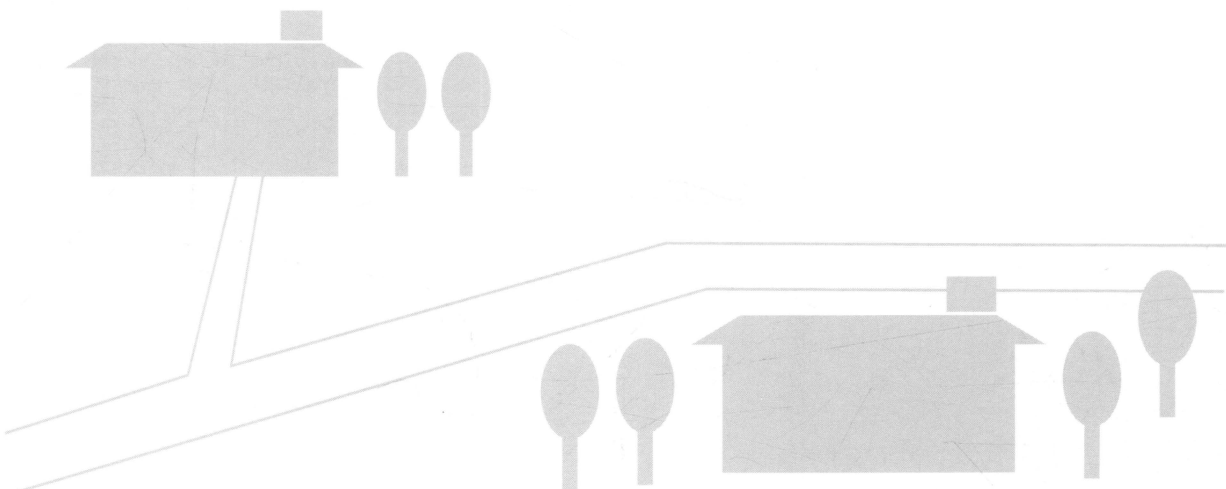
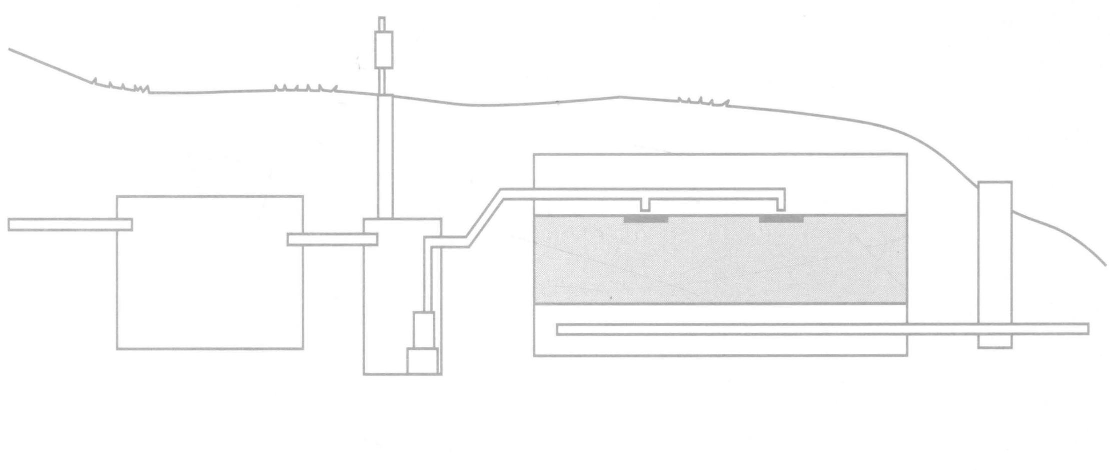
Bulletin 876

Sand Bioreactors for Wastewater Treatment

for Ohio Communities





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Sand Bioreactors for Wastewater Treatment

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Figures and Tables

Sand bioreactors are fixed-film biological treatment units. They are in the same category as trickling filters and rotating biological contactors, and are sometimes referred to as sand filters. As wastewater is applied to the top of a bed of sand, gravity draws it down between the sand particles. The surface of the sand grains is soon colonized by a film of microorganisms, as shown in **Figure 1**. The microorganisms draw nutrients, organic matter, and oxygen from the wastewater and air that passes through the sand bed. The sand also traps suspended solids. Sand bioreactor effluent is typically very clear with low biochemical oxygen demand (BOD_5) and ammonia levels. Small sand bioreactors can serve individual dwellings, or larger ones can be used to serve an entire community.

Sand bioreactors differ from trickling filters and rotating biological contactors in that the small grain size of the sand media does not allow for sloughing of excess biomass. If continually overloaded, the sand tends to clog. In this way they are fail-safe, requiring the owner or operator to take corrective action. A malfuctioing sand bioreactor backs up rather than release poorly treated effluent to a receiving stream. These sand bioreactors also differ from those which receive secondary treated effluents. Sometimes a filter of sand is used after an aerobic treatment plant to physically filter the wastewater in order to remove excess suspended solids and "polish" the effluent. A filter of sand used for effluent polishing serves a different function than a sand bioreactor, has different design requirements, and is not covered in this document.

Sand bioreactors respond well to gradual increases in wastewater loading. Therefore, they are very appropriate for new developments with a gradual build out rate. Sand bioreactors also tolerate fluctuations in flow, especially changes from a negligible flow to very high flows. In this way, sand bioreactors are appropriate for seasonal use and recreational areas.

This bulletin is intended for designers and regulators of wastewater treatment systems. The types, design criteria, construction, operation, and maintenance practices for sand bioreactors are described along with regulatory and permit requirements.

Categories of Sand Bioreactors

Intermittent (single pass) sand bioreactors receive wastewater from a primary treatment unit through periodic surface applications totaling 0.5 to 1 gal/ft²/day. The wastewater is allowed to flow through the sand by the force of gravity between applications. Air penetrates the surface of the reactor between each wastewater application, and newly applied wastewater pushes trapped air down through the sand. Through intermittent applications of small amounts of wastewater, the filter remains aerobic.

Intermittent sand bioreactors are constructed of a 24-inch deep bed of medium to coarse sand. A supporting layer of gravel and a collection drain are placed beneath the sand to collect treated wastewater for ultimate disposal. **Figure 2** shows a cross section of an intermittent sand bioreactor system.

Recirculating sand bioreactors resemble intermittent sand bioreactors in that they receive periodic surface applications of wastewater, but are smaller. About 3 to 5 gal/ft²/day of primary treated wastewater is mixed with 9 to 25 gal/ft²/day of treated effluent. The mixture is applied in small doses, throughout the day, to the surface of a sand bioreactor. Therefore, in addition to the sand bioreactor, this system requires a recirculation tank to mix treated

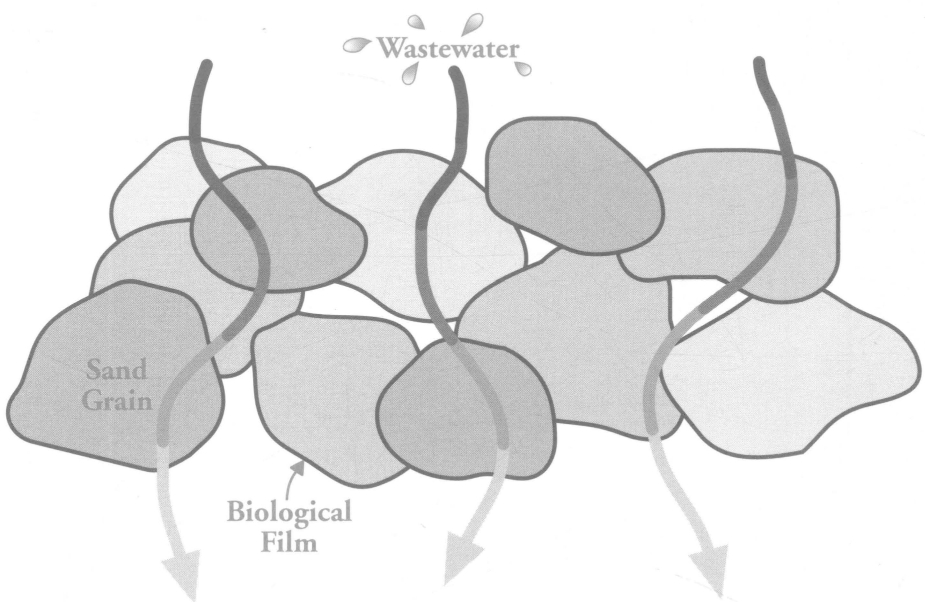


Figure 1. Microorganism growth on sand grains in sand bioreactor system.

Cattaragus, New York, a community of 200 homes, treats all of its wastewater through 4 intermittent sand bioreactors. The wastewater is pretreated in one of 4 parallel, 2,500 gallon septic tanks and is applied in 3 to 4 doses per day to a 36-inch deep bed of sand at a dry weather application rate of 1.5 gal/ft²/day and a wet weather application rate of 6.25 gal/ft²/day. After UV disinfection, effluent with an average BOD_5 of 7 mg/l is discharged to a stream.

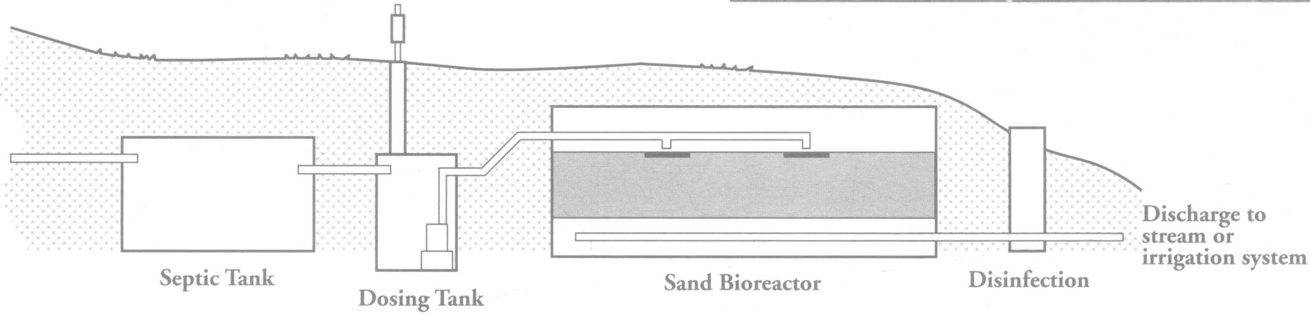


Figure 2. Intermittent sand bioreactor system.

Oriskany Falls, New York, a community of 900 homes, treats all of its wastewater through 4 recirculating sand bioreactors. The wastewater is pretreated in a septic tank. The septic tank effluent and 33% of the sand filter effluent are mixed in a recirculation tank and applied in 12 doses per day at 10 minutes per dose. The sand beds are 36 inches deep with an application rate of 4 gal/ft²/day. After UV disinfection, effluent with average BOD_5 of 2 mg/l and ammonia ranging from 1.1 to 2.0 mg/l is discharged to a stream.

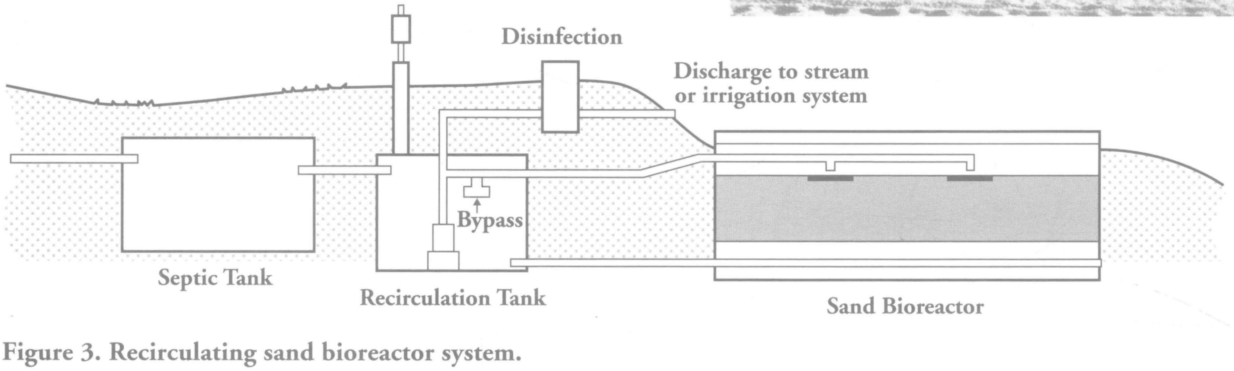


Figure 3. Recirculating sand bioreactor system.

and untreated wastewater, the appropriate pump, and controls. Another important difference between a recirculating and an intermittent sand bioreactor is the sand specifications. Coarse sand is used to construct recirculating sand bioreactors, whereas intermittent sand bioreactors utilize medium to coarse sand. **Figure 3** shows a cross section of a recirculating sand bioreactor system.

Recirculating the effluent several times has many advantages. The partially treated wastewater applied to the filter surface has practically no odor. Because the applied wastewater has a lower BOD_5, more can be applied with each dose, resulting in a smaller bioreactor.

By mixing partially treated wastewater containing nitrate with full strength, anaerobic septic tank effluent, some denitrification can occur to achieve nitrogen removal. Denitrification rates of up to 50% have been achieved with recirculating sand bioreactors. Denitrification rates increase at higher temperatures.

Styles of Bioreactors

Sand bioreactors can be designed and constructed in three ways: open, covered with a roof, or buried.

The surface of an **open sand bioreactor** is always exposed to outside elements. Open bioreactors offer the best accessibility for maintenance and observations of ponding, a precursor to clogging. They are also the least expensive type to construct. Open sand bioreactors are exposed to variations in hydraulic load, due to precipitation and variations in temperature. In cold climates, a layer of ice forms on the sand surface but the applied wastewater will easily flow underneath the ice. In addition, weeds tend to grow on open sand bioreactors which can become an eyesore, and provide a protected, moist place for animals to inhabit. Regular raking eliminates weeds.

By **burying a sand bioreactor,** it is protected from extreme fluctuations in temperature and hidden from view. The final depth of a sand bioreactor ranges from 4–5 feet, in order to accommodate for the 24 inches of sand depth, the supporting gravel and drainage system, the surface distribution system in a gravel cap, and a 1-foot layer of insulating soil. Therefore, it is common for a buried sand bioreactor to be constructed in a shallow excavation and be mounded above the ground surface **(Figure 4)**.

Access and easy observation to the buried sand bioreactor has been eliminated. Observation ports become the only way to determine the onset of ponding. To assure a 20-year design life, buried sand bioreactors should be designed for extremely small loading rates to reduce the need for maintenance and the likelihood of ponding. If ponding does occur, a second buried sand bioreactor built on a site can be used to rest the primary bioreactor. The second sand bioreactor will only be used for a few months during the resting period, therefore it can be smaller than the primary.

A roof cover over a sand bioreactor may be an appropriate compromise. The roof protects the bioreactor from precipitation and extreme fluctuations in temperature. The shade provided by the roof also eliminates weed growth on the sand surface. However, roofs add to the construction cost, and must be constructed with easy access, wind and snow loads, durability, and appearance in mind. **Figure 5** shows some photographs of roofs over sand bioreactors.

Roof designs vary greatly and must perform three functions: insulate the bioreactor, allow for easy access for

Figure 4. Buried sand bioreactor, Anchorage, Alaska.

maintenance, and be esthetically pleasing. The most common roofs are lifted off as a single piece, or in sections as necessary. Some roof designs used on sand bioreactors include a sloped, fixed roof built on posts about two feet above the sand surface. In this way an operator can reach under the roof edge to make observations and access the bioreactor to perform necessary maintenance. Hinges can be placed along one edge of flat or monosloped roofs so they can be propped up. Roofs are made of a variety of materials ranging from small roof trusses with sheathing and shingles to match nearby buildings, to 2 x 4 frames with exterior plywood and roofing paper. Corrugated metal and fiberglass have also been used.

Bioreactor Design

Sand bioreactor design is very simple. Three major factors must be considered in the design: media depth, media characteristics, and area loading rate. **Sand depth** is the first design consideration. In general, the deeper the bioreactor, the greater the level of treatment. However, most of the treatment occurs in the top 9 to 12 inches. Deeper filters produce a more consistent quality effluent, but after 24 inches no significant treatment improvement is achieved with added depth. Additionally, air penetration into deep sand beds is more difficult, so deeper bioreactors are more likely to clog. Therefore, a sand depth of 24 inches is appropriate for most domestic wastewaters.

Of all of the design criteria, **media characteristics** are the most important. Sand bioreactor clogging is usually the result of using sand that is too fine, has too many fines, or has a weak or platey structure. The most important feature of the sand is not the grains, but rather the pores the sand creates. The treatment of wastewater occurs in the pores, where suspended solids are trapped, microorganisms grow, and air and water flow.

The ideal media is hard and nearly spherical in shape. Quartz sand is often used because it is inexpensive and readily available. Garnet sand, mineral tailings, expanded clays, and other materials have all been successfully used. Some plastic media may also be appropriate.

The size distribution of the sand is measured as the effective size and the uniformity coefficient. Ideal sands for intermittent bioreactors are a medium to coarse sand with an effective size between 0.3 mm and 1.5 mm. The uniformity coefficient should be less than 4.0. A summary of sand effective size and uniformity coefficients by bioreactor type is listed in **Table 1**.

Sand effective size and uniformity

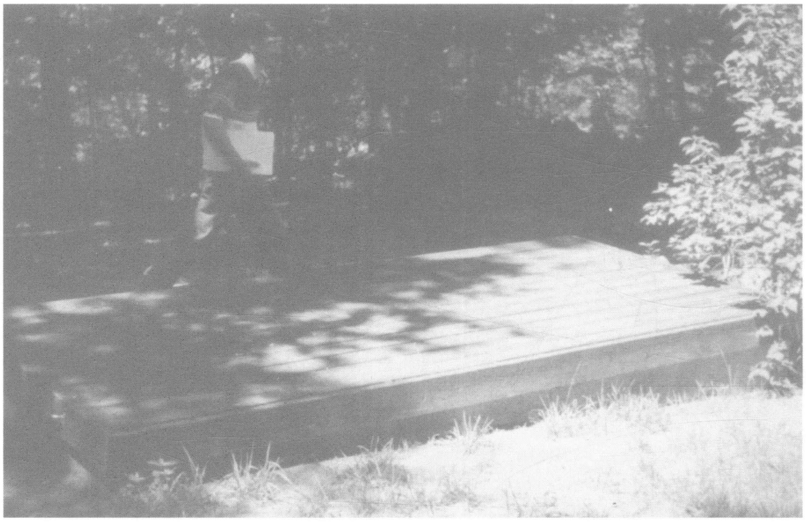


Figure 5. Examples of roofs used for bioreactors in Ann Arundel County, Maryland.

coefficient affect filter performance. BOD_5 and ammonia removal are a function of effective size. If the bioreactor effluent will be discharged to a stream, very low $CBOD_5$ (10 mg/l) and ammonia (1 mg/l in summer and 3 mg/l in winter) effluent concentrations are typically required. Bioreactors for this purpose should be constructed of sand with effective size between 0.3 and 0.5 mm. Clogging becomes a major concern when using sand with an effective size between 0.3 mm and 0.5 mm, therefore filters using this size sand must be lightly loaded or rested periodically.

If the effluent will be reused through irrigation, required $CBOD_5$ levels are less stringent (25 mg/l) and ammonia removal is not necessary. Sand effective size of 0.5 mm to 1.0 mm for single pass bioreactors, and 0.5 mm to 1.5 mm for recirculating bioreactors are appropriate. Clogging is less of a concern when using coarser sand.

The sand uniformity coefficient will have an effect on the time of clogging or longevity of the bioreactor. Bioreactors constructed of sand with high uniformity coefficients will begin ponding more quickly and require more frequent resting. If a bioreactor must operate for many years without resting, use sands with a uniformity coefficient less than 3. If periodic resting is planned, sand with a uniformity coefficient of up to 4 can be used. The availability and cost of the sand will greatly impact the decision. Sands with uniformity coefficients between 3 and 4 are more readily available and are lower in cost than sands with a uniformity coefficient less than 3. If sand with a uniformity coefficient between

Table 1. Basic Sand Bioreactor Design Criteria.

Bioreactor Type and Performance	Effective Size	Uniformity Coefficient	Daily Area Loading Rate of Primary Treated Wastewater
Intermittent (Single pass)			
Very low effluent $CBOD_5$ and ammonia (for stream discharge)	0.3–0.5 mm	less than 4	up to 1 gal/ft²/day
Low effluent $CBOD_5$ (for irrigation on public access sites)	0.5–1.0 mm	less than 4	up to 1 gal/ft²/day
Long operation without resting (for buried bioreactors)	0.5–1.5 mm	less than 3	up to 0.5 gal/ft²/day
Recirculating			
Very low effluent $CBOD_5$ and ammonia (for stream discharge)	0.3–0.5 mm	less than 4	up to 5 gal/ft²/day
Low effluent $CBOD_5$ (for irrigation on public access sites)	0.5–1.5 mm	less than 4	up to 5 gal/ft²/day
Long operation without resting	1.0–1.5 mm	less than 3	up to 3 gal/ft²/day

3 and 4 is used, simply make provisions for multiple beds with periodic resting capability.

The effective size is defined as the sand size, when no more than 10% by weight is smaller, referred to as D10. The uniformity coefficient is the ratio of the sand size when 60% by weight is smaller, or the D60, over the size when no more that 10% by weight is smaller, the D10. Determining the effective size and uniformity coefficient is accomplished by screening the sand through a series of sieves, as described in **Box 1** on the next page.

Sand meeting these standards does not occur naturally in Ohio and must be manufactured. Many aggregate companies in Ohio have the capability to clean naturally occurring sand to meet sand bioreactor specifications.

The **area loading rate** of the bioreactor is the third design criteria. In general, the higher the area loading rate, the more likely the bioreactor is to clog and back up. Once clogged, the bioreactor must be rested for four to six months.

Design area loading rates differ with filter type. A typical design area loading rate for an intermittent sand bioreactor of 1 gal/ft^2/day balances the organic loading from domestic sewage to the degradation activities of the microorganisms. Bioreactors loaded at this rate can operate for many years with no ponding. Because access and air penetration is restricted in buried sand bioreactors, a very low area loading rate of 0.5 gal/ft^2/day is recommended.

To save space, some intermittent sand bioreactors are loaded up to 5 gal/ft^2/day. When loading bioreactors at this high rate, clogging can occur in as quickly as one to two years. Therefore, it is necessary to construct two or more bioreactor cells and carefully manage the whole system through alternating loading onto cells throughout the year. One management strategy is to divide the bioreactor into four cells as shown in **Figure 6**. During the warmest months of the year, rest one cell beginning in the spring (March through June) and one in the fall (July through October), while temporarily increasing the area loading rate to the other three. Continue to rest each of the other cells in the next year to complete a two-year management schedule. In this way, the per cell area loading rate is lowest in the coldest time of the year when the biological activity is also at its lowest.

Another way to reduce the area of the bioreactor is through recirculation. From 3 to 5 gallons/ft^2/day of primary treated wastewater is mixed with 9 to 25 gallons/ft^2/day of sand bioreactor effluent. The resulting mixture is applied throughout the day in small doses totaling 12 to 30 gallons/ft^2/day.

Rest Spring Year 1	Rest Spring Year 2
Rest Fall Year 1	Rest Fall Year 2

Figure 6. Management strategy for bioreactor systems with high loading rates.

Wastewater Application

Wastewater is applied to the surface of intermittent and recirculating sand bioreactors in doses. The dosing frequency has a tremendous influence on the performance of each sand bioreactor. After each dose of wastewater, air is naturally drawn into the bioreactor, maintaining an aerobic treatment environment. Do not use a gravity distribution system that results in a trickle flow onto the bioreactor surface. The constant application of wastewater will result in premature clogging.

For intermittent sand bioreactors, the simplest dosing strategy of once per day is also the poorest. It has been known for decades that by simply dividing the daily waste flow into two equal doses per day, the treatment efficiency can be greatly increased **(see Figure 8 on page 13)**. Small, frequent doses of wastewater spaced throughout the day is one objective of a wastewater application system.

Recirculating sand bioreactors require a different dosing strategy with more frequent doses. This is a result of the increased amount of water that must recirculate through the system. Recirculation ratios typically range from 3:1 to 5:1. As a result, the amount of water applied to the bioreactor surface is increased three to five times. Once the total amount of water to be applied to the bioreactor is established, a simple dosing pattern is developed. The following calculations provide a typical dosing strategy for recirculating sand bioreactors.

BOX 1

Determination of Sand Effective Size and Uniformity Coefficient

Apparatus

- No. 200 sieve
- Set of sieves Nos. 3½, 10, 20, 30, 40, and 60, lid, and receiver.
- Drying oven at a controlled temperature of 105–110°C.
- Set of metal pans for drying and weighing samples.
- A balance of 250 gram capacity and accurate to 0.01 gram.

Begin with about a 100-gram sample of sand. Dry in 105–110°C oven for two hours. Weigh dry sand sample (WD). Label and weigh metal sample pans, and set aside.

Fill sand sample container with tap water, shake and decant wash water through No. 200 sieve. Wash material retained on sieve back into sample container. Repeat several times until wash water is clear.

Dry sand again in 105–110°C oven for two hours. Weigh dry washed sand (WDS) and subtract from dry weight to determine weight of fines.

Wt. of fines = WD – WDS

Arrange a set of sieves from largest opening to smallest as shown in **Figure 7**. Shake stacked sieves, vibrating, jogging, and jolting them to keep the sand in continuous motion for two minutes. Shake each sieve individually over a clean tray to make sure all the sand has passed through and is distributed by size.

Pour the sand off each sieve into labeled, weighed pans. Weigh and determine the sample weight (WS) by subtracting the weight of the pan. Determine the percent passing for each sieve by:

$$\textbf{Percent of material retained on the sieve} = \frac{\textbf{WS x 100\%}}{\textbf{WDS}}$$

Percent passing = percent passing the next largest sieve – percent retained on sieve

An example calculation of percent passing each sieve for a 120 gram sample is summarized in **Table 2**. Graph the percent passing results on semilog paper as shown in **Figure 14** (page 24).

From the graph, find the Effective Size as D10, where only 10% of the sample is a smaller size. Also from the graph, find D60, where 60% of the sample is a smaller size. The Uniformity Coefficient is D60/D10.

Table 2. Sand Particle Size Analysis—Calculating Percent Passing Selected Sieves.

Sieve number	Sieve size	Sample weight	% passing next larger sieve	% retained	% passing
3.5	5.60	6.00	100	5	95
10	2.00	8.40	95	7	88
20	0.85	57.60	88	48	40
30	0.60	14.40	40	12	28
40	0.425	12.00	28	10	18
60	0.25	15.60	18	13	5
pan		6.00	5	5	
Total sample weight		120.00			

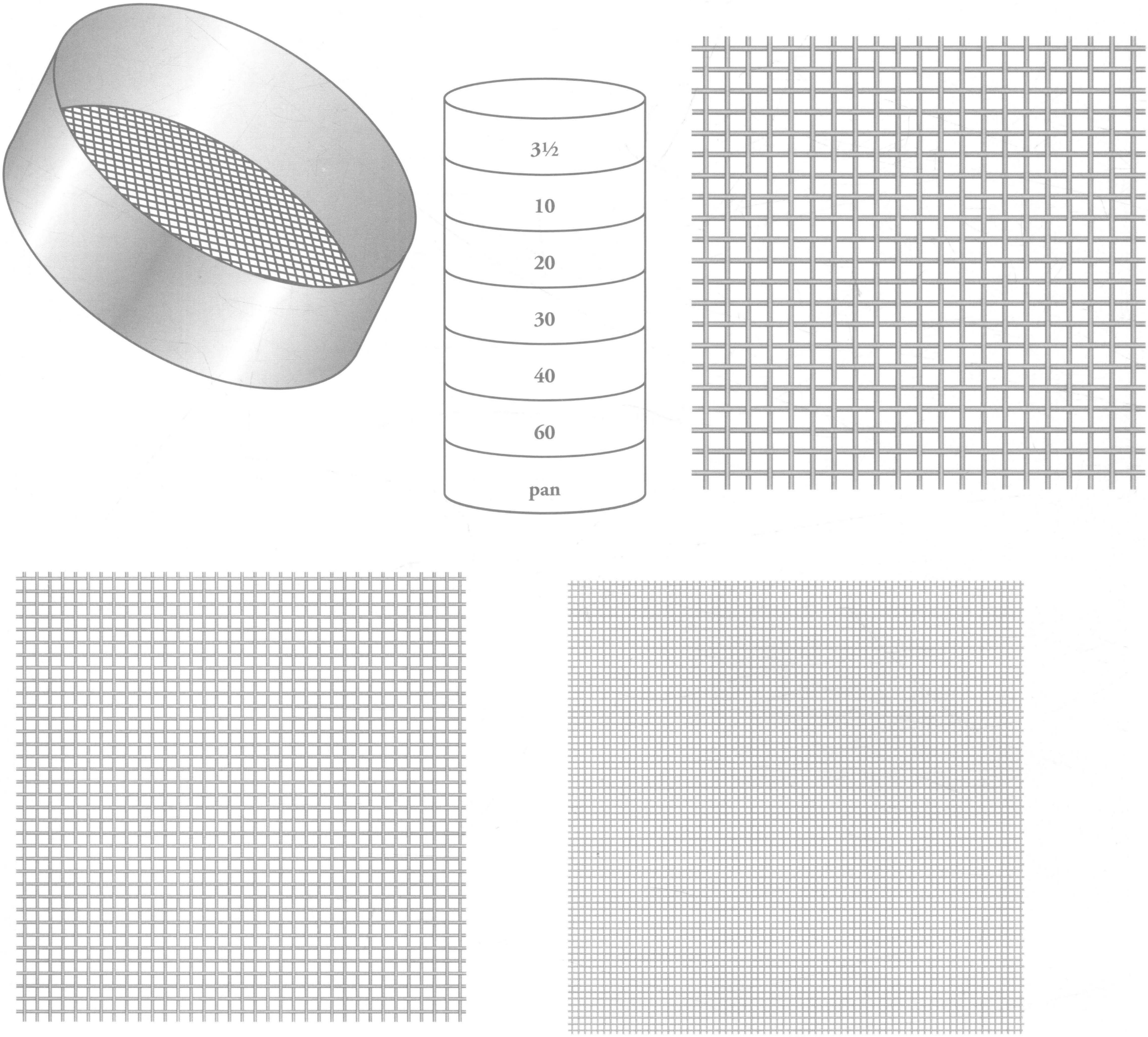


Figure 7. Sieves with various sized openings are used for sand analysis. The sieves are arranged largest to smallest from top to bottom, as shown.

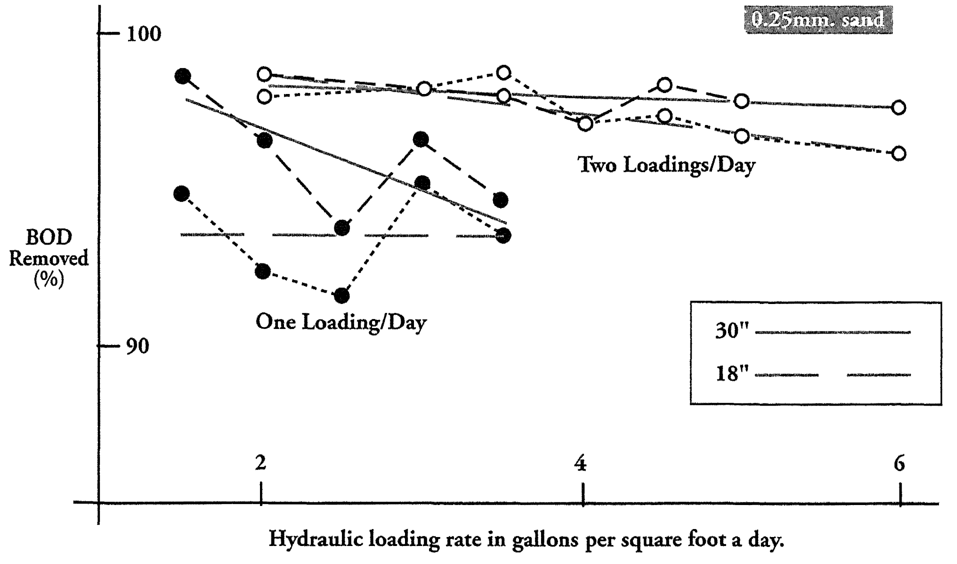


Figure 8. BOD removal by 18-inch deep and 30-inch deep sand bioreactors under one and two loadings per day. (after: DeS Furman, T., W.T. Calaway, and G.R. Grantham. 1955. Intermittent sand filters—multiple loadings. Sewage and Industrial Wastes. 27(3): 261–274.)

Example

Average daily flow: 10,000 gallons per day (gpd)
Recirculation ratio: 5:1
Dosing frequency: 1 dose per hour

10,000 gpd * 5 recirculations = 50,000 gpd applied to the bioreactor

1 dose per hour * 24 hours per day = 24 doses per day

$$\frac{\text{50,000 gpd}}{\text{24 doses per day}} = \text{2,083 gallons per dose}$$

The dosing strategy is based on an average daily flow into the treatment system, not the design flow. Therefore, adjustments to the dosing system must be made when influent flows change substantially.

The following techniques could be used to divide the daily load into several small doses. Remember, the objective is to apply as many small doses per day as possible.

The most reliable way to divide the daily flow of wastewater into a large number of small doses is to accumulate the wastewater in a tank equipped with a pump and a timer. The timer turns the pump on and off several times per day. A timer can be easily adjusted by the system operator to reflect water use patterns. Float switches are used to override the timer during low and high flow periods. The timer should be set to turn on and off as many times as possible

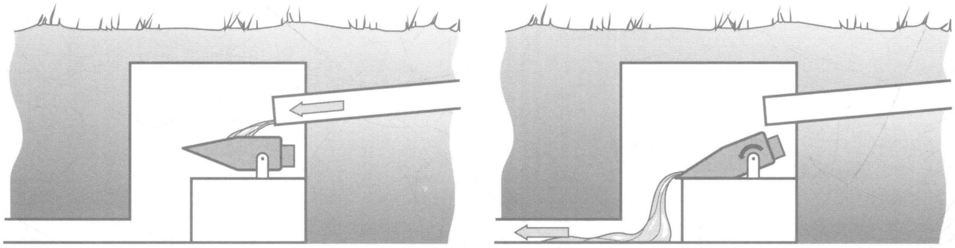


Figure 9. Dosing system with tipping pan.

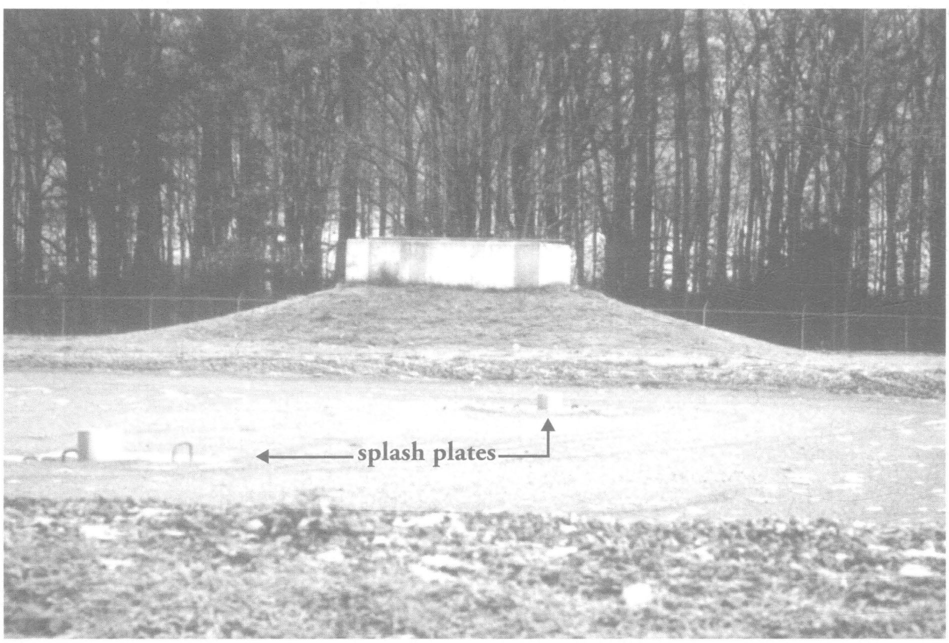
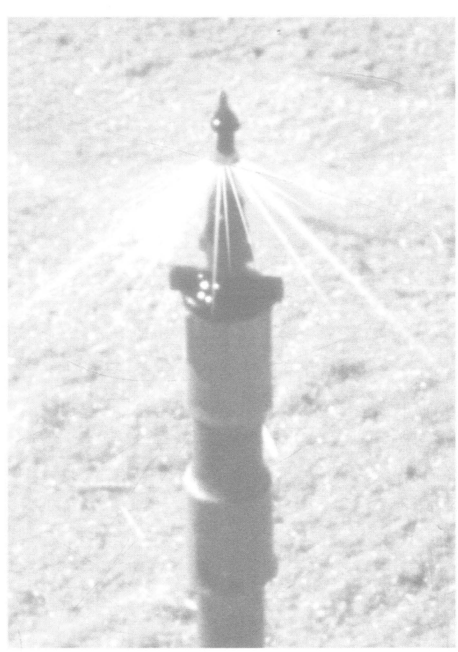


Figure 10. Examples of wastewater application systems for sand bioreactors.

Above: Large diameter pipe discharging onto a splash plate away from the sand bioreactor edge.

Right: Sprinkler to deliver a fine spray of wastewater in small, even doses to the bioreactor.



with a minimum of once every four hours.

For some small systems (less than 1,000 gpd), a timer may not be practical. A submersible sewage pump controlled by float switches in a dosing chamber can be used to deliver the accumulated wastewater to the bioreactor surface in small doses. A predetermined amount of wastewater is delivered to the bioreactor surface based on a flow-weighted proportion. Set the float switches so that one pump cycle pumps ⅙ to 1⁄24 of the daily design flow.

Some Ohioans, such as the Amish, do not use electricity and some bioreactor systems may be considered for remote locations that do not have electrical service. To meet this special need, consider dosing a sand bioreactor with a tipping pan as shown in **Figure 9**. A tipping pan allows a predetermined amount of wastewater to be applied to the sand bioreactor based on a flow-weighted proportion.

Short circuiting along the edge of the bioreactor is another concern. Keep applications near the center of the sand and keep the sand surface level. A single large diameter pipe, along the center of the bioreactor, with three holes widely spaced, is one approach. An elbow at the end of a pipe, directed onto a concrete splash plate, is also effective. Another configuration is to bring the pipe up through the center of the bioreactor and surround it with a splash plate. The splash plate prevents erosion of the sand by the running water, and distributes the wastewater radially. Sprinklers that evenly distribute the wastewater in a fine spray over the bioreactor surface are also used, but an operator must make frequent inspections and correct clogged sprinklers. Examples of application systems are shown in **Figure 10**.

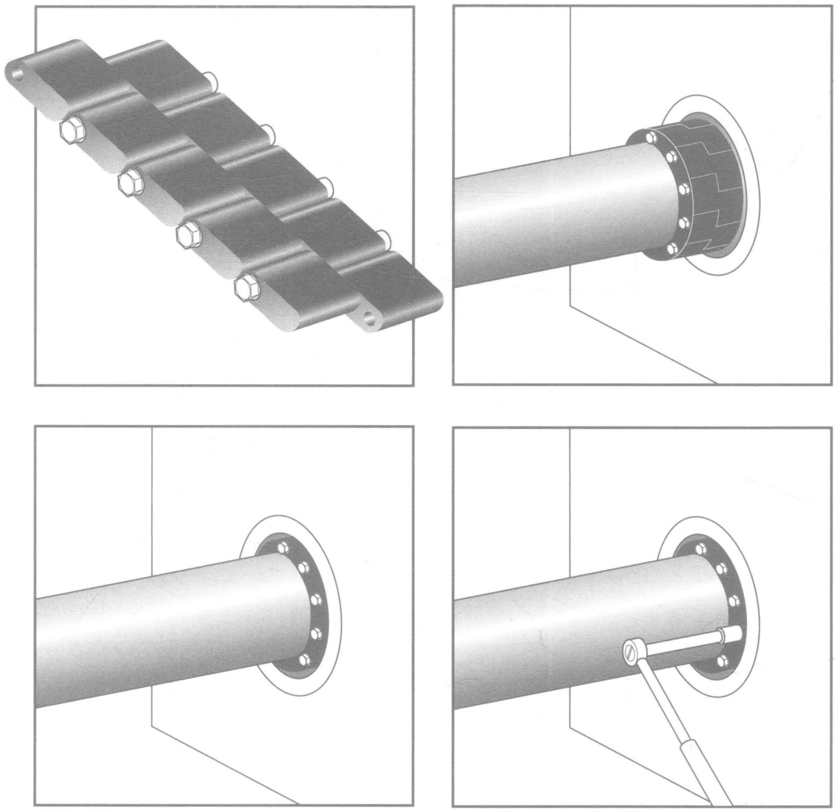


Figure 11. Example of a seal to prevent groundwater infiltration around outlet pipe that is passing through a concrete tank wall. The seals are shipped as a belt of interconnected links, wrapped around the pipe, and connected end to end. The seal is then slid between the pipe and tank wall. As the bolts are tightened the seal expands water tight seal is acheived.

Sand Bioreactor System Construction

Keeping groundwater and surface water out of the sand bioreactor is the single most important goal in construction. Liners, or cast or precast tanks, are required with sand bioreactors to keep out groundwater. Liners and tanks are also used to keep untreated wastewater from entering groundwater. Berms and surface grading must be provided in such a way as to keep surface water from draining into a sand bioreactor.

Liners are an effective way to prevent infiltration of groundwater into the system. A PVC liner of at least 20 mil is recommended in an earthen basin with provisions for UV protection. As with any liner system, it is important to use as few seams as possible. If an outlet must penetrate the bottom of the liner, great care must be taken at this point to prevent leaks.

Precast, or poured in place, concrete tanks are an alternative to lined earthen basins. Small bioreactors have been constructed in the bottom section of precast septic tanks. The tanks from an existing aeration basin can be retrofitted with a drain, filled with suitable sand, and a distribution system for use as a sand bioreactor.

As with plastic lined earthen basins, all connections through a concrete tank wall must be watertight. Linkseals are effective in eliminating infiltration for connections into concrete structures **(Figure 11)**.

Short circuiting through or around the sand is another concern with sand bioreactors. Careful sand placement to avoid internal layering is necessary to avoid forming internal clogging and channels. Dropping the sand from a height of several feet should be avoided, because it promotes segregation by grain size. If sand layering is suspected, plow or rototill to redistribute the sand.

Draining renovated wastewater from the bottom of the bioreactors is accomplished by simply sloping the bottom of the structure to an outlet. A layer of gravel should be placed at the bottom of the bioreactor to support the sand and promote the free flow of effluent to the outlet.

Four-inch diameter, perforated vent pipe, on six-foot centers should be positioned in the gravel layer and brought up to the ground surface. Bringing air into the bottom of the bioreactor promotes aerobic conditions.

Wastewater Pretreatment

Since treatment in a sand bioreactor is accomplished by natural flow through a bed of sand, particles in the wastewater are easily filtered out in the sand and can quickly clog the bioreactor. Primary settling in a septic tank or clarifier is required to reduce the risk of surface clogging.

Septic tank effluent filters and screens around dosing pumps have also proven effective in protecting sand bioreactors from solids that escape the settling tank. Protecting sand bioreactors from excess solids is especially important for buried sand bioreactors where periodic observations and management are difficult.

Fortunately, most solids carried over from septic tanks or clarifiers are biodegradable. For ultimate biodegradation of open or covered bioreactors, raking of the surface to incorporate the solids into the beds of bioreactors can be practiced on a regular basis. In this way, a sand bioreactor can recover from occasional doses of solids which may occur during high flow periods.

Greases from restaurants and other food handling operations can quickly clog sand bioreactors. Removal of fats from wastewater through grease traps is currently recommended. Ongoing research on using sand bioreactors for high grease-content wastewater is summarized in **Box 2** below.

Disinfection

Sand bioreactors by themselves do not filter out disease causing organisms. Disinfection is needed before surface discharge.

Ultraviolet (UV) light disinfection is an appropriate option for sand bioreactor effluent. When used properly, UV light will destroy bacteria, viruses, algae, and other microorganisms in renovated wastewater. UV light disinfection becomes more efficient as the amount of suspended solids in the effluent decreases. Therefore, sand bioreactors with their extremely clear effluent are especially well suited to UV light disinfection.

When considering UV light, the system design for effluent quality should reflect a worst case scenario. Sand filter effluent typically contains less than 10 mg/l of suspended solids. For design purposes, assume an effluent containing 30 mg/l. In this way, the UV light system should be able to destroy bacteria levels to well below those required for any surface discharge. For recreational use of the receiving stream, fecal coliform bacteria must be within the range of 200 counts per 100 ml to 2,000 per 100 ml on a 30-day average. Fecal coliform limits for irrigation of treated effluent can be as low as 23 counts per 100 ml.

Many other disinfection alternatives are available such as chlorine and ozone, and should also be considered.

Disposal of Discharge

Effluent from a sand bioreactor can be discharged to three places: surface irrigation, subsurface discharge, or steam discharge under permit. Because sand bioreactor effluent is extremely low in solids, low in ammonia, and low in $CBOD_5$, it is well suited for all three discharge scenarios.

BOX 2

Research is being conducted at The Ohio State University and elsewhere on how to use sand bioreactors to renovate wastewaters that contain grease. Some of the findings to date include:

- Animal fats and vegetable oils are degradable by microorganisms, but degradation is slow.
- Emulsifying agents play a key role in dispersing grease into smaller, more quickly degraded particles.
- Grease particles are easily trapped in beds of sand, providing the contact time needed for microbial degradation.
- Gravel filters show potential as a pretreatment device. The gravel traps grease and initiates the degradation of fats and oils before final treatment in a sand bioreactor.
- The high chemical oxygen demand (COD) of restaurant and food handling wastewater requires lower loading rates (on the order of 0.25 gal/day/ft2).

Surface irrigation is described in detail in Ohio State University Extension Bulletin 860, *Reuse of Reclaimed Wastewater Through Irrigation*.

The very low solids content of sand bioreactor effluent and low BOD_5 makes it well suited for **subsurface irrigation**. Trickle irrigation systems with their very low application rates are disposal options for sand bioreactor effluent. Soil absorption systems are also used to dispose of sand bioreactor effluent. Research suggests that sand bioreactor effluent can be applied to soil absorption fields at loading rates four times higher than septic tank effluent.

At some sites **stream discharge** may be an acceptable option. Sand bioreactors produce very high quality effluent that is very low in $CBOD_5$, total suspended solids, and ammonia. Sand bioreactor systems also have a built-in, fail-safe mechanism. Unlike most wastewater treatment systems that discharge poor quality wastewater if neglected, poorly maintained sand bioreactors clog up and do not discharge any wastewater to the stream. Sand bioreactors also present an easily detected, early warning of clogging, in that wastewater begins to pond after each dose. When ponding occurs for even a few minutes, preventative measures can be taken early before problems occur. UV light for disinfection also works well, due to the very low suspended solids content, eliminating the concerns of chlorine in renovated wastewaters discharged to streams.

Bioreactor Operation and Maintenance

It takes from four to eight weeks to **start up a new sand bioreactor** to produce a high quality effluent. Naturally occurring microorganisms in the wastewater, sand, and even air, begin to colonize the surface of the sand grains with the first application of wastewater. As wastewater application continues, the microorganisms grow and form a biofilm on the sand grain surfaces. The effluent quality reflects the biofilm formation. Over the first few days of wastewater application, the effluent may appear cloudy from any fine clay and silt particles washing out of the sand. From then on, sand bioreactor effluent is extremely clear.

$CBOD_5$ levels and ammonia levels drop steadily after the first few days of wastewater application. When ambient temperatures are near 70°F, nitrification begins within the first two weeks of wastewater application, and full nitrification is observed within one month. At cooler ambient temperatures, the same pattern occurs, but will take longer to fully develop.

To minimize start-up time and potential environmental impact, new bioreactors should be established during warm weather. Once established, sand bioreactors are extremely resilient to fluctuations in loading. During periods of low or no loading, the microorganisms utilize food and nutrients stored in the biofilm itself. Short term high loadings can stress the biofilm by decreasing the amount of air that flows through a more flooded bed of sand. Because the microbial film is fixed, it does not wash away and is ready to continue renovating wastewater.

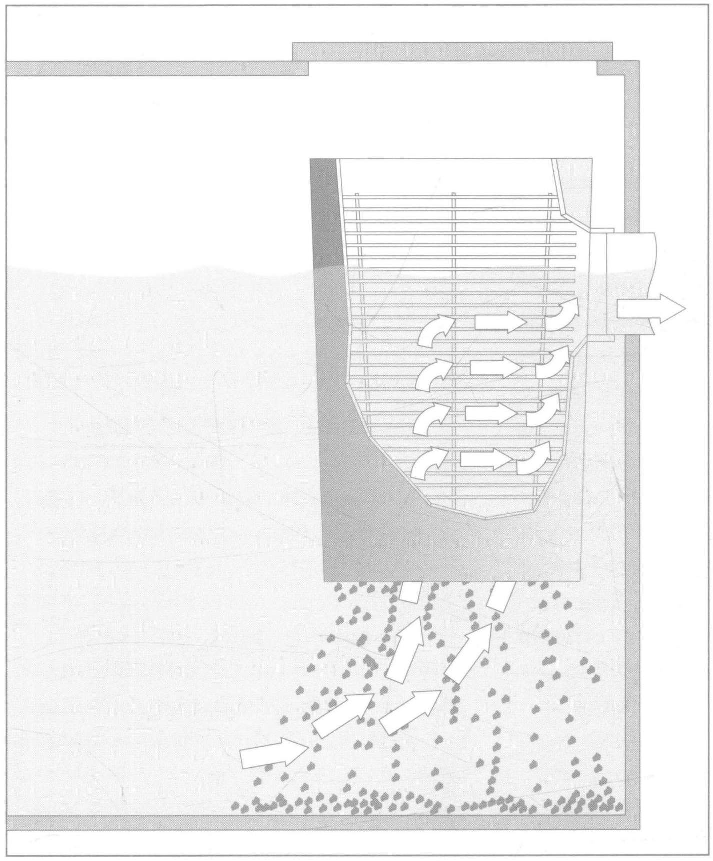
The primary goal of **sand bioreactor management** is to manage clogging. Sand bioreactors are predisposed to clog over time. This is an important fail-safe feature of sand bioreactors that acts to protect the receiving environment from poorly treated wastewater. The predisposition to clogging also penalizes the negligent treatment system owner.

Unlike mechanical treatment plants that require extensive training and daily attention, sand bioreactors are extremely easy to manage, requiring little time or training. Unfortunately, maintenance free systems do not exist, so no one has the luxury of totally neglecting their wastewater treatment system.

Routine Maintenance

1. Check bioreactor for surface ponding. Wastewater should penetrate the sand in a matter of minutes. If wastewater stands on the surface for even a few minutes, begin to take corrective action.

- Possible excess solids are being applied to the sand surface. Add additional primary settling capacity or add an outlet filter to improve primary treatment performance **(Figure 12)**. Rake the sand surface to break up and incorporate the solids that have collected on the surface. Also, if possible, rest the sand bed for about four months.
- Check the sand used to build the bioreactor. It may be finer than specified or have too high a uniformity coefficient. If this is the case, resting the sand for four months may restore the bioreactor. If the sand is indeed too fine or too nonuniform, continue to use the bioreactor, but at lower application rates. This most likely means the construction of an additional sand bed.
- Check the loading rate. Over time, water use may increase or water leaks may develop, causing the loading rate to be more than the designed recommendations. Rest the sand bed for four months and reduce the loading rate. This may mean finding and repairing water leaks or constructing an additional sand bed.
- Check the dosing system. Sometimes on/off switches malfunction and the necessary periodic dosing is compromised. A constant, trickle application of wastewater will result in premature



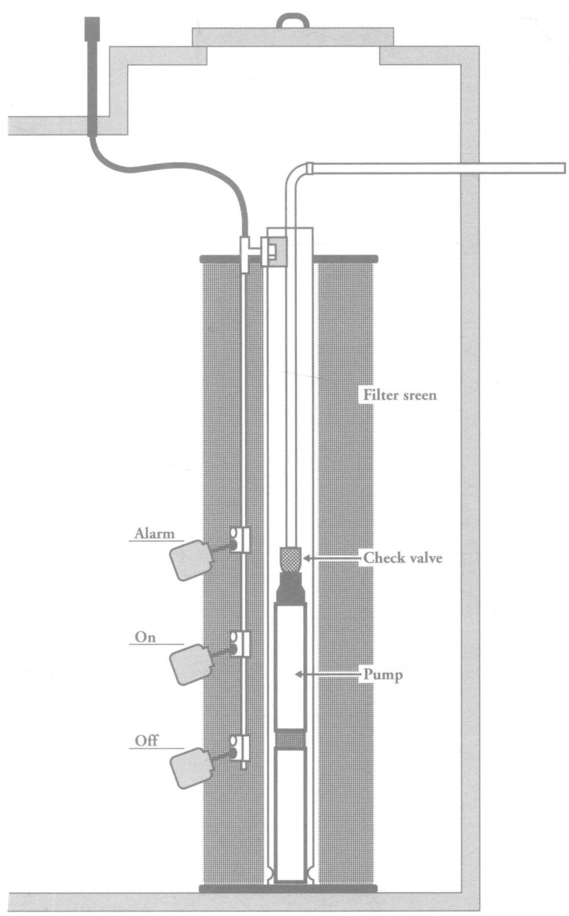


Figure 12. Septic tank effluent filter (above top) and pump chamber filter (above bottom).

clogging. Rest the sand bed for four months and restore the dosing system.

2. Ponding deep in the sand bed can only be observed through an inspection port that extends down to the bottom of the sand. Anaerobic conditions can develop deep in the sand bed causing the formation of a black, mineral crust (iron sulfide) on the sand deep in the bioreactor. Bioreactor effluent will begin to show a brown stain when this occurs. When this begins, corrective action should be taken.

- Check the loading rate. Over time, water use may increase or water leaks may develop, causing the loading rate to be more than the designed recommendations. Rest the sand bed for four months or treat the bottom layer of the sand filter with hydrogen peroxide, delivered up through the discharge pipe to oxidize the iron sulfide crust. Most importantly, reduce the loading rate. This may mean finding and repairing water leaks or constructing an additional sand bed.
- Check the BOD_5 of the wastewater being applied. The sand bioreactors described in this bulletin are intended for domestic sewage following primary treatment. Expected BOD_5 levels for this type of wastewater are between 75 and 150 mg/l. If the BOD_5 levels are a great deal higher than that, the surface loading rate must be reduced to prevent the creation of anaerobic conditions deep in the sand bed. Rest the sand bed for four months or treat the bottom layer of the sand filter with hydrogen peroxide, delivered up through the discharge pipe to oxidize the iron sulfide crust. Most importantly, reduce the loading rate by constructing an additional sand bed.

3. Check the dosing system. Because they are mechanical systems, pumps with electrical connections should be checked at least once a year.

- Conduct a simple pump test to check the performance of the pump, the switches, and the alarm system. If possible, begin by turning off the power to the pump and filling the dosing tank with water up to the emergency level. Turn on the power. The emergency light or alarm should be activated and the pump should come on.
- Check the dose volume by filling the dosing tank again with water until the pump turns on and measure the water level in the tank. Continue to pump out water until the pump turns off, and again measure the water level. Compare the drop in inches to the original settings, and based on the inside dimensions of the tank, calculate the dose volume. Use the calculations below for round and rectangular tanks. See calculations below.
- Check the dosing tank for apparent leaks that are bringing excess water into the tank. Look for leaks around the tank inlet and outlet pipes and around the access port.
- Visually inspect the wiring for signs of rodent damage, wear, cracks, or corrosion Do not touch the wiring, because of the great risk of electrical shock. Remember, make no electrical connections inside a pumping chamber because it is a wet, corrosive environment If damage is evident, rewiring is probably necessary. For more information on proper wiring refer to Ohio State University Extension Bulletin 829, *Mound Systems Pressure Distribution of Wastewater,* for sale at county Extension offices.

4. Check the septic tank for necessary pumping Pumping frequency can be estimated by:

$$P = \frac{0.0228\ C}{Lned}\ (V - Qnt)$$

P = pumping frequency, in years
C = percent solids in septic tank sludge (usually 4%)
e = trap efficiency (usually 70%)
d = fraction of solids digested (usually 50%)
n = number of persons served
L = per capita solids loading rate, in pounds per person daily (usually 0.2)

For Round Tank

$$\text{Gallons per inch of depth} = \frac{\text{tank diameter in inches} * \text{tank diameter in inches}}{294}$$

For Rectangular Tank

$$\text{Gallons per inch of depth} = \frac{\text{tank width in inches} * \text{tank length in inches}}{231}$$

Q = volumetric loading, in gallons per person daily
t = liquid detention time, in days (usually 1 day)
V = tank volume, in gallons

5. Check condition of septic tank inlet and outlet baffles. If a baffle is damaged or missing, replace with a sanitary tee. Also, consider replacing the outlet baffle with an outlet filter to reduce the amount of solids discharged to the bioreactor. **(Figure 12 on page 18)**

6. Measure wastewater flow to check for leaks and excessive water use. In time, excess wastewater can cause the pump to fail prematurely, or the bioreactor to clog. A simple event counter can check how frequently a pump comes on. Household water meters can be checked for evidence of excess water use.

7. Maintain the sand surface, roof, or earth cover.

- For open sand bioreactors, rake the sand surface, pull any weeds, and level the sand surface **(Figure 13).**
- For buried sand bioreactors, tree roots can clog pipes. Keep trees from growing on the earthen cover.
- For covered sand bioreactors check roof for leaks.

8. Watch for changes in surface water drainage. Excess water is the greatest threat to the proper performance of a sand bioreactor. Changes in landscaping near the bioreactors may divert excess drainage water and overwhelm the bioreactor, causing premature clogging. Watch out for surface drainage when new roads or driveways are constructed in the area. Also, divert drainage off nearby building roofs away from the bioreactor.

Diagnosing Problems

Sand bioreactors have a reputation of producing extremely high quality effluent even with fluctuating waste loading. Sometimes an individual reactor is plagued with poor performance. Poor performance is usually the result of short circuiting through the bioreactor. Short circuiting can occur along the edges of the bioreactor if it is neglected and allowed to pond. Short circuiting may also occur along discharge, vent, or inspection pipes that extend through the sand. Diversion collars placed around the pipes, just below the sand surface, can be retrofitted if this begins to happen. Another source of short circuits is channels through the sand. Channels seldom form if the wastewater is applied in small doses. Though rare, it is difficult to predict which bioreactors will form channels. Channeling has been observed in one filter when all the other filters in the system, built at the same time, in the same way, with the same materials, do not form channels. Try to eliminate the channels through a four-step process.

1. Check switches and timers in the application systems to make sure the bioreactor is receiving only small doses of wastewater spaced throughout the day.
2. Till the surface of the filter with a rototiller or moldboard plow.
3. Remove all of the sand from the bioreactor and put it back in again.
4. As a last resort, replace the sand with new sand.

With open sand bioreactors dosed with septic tank effluent, odors should not be a problem. However, nearby neighbors may become concerned. One way to avoid conflicts is to reset the timer to dose during the night or when neighbors are not around.

Figure 13. Weed control is needed for open sand bioreactors. In addition to grass and weeds, algae can grow on an open bioreactor surface. Regular raking helps to prevent clogging. (Top) Raked and unraked sand bioreactors. (Bottom) Rake for maintaining sand bioreactor.

Monitoring

The monitoring approach for a sand bioreactor is dictated by the ultimate point of disposal; either reuse through irrigation or stream discharge. Details on monitoring needed for reuse systems are outlined in Ohio State Extension Bulletin 860, *Reuse of Reclaimed Wastewater Through Irrigation in Ohio,* for sale at county Extension offices. In general, bioreactor effluent should be monitored for $CBOD_5$ and fecal coliform bacteria when reusing the effluent through irrigation, as shown in **Table 3**. Also, flow should be monitored using a water meter, wastewater flow meter, or a pump event counter.

Monitoring approaches for bioreactors that are approved for stream discharge are described in detail in Ohio EPA policy 1.10. **Table 4** summarizes the monitoring requirements. In general, bioreactor effluent must be monitored for temperature, dissolved oxygen, $CBOD_5$, total suspended solids, turbidity, ammonia, fecal coliform bacteria, chlorine residual, and effluent volume, before stream discharge. Monitoring frequency and number of parameters monitored increases with increasing design flow, poor record of operation and maintenance, previous water quality violations, and sensitive stream considerations.

Table 3. Summary of Ohio Basic Bioreactor Monitoring Requirements for Wastewater Reuse Through Irrigation in Systems Less Than 0.15 mgd.

Effluent Parameter	Unrestricted Access Sites	Restricted Access Sites	Agricultural Sites
Flow	Daily	Daily	Daily
$CBOD_5$	1 per week	1 per week	1 per week
Fecal coliform bacteria (when irrigating)	Daily	Daily	Daily

Table 4. Summary of Ohio Basic Bioreactor Monitoring Requirements for Stream Discharge.*

	Design Flow (mgd)		
Effluent Parameter	Less than 0.025	0.025–0.1	0.1–0.25
Flow	Daily	Continuous	Continuous
Temperature	1 per week	Daily	Daily
Chlorine residual	1 per 2 weeks	Daily	Daily
Dissolved oxygen	1 per week	Daily	Daily
pH	—	1 per week	Daily
Suspended solids	1 per month	1 per week	2 per week
$CBOD_5$	1 per month	1 per week	2 per week
Ammonia	1 per month	1 per 2 weeks	1 per 2 weeks
Fecal coliform bacteria	1 per month	1 per month	1 per week
Turbidity	Daily	Daily	—

*More frequent monitoring for more parameters is required for large plants.

Regulations and Permits

Like monitoring, permit requirements differ based on the ultimate disposal of the bioreactor effluent. Systems serving a single family dwelling, duplex, or triplex, require an installation permit from the local health department. All other systems require a *Permit to Install* from the Ohio Environmental Protection Agency (OEPA). The agency staff reviews the plans to insure the system is adequately designed. An operation and maintenance plan needs to be submitted with the permit application. This plan will likely require revision after the bioreactor has been in use for several years.

Monitoring requirements and effluent limitations are typically specified in a *Permit to Install* for wastewater reuse systems. Monitoring results must be submitted regularly to the OEPA.

If the bioreactor is designed to discharge into waters of the state, a discharge permit (referred to as a NPDES permit) is required in addition to a *Permit to Install*. The NPDES permit is issued for five years and requires renewal. It specifies the required effluent limits and monitoring conditions that must be met. Effluent limits for conventional treatment technologies are listed in **Table 5**.

More stringent limits are required if water quality standards cannot be maintained within the limits for conventional technologies. As with any new discharge to the waters of the state, the provisions in Ohio's antidegradation rule (3745-1-05) must be complied with as summarized in **Table 6**. Most of Ohio's streams are classified as general high quality waters. A complete list of stream designations is found in 3745-1.

Early contact with the district OEPA office is highly recommended. By obtaining the necessary application forms early, and discussing the desire to use a sand bioreactor for wastewater treatment, the planning and permit process can help avoid confusion and determine special environmental conditions.

Table 5. Effluent Limits for Stream Discharge from Conventional Treatment Technologies.*

Effluent Parameter	30 Day Average	7 Day Average
TSS	12 mg/l	18 mg/l
$CBOD_5$	10 mg/l	15 mg/l
Ammonia		
summer	1.0 mg/l	1.5 mg/l
winter	3.0 mg/l	4.5 mg/l
DO	not less than 6.0 mg/l	not less than 6.0 mg/l
Fecal coliforms	1,000 mpn/100ml	2,000mpn/100ml
Chlorine (if applicable)	less than 0.038 mg/l	less than 0.038 mg/l
pH	6.5 to 9.0	6.5 to 9.0
Oil and grease	less than 10 mg/l	less than 10 mg/l

*Sand bioreactors may be required to meet these limits.

Table 6. Summary of Provisions of Ohio's Antidegradation Rule for Waters of the State. Discharges may not interfere with any designated or existing use.

	Outstanding National Resources	Outstanding High Quality	Superior High Quality	General High Quality	Limited Quality	State Resource
Examples			Lake Erie	Warm water habitat		Scenic Rivers & Publically Owned Lakes
Impact of Discharge on Ambient Water	May not be degraded	May not exceed a 5% change	Up to water quality criteria set aside	Up to water quality criteria	Up to water quality criteria	Up to water quality criteria or up to set aside for oxygen demand, if exists
Renewing NPDES	No increase in concentration or load	No increase in load	Up to water quality criteria set aside	Up to water quality criteria	Up to water quality criteria	Up to water quality criteria or up to set aside for oxygen demand or less than 5% change in ambient for toxics
New NPDES and/or PTI	Not allowed	At existing background water quality	Up to water quality criteria set aside	Up to water quality criteria	Up to water quality criteria	Table 4 levels and less than 5% change in ambient for toxics
Exclusions*	None apply	None apply	If none apply must evaluate**	If none apply must evaluate**	All limited quality waters meet exclusions	If none apply must evaluate**

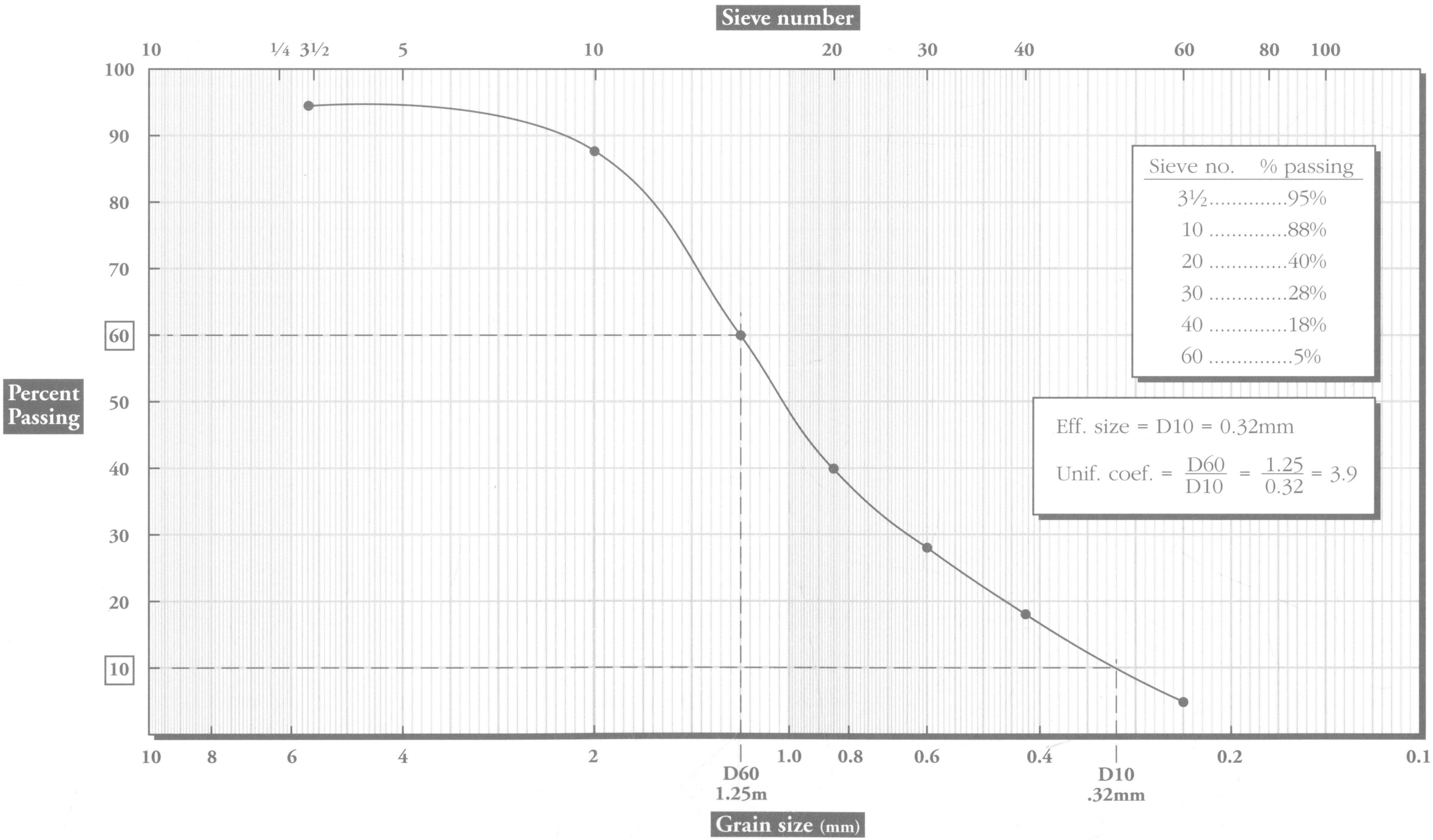
***Exclusions**

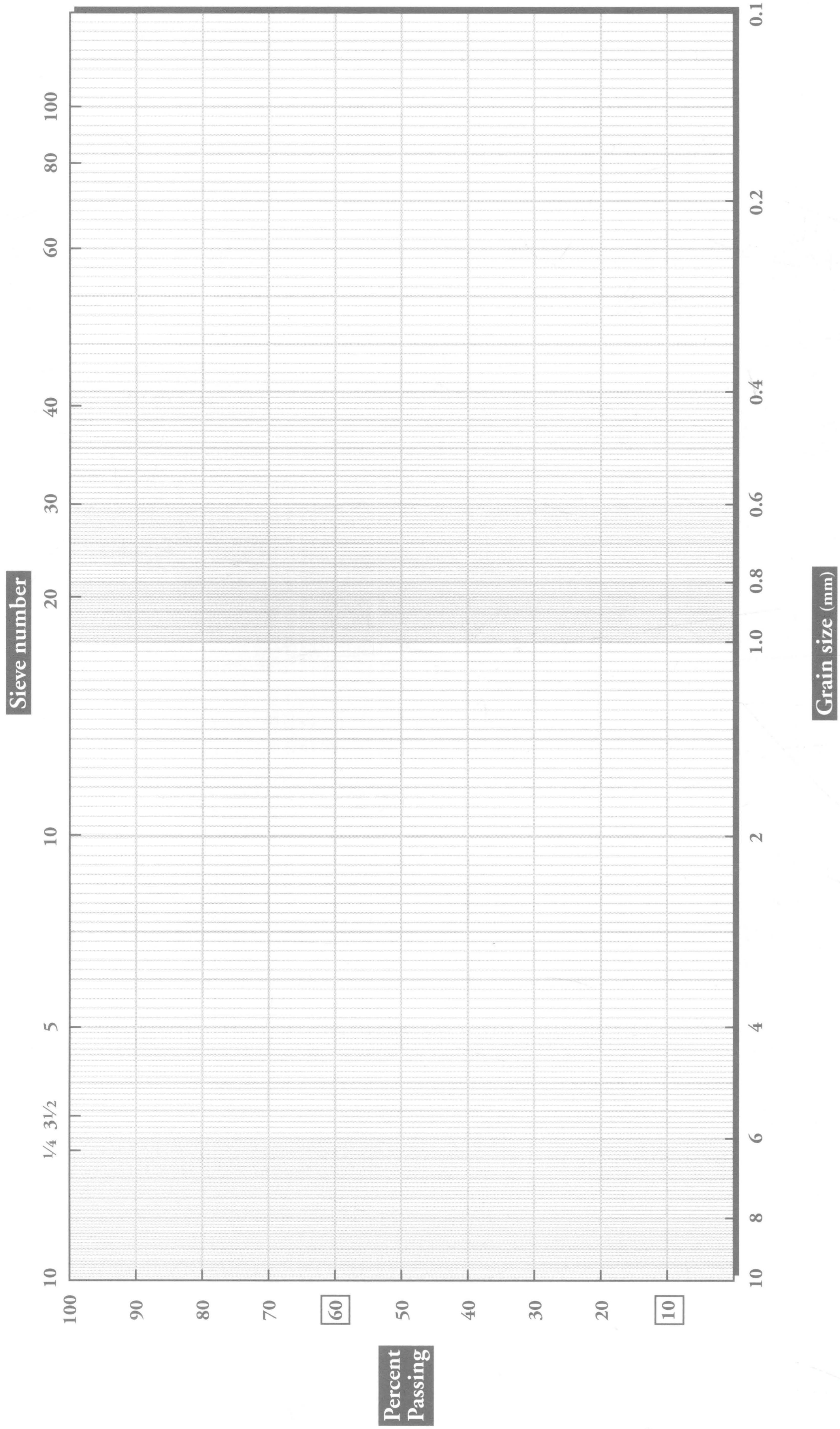
1. Very small amounts
   For general high quality, 10% of wasteload allocation, not to exceed 80%
   For superior high quality, 5% change in ambient water quality
   For Lake Erie, 10% of assimilative capacity
   For state resource water, 5% change in ambient water quality (limit 1 per 5 mile stream segment)
2. Land application and controlled discharge
3. Restoration of design capacity
4. Combined sewer overflow projects

****Evaluation of:**

1. Non- and minimal degradation alternative analysis
2. Mitigative technique alternatives
3. Social/economic issues review

Figure 14. Graph of sand sieve analysis to determine effective size and uniformity coefficient.




Sieve number
100
80
60
40
30
20
10
5
3½
¼
Grain size (mm)
0.1
0.2
0.4
0.6
0.8
1.0
2
4
6
8
10
Percent Passing
100
90
80
70
60
50
40
30
20
10

Design Examples

In College County, sand with an effective size of 0.9 mm and a uniformity coefficient of 3.5 is available from a local aggregate company at a reasonable cost. Propose an intermittent, buried sand bioreactor for an individual three bedroom home that uses the locally available sand.

Design wastewater flow	Bioreactor depth	Exposure	Recirculation	Dosing frequency
3 bedrooms * 120 gals. = 360 gal.	2 ft.	buried	No	12 times/day

A community library needs a wastewater treatment system to replace an old, failed soil absorption system. Much of the land owned by the library has been paved for parking. The paving even covered up the old septic system that likely contributed to its failure. Only a 15 x 25 ft. area is available for a wastewater treatment system and a nearby stream could be considered for a discharge. Propose a sand bioreactor to fit in this small space.

Design wastewater flow	Bioreactor depth	Exposure	Recirculation	Dosing frequency
6 FTE employees * 45 gals./employee = 270 gal.	2 ft.	covered	Yes	24 times/day

A developer is planning an executive housing development for 25 homes. An elaborate landscaped entrance and roadway is planned and wastewater is being considered for irrigation. Appearance, odors, noise, and space are all limitations. Propose a sand bioreactor system for this community with the aesthetic considerations in mind.

Design wastewater flow	Bioreactor depth	Exposure	Recirculation	Dosing frequency
25 homes * 5 bedrooms * 120 gals./bedroom = 15,000 gal.	2 ft.	covered	Yes	48 times/day

Sand Characteristics	Loading Rate	Size	Management	Discharge
ES = 0.9 mm UC = 3.5	0.5 gal/ft^2/day	15 ft. x 50 ft.	Pump septic tank Service pump & chlorinator Check for ponding	On-lot irrigation

Sand Characteristics	Loading Rate	Size	Management	Discharge
ES = 0.3 mm UC = 2.5	3 gal/ft^2/day	2 reactors each 5 ft. x 10 ft.	Pump septic tank Service pump & chlorinator Check for ponding	Stream discharge with NPDES permit

Sand Characteristics	Loading Rate	Size	Management	Discharge
ES = 1.2 mm UC = 3	3 gal/ft^2/day	2 reactors each 50 ft. x 50 ft.	Pump septic tank Service pump & chlorinator Check for ponding Flush irrigation lines	Trickle irrigation system

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