Solids Capture

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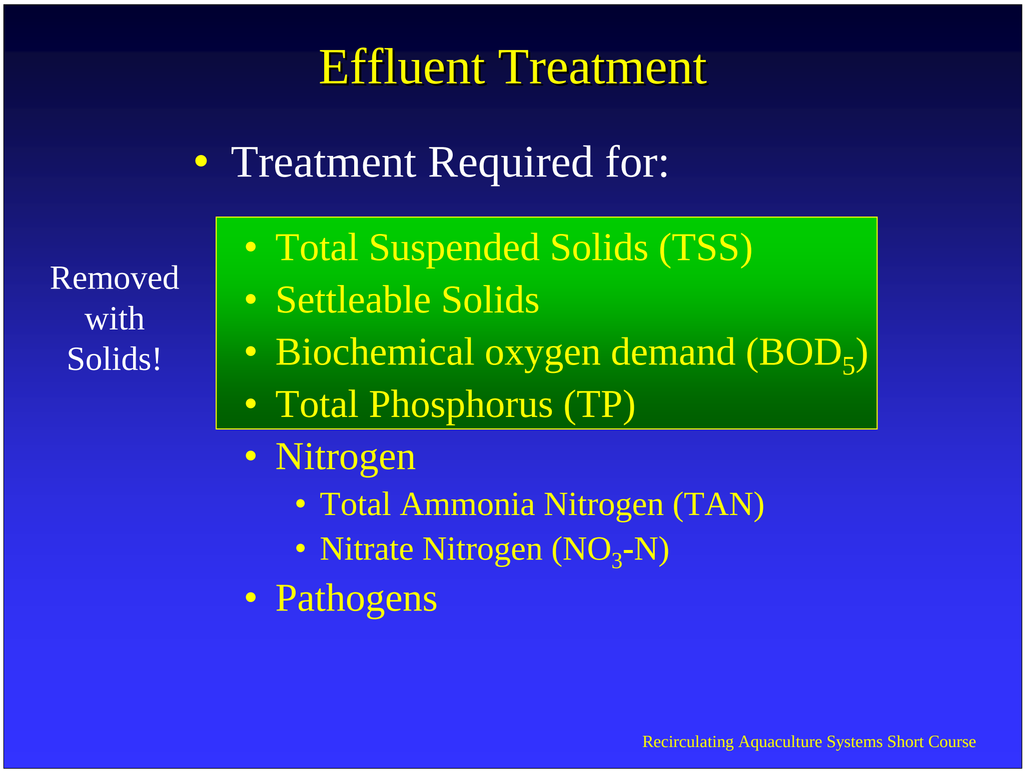
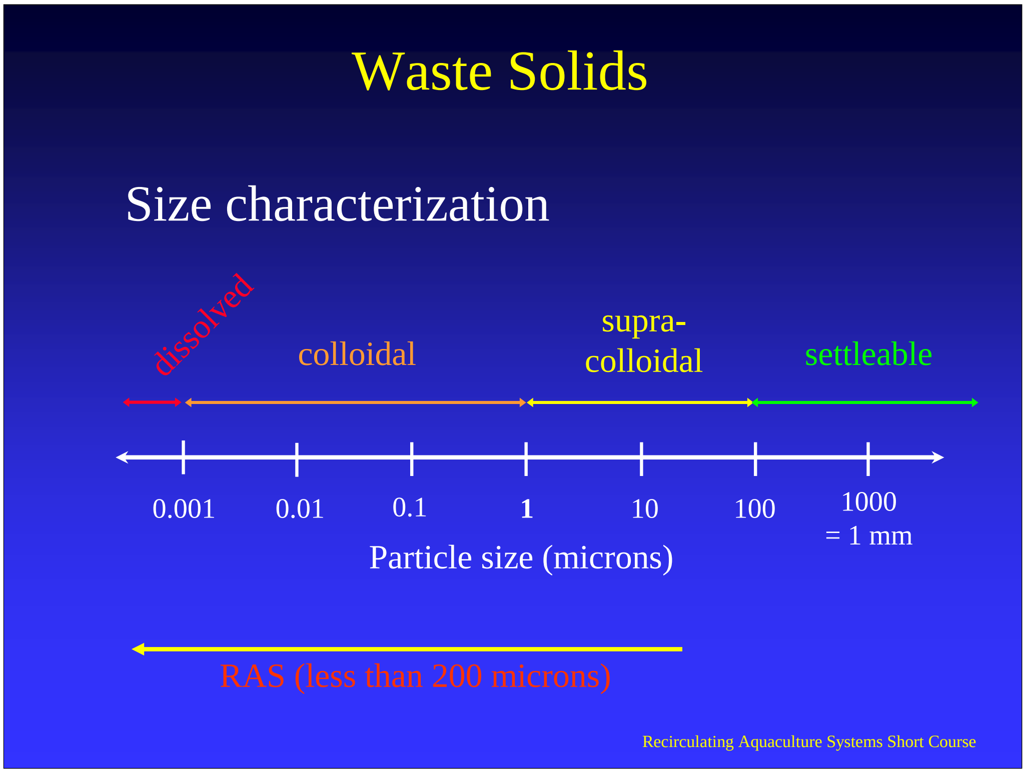


Given the increased emphasis placed on aquacultural effluents it is important to note that the first four pollutants which are often regulated, TSS, Settleable Solids, BOD, and Total Phosphorus can be significantly reduced in concentration by the removal of solids containing feces and uneaten feed.

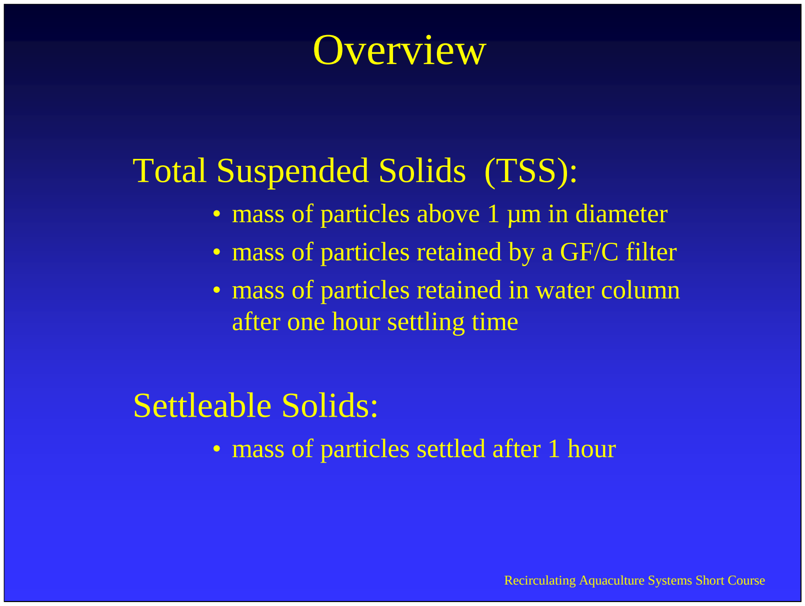
Suspended solids adversely impact all aspects of a recirculating aquaculture system (RAS), so the first objective of any recirculating treatment scheme is the removal of solid wastes. Suspended solids are the result of feces, biofloc (dead and living bacteria), and uneaten food. These suspended particles will vary greatly in size from the cm size to the micron (µm) size.

It cannot be overemphasize the importance of rapid and complete solids removal from the culture vessel. All other unit processes will fail if this primary function is poorly performed. The case history failures described in Chapter 15 were primarily attributed to lack of effective solids removal from the culture vessels.



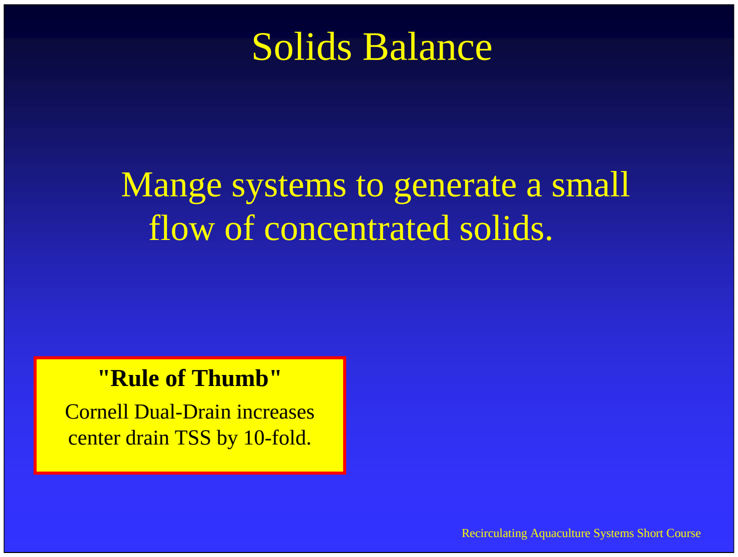
Aquacultural solids are characterized by size into classes, as shown above. The term "fine solids" is used herein to identify the solid particulates that do not readily settle from the water column. As a prelude to understanding the descriptions of size distribution and contribution by weight of the various size classes, it is important to know that samples are usually pre-filtered to remove very large particles, i.e., >200 µm. The contribution of these large solids to TSS measurements is added to the solids concentration obtained from the filtered water when TSS is reported for a system's performance characterization. In practical applications, of course, these larger particles should always be removed first and must be a primary focus, since if they are not removed; they become "smaller" more difficult particles to remove.

In RAS, the majority of particles by weight will be less than 100 µm in size; and in intensive RAS systems the majority of particles by weight will be 30 µm or less in size. In such cases, mechanical filtration will be ineffective. All sizes of particulates must be addressed and managed by an appropriately selected treatment method for particles within each size range, e.g., sedimentation and screening for removal of large particles and foam fractionation or ozone treatment for fine solids removal. Granular media filters can control the widest range of solids. This type of filter is effective in removing solids down to about 20 µm, and is the favored choice of many designers for systems that have high reuse or high clarity demands.

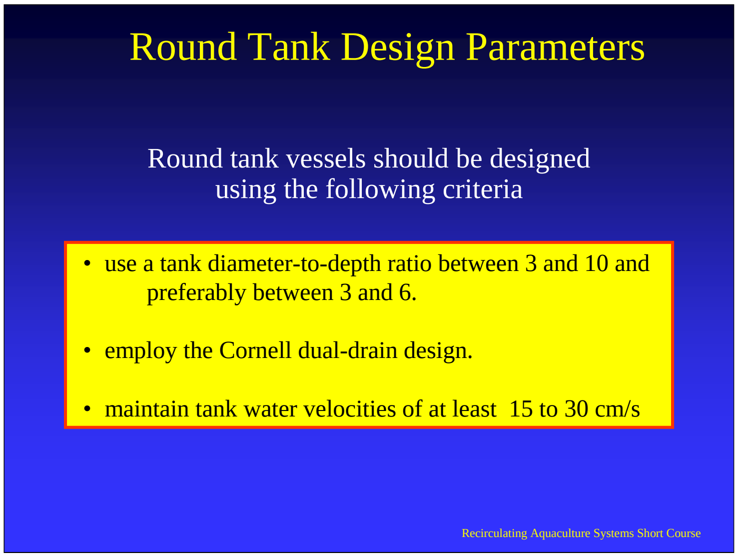


Total suspended solids (TSS) concentration is defined as the mass of particles above 1 µm in diameter (APHA, 1989) occurring in a known volume of water. Suspended solids have both inorganic and organic components. The organic portion, known as volatile suspended solids (VSS), contributes to oxygen consumption and biofouling problems. The inorganic components contribute to formation of sludge deposits. Physically, suspended solids can be partitioned further into settleable solids, typically greater than 100 µm, and non-settleable suspended solids, which are less than 100 µm (EPA, 1975). The finer, non-settleable suspended solids are more difficult to control and cause most of the problems in recirculating systems.

Fine suspended solids are extremely detrimental to general fish health. However, the experts in the field have not yet agreed on a set of definitive design values for acceptable TSS concentrations, which would then serve as a system design goal for the TSS removal efficiency of RAS designs. For example, according to Alabaster and Lloyd (1982), for inland fisheries, there is no evidence that concentrations of suspended solids up to 25 mg/L have any harmful effect on fish. The FIFAC (1980) suggests that TSS concentrations be maintained below 15 mg/L as a safe value in recirculating systems, while Muir (1982) recommends a limit of 20 to 40 mg/L for these same systems. The authors have grown tilapia in systems that had TSS in excess of 100 mg/L and still maintained good fish productivity, but this was in an absence of virtually all other stressors. Keep in mind that different fish species may have significantly different tolerance levels to solids concentrations and that other water quality parameters may impair a fish's ability to withstand high TSS concentrations.



Whenever possible, water flows should be managed to concentrate solids in a small portion of the total flow for the system. An effective way to do this is by using the Cornell Dual-Drain. In this system, 10% to 20% of the total flow exits the tank from a center bottom drain while the majority of the flow exits from the tank sidewall. Use of the dual-drain approach greatly increases the concentration of solids being removed from the low flow bottom center drain. The concentration of solids in this low flow is typically 10 times or more higher than the concentration of solids that exit through the main flow drain, whether it is located in the tank sidewall or as an upper center drain.



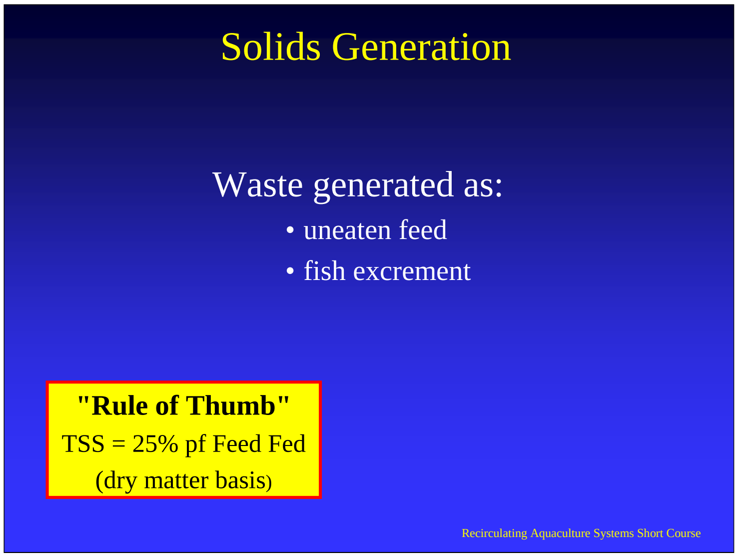
Round tanks will operate as self-cleaning vessels, if the diameter-to-depth ratios are maintained within a recommended range. It is for this reason that we highly recommend round tank culture vessels. Round tank vessels should be designed using the following criteria:

•use a tank diameter-to-depth ratio between 3 and 10 and preferably between 3 and 6. For example, if you are using a tank that is 4 feet deep, then the acceptable range of diameters is from 12 feet to 40 feet (the 3 to 10 range for diameter to depth ratio) or a 1 m deep tank could be from 3 to 10 m in diameter.

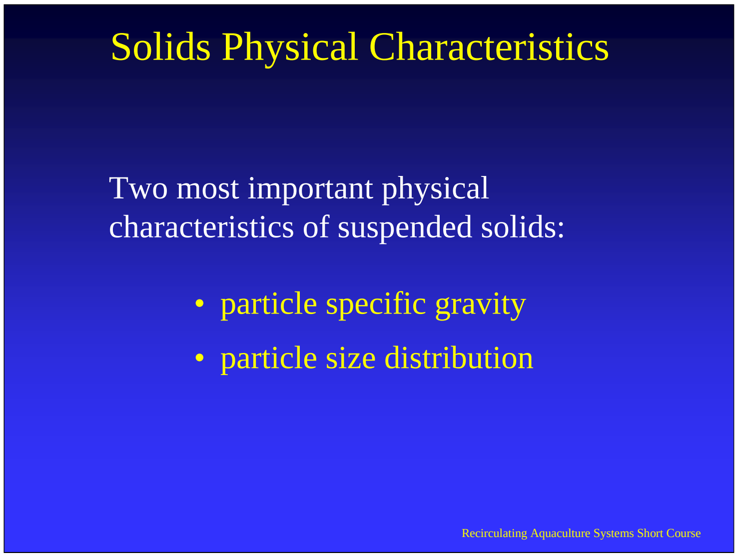
•employ the Cornell dual-drain design with the center drain sized to accommodate 5% to 20% of the total flow used to operate the tank; remove the remaining percentage of flow, i.e., 80% to 95%, from the upper half of the outside tank wall.

•maintain tank water velocities of at least 15 to 30 cm/s to promote the movement of solid wastes towards the center drain.

Once the larger solids have settled and been "flushed" from the culture tank, the next step is to remove the suspended solids from the water column before returning the water to the culture tank vessel



Virtually all the wastes generated within a recirculating system originate from the feed. This manifests in two ways: a) uneaten feed, and b) fish excrement in the form of solids, liquid, or gas. Of the feed that is eaten, 80% to 90% will eventually be excreted in some form. As a rule of thumb, use 25% of the quantity fed to the fish as the volume that will be produced as suspended solids (or total suspended solids, TSS) on a dry matter basis. TSS produced by fish is primarily in the form of feces. The mass production rate of feces is proportional to the feeding rate.



From the perspective of solids control, the two most important physical characteristics of suspended solids in a recirculating system are:

•particle specific gravity

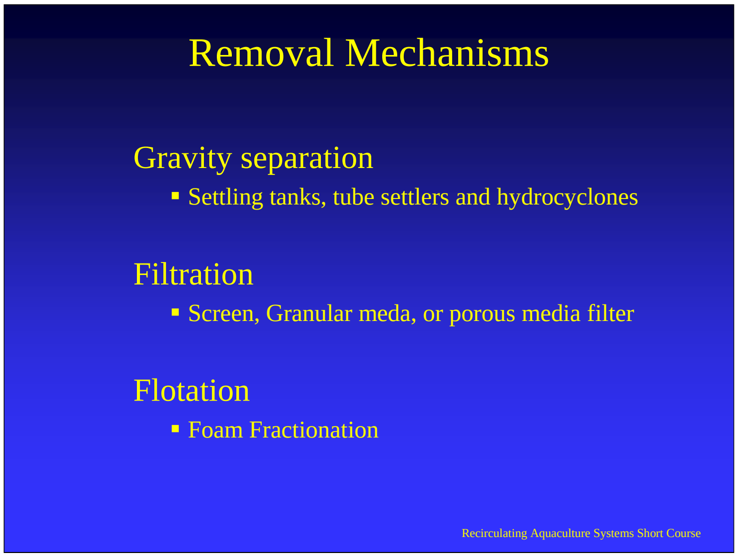
•particle size distribution

Specific gravity is determined by the source of the particles, while the size distribution is determined by a combination of factors, including the solids removal process, the source of particles, fish size, water temperature, and turbulence in the system.

The behavior of suspended particles in water is determined by the specific gravity of the particles. Specific gravity is defined as the ratio of the density of a wet particle to that of water (APHA, 1989). Fish feces is not much "heavier" than water and therefore does not settle as rapidly as would aggregate material of the same size.

While feces is the source of most of the suspended solids, uneaten feed is also a significant source of TSS in fish culture water. TSS from feed typically has a different particle size distribution than the TSS originating as feces. Uneaten feed subsequently breaks down slightly in the water column, but even after several hours and repeated passage through pumps, over 97% of the feed particles will be greater than 60 µm in size and 73% will be larger than 500 µm (0.5 mm). The particles of suspended solids originating from these two sources (feces and uneaten feed) are notably different in size and specific gravity and therefore respond to control mechanisms in different ways. In RAS waters, fine particles (particles less than 30 µm) are the most prevalent and dominate the water column. In water reuse systems (the focus of this book), fine particles (particles less than 30 µm) will dominate the water column.

Sedimentation techniques will not remove the fine particles from the water. This is because fine particles (<30 µm) have low settling velocities that make gravitational removal methods impractical. For example, fine particles need a retention time of several hours to settle a distance of 0.5 m. Sedimentation tanks are often regarded as being inefficient, but this opinion is usually caused by the settlement characteristics of fine particles, which require a lengthy retention time to settle or because the sedimentation tank(s) were simply poorly designed to begin with.



The treatment processes and system strategies should remove solids rapidly before they degrade, with the least turbulence, shear or opportunity for microbial degradation.

There are three methods that are used to remove suspended solids from fish culture waters. These are:

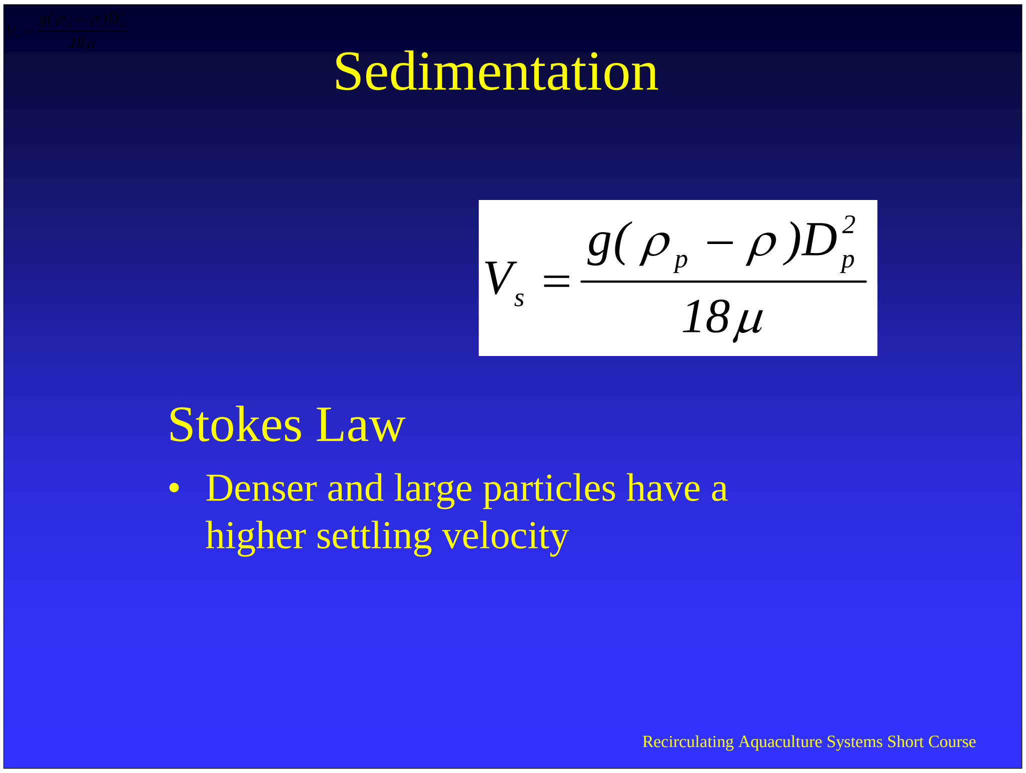
- gravity separation
- filtration
- flotation

These classifications of methodology are based on the removal mechanisms used to effect the removal (flotation is sometimes considered as another kind of gravity separation, but it is a different principle of application so it is described separately). Large particles (larger than 100 µm) can be effectively removed by settling basins or mechanical screen filtration. However, fine particles cannot be removed effectively by either gravity separation or granular filtration methods. Granular filters are effective only in the removal of particles larger than 20 µm.

<u>Gravity Separation</u>. Gravity separation works on the principle of sedimentation and settling velocities. Unit processes in this category include clarifiers (settling tanks), tube settlers, and hydrocyclones.

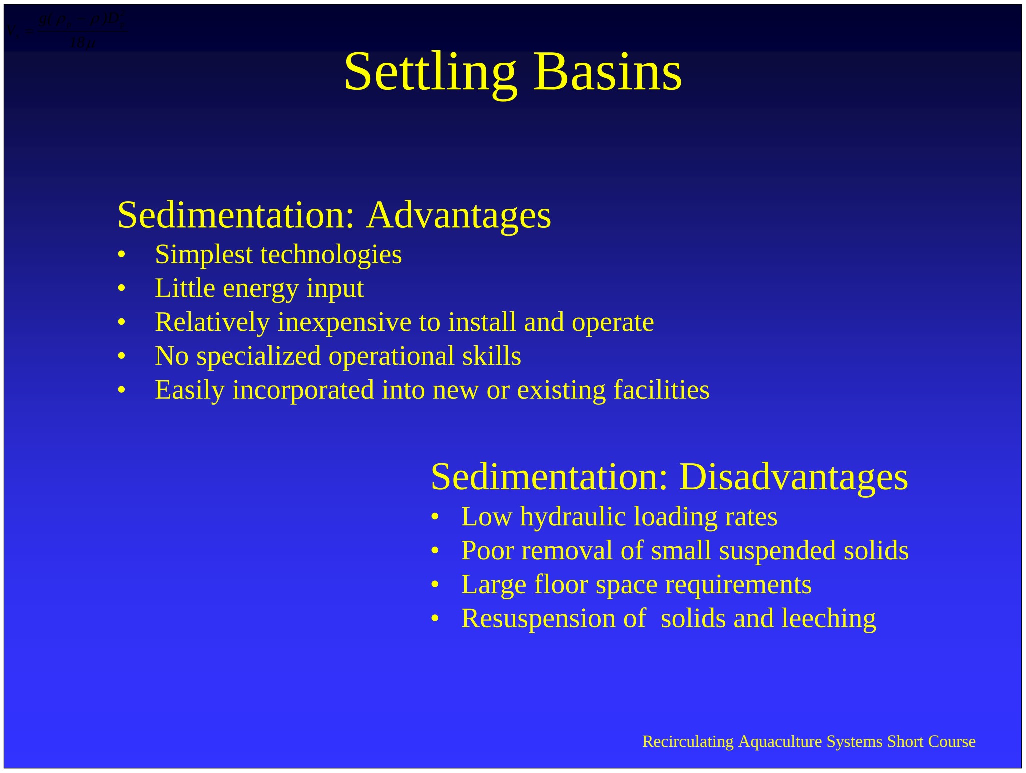
<u>Filtration Removal</u>. Particle removal from the water can be accomplished by one or more filtration processes. These are sedimentation, straining, Brownian diffusion, and interception. These processes are implemented in filtration systems by screen, granular media (GM), or porous media (PM) filters.

<u>Flotation Process</u>. In a flotation process, particles attach onto air bubbles and are separated from water. The flotation process involves all the transport mechanisms that occur in a filtration process with the exception of straining.



Sedimentation occurs due to the density difference between the solid particles and water. Assuming a particle to be heavier than water, under the force of gravity it will fall through the water with increasing speed until it reaches a terminal value for its settling velocity. Each discrete particle has an equilibrium settling velocity.

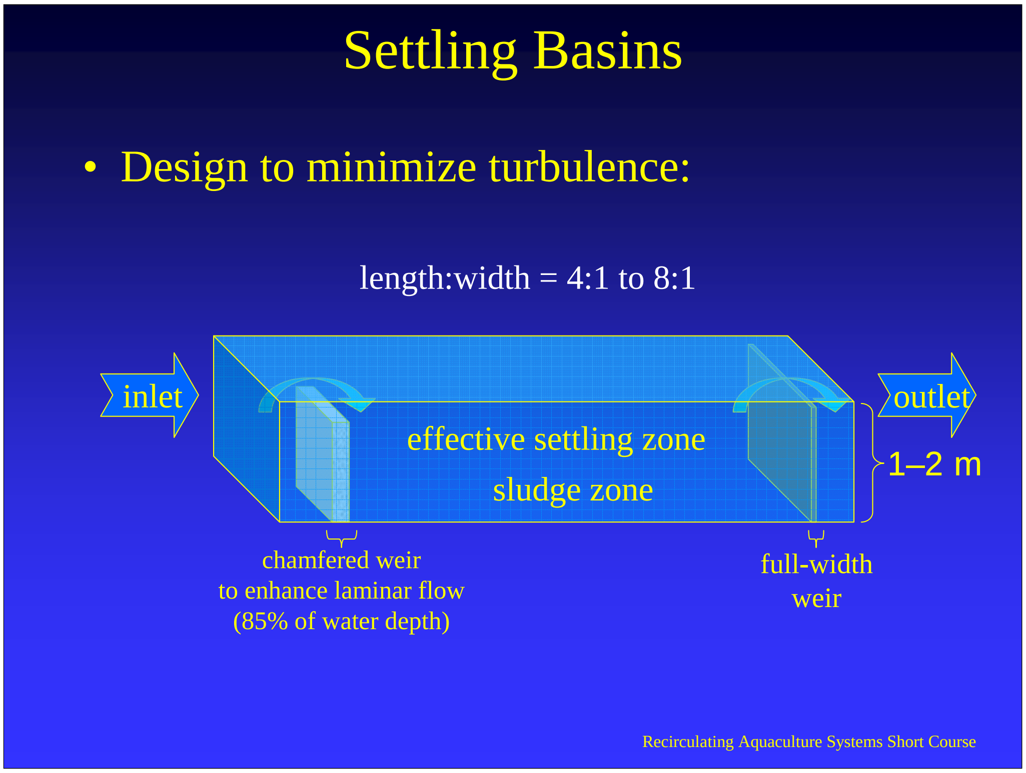
For a small particle having a low Reynolds number, Stoke's Law applies and the settling velocity can be described as shown above. This equation indicates that denser and larger particles will settle out of water faster than smaller, less dense particles. This is true for all types of removal processes and why you should do everything possible to maintain large particle sizes. The best technique for maintaining large particle sizes is to remove the particles as quickly as possible from the fish culture vessel and before any pumping has occurred. Also, you should try to minimize any turbulence/falling water situations prior to the primary TSS capture event.



Settling basins are very effective if properly configured and operated. Sedimentation, i.e., gravity separation, is one of the simplest of technologies available to control particulate solids in process water and wastewater. Sedimentation basins require little energy input, are relatively inexpensive to install and operate, require no specialized operational skills, and can be easily incorporated into both new and existing facilities.

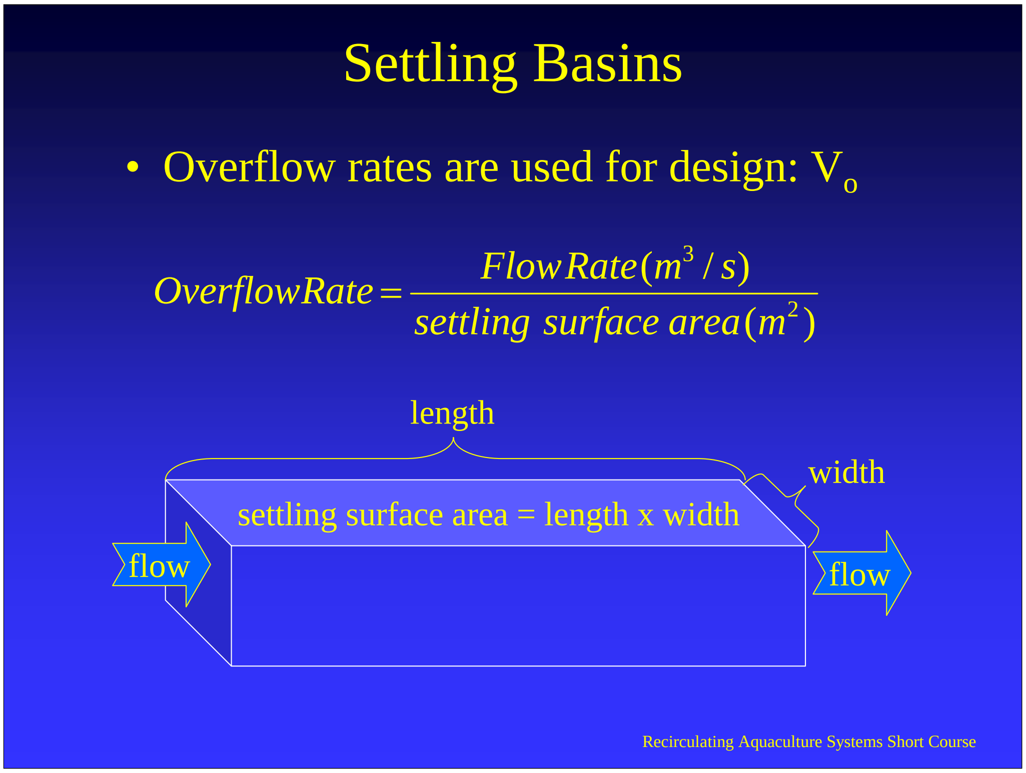
The disadvantages of sedimentation are low hydraulic loading rates and poor removal efficiency of small suspended solids (<100 µm). Also, they require additional floor space for their incorporation in comparison to microscreen filters. Innovative uses of vertical space over the settling bed or placing the settling bed in less expensive space can reduce this cost considerably.

Another potentially serious disadvantage is that settled manure remains in the system until the settling basin is cleaned. This condition is one of the major concerns in their use. Dissolution of nutrients and the resuspension of solids that have settled and collected on the bottom of settling basins can markedly reduce the expected performance of these clarifiers (Cripps and Kelly, 1996). Henderson and Bromage (1988) estimated that settling ponds could capture an estimated 97% of their solids loading if resuspension of settled solids was not a factor. They suggest that settling basins are not effective in removing TSS when inlet concentrations are <10 mg/L or attaining effluent concentrations of <6 mg/L. Eliminating resuspension of TSS is difficult at best in most settling basins. Thus, settling basins will generally require further TSS treatment to meet the stringent removal criteria necessary to achieve mandated levels of TSS.



All continuous flow settling basins are conceptually divided into four zones according to function, see above. The inlet zone serves to uniformly distribute the suspension over the entire cross-section of the basin. Sedimentation occurs in the settling zone and, upon removal from the water column, the solids accumulate in the sludge zone. The clarified liquid is generally collected over the entire cross-section of the basin at the outlet zone and is discharged. Under ideal conditions (no mixing or turbulence), required retention time is the time required for a particle that starts at the top of the inlet zone and settles to the floor of the basin at or before the junction of the outlet zone. The key parameter for the design of settling basins is the volumetric flow of water per unit surface area of the basin or overflow rate (V_o).

Any particle with a settling velocity (V_s) greater than the overflow rate (V_o) will settle out of suspension. Other particles, for which $V_s < V_o$, will be removed in the ratio V_s/V_o, depending upon their vertical position in the tank at the inlet.



Settling basin design is based on overflow rates which are the flow rate being treated divided by the effective settling surface area. The settling surface area is just the basin length times the basin width. Stechey and Trudell (1990) recommend an overflow rate (V_o) for the design of settling basins in intensive salmonid aquaculture to be between 40–80 m^3/m^2 per day (982–1964 gpd/ft^2). These overflow rates translate to particle settling rates (V_s) equaling 0.046–0.092 cm/s.

Translating this into easy to understand language, for every gpm of water flowing through the settling basin, 0.73 to 1.47 square feet of surface area are required for settling; or, 1.0 gpm flow per square foot of settling zone area (40.7 Lpm/m^2). Mudrak (1981) reported on the performance of several settling basins used in intensive trout culture operations. He found that when the design overflow rate was at approximately 60 m^3/m^2 per day, the removal of settleable solids was 90% or greater, typically above 95%, although TSS removal was about 10% less. Also, there was no notable improvement in removal efficiencies when the loading rate was further reduced by as much as a factor of three, i.e., the conclusion is that a significant portion of TSS fine solids will not be removed by the settling basin. One design fundamental that must be kept in mind is that if you can see water currents in your settling basin, it will not efficiently remove the TSS except for the larger particles, e.g., >500 µm. Even if you double the settling basin floor area, this will not compensate effectively for a poorly designed settling basin where turbulence and mixing are present that are caused by ineffective inlet and outlet weir design.

Settling Basins

Design overflow rates:

	Surface Loading Rate	
	m^3/m^2 per hr	gpm per ft^2
Full-flow settling basin	14.3	5.9
Quiescent zone	34.0	13.9
Off-line settling basin	1.66	0.7

The loading rates suggested above are applicable to off-line settling basins (the most widely used application in RAS). The Idaho Waste Management Guidelines for Aquaculture Operations (1998) suggests overflow rates for three typical settling basins used in aquaculture, i.e., full-flow, quiescent zone, and off-line.

On the right is an example a full-flow settling basin for effluent treatment at the Green Lake NFH in Maine. Note the orchard valve influent which creates turbulence in the basin.

On the left is an example of a quiescent zone in a trout raceway. The settling area is separated from the fish rearing area with a screen and the level is set with dam boards. Solids settle in the quiescent zone and must be flushed out or vacuumed out by siphon or pumping. Cleaning quiescent zones is a labor intensive process and must be done regularly or solids will resuspend and flow downstream.

Off-line settling basins are basins designed for solids collection, thickening, and storage. These basins are usually intermittently loaded from quiescent zone cleaning, filter backwashing or system cleaning.

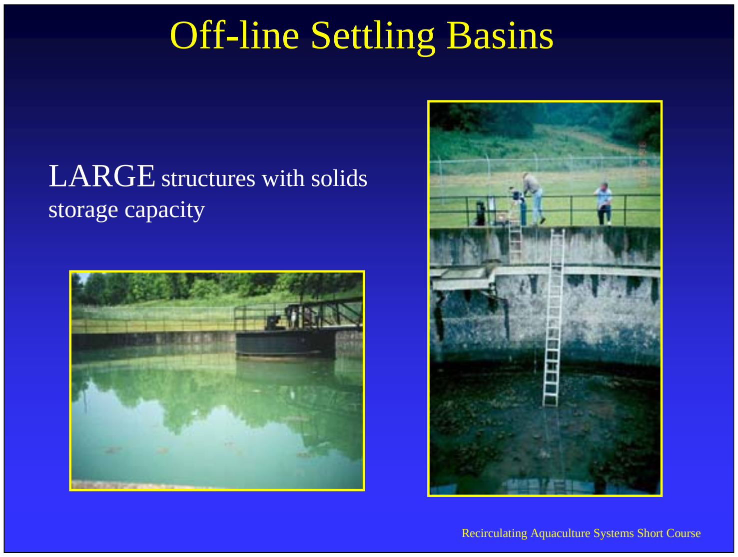
The Freshwater Institute (Shepherdstown, WV) has successfully applied this approach to concentrating the effluent coming off of drum filters in thickening tanks. They used three off-line settling basins to capture and store solids from the intermittent backwash of three drum filters (see Fig. 6.6). The solids-laden backwash flow is introduced intermittently into the top and center of each tank. At the top of each tank, the flow is introduced within a cylinder with an open bottom that is centered within the tank. The cylinder improves the hydraulics of the tank's radial flow by directing the water to first flow down (underneath the cylinder and towards the cone of the tank) and then up as it travels radially towards the effluent collection launder about the top circumference of the tank. These thickening tanks have performed well, capturing 97% of the solids discharged from the microscreen filter backwash flows.

Off-line Settling Basins

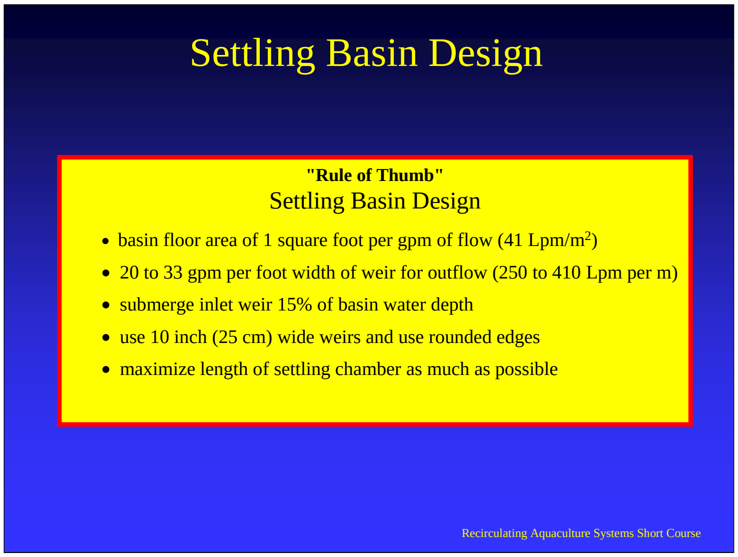
Off-line Settling Tanks
at Freshwater Institute

Recirculating Aquaculture Systems Short Course

This is an example of three off-line settling basins at the Freshwater Institute. Each cone-bottom tank receives backwash from a separate drum filter in use at Freshwater. The solids-laden water comes in the top, flows down, and then back up over a weir as the solids settle and thicken in the cone. The solids are then regularly pumped out and land disposed off. The supernatant is recycled through the system.



Off-line settling basins are often large structures with considerable solids storage capacity like this one at a state trout production facility in PA.



When designing inlet structures, the following factors must be considered:

- The influent stream should be introduced evenly across the entire cross-section of the settling zone.
- All flow through the settling zone should begin in even, horizontal path

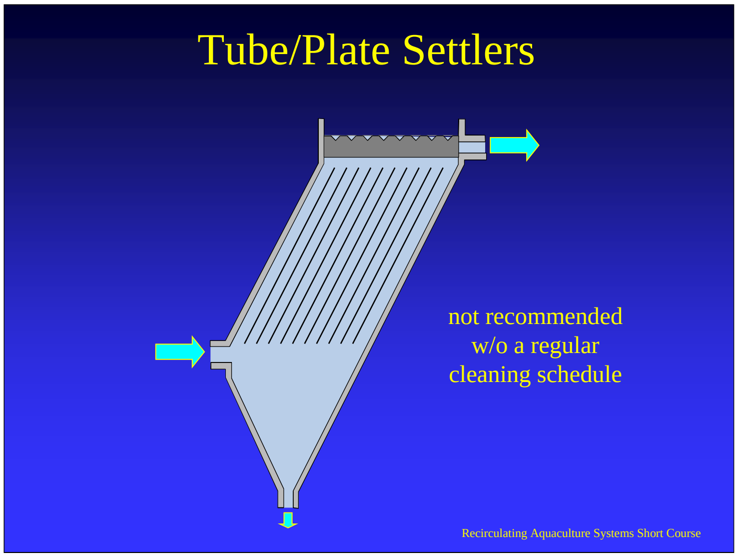
The influent velocity to the settling zone should be slow enough to prevent excessive turbulence and mixing.

Inlets. Inlets should consist of a submerged inlet weir that separates the settling zone from the inlet zone. The inlet weir should extend across the full width of the settling basin, and should be submerged approximately 15% of the basin depth. The weir crest should be about 20 to 30 cm wide (8 to 12 inches) and have rounded edges to smooth the flow as it enters the settling zone. For circular clarifiers, the inlet is generally at the center of the basin. A baffle surrounding the inlet pipe serves to reduce turbulence and distribute the flow in a radial pattern through the full depth of the basin.

Outlets. Rectangular settling systems are more efficient than are circular settling tanks, but they require considerably more floor space. The sub functions of rectangular systems are more easily recognized as functional zones. These are the inlet zone, the settling zone, and the outlet zone. The outlet weir divides the settling zone from the outlet zone, as it skims clear water from the surface of the settling zone. The outlet weir should be designed and constructed so that it distributes the water exiting the settling zone at a uniform depth and velocity across its width. This is necessary to avoid generating currents and the accompanying turbulence in the settling zone. The outlet zone area should be the same width as the settling zone, and the length not less than 1.5 times the depth of the settling zone. For example, if the settling zone is 8 feet (2.4 m) wide, 30 feet (9 m) long, and 4 feet (1.2 m) deep, the outlet zone should be 8 feet (2.4 m) wide, 4 feet (1.2 m) deep, and at least 6 feet (1.8 m) long.

It is critical that the weir edge be level to assure a uniform discharge rate across the entire weir length. The weir discharge rate (volume of water discharged per unit length of weir per unit time) governs the length of the outlet weir. For weirs that are long in relation to the flow, i.e., having a low weir rate, a saw-toothed or V-notch edge is necessary for uniform discharge along the weir length. Weir discharge rates should be 400 to 600 m^3/d per meter length of the outlet weir (22 to 33 gpm/ft).

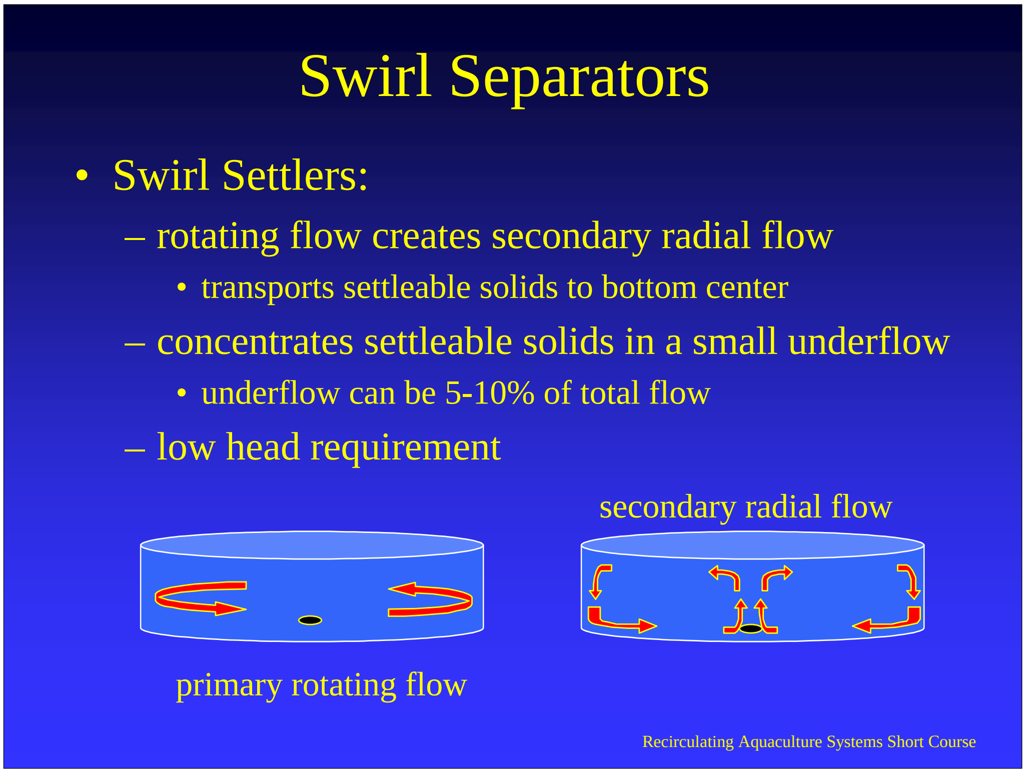
The total length of the settling basin is comprised of the actual settling zone plus the length (area) required for both the inlet and outlet zones. This total area requirement is often ignored and thus the settling basin will not perform as intended. In addition, remember that uncontrolled turbulence, i.e., mixing and stirring of the inlet waters with the incumbent waters, will decrease the effectiveness of the settling process. The solution for this problem is to lengthen the sedimentation basin. Do not compromise on the size of the settling basin.



A major objection to the use of settling basins is that they require a large floor area, and square footage of floor area can be expensive. If this is a problem, the "footprint" of the settling basin can be decreased by adding obstructions inside of the settling basin to increase rates of settling. Tube settlers, also known as "settling decks", can be used to do this. The basic function of the settling deck (tube settlers) is shown above where the incoming flow is brought into the settling basin under the settling deck and forced to upflow to exit the chamber. In the process, solids settle within the tubes.

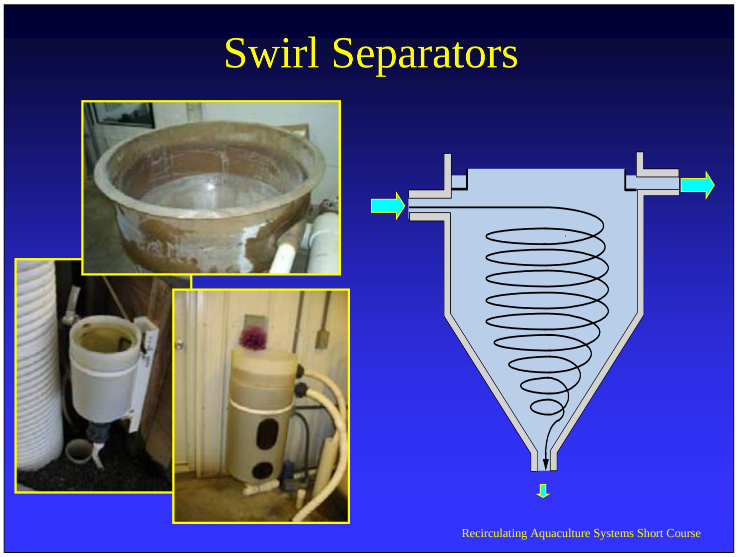
Separation distance between the inclined surfaces is typically 5 cm (2 inches) with a total inclined length of 0.9 to 1.8 m (3 to 6 ft). Tube or plate plastic media are usually manufactured in structured bundles of tubes or stacks of parallel plates in a variety of opening shapes (square, rectangular, tubes, hexagonal, chevron). In operation, influent water flows into a tube or plate settler and then upward through the inclined tubes or plates as solids settle on the plastic surfaces. Generally the inclination of the tubes or plates is between 45°–60° above horizontal. This angle provides for the greatest degree of gravity self-cleaning of settled solids out of the media and into the basin bottom. A fairly broad range of hydraulic loading rates have been suggested in the literature, e.g., 1.5 m^3/m^2 per hr, 7.4 m^3/m^2 per hr, and 67 m^3/m^2 per hr. The disadvantage to the use of tube settlers is that tube or plate settlers do not adequately self-clean, so they must be periodically cleaned by other means to prevent biofouling.

Once the tubes begin to fill with fine solids settling out of the water flow, the water velocity rates through the tubes will increase due to reduced tube cross sectional area. As this happens and resistance to flow increases, water begins to seek a least resistance approach and will eventually simply bypass the tubes, thereby eliminating any solids capture at all. Therefore, periodic cleaning is necessary, but cleaning the settling deck is a dirty, nasty job that nobody likes to do and as a result is often neglected. In turn, neglect leads to poor performance of the settling device and subsequent deterioration in water quality. For this reason, we do <u>not</u> recommend tube settlers for use in highly loaded systems.



Hydrocyclones employ the principle of centrifugal sedimentation, i.e., the suspended solid particles are subjected to centrifugal acceleration, which makes them separate from the liquid more rapidly by effectively increasing their density. Hydrocyclones are also called swirl separators and tea-cup settlers. The Cornell dual-drain is effective because the tanks are round and are operated as swirl separators. The rotational flow of the inlet water imparts a centrifugal motion in the particles that causes the heavier particulate material to move to (or remain at) the outer portion of the vessel. Simultaneously, the particles are affected by gravity, which causes them to fall through the water, and move towards the bottom center drain. Here, at the bottom center drain, a small percentage of the total flow is removed, which is referred to as the underflow.

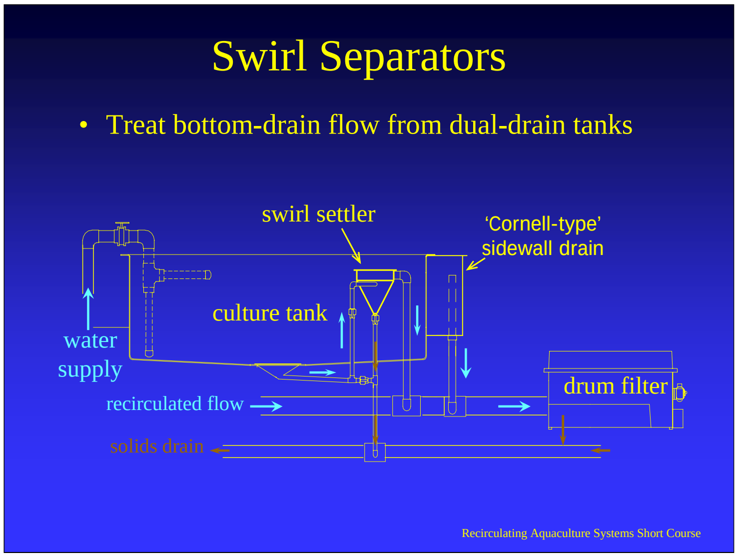
The underflow in a swirl separator should be about 5% to 15% of the total flow, which is the same percentage used for the Cornell dual-drain in the culture tank vessel. Downward spiral flow moves dominantly along the outside walls and creates an inward spiral flow in the center. Between these two spirals there is a layer, called the mantle, where zero vertical velocity exists. The entrance to the outlet pipe should be placed at the center of the mantle. This mantle plane is located at a distance equal to 1/2 to 2/3 D below the top surface of the water (where D is the diameter of the vessel). Strategic placement of the outlet takes advantage of the zero vertical velocity condition by minimizing TSS in the outlet flow. Ideally, you should test your own particular waste water prior to full design implementation to have any reasonable chance of getting it "right", or design the swirl separator so that adjustments in outlet placement can be made during operation.



The inlet is typically placed about 1/3 diameter below the top of the water column with the flow directed tangentially to the vessel walls. The figure above illustrates the design concepts of a swirl separator and the swirl separator used by the Freshwater Institute.

Loading rates for hydrocyclones are approximately four times greater than the recommended loading rates for conventional settling basins, or 10 m^3/m^2 per hr (4 gpm per ft^2). This means that the footprint area requirements for handling the same amount of water have been reduced by a factor of four. Some engineers will use even higher loading rates, but hydraulic retention times should be maintained at a minimum of 30 seconds. If loading rates are increased, then the volume of the vessel must be correspondingly increased so that the minimum 30 second hydraulic retention rate is preserved.

Hydrocyclones are relatively expensive, and just as settling basins and drum filters, they are not effective at removing fine solids (diameter <50 µm). However, they can be quite effective in removing TSS; Scott and Allard (1984) reported that hydrocyclone prefilters removed over 87% of the particulate matter greater than 77 µm in diameter.



A currently popular approach is to use a commercially available swirl developed by SINTEF NHL (Trondheim, Norway) called the Eco-TrapTM. Twarowska et al. (1997) reported that a particle trap (swirl separator) that took 5% of the total center drain flow (the underflow with concentrated solids) removed 80% ±16% of the solids. The surface loading rate on this unit, which accepted 16 L/min of flow, was approximately 5.6 m/h[a] (2.3 gpm/ft^2). Referring back to the table for settling basin design, this loading rate is less than a full-flow settling basin (14.3 m/h) but more than an off-line settling basin (1.66 m/h). The swirl settling feature has improved the effectiveness of the settling process by a factor of 3.4 which is consistent with the earlier note that surface loadings could be increased by a factor of four compared to conventional settling basins.

An interesting application would be to use a three times higher hydraulic loading level (30 m^3/m^2 per hr; equivalent to Full-flow settling basin) to remove large heavy solids as a pre-treatment step prior to the waste flow before being sent to a drum filter or other TSS removing area. This approach is being implemented in recently designed systems by taking the Cornell dual-drain flow and directing this into a swirl separator. Since the effluent from the center drain in a Cornell dual-drain is only 5 to 15% of the total flow, the size requirements of the swirl separator can be reduced by a factor of 10 to 20. Also, the hydraulic loading rates may also be increased depending upon whether or not this treatment constitutes the total TSS removal process or is only a partial treatment, e.g., removal of easily removed large particle TSS.

[a] Note that m3/m2 per hour is equivalent to m/h or meter per hour.

Swirl Separators

- Advantages
  - do not store solids
    - reducing particulate dissolution and nutrient leaching
  - requires less space than settling basins
- Disadvantages
  - only effective removing
    - solids with specific gravity considerably > water
    - larger particles
  - hydraulics are critical

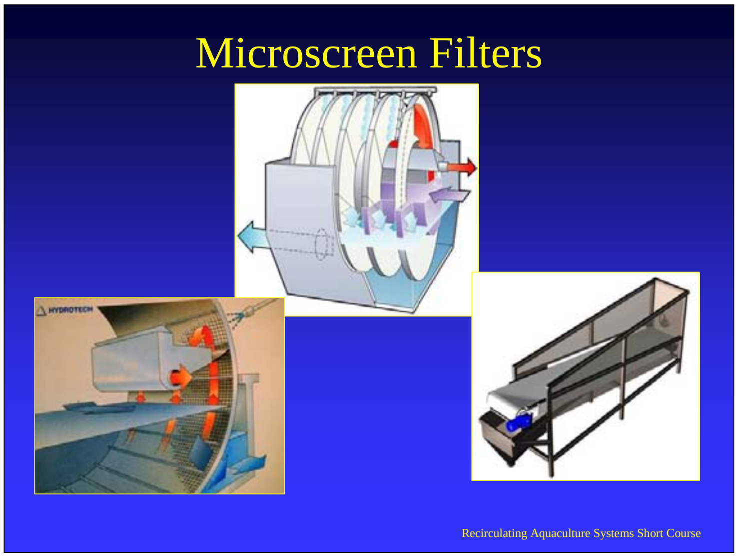
Advantages to swirl separators are that they do not store solids which reduces solids degradation and that they require less space than settling basins. Disadvantages are that they are only effective at removing larger solids with specific gravity greater than water and also that maintaining proper hydraulics is critical to effective operation.

Microscreen Filters

- Sieves that strain water-bound particles
- Frequent backwash removes solids rapidly
- Produces a backwash 0.2 to 2% of the treated flow

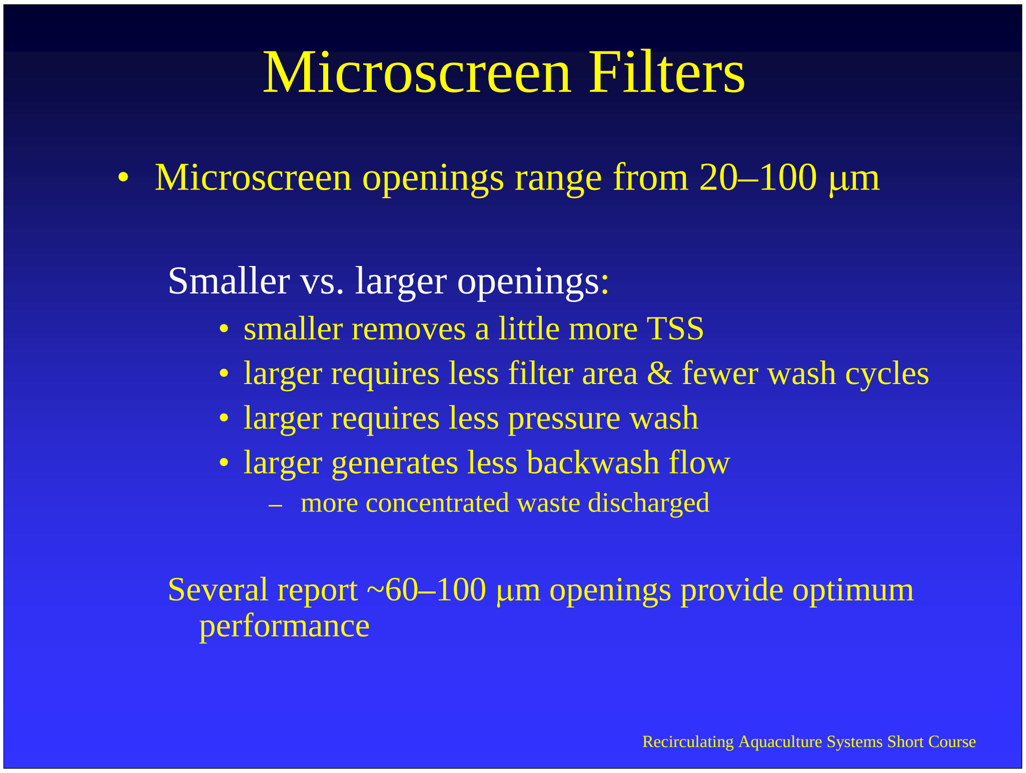
Recirculating Aquaculture Systems Short Course

Microscreen filters for filtration are popular because they require minimal labor and floor space in comparison to settling basins. As in sedimentation processes, the head loss of a screen filter is small. Screen filters remove solids by virtue of physical restrictions (or straining) on a media when the mesh size of the screen is smaller than the particles in the wastewater.



Microscreen filters are commercially available in a variety of different configurations. Typical microscreen filters used in aquaculture are the drum filter - left, disk filter- center, and inclined belt filter- right.

All three types of microscreen filters are similar in that they have a separate solids waste stream that must be managed to result in a complete waste management system. This waste stream is a higher-solids, screen backwash flow. The backwash flow will vary in volume and solids content will vary based on several factors. These are the screen opening size, type of backwash control employed, frequency of backwash, and influent TSS load on the filter. Backwash flow is generally expressed as a percentage of the flow the filter treats, with reported backwash flows ranging from 0.2 to 1.5% of the treated flow (Summerfelt, 1999). This discharge is typically directed to a settling pond or other such device for final solids capture and storage.



Microscreen openings range from 40 to 100 microns. The smaller openings remove a little more TSS and the larger openings require less filter area and fewer wash cycles. The larger openings require less pressure in the backwash system and because of the fewer wash cycles the waste captured is often more concentrated in the backwash.

Obviously, the size of the particles that can be removed by a screen filter is determined by the size of the screen opening. To a limited degree, even particles smaller than the nominal screen mesh size can be trapped if several smaller particles bridge together and subsequently become trapped by the screen. However, on a practical basis, simply assume that the screen size defines the smallest particles that will be removed. In addition to screen size, microscreen filter performance is dependent on the influent TSS concentration. Typical screen openings used in the treatment of aquacultural wastewater are 40–100 µm. In this screen opening size range, TSS removal can be between 30 and 80%. Several investigators have reported that 60 to 100 micron screen openings provide optimum overall performance.

Microscreen Filter Comparison

Filter Type	Removal Rate at 60–100 μm (%)	Costs* (USD/unit)
Drum	SS inlet < 5 mg/L: 31–67 SS inlet > 50 mg/L: 68–94	$15,000
Disc	SS inlet < 5 mg/L: 25–68 SS inlet > 50 mg/L: 74–92	$8,600
Belt	SS inlet < 5 mg/L: 0–62 SS inlet > 40 mg/L: >89	$18,000

*Costs at a unit flow capacity of 10 m^3/min & 100 μm screen

Recirculating Aquaculture Systems Short Course

Comparing all three types of microscreen filters, drum, disc, and belt. Note that removal rates are relatively similar but with a wide range of reported numbers.

Microscreen Filter Comparison

Filter Type	Advantages	Disadvantages
Drum	Intermittent backwash, reduced backwash volume	
Disc	Lowest capital costs	High backwash flow volume Grinding/crushing of bigger particles
Belt	Gently removes particles Low maintenance	High capital costs at low flow (< 3–5 m^3/min)

Recirculating Aquaculture Systems Short Course

Advantages to the drum filter are its intermittent backwash which produces a reduced backwash volume. Advantages to the disc filter are its lower capital costs, but it can have a higher backwash volume and it can roll bigger particles, breaking them up. Belt filter advantages include its gentle treatment of solids and low maintenance, but it has higher capital costs.

Microscreen Filters

- Advantages
  - large water treatment capacity in small space
    - treat flows from 0.4 m^3/min to 50 m^3/min
  - low pressure drop (< 0.3 m)
  - modular and relatively easy to install
  - rapidly removes solids from bulk flow
    - does not store solids within flow
    - reduces particulate break-down and nutrient leaching
  - removes majority of particles > 40 µm

Recirculating Aquaculture Systems Short Course

Advantages to microscreen filters are that they have a large water treatment capacity in a relatively small unit and come in a range of sizes to treat flows from 0.4 m3 per minute to 50 m3 per minute. They have a low pressure drop, they are modular and relatively easy to install and they rapidly remove solids from the treated flow reducing solids breakdown and nutrient leaching.

Microscreen Filters

- Disadvantages
  - requires 414–690 kPa pressure wash system
  - mechanical and requires service
    - pressure wash failures
    - screen and gasket maintenance
  - does not capture particles < 20 μm
  - large surges in flow and concentration may cause partial flow-bypass around unit

Disadvantages to microscreen filters are that they require a high pressure backwash system, they are mechanical and will require service for the pressure wash system or gaskets, they do not capture solids less than 20 microns and if there is a large surge in flow or solids concentration then the filter may be bypassed.

Granular Media Filters

- Sand Filters
  - effective at removing fine solids
  - relatively expensive
  - large backwash requirements
  - not often used unless required by effluent regulations

Recirculating Aquaculture Systems Short Course

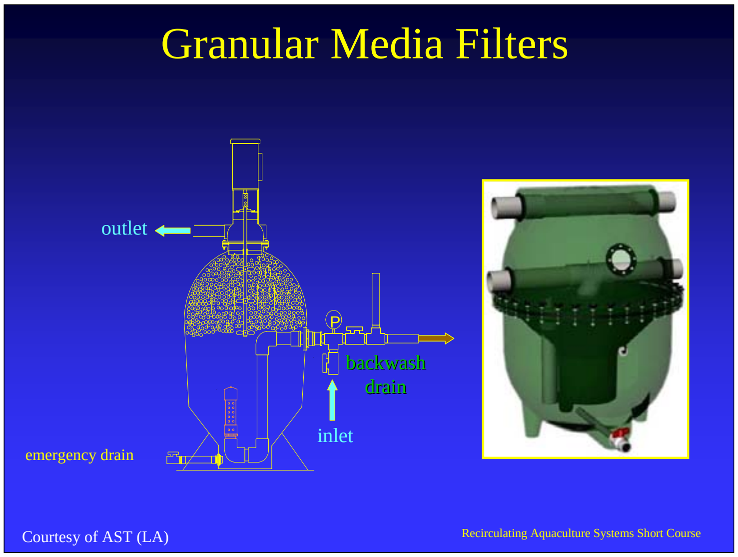
Granular media filtration involves passage of water through a bed of granular material (media) and deposition of solids onto the media. This type of filtration system is generally classified as packed-bed or depth filtration. The major mechanisms that function to remove the particulates in a packed-bed filter are straining, sedimentation, impaction, interception, adhesion, flocculation, chemical adsorption, physical adsorption, and biological growth. However, straining has been identified as the principal mechanism for the removal of suspended solids in the filtration of secondary effluent from biological treatment processes. Granular-medium filters are often used in combination with other treatment processes to increase the level of treatment. These filters provide increased removal of solids, phosphorus, algae, turbidity, and pathogens.

The most commonly used downflow pressurized sand filter is available in a variety of configurations because it is widely used in water treatment systems and can be readily purchased "off the shelf". Downflow sand filters (or swimming pool filters) are not appropriate for use in RAS that are even moderately loaded. There is simply so much TSS being generated in a RAS that a downflow sand filter will be constantly going into backwash mode. For the exceptionally stubborn, or those having very low loaded systems, design guidelines for large scale gravity or pressurized sand filtration units are of 12 to 30 m^3/hr per m^2 (Metcalf and Eddy, Inc., 1991).

Upflowing sand filters used for biofiltration will capture TSS depending upon their hydraulic loading rates. Upflow sand filters should not be used for the primary purpose of solids capture. If used in this manner, they will probably fail in their primary function of as biological filtration. However, they can be used to capture fine solids at low hydraulic loading rates.

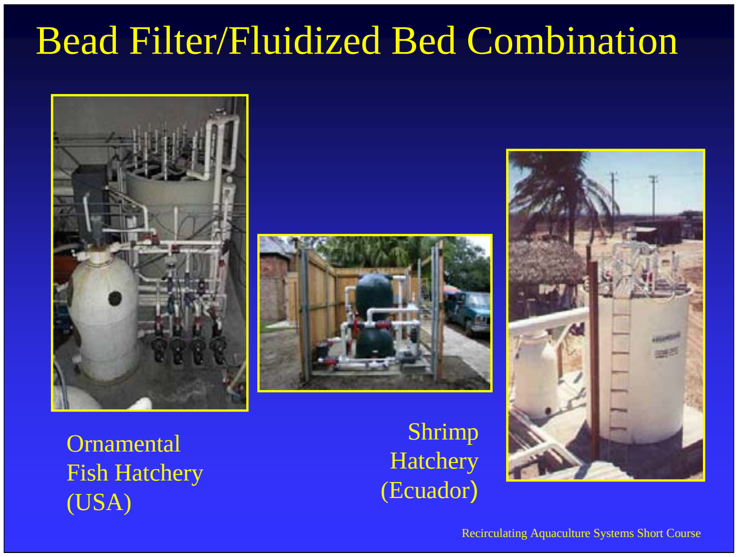
RAS applications have effectively used "bead" filters, which use a floating plastic media to reduce the water losses associated with backwashing of the media. Bead filters are operated to capture solids and provide biological filtration. Bead filters also require backwashing to remove solids, but their water loss compared to traditional downflow sand beds is very small.

Bead filters can be designed to obtain most of the benefits of the sand filters without incurring the high water losses during the backwashing operation. These filters are multi-functional, providing both solids removal and biofiltration processes. Pressurized bead filters contain floating plastic beads that provide a medium to which nitrifying bacteria attach. The floating plastic beads commonly used in these filters are 3–5 mm (0.12–0.20 inch) diameter polyethylene spheres that have moderately high specific surface areas (1,145 m^2/m^3 (350 ft^2/ft^3) (Malone et al. 1993).

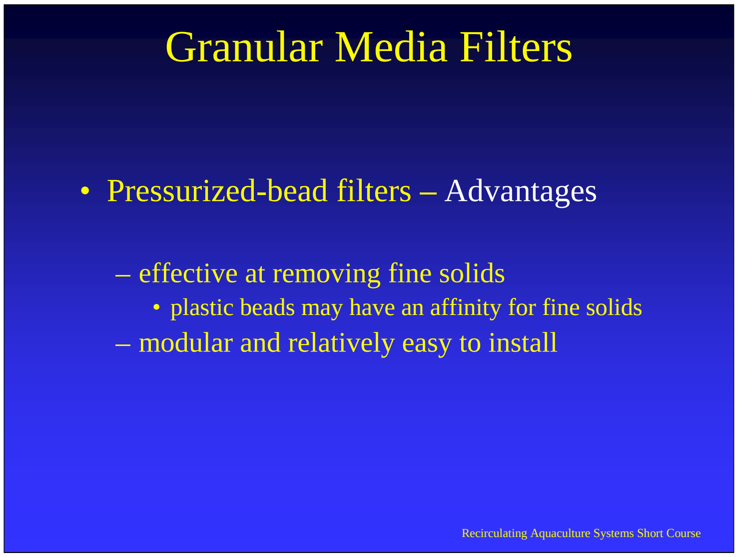


Floating bead filters are a type of granular media filter. Bead filters have a floating bead bed that the water must flow through as it captures solids. In operation, water is typically pumped into the bead filter through a media retaining screen located at the bottom of the bead chamber. Particles are captured within the filter as the water flows upward through the floating bead bed. The bead bed floats against a screen installed at the top of the pressure vessel, which is used to retain the beads while allowing the filtered water flow to pass out through the top of the filter. Operating pressures, typically 0.34–1.02 atm gauge pressure (5–15 psig), increase as solids capture across the filter increases. To maintain adequate flow through the bead filter as solids build up, the filter is backwashed through the use of a motor-driven propeller mechanism or through injected bubbles. Backwashing occurs as the influent flow is stopped and the beads are turbulently disturbed, which breaks loose any collected solids. The solids are then removed from the filter through the media retaining screen located at the base of the filter, and normal flow is resumed.

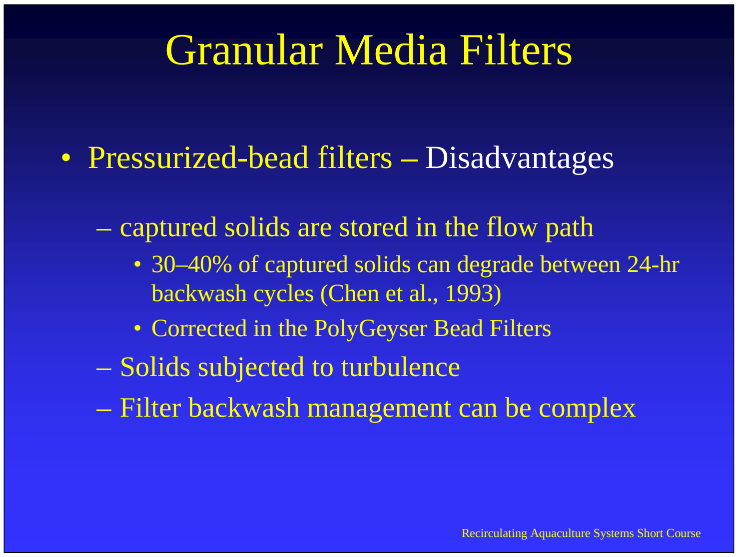
Solids captured by the filters are retained within the filter until the unit is backwashed. Typically, the plastic-bead filter unit is backwashed every 24 hours. During this retention period, 30–40% of the total retained solids will decay. This is a very undesirable activity, because the entrapped solids begin to dissolve and mineralize, which adds soluble BOD and ammonia loads to the system. Removal of these solids is the only way to minimize this condition. There is a complex relationship between plastic-bead filter backwash intensity and frequency, solids degradation, and nitrification efficiency. The fact that the pressurized bead filter collects solids so effectively means that heterotrophic bacteria populations can grow and become a problem if the filter is not backwashed frequently. Heterotrophic activity in the filter depletes oxygen and generates ammonia as protein contained in the captured solids is metabolized. While backwashing will remove solids and unwanted bacterial growth, too frequent backwashing will also remove beneficial nitrifying bacteria. Obtaining optimum performance from the bead filter requires careful management of the intensity and frequency of backwashing these filters.



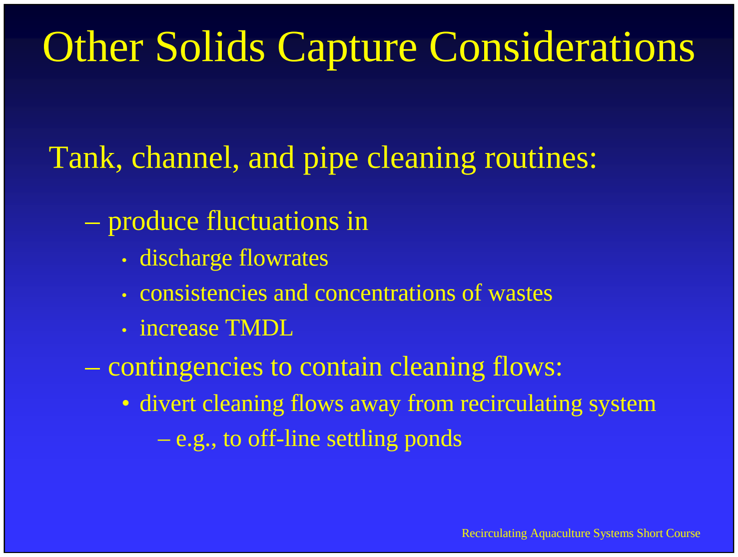
Bead filters can act as clarifiers and/or biofilters, and relatively recently they have been applied in combination with a fluidized sand bed biofilter, where the bead filter acts as a clarifier, removing solids before the fluidized bed. These are two examples of bead filters applied in this configuration.



Advantages to bead filters include their ability to remove fine solids and that they are modular and relatively easy to install.



Disadvantages are that the captured solids are stored in the filter flow path and can degrade, they can have a pressure drop up to 15 psi, the solids are subjected to turbulence in a backwash cycle, and backwash management can be complex if the filter is operated as a clarifier and biofilter.



Whenever solids are pumped out of settling basin or a system is cleaned and cleanouts are utilized to remove solids from a RAS this results in large fluctuations in the discharge flowrate and the waste concentration in the discharge. This is important to consider for downstream treatment components (settling basins, screen filters, etc.) and for the total mass of pollutants discharged. Downstream components should be sized to handle the increased flow and solids loading during a cleaning event. Again, any cleaning flows should be directed away from the RAS to avert any impact on the fish and water treatment components from a spike in solids concentrations.

Effluent Control

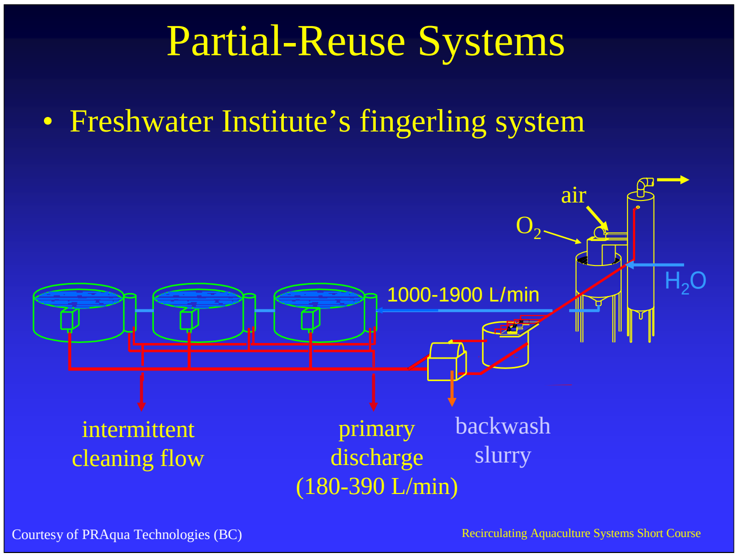
Overall waste capture efficiency of culture system

– depends upon type of reuse systems!

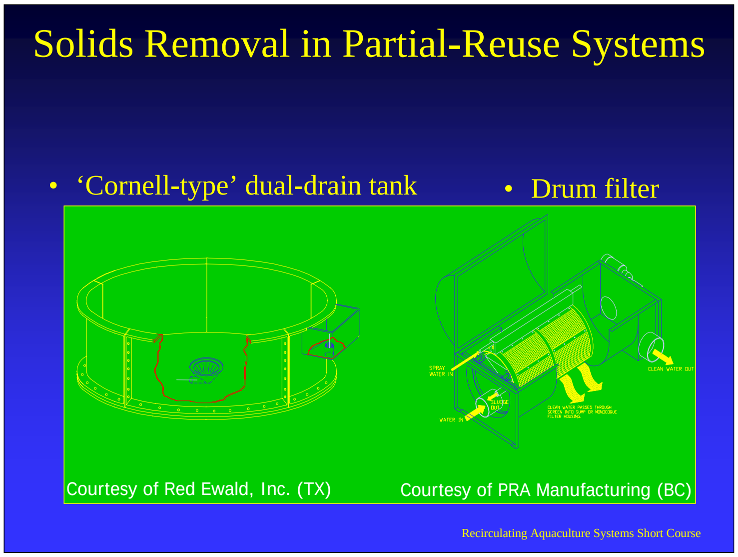
	TSS capture efficiency
serial-reuse raceway systems	25–50%
partial-reuse tank systems	80%
fully-recirculating tank systems	> 97%

Overall, solids capture is highly dependent on the type of water use in an aquaculture system. Serial reuse systems have TSS capture efficiencies from 25-50%; Partial reuse systems can have TSS capture efficiencies up to 80%; and fully-recirculating systems can get to 97% and higher TSS capture.

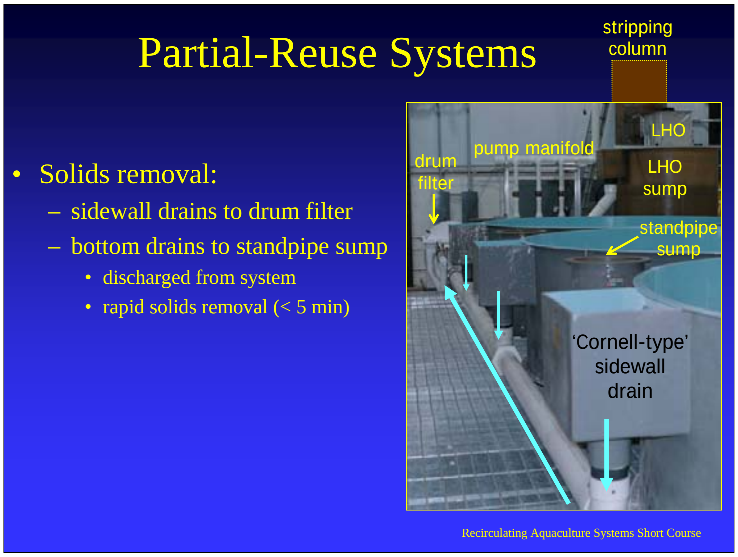
The type of water reuse has a dramatic impact on solids control. Serial-reuse aquaculture typically uses large water flows which result in dilute waste concentrations. Dilute waste effluents are more difficult to treat because solids removal efficiency decreases with decreasing solids concentrations. Also the large water flows employed in serial-reuse systems increases the size of treatment components required to treat those flows. This results in increased treatment component costs.



Partial water reuse systems can be very efficient at controlling and capturing solids. This is a schematic of the partial water reuse system at the Freshwater Institute. There are three culture tanks receiving 1,000-1,900 L/min of treated water in a reuse loop. The culture tanks are Cornell dual-drain type tanks with a bottom center discharge and a side-wall discharge. The bottom center discharge that is high in solids is wasted from the system as the primary discharge. The side-wall discharges that are low in solids are combined and treated in a microscreen drum filter. The screened water flows to a pump sump and is pumped to a CO_2 stripping tower and LHO for gas conditioning (CO_2 removal and O_2 addition). The 180-390 L/min of flow discharged from the bottom drains is made-up with fresh water that is input immediately before the CO_2 stripping tower.



The two solids control/removal components in our partial water reuse system are the Cornell dual-drain type culture tank and the microscreen drum filter.



The side-wall discharges are combined and directed to the drum filter and the bottom drains flow to individual external standpipes and are discharged from the system.

Partial-Reuse System

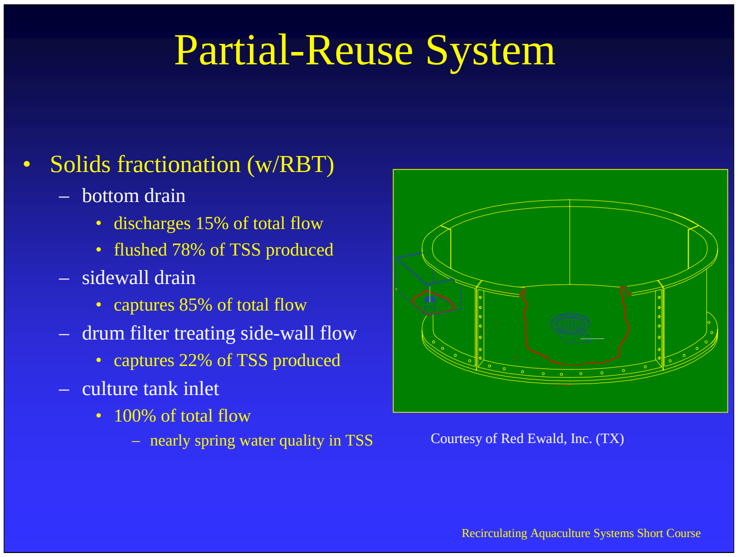
Solids fractionation:

	TSS (mg/L) rainbow trout	TSS (mg/L) arctic charr
Tank inlet flow	1.3 ± 0.1	1.5 ± 0.1
Side-drain flow	2.5 ± 0.2	1.9 ± 0.1
Bottom-drain flow	26.2 ± 2.1	13.1 ± 1.5

Make-up water contained 0.5 ± 0.2 mg/L TSS

Recirculating Aquaculture Systems Short Course

Results from a study done at Freshwater shows how well the Cornell dual-drain type culture tanks partition the solids and how well the partial reuse system does overall at controlling solids. In both studies with Rainbow Trout and Artic Char the side-wall discharge was very low in TSS, 2.5 and 1.9 mg/L respectively. While the bottom center discharge was high in TSS, 26.2 and 13.1 mg/L, showing how well solids are concentrated in the bottom drain flow. After treatment for solids and gas conditioning the reuse water comes back to the culture tanks at 1.3 and 1.5 mg/L TSS, which is almost as “clean” as our incoming fresh water.



Analysis of the data from the study done with Rainbow Trout shows that the bottom drain discharged only 15% of the total flow but flushed 78% of the TSS produced. The side-wall discharge had 85% of the total flow and 22% of the TSS which was subsequently treated in the drum filter.

These results indicate that a partial water reuse system that uses Cornell dual-drain type tanks can benefit from the solids concentration in the bottom center drain. Because a relatively small flow contains close to 80% of the solids generated this allows for reduced size, cost, and space requirements for downstream solids treatment of this flow before final discharge. The high TSS levels in this flow also result in increased capture efficiencies of downstream solids treatment.


Questions?
Recirculating Aquaculture Systems Short Course