ratios required for 75, 85 and 95 percent phosphorus removal. Laboratory, pilot plant, or full-scale trial runs are often necessary to determine the most effective mineral dosages.

7. PHOSPHOROUS REMOVAL.

Phosphorus Removal percent	Al:P Weight Ratio	Fe:P Weight Ratio
75	1.2:1	2.3:1
85	1.5:1	2.7:1
95	2.0:1	3.0:1

Table 5

Mineral to phosphorous ratios for given removal efficiencies

7. PHOSPHOROUS REMOVAL.

7.2.2 ADDITION AT PRIMARY TREATMENT STAGE. In the primary treatment stage, the mineral is added directly to the raw sewage which is then mixed, adjusted for pH (if necessary), flocculated, and clarified. The mixing and flocculation are to be carried out in specially designed units, or within existing systems at appropriate locations such as manholes, Parshall flumes or pre-aeration tanks. For maximum phosphorus removal, the mineral addition will be downstream of return streams such as digester supernatant. The required procedure for mineral addition at the primary stage is as follows:

- Add mineral to raw sewage and mix thoroughly;
- Add alkali (if necessary for pH adjustment) 10 seconds later;
- Allow reaction for at least 10 minutes;
- Add anionic polymer and flash mix for 20 to 60 seconds;
- Provide mechanical or air flocculation for 1 to 5 minutes; and
- Deliver flocculated wastewater to sedimentation units.

The advantages of removing phosphorus at the primary stage are the flexibility of chemical feeding, the adequate detention times and mixing conditions available, the reduced suspended solids and biochemical oxygen demand loading on the ensuing secondary treatment stage, and the ease of process instrumentation. The principal disadvantage is that a significant portion of the phosphates is not in the orthophosphate form at the primary treatment stage and therefore does not precipitate easily. Mineral addition also causes increased solids production (1 .5 to 2.0 times the weight of normal primary solids), and the solids density increases with increasing aluminum dosages. Solids increases attributable to aluminum addition are about 4 pounds per pound of aluminum added, up to stoichiometric proportions, after which the weight gain is less. The addition of alum to the primary stage generates large quantities of metal hydroxide sludge, which is difficult to dewater.

7. PHOSPHOROUS REMOVAL.

7.2.3 ADDITION AT SECONDARY TREATMENT STAGE. The advantages of mineral addition to the activated sludge process are enhanced sludge removal properties, shorter residence times, more effective phosphorus removal because of sludge recycle, relatively small additional solids production (which improves sludge density and dewaterability), and flexibility to changing conditions. The extra solids production, however, does involve additional sludge handling just as when alum is added at the primary stage. In the activated sludge process, the chemical is added near the discharge point(s) into the aeration basin(s). Mixing of the chemical and wastewater must occur in the basin but premature precipitation must be prevented. Phosphorus capture will occur primarily in the sedimentation units following aeration in the basin. For trickling filter plants, it has been demonstrated that precipitation in the final clarifier can be both effective and controllable, as per EPA Manual 670/2-73-060. Orthophosphate predominates at this point and it precipitates readily; also, biodegradable detergents, which can interfere with precipitation, are largely absent. If underflow solids from a dosed final clarifier are returned to the primary clarifier, it will result in unusually effective clarification there. If the operation is not done effectively, poorly treated effluent can escape into the receiving water. In order to allow for incorporating the advantages of chemical treatment in both the primary and secondary clarifiers, provisions for future installation of chemical addition and mixing facilities will be provided at the primary clarifier. Facilities or provisions for mineral addition to both primary and secondary clarifiers will provide flexibility of operation. Chemical treatment in both clarifiers can then be used if experience shows it to be the most effective technique at the particular plant involved. Initially, equipment will be provided only at the secondary clarifier unless bench studies or pilot plant operations show a more effective performance at another location or show the necessity of chemical feed at the primary clarifier also.

7. PHOSPHOROUS REMOVAL.

7.2.4 ADDITION AT FINAL SETTLING BASIN. At the final settling basin, phosphorus removal is very effective because most of the soluble phosphates are in the orthophosphate form, which is the easiest to precipitate. The general procedure for mineral addition is essentially the same as in the primary stage. A surface overflow rate of 500 gallons per day per square foot should be used to size the final settling basin.

7. PHOSPHOROUS REMOVAL.

7.3 MINERAL ADDITION USING IRON.

7.3.1 IRON REQUIREMENTS. The theoretical requirement for iron in phosphorus precipitation in terms of mole ratio of iron to phosphorus (Fe:P) is 1:1 for the ferric ion and 3:2 for the ferrous ion. Actual plant results indicate that the mole ratio for the ferrous ion is closer to 1:1. With the same mole ratio for ferrous and ferric ions, the weight ratio (Fe:P) is 1.8:1. As with aluminum, however, experience has indicated that the weight ratios are higher. The optimum pH range for ferric iron precipitation of phosphorus is 4.5 to 5.0, and for ferrous iron about 8.0. Ferrous salts cause a lowering of pH and may necessitate addition of alkali; however, alkali addition is not necessary when there is a subsequent aeration step.

7. PHOSPHOROUS REMOVAL.

7.3.2 EFFECTIVENESS. Addition of ferric forms of iron tends to yield a fine, light floc which does not settle well, but subsequent addition of lime and/or a polymer aids flocculation and settling. Ferrous iron addition may present residual problems in that excess ferrous ions may not hydrolyze and settle out at a pH lower than 8.0; lime addition will raise the pH and alleviate this problem. Ferrous salts yield good results when oxygen is available, such as in the activated sludge process. Ferric and ferrous iron addition, together with lime or polymer flocculation aids, is particularly applicable to primary treatment without a subsequent activated sludge step because there is little effluent floc carryover. However; for military installations, it is preferred that chemical addition follow the biological reactor.

7. PHOSPHOROUS REMOVAL.

7.4 MINERAL ADDITION TREATMENT SCHEMES. Pilot plant study and full-scale plant operation will determine the most effective and practical treatment scheme for a particular situation. This most often involves multiple-point chemical addition with recycle of mineral sludges. In the case of trickling filter plants, mineral addition, with a split of about 20 percent at the primary stage and 80 percent at final clarification with sludge recycle from the final settler to the primary settler; provides very effective phosphorus removal and good clarification. When removal requirements permit 5 milligrams per liter or more of phosphorus in the effluent stream, required treatment will follow the trickling filter. For very high phosphorus removal efficiencies, multi-media filtration is added after secondary settling.

7. PHOSPHOROUS REMOVAL.

7.5 MINERAL SELECTION AND DOSAGES.

7.5.1 COST AND AVAILABILITY. The choice of minerals should be based on cost of materials, availability of materials, and process performance. Costs and availability will be determined for each particular situation. Aluminum and iron salts are in the same cost range, with aluminum salts somewhat more expensive.

7. PHOSPHOROUS REMOVAL.

7.5.2 SIDE EFFECTS OF VARIOUS MINERALS. Both aluminum and iron additives will produce soluble side products in the form of chlorides, sulfates, and sodium compounds, as well as some free acids and alkalis due to hydrolysis. These side products are seldom a serious problem, however, and can be controlled by adding only the proper amount of chemical and through the use of the automatic monitoring instrumentation. Alum and FeCl are the most commonly used mineral salts, and both cause an alkalinity drop which can lower pH 3 if the buffering capacity is not adequate. Iron tends to yield higher effluent residuals (around 6 milligrams per liter as Fe) than aluminum (less than 0.5 milligrams per liter as Al). Aluminum addition produces 30 to 50 percent less additional solids than iron additives, and the sludge has greater dewaterability and sludge density. Aluminate and alum produce about the same amount of sludge but the aluminate sludge is considerably less dense. Alum addition tends to produce better effluent clarity than does aluminate.

7. PHOSPHOROUS REMOVAL.

7.5.3 DETERMINATION OF DOSAGE. Mineral dosages will be determined by the weight ratios and, when applicable, by pilot plant and laboratory studies and full-scale plant test runs. Alum dosages are usually in the range of 150 to 250 milligrams per liter for an average influent phosphorus concentration of about 10 milligrams per liter. Typical iron dosages range from 10 to 25 milligrams per liter as Fe. These typical dosages will accomplish 80 to 90 percent phosphorus removal. Greater phosphorus removal (down to residuals less than 0.5 mg/L as P) can be obtained by using multi-media filtration techniques. Refer to the *EPA Process Design Manual for Phosphorous Removal.*

7. PHOSPHOROUS REMOVAL.

7.6 LIME TREATMENT.

7.6.1 PROCESS DESCRIPTION AND CONDITIONS. Lime addition accomplishes phosphorus removal through the chemical precipitation of hydroxyapatite ($CA_5OH(PO_4)_3$). Although the solubility product theoretically determines the amount left in solution, the actual determining factor in removal efficiency is the efficiency of the clarifiers. The precipitation of phosphorus by lime requires a high alkalinity, with a pH of 11 being optimum. Therefore, the lime dosage is not a function of phosphate concentration, but rather it depends on the amount of lime necessary to attain the proper pH. This in turn is largely dependent on influent wastewater alkalinity, which is illustrated in figure 2. Typically, a lime dosage of as much as 400 milligrams per liter as CaO will be necessary to attain a pH of 11.

7. PHOSPHOROUS REMOVAL.

7.6.2 ADVANTAGES OF LIME TREATMENT. Phosphorus removal by lime addition has these advantages: no soluble side products; improved oil, grease and scum removal; less corrosion in sludge handling systems; and recovery of the lime. The disadvantage is that the high pH required for lime addition has a detrimental effect on any downstream biological treatment process, including activated sludge, trickling filters and sludge digestion.

7. PHOSPHOROUS REMOVAL.

7.6.3 TREATMENT CONFIGURATIONS. Lime treatment can be either a single-stage or a two-stage process depending on the degree of phosphorus removal required and the alkalinity of the wastewater. A low alkalinity of about 150 milligrams per liter as $CaCO_3$ will yield a poorly settleable floc. A high alkalinity requires subsequent recarbonation (CO_2 contact) to lower the ph, which in turn causes $CaCO_3$ to percipitate, and requires a second stage to settle out the $CaCO_3$ sludge and provide better clarification. A high alkalinity (200 mg/L as $CaCO_3$), on the other hand, will yield a good settling floc at a pH as low as 9.5, thus eliminating the need for a second stage since the $CaCO_3$ precipitate will come out in the first stage. This process will be 3 considered as an alternative where the use of mineral salts would not be satisfactory.

7. PHOSPHOROUS REMOVAL.

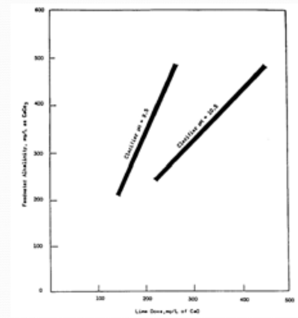

Figure 2

Feedwater alkalinity versus lime dose

7. PHOSPHOROUS REMOVAL.

7.6.4 SINGLE-STAGE LIME TREATMENT. The general procedure for single stage treatment is as follows:

7.6.4.1 Add lime slurry to wastewater as needed to obtain a pH of 9.5 to 10.5 and provide rapid mixing for about 30 seconds.
7.6.4.2 Provide flocculation and sedimentation.
7.6.4.3 If recalcination is used, thicken the sludge to 8-20 percent solids, centrifuge to 30-40 percent solids, and then recalcine to CaO and $Ca(OH)_2$. This is usually not economical for the smaller Installations.
7.6.4.4 After sedimentation, recarbonate for about 15 minutes to obtain the pH necessary for subsequent treatment or discharge.

7. PHOSPHOROUS REMOVAL.

7.6.5 TWO-STAGE LIME TREATMENT. For two-stage treatment, the procedure is as follows:
7.6.5.1 Add lime to wastewater as needed to obtain pH equal to 11-11.5 and provide mixing for about 30 seconds.
7.6.5.2 Provide flocculation and settling (sludge can be recalcined as in single-stage).
7.6.5.3 Provide recarbonation for 5 to 15 minutes to obtain a pH of 9.5 to 10.0.
7.6.5.4 Provide second stage settling (sludge recalcined as required).
7.6.5.5 Again recarbonate for about 15 minutes to obtain the pH required for following treatment ordinary discharge.

7. PHOSPHOROUS REMOVAL.

7.6.6 EFFECTIVENESS. Lime addition at the primary treatment stage is effective in removing from 80 to 90 percent of phosphorus. It also reduces biochemical oxygen demand by 50 to 70 percent, suspended solids by 85 percent, nitrogen by about 25 percent, and coliforms by as much as 99.9 percent. However, the high pH necessary for this type of treatment causes difficulties in downstream biological treatment processes.

Neutralization (recarbonation) may be required before biological treatment. Primary lime treatment will reduce the organic load on the secondary treatment stage and will reduce secondary sludge by almost half; the primary sludge, however, will increase about threefold. With lime treatment in the primary treatment stage, recalcination is often impractical because $CaCO_3$ may not precipitate in sufficient quantities. A more effective and flexible technique is lime addition as a separate stage after secondary treatment. The advantages of this are the flexibility of operation and the backup function of the secondary system. Either single-stage or two-stage lime treatment can be used; however, two-stage treatment is preferred becaue it produces a better clarified effluent, has more lime recovery potential, and provides higher phosphorus removal efficiencies. The mixing, flocculation and settling units can be separate or integrated units. The integrated type unit (upflow clarifier) works well but sludge blanket problems are encountered. Integrated units that work without sludge blankets and separate units are recommended.

7. PHOSPHOROUS REMOVAL.

7.6.7 LIME ADDITION TREATMENT SCHEMES. Lime addition in the primary treatment can make use of existing process units, or separate units can be used. Modifications such as sludge recycle to the flocculation chamber and polymer addition improve settleability of the sludge and thereby improve phosphorus removal efficiency. Mineral addition can also be used (after primary treatment with lime) to improve overall phosphorus removal efficiency. For additional information refer to the *EPA Process Design Manual for Phosphorous Removal.*

7. PHOSPHOROUS REMOVAL.

7.6.8 PERFORMANCE AND DOSAGE CRITERIA. The lime requirement can vary over a wide range, depending on operating pH and water composition. Alkalinity affects the lime dose, as can calcium hardness. One part by weight of calcium carbonate can react with from 0.89 to 1.79 parts of bicarbonate alkalinity (expressed as calcium carbonate); the lower value applying to very soft waters and the higher value to very hard waters. In addition to the reaction of lime with hardness, other competing reactions occur in lime treatment of wastewater. Also, there may be incomplete reaction of the lime. These complications make calculation of lime dose difficult; consequently, determination of lime dose is largely empirical. Some approximate values are given in the *U.S. EPA Process Design Manual for Phosphorous Removal.* The lime dose will usually be in the range of 300 to 400 milligrams per liter as CaO for two-stage treatment, and from 150 to 200 milligrams per liter where single-stage treatment is satisfactory.

J. Paul Guyer 2014 61

7. PHOSPHOROUS REMOVAL.

7.6.9 RECARBONATION. This subject is discussed in detail in the *EPA Process Design Manual for Phosphorous Removal.*

J. Paul Guyer 2014 62

8. LAND APPLICATION SYSTEMS.

8.1 BACKGROUND. The use of land and biomass growth upon and within the soil has a long and interesting history. This history, as well as a much more detailed treatment of land application of wastewaters is covered in EPA 625/1-81-013. It should be noted that this discussion is intended to be supplemented by the U.S. EPA manual for detailed design criteria. This has been done because of the broad site-specific design conditions that exist for land application systems.

J. Paul Guyer 2014 63

8. LAND APPLICATION SYSTEMS

8.2 HEALTH HAZARDS AND REGULATORY LIMITATIONS. Because land treatment of wastewater entails a higher risk than other treatment processes of introducing pathogenic micro-organisms and toxic chemicals into groundwater and surface water, land treatment system design must carefully consider all possible means to prevent water supply contamination. Additionally, state and local health regulations often dictate land treatment process design criteria. Therefore, these regulations must be consulted early in the design phase and frequently throughout construction and operation to ensure consistent compliance.

J. Paul Guyer 2014 64

8. LAND APPLICATION SYSTEMS

8.3 TREATMENT CAPABILITIES AND OBJECTIVES. Land treatment of domestic wastewater which has undergone secondary treatment and sludges from wastewater treatment plants may involve one of the following modes (Land treatment of wastewater after primary treatment is acceptable for isolated locations with restricted access when limited to crops which are not for direct human consumption.):

- Slow rate filtration;
- Rapid infiltration;
- Overland flow;
- Use of wetlands; and
- Subsurface incorporation.

Two methods of land treatment apply to sludges:

- Composting and land spreading; and
- Subsurface incorporation.

J. Paul Guyer 2014 65

8. LAND APPLICATION SYSTEMS

8.4 SLOW RATE PROCESSES. Slow rate processes essentially mean irrigation of crops, grassland or forest land based upon the demand of the vegetation. Typical application methods involve pipeline to row crops, surface distribution along furrows and ridges on the contour, sprinkler irrigation, or drip irrigation. Sprinklers and drip irrigation require that wastewater is quite free of solid suspended matter In arid to semi-arid areas, utilization of such wastewaters-even if only to recreational areas on a military compound-should be seriously considered both for conservation and to improve local aesthetics.

J. Paul Guyer 2014 66

8. LAND APPLICATION SYSTEMS

8.5 RAPID INFILTRATION. Rapid infiltration, often called "infiltration percolation," involves almost complete saturation of the soil column and potentially also the rock beneath. A thick, sandy regolith with low water table is required. Fresh water wells, well points and springs must be sufficiently far away as to not receive contamination. Often the object is to renovate water and to recapture the effluent again with special wells or underdrains for re-use in cooling or irrigation. Rapid infiltration may often be used to prevent the intrusion of saline water on an atoll or sandy coastal plain site. Although vegetation utilization is not planned for rapid infiltration systems, studies have shown that use of deep rooted plants, an active root and humus mat, and tolerant vegetation will much improve the quality of the recovered water. Vegetation must be carefully selected and, of course, some water will be lost to evapotranspiration and to production of biomass but the "living filter" will produce excellent quality water beneath the surface.

8. LAND APPLICATION SYSTEMS

8.6 OVERLAND FLOW. This process involves a surface phenomena and depends strongly on vegetation and the myriad organisms in the humus layer of a sloped field. Wastewater is applied over the upper reaches of sloped terraces carefully constructed to match the contour of the land. Runoff after surface flow is collected in ditches. Application may be from linear pipeline sprayers, plastic trickle irrigators, or using rotating sprinklers. Overland flow could be used in forested land or to produce forage. Like the bio-filter concept, such systems not only remove suspended solids, kill pathogens and lower biochemical oxygen demand, but dramatically lower levels of nitrogen and phosphorus.

8. LAND APPLICATION SYSTEMS

8.7 NATURAL WETLANDS. Although true wetlands occupy only 3 percent of U.S. land surface, these areas offer great potential for recharging water tables and refurbishing wastewaters. Purposeful utilization of the ecologically complex habitats is new to modern man, who began to recognize around 1970 that fresh and salt water marshes, swamps, peat bogs, cypress domes, and strands could provide excellent, very inexpensive treatment. With proper system management and design, wetlands can treat wastewater without damaging the existing ecology; in fact, nutrient addition can enhance productivity and increase wildlife and overall aesthetic value. During cold periods, wetlands cannot handle discharges; therefore, storage in lagoons in necessary. Loading capacity has been estimated at about 40 persons per acre. Artifical wetlands have been constructed on sandy soil, using impervious plastic liner. Others have been made of less pervious silt and lined with clay. Peat bogs have been very successfully used in Minnesota and in Europe. In deep swamps-natural or artificial-water hyacinth, duckweed, wolffia and other aquatic plants have been used to remove nutrients from wastewater. Limitations of such vegetational techniques have been placed at 35 º N latitude.

8. LAND APPLICATION SYSTEMS

8.8 SUBSURFACE APPLICATION. Basically, the subsurface systems involve either soil mounds or subsurface filters. Such systems are used where adverse soil conditions exist, such as high water table, relatively impermeable clay-rich soils, or shallow bedrock.

8. LAND APPLICATION SYSTEMS

8.9 COMPOSTING OF SLUDGE. Where sufficient, inexpensive biomass is available (such as bark, wood chips, sawdust or other agricultural wastes), sewage may be directly mixed with organic matter and composted in open windrows or in a ventilated building. Such processes require a great deal of biomass, but the biomass may be dried in the sun with mechanical turning and then re-used to soak up more sewage. This systems may be used only if flows are small. Composting has most successfully been used on sludges from any of the unit operations discussed in this manual. Composting techniques were developed in China and India in ancient times, rediscovered in Europe in the 1800s, and recently have been utilized in the U.S.

8.9.1 MOISTURE CONTROL. Sludges may be composted without addition of organic matter but are generally too moist. Some bulky organic matter such as the organic portion of solid waste should be used to blend with the sludge and chipped media to entrain air and soak up moisture. Moisture content should be kept at around 65-72 percent.

8. LAND APPLICATION SYSTEMS

8.9.2 TECHNIQUES. The easiest and least expensive composting technique involves using partially dried, recycled compost, some new "bulking agent," and sludge mixed with a front-end loader or with mechanical mixers to the correct moisture content. The compost is then windrowed and turned "inside-out, outside-in" several times at about one month intervals. An even simpler technique involves collecting leaves or other biomass during the year, piling the bulking agent in windrows, and pouring sludge into a depression shoveled along the length of the windrow. Such simple techniques and a six-month curing period will assure sufficient pathogen kill to allow use of the compost on military base shrubs, lawns or parks. A more elaborate scheme has been developed at Beltsville by USDA. In this system, blowers, aeration pipes and, usually, a roofed building allow more rapid "curing" and a more continuous sludge processing. By this system, about 2.5 dry tons osludge may be composted per acre, including space for the building, office, runoff control and adequate landscaping. Before any composting technique is used, a belt of trees should be established surrounding the work area for odor control (which in proper composting is minimal), dust dampening and seclusion. Partially finished compost combined with fresh sludge has been treated f with earthworms, which stabilize compost even more rapidly. Earthworms may be removed from the compost by drum screening; but on military posts, their main function would be to speed up sludge stabilization and produce an easily handled, granular soil amendment from what had previously been a noxious slurry.

8. LAND APPLICATION SYSTEMS

8.10 LAND SPREADING OF SLUDGES. Soil biota are capable of stabilizing most organic wastes, including oily sludges. Today, only about 25 percent of sludges are spread on land; even less are composted. However, the organic materials in sludges are beneficial in restoring fertility to soils disturbed by mining, gravel operations or poor agricultural practices. There are, however, some major limitations. Concentrated sludges (if not composted or otherwise stabilized) placed on land should be immediately covered to prevent odor production and insect breeding.. Sludges can be sliced or injected into soil or into stubble, using special equipment. Deep snow and deep frost will stop land spreading operations. Although heavy metals concentrations in some city or industrial sludges have prevented their agricultural use, this limitation should not apply to waste sludges. Particularly useful for design of sludge land disposal is EPA Report 625/1-77-008.

J. Paul Guyer 2014 73

9. NITRIFICATION

9. NITRIFICATION.

9.1 PROCESS DESCRIPTION. Nitrification occurs in two steps: first NH_4 is converted to NO_2 Nitrosomonas bacteria; then the NO_2 is converted to NO_3 by Nitrobacter bacteria. This process is limited by the relatively slow growth rate of Nitrosomonas. The following discussion is mainly applicable to activated sludge processes and nitrification. Additional information may be found in *EPA Process Design Manual for Nitrogen Control.*

J. Paul Guyer 2014 74

9. NITRIFICATION

9.2 SINGLE-STAGE NITRIFICATION. When nitrification utilizing the activated sludge process is designed as a single stage, a longer detention time (12 to 24 hours as compared with the usual 2 to 8 hours) is necessary in the aeration basin in order to provide an effective microbial population. This is interpreted in terms of "mean solids residence time" (SRT), which is defined as the amount of mixed-liquor, volatile suspended solids under aeration (in pounds) divided by the sum of suspended solids wasted and suspended solids lost in the effluent (in pounds per day). The mean solids residence time will be maintained at 10 to 20 days or longer, depending on the temperature; in terms of hydraulic detention time, 12 to 24 hours is typical. Temperature has a significant effect on the nitrification reaction rate, which approximately doubles for every 10ºC rise in temperature between 6ºC and 25ºC. A minimum dissolved oxygen level of 1.0 milligrams per liter is sufficient for nitrification. However, since dissolved oxygen concentration is a critical parameter, the aeration system will be designed to provide residual dissolved oxygen of 2.0 milligrams per liter and pH 8.5, using lime addition if necessary. The optimum pH has been reported to be 8.4. Lime requirements will vary with the temperature and must be determined for each case. Nitrification consumes approximately 7.5 milligrams per liter of alkalinity per milligram per liter ammonia nitrogen oxidized.

J. Paul Guyer 2014 75

9. NITRIFICATION

9.2.1 EFFECT OF TOXIC SUBSTANCES. Nitrification can be inhibited by certain toxic substances, such as halogen-substituted phenolic compounds, thiourea and its derivatives, halogenated solvents, heavy metals, cyanides, phenol, and cresol. These, however, are usually associated with industrial wastes.

9.2.2 DESIGN CRITERIA FOR SINGLE-STAGE NITRIFICATION IN ACTIVATED SLUDGE, EXTENDED AERATION PROCESSES.
The design of single-stage nitrification systems will provide for:
9.2.2.1 Increased aeration tank capacity and additional aeration to maintain dissolved oxygen level at 2.0 milligrams per liter;
9.2.2.2 A hydraulic detention time of 12 to 24 hours;
9.2.2.3 Sludge handling equipment suited to light, poorly compacted sludge, with recycle capacity of 150 percent of average flow;
9.2.2.4 Food-to-micro-organism ratio of less than 0.25 pounds biochemical oxygen demand per pound mixed liquor, volatile suspended solids;
9.2.2.5 Sludge retention time during winter conditions in excess of 20 days; and
9.2.2.6 Lime feeding equipment to provide alkalinity at a rate of 7.5 milligrams per liter per milligram per liter of ammonia oxidized, and a pH between 8.0 and 8.5.

J. Paul Guyer 2014 76

9. NITRIFICATION

9.2.3 SEPARATE-STAGE NITRIFICATION. Separate-stage nitrification simply separates the nitrification process from the activated sludge process. A typical system is illustrated in figure 3. The main advantage to this system is that it allows individual optimization of the activated sludge and nitrification processes in terms of hydraulic and organic loadings. The relationship between ammonia removal rate and mixed liquor, volatile suspended solids concentration is shown in figure 4. There is little sludge waste in the separate nitrification system and total sludge recycle is to be used. Detention time will be from 3 to 5 hours, based on influent flow with clarifier overflow rates between 500 and 800 gallons per day per square foot. Diffused air will be supplied at approximately 1 standard cubic foot per minute per gallon of wastewater treated.

J. Paul Guyer 2014 77

9. NITRIFICATION

9.2.4 NITRIFICATION IN TRICKLING FILTER PLANTS. Low biochemical oxygen demand loadings (less than 5 pounds per day per 1,000 cubic feet) and high wastewater temperature (20 ºC or higher) are necessary for good nitrification (80-90 percent) in trickling filters although they are often run at 12 degrees Centigrade with some loss of overall efficiency. A trickling filter filled with plastic packing can obtain 90 percent nitrification of secondary effluent at a loading rate of 0.05 gallons per minute per cubic foot. Year-round nitrification facilities must be designed for the lowest wastewater temperatures experienced in the winter months. In this instance, the required filter volume will be much greater than that required for seasonal nitrification and will require at least two-stage treatment.

J. Paul Guyer 2014 78

9. NITRIFICATION

9.2.5 ROTATING BIOLOGICAL CONTACTORS AS NITRIFICATION UNITS. Ninety percent nitrification can be accomplished using rotating biological contactors if the influent biochemical oxygen demand is less than 150 milligrams per liter and the hydraulic application rate is 2 gallons per day per square foot or less. For further information, consult the *EPA Process Design Manual for Nitrogen Control.*

9. NITRIFICATION

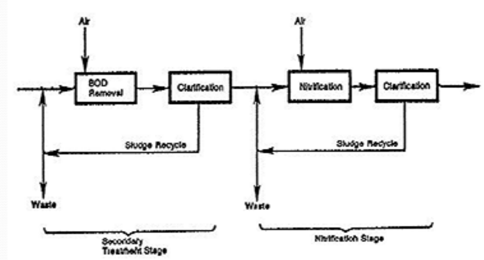

Figure 3

Separate-stage nitrification

9. NITRIFICATION

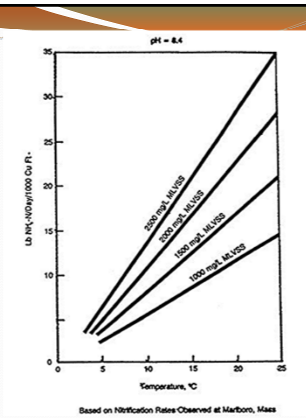

Figure 4

Nitrification tank loadings

9. NITRIFICATION

9.2.6 Air stripping. Ammonia, in the molecular form, is a gas which dissolves in water to an extent controlled by the partial pressure of the ammonia in the air adjacent tot he water. Therefore, ammonia removal from wastewater can be accomplished by contacting water droplets with large amounts of ammonia-free air. This process is desorption, but is commonly referred to as ammonia stripping. For additional information, refer to the *EPA Process Design Manual for Nitrogen Control.*

10. DENITRIFICATION

10. DENITRIFICATION

10.1 SUSPENDED GROWTH DENITRIFICATION. Denitrification is performed by heterotrophic anaerobic organisms and, therefore, requires an organic carbon source and anaerobic conditions. Suspended growth denitrification will provide gentle mixing (no aeration) with the mixed liquor being clarified. The effluent is aerated to provide dissolved oxygen and to drive off entrained nitrogen, and the sludge is recycled to the contact tank. Methanol is the most common organic carbon source used and is usually applied at a dosage of 2 to 4 pounds methanol per pound of nitrate nitrogen removed. This dosage will be carefully adjusted according to nitrate concentration and temperature in order to avoid the effects of under-dosage and over-dosage. Raw or partially treated sewage and sludge can be used as a carbon source but yield lower denitrification efficiencies. Typical design factors for this system include:

10. DENITRIFICATION

- Mixed liquor volatile suspended solids concentrations of 1,500 to 2,500 milligrams per liter;
- Detention time of 4 hours;
- Clarifier overflow rates not more than 600 gallons per square foot;
- Dissolved oxygen levels of up to 0.5 milligrams per liter (pH 7.0);
- Optimum pH from 6.5 to 7.5;
- 5 minutes of effluent aeration; and
- Sludge recycle from 50 to 100 percent of average flow.
- Temperature effects are very significant and should be kept in mind when designing contact tanks since a 10
- degrees Centigrade decrease would require twice the tank capacity.

10. DENITRIFICATION

10.2 FIXED DENITRIFICATION. Fixed denitrification utilizes a flooded packed column, with denitrifying microbial populations attached on the media surface. Sand, activated carbon, gravel, coal, and plastic packing can be used; with the finer media having shorter contact times. Columns can be either downflow or upflow configuration. Upflow columns have much longer contact times and operate at lower hydraulic loadings, but they are more efficient at lower temperatures than downflow columns. Temperature again is a very significant factor affecting denitrification efficiency. Typical design factors for both downflow and upflow denitrification are given in table 6. Fixed denitrification is capable of nitrate removal efficiencies of over 90 percent; however, the efficiency of the overall nitrification-denitrification process is limited by the performance of the nitrification system (i.e., around 90 percent nitrogen removal).

10. DENITRIFICATION

Parameters	Typical Values Downflow	Upflow
Contact time	5–10 min (fine media)	1–2 hr
Hydraulic loading	7 gpm/sq ft	0.4 gpm/sq ft
Media size	3.4–15.4 mm diameter	3.4–15.4 mm diameter
Methanol dose ratio	1.8/1 (DO = 0.6)	2.7/1
Moles methanol/moles N	2.4/1 (DO = 5.4)	
Dissolved oxygen level	1.0–1.5 mg/L	1.0–1.5 mg/L
Column depth	10 ft (fine media) 14 ft (coarse media)	6–10 ft

Table 6

Typical performance parameters for fixed-growth denitrification

11. THREE-STAGE BIOLOGICAL SYSTEMS

11. THREE-STAGE BIOLOGICAL SYSTEMS. Three-stage systems are essentially a combination of separate stage nitrification and denitrification (fig 5). The advantage of this system is its flexibility of operation and the main disadvantage is the capital cost involved. This configuration also works to prevent short circuiting, which can be a problem in nitrification/denitrification when plug flow is not achieved. The specific design factors are the same as for the individual processes involved. Three-stage biological treatment can achieve nitrogen removals of over 95 percent.

11. THREE-STAGE BIOLOGICAL SYSTEMS

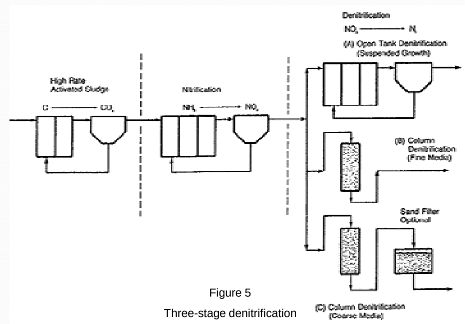

Figure 5

Three-stage denitrification

12. ANAEROBIC CONTACT PROCESS.

12. ANAEROBIC CONTACT PROCESS. A further development of the high-rate digestion process allows separation and recycling of digested sludge solids. Like the activated sludge process, detention and mean cell residence times are controlled. Denitrification within these contact vessels approached 95 percent.

13. GLOSSARY.

ACTIVATED SLUDGE is a suspended growth process for removing organic matter from sewage by saturating it with air and microorganisms that can break down the organic matter.

ADVANCED TREATMENT involves treatment levels beyond secondary treatment.

AERATION TANK is a chamber for injecting air and oxygen into water.

AEROBIC refers to a life or a process that occurs in the presence of oxygen.

AEROBIC TREATMENT UNITS provide wastewater treatment by injecting air into a tank, allowing aerobic bacteria to treat the wastewater.

13. GLOSSARY.

ALGAE are aquatic plants which grow in sunlit waters and release oxygen into the water. Most are a food for fish and small aquatic animals, but some cause water quality problems.

ALTERNATIVE SYSTEM. A wastewater treatment or collection system utilized in lieu of a conventional system.

ANAEROBIC refers to a life or a process that occurs in the absence of free oxygen.

BACTERIA are small living organisms which help consume the organic constituents of sewage.

BARMINUTOR is a device mounted on bar screens in a wastewater treatment plant to shred material, such as rags and debris, that accumulates on the bars.Bar Screen is composed of parallel bars that remove larger objects fromwastewater.

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13. GLOSSARY.

BLACK WATER is the term given to domestic wastewater that carries animal, human, or food wastes. Biological Nutrient Removal (BNR) is the use of bacteria to remove nutrients from wastewater.

BIOMASS is microbial growth.

BIOSOLIDS are treated sewage sludge solids that have been stabilized to destroy pathogens and meet rigorous standards allowing for safe reuse of this material as a soil amendment.

BIOTOWER is a unit in which the waste is allowed to fall through a tower packed with synthetic media on which there is biological growth similar to the trickling filter.

BOD (BIOCHEMICAL OXYGEN DEMAND) is a measure of oxygen consumed in biological processes that break down organic matter in water.

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13. GLOSSARY.

CARBON ADSORPTION is a method to treat wastewater in which activated carbon removes trace organic matter that resists degradation.

CHLORINATION is the process of adding chlorine gas or chlorine compounds to wastewater for disinfection.

CHLORINATOR is a device that adds chlorine, in gas or liquid form, to wastewater to kill infectious bacteria.

CLARIFIER also known as a settling tank, removes solids from wastewater by gravity settling or by coagulation.

CLEAN WATER ACT (Federal Water Pollution Control Act) originally enacted in 1948 and amended in 1972, 1981 and 1987, the Clean Water Act has as its objective the restoration and maintenance of the "chemical, physical, and biological integrity of the Nation's waters."

J. Paul Guyer 2014 93

13. GLOSSARY.

COAGULATION is the clumping together of solids to make them settle out of the sewage faster. Coagulation of solids is improved by the use of chemicals such as lime, alum, iron salts, or Polymers.

COMBINED SEWERS carry both sewage and stormwater runoff.

COMMINUTOR is a device to catch and shred heavy solid matter at the headworks of the wastewater treatment plant.

COMPOSTING is the natural biological decomposition of organic material in the presence of air to form a stabilized, humus-like material.

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13. GLOSSARY.

CONVENTIONAL SYSTEMS are wastewater treatment systems that have been traditionally used to collect municipal wastewater in sewers and convey it to a central facility for treatment prior to discharge to surface waters. Either primary or secondary treatment may be provided in a conventional system.

DENITRIFICATION is the reduction of nitrite to nitrogen gas. Denitrification is carried out in wastewater treatment tanks by bacteria under anoxic conditions. The bacteria use the nitrate for energy, and in the process, release nitrogen gas. The nitrogen gas, a major constituent of air, is released to the atmosphere.

DIFFUSED AIR is a technique by which air under pressure is forced into sewage in an aeration tank. The air is pumped into the tank through a perforated pipe and moves as bubbles through the sewage.

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13. GLOSSARY.

DIGESTION of solids takes place in tanks where volatile organic materials are decomposed by bacteria, resulting in partial gasification, liquefaction, and mineralization of pollutants.

DISINFECTION is the killing of pathogenic microbes including pathogenic bacteria, viruses, helminths, and protozoans. Dispersal/Percolation involves a volume of wastewater applied to the land, penetrating the surface, and passing through theunderlying soil.

DISSOLVED OXYGEN (DO) is the amount of free oxygen in solution in water, or wastewater effluent. Adequate concentrations of dissolved oxygen are necessary for fish and other aquatic organisms to live and to prevent offensive odors.

ELIGIBLE COSTS are those wastewater reduction activities that can be funded with State Revolving Fund (SRF) loans.

J. Paul Guyer 2014 96

13. GLOSSARY.

EFFLUENT is the treated liquid that comes out of a treatment plant after completion of the treatment process.

EUTROPHICATION is the normally slow aging process by which a lake evolves into a bog or marsh and ultimately disappears. During eutrophication, the lake becomes enriched with nutrients, especially nitrogen and phosphorus, which support the excess production of algae and other aquatic plant life. Eutrophication may be accelerated by many human activities.

EVAPOTRANSPIRATION is the uptake of water from the soil by evaporation and by transpiration from the plants growing thereon.

FLOC is a clump of solids formed in sewage by biological or chemical action.

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13. GLOSSARY.

FLOCCULATION is the process by which clumps of solids in sewage are made to increase in size by chemical action.

GRAY WATER refers to domestic wastewater composed of wash water from sinks, shower, washing machines (does not include toilet wastewater).

GRINDER PUMP is a mechanical device which shreds wastewater solids and raises the fluid pressure level high enough to pass wastewater through small diameter pressure sewers.

GRIT CHAMBER is a small detention basin designed to permit the settling of coarse, heavy inorganic solids, such as sand, while allowing the lighter organic solids to pass through the chamber.

J. Paul Guyer 2014 98

13. GLOSSARY.

GROUNDWATER is the zone beneath the ground surface saturated with water that has seeped down through soil and rock.

IMPERVIOUS means resistant to penetration by fluids or by roots.

INCINERATION involves combustion of the organic matter in sewage sludge, producing a residual inert ash.

INFILTRATION is the penetration of water through the ground into sub-surface soil or the passing of water from the soil into a pipe, such as a sewer.

INFLUENT refers to water, wastewater, or other liquid flowing into a reservoir, basin or treatment plant, or any unit thereof.

J. Paul Guyer 2014 99

13. GLOSSARY.

INORGANIC refers to compounds that do not contain carbon. Interceptors are large sewer lines that collect the flows from smaller main and trunk sewers and carry them to the treatment plant.

INTERMITTENT SAND FILTER involves a bed of sand or other fine-grained material to which wastewater is applied intermittently in flooding doses.

LAGOON is a shallow pond in which algae, aerobic and anaerobic bacterial purify wastewater.

LAND APPLICATION is the controlled application of wastewater or biosolids onto the ground for treatment and/or reuse.

LATERAL SEWERS are small pipes that are placed in the ground to receive sewage from homes and businesses and convey it to main, trunk and interceptor sewer lines leading to the wastewater treatment plant.

J. Paul Guyer 2014 100

13. GLOSSARY.

MECHANICAL AERATION uses mechanical energy to inject air from the atmosphere into water to provide oxygen to create aerobic conditions.

MEDIA FILTERS involves a bed of sand or other fine-grained material to which wastewater is applied, generally to physically remove suspended solids from sewage. Bacteria on the media decompose additional wastes. Treated water drains from the bed. Solids that accumulate at the surface must be removed from the bed periodically.

MICROBES is shorthand for microorganisms.

MILLION GALLONS PER DAY (MGD) is a measurement of the volume of water.

J. Paul Guyer 2014 101

13. GLOSSARY.

MOUND SYSTEM is an effluent disposal system involving a mound of soil built up on the original ground surface to which effluent is distributed.

NATIONAL POLLUTANT DISCHARGE ELIMINATION SYSTEM (NPDES) is a program established by the Clean Water Act (CWA) that requires all wastewater discharges into "waters of the United States" to obtain a permit issued by the US Environmental Protection Agency (EPA) or a state agency authorized by the EPA.

NITRIFICATION is the biochemical oxidation of ammonium to nitrate.

NITROGENOUS WASTES are wastes that contain a significant concentration of nitrogen.

NUTRIENTS are elements or compounds essential as raw materials for plant and animal growth and development.

J. Paul Guyer 2014 102

13. GLOSSARY.

ORGANIC MATTER is the carbonaceous material contained in plants or animals and wastes.

OVERLAND FLOW is land treatment which involves the controlled application of wastewater onto grass-covered gentle slopes, with impermeable surface soils. As water flows over the grass-covered soil surface, contaminants are removed and the water is collected at the bottom of the slope for reuse.

OXIDATION involves aerobic bacteria breaking down organic matter and oxygen combining with chemicals in sewage.

OXIDATION POND is an aerated man-made pond used for wastewater treatment.

OZONATION is a disinfection process where ozone is generated and added to wastewater effluent to kill pathogenic organisms.

J. Paul Guyer 2014 103

13. GLOSSARY.

PATHOGENS are disease-causing microorganisms, including pathogenic bacteria, viruses, helminths, and protozoans.

PERCOLATION is the movement of water through subsurface soil layers, usually continuing downward to the groundwater.

PERMEABILITY is a measure of the ease with which water penetrates or passes through soil.

PHOSPHORUS is a nutrient that is essential to life, but in excess, contributes to the eutrophication of lakes and other water bodies.

POLLUTION results when contaminants in human, animal, vegetable, mineral, chemical or thermal waste or discharges reach water, making it less desirable for domestic, recreation, industry, or wildlife uses.

J. Paul Guyer 2014 104

13. GLOSSARY.

POLYMER is a long chain organic compound produced by the joining of primary units called monomers. Polymers are used to improve settling of suspended solids, remove solids from wastewater, and improve dewatering of biosolids.

PRESSURE SEWERS are a system of pipes in which the water, wastewater or other liquid is transported under pressure supplied by pumps.

PRETREATMENT involves treatment of wastes or wastewater by industries performed prior to the discharge to the sewer system.

PRIMARY TREATMENT is the initial stage of wastewater treatment that removes floating material and material that easily settles out.

PUMP is a mechanical device for raising or lifting water or other fluid, or for applying pressure to fluids in pipes.

J. Paul Guyer 2014 105

13. GLOSSARY.

RECEIVING WATERS are waterbodies (i.e. rivers, lakes, oceans, or other water courses) that receive discharges of treated or untreated wastewater.

ROTATING BIOLOGICAL CONTACTOR (RBC) is a wastewater treatment process involving large, closely-spaced plastic discs rotated about a horizontal shaft. The discs alternately move through the wastewater and the air, developing a biological growth on the surface of the discs that removes organic material in the wastewater. Sanitary Sewer is the collection system for transporting domestic and industrial wastewater to municipal wastewater treatment facilities. Stormwater is not directed into this system but is handled by a separate system.

SECONDARY TREATMENT is the second stage in most wastewater treatment systems in which bacteria consume the organic matter in wastewater. Federal regulations define secondary treatment as meeting minimum removal standards for BOD, TSS, and pH in the discharged effluents from municipal wastewater treatment facilities.

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13. GLOSSARY.

SEDIMENTATION TANKS are wastewater treatment tanks in which floating wastes are skimmed off and settled solids are removed for disposal.

SEEPAGE is the slow movement of water through small cracks or pores of the soil, or out of a pond, tank or pipe.

SEPTAGE refers to the residual solids in septic tanks or other on-site wastewater treatment systems that must be removed periodically for disposal.

SEPTIC TANKS are a type of onsite wastewater treatment system in which the organic waste is decomposed and solids settle out. The effluent flows out of the tank to a soil adsorption field or other dispersal system**.**

SEQUENCING BATCH REACTORS (SBR) are a variation of the activated sludge process where all treatment processes occur in one tank that is filled with wastewater and drawn down to discharge after treatment is complete.

J. Paul Guyer 2014 107

13. GLOSSARY.

SETTLEABLE SOLIDS are solids that are heavier than water and settle out of water by gravity.

SEWERS are a system of pipes that collect and deliver wastewater and/or stormwater to treatment plants or receiving waters.

SOIL ABSORPTION FIELD is a subsurface area containing a trench or bed with a minimum depth of 12 inches of clean stones and a system of piping through which treated wastewater effluent is distributed into the surrounding soil for further treatment and disposal.

SLOW RATE LAND TREATMENT involves the controlled application of wastewater to vegetated land at a few inches of liquid per week.

STORM SEWERS are a separate system of pipes that carry rain and snow melt from buildings, streets and yards to surface waters.

SUSPENDED SOLIDS are the smallparticles suspended in water or wastewater

J. Paul Guyer 2014 108

13. GLOSSARY.

TRANSPIRATION is the process by which water vapor is released to the atmosphere by living plants.

TRICKLING FILTER is a fixed film process that involves a tank, usually filled with a bed of rocks, stones or synthetic media, to support bacterial growth used to treat wastewater.

ULTRAVIOLET RADIATION (UV) is a disinfection process where wastewater is exposed to UV light for disinfection.

VIRUS is the smallest form of a pathogen which can reproduce within host cells.

WASTEWATER TREATMENT PLANT is a facility involving a series of tanks, screens, filters, and other treatment processes by which pollutants are removed from water.

WATER TABLE is the elevation of groundwater or saturated soil level in the ground

J. Paul Guyer 2014 109

That's all folks!

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