



Western Regional Aquaculture Center

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Settling Basin Design

Introduction

The majority of fish production in flow-through aquaculture systems occurs in raceways. Raceways discharge continuously during production and therefore, solids and nutrients resulting from fish production are discharged in the effluent. The solids, consisting of fecal matter and wasted feed, and the nutrients, primarily phosphorous and nitrogenous compounds, can degrade the water quality of the receiving water. To regulate the discharge of pollutants, the Environmental Protection Agency (EPA) issues discharge permits. Known as the National Pollutant Discharge Elimination System (NPDES) permit, the NPDES permit regulates the discharge of pollutants from point sources to waters of the United States. Specific permit requirements, including effluent limits, monitoring frequency, and which type of facilities are required to have a permit, vary from location to location. Contact your regional EPA office, state environmental agency or state department of agriculture for information regarding regulatory requirements specific to your area.

To minimize the discharge of solids and nutrients, and to comply with effluent regulations it is necessary to have a waste management system. The objectives of a waste management system should include:

- Efficient capture of solids and nutrients
- Frequent solids removal from settling basins and proper disposal
- Compliance with applicable standards and regulations

Intensive raceway fish culture typically generates a waste stream high in volume but low in concentration of solids and nutrients. Given current technologies, this characteristic generally limits practical and affordable effluent treatment to the capture and removal of solids using settling basins. This fact sheet seeks to provide design criteria for settling basins that will minimize solids and

nutrients in the effluent when properly constructed and managed.

Sedimentation Process

Traditionally, settling basins were built based on retention time. The settling basins were designed to retain water for a specified period of time. However, most settling basins built this way were oversized and inefficient because critical design criteria were not considered or inadequate. According to sedimentation principles, the removal of solids from a waste stream and the selection of appropriate treatment technologies should be based upon particle size, specific gravity and the shear resistance of the particle. The sedimentation process can be classified as discrete, flocculent, zone or compression settling depending upon particle size and density, and the physical characteristics of the solids and liquid medium, including solids concentration. The factors that control the sedimentation rate differ among the four categories.

Raceway effluent characteristics are such that settling is considered discrete. Generally, sedimentation is considered discrete when solutions have less than 500 mg/L total suspended solids (TSS). Typical concentrations of raceway effluent TSS from trout farms in the west are less than 5 mg/L net (effluent concentration minus influent concentration). Off-line settling basin effluent TSS concentrations are usually less than 100 mg/L net. During discrete settling the particles maintain their size and shape. Each discrete

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particle has a settling velocity independent of other particles. Due to the remote chance of particles colliding in such dilute concentrations flocculation tends not to occur. The surface area of the settling basin governs sedimentation rate.

All continuous flow settling basins have an inlet zone, settling zone, sludge zone and outlet zone (figure 1). Each zone has a separate function. The inlet zone evenly distributes the flow over the cross-section of the basin. Sedimentation occurs in the settling zone and once the solids are removed from the water column they settle in the sludge zone. The outlet zone discharges the clarified liquid.

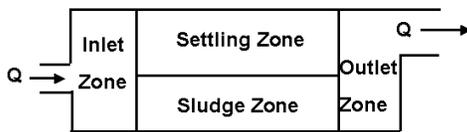


Figure 1. The four functional zones of a continuous flow settling basin

Overflow Rate

Settling basin design should be based on overflow rate, i.e., the settling velocity of the smallest particle to be theoretically 100% removed. To better understand this concept, an "ideal settling basin" will be used to demonstrate the theory behind overflow rate with the following assumptions:

- The direction of water flow is horizontal and water velocity is constant at all points in the settling zone;
- There are no interactions between particles;
- The concentration of suspended particles of each size is evenly distributed across the vertical cross-section of the inlet zone; and
- Once a particle settles to the sludge zone it is permanently removed.

In an ideal settling basin the settling paths of all discrete particles are straight lines and all particles with the same settling velocity move in parallel paths. Two forces are acting upon the discrete particles. Gravity is pulling the particles down as the flow of water is moving the particles forward through the basin. The result of both forces is a trajectory moving both forward and down. Under ideal conditions, a particle, which starts at the top of the inlet zone and settles at the bottom of the basin at the junction of the outlet zone during its

theoretical detention time, represents the overflow rate (figure 2).

Overflow rate (V_o) is defined as the volume of water flow per unit of time (Q) divided by the surface area of the settling basin (A):

$$\text{Overflow Rate } V_o = Q/A$$

Overflow rate can be expressed numerous ways, but for practical purposes its common to use cubic feet per second of flow per square foot of settling area:

$$V_o = \text{ft}^3/\text{s}/\text{ft}^2$$

This equation reduces down to feet per second, and overflow rate is expressed as feet per second, which is a velocity. Settling rates for solids are also expressed as ft/s. The relationship between overflow rate (V_o) and settling velocity (V_s) of a particle is:

any particle with a settling velocity (V_s) greater than or equal to the overflow rate (V_o) will settle out in the basin.

Other particles, which have settling velocities less than the overflow rate, will settle in the ratio V_s/V_o , depending upon their vertical position in the basin at the inlet zone.

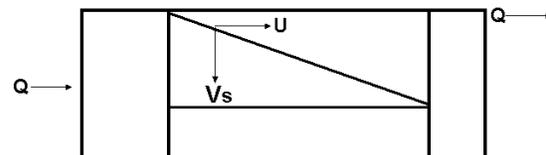


Figure 2. The diagonal line is the trajectory of a particle settling at the critical velocity. The velocity has two components, horizontal flow (U) and settling velocity (v_s) acting upon the particles. Based on Stecney and Trudell.

Types of Settling Basins

There are three basic settling basins used for solids settling in raceway production systems:

- 1) Quiescent zones
- 2) Full-flow settling
- 3) Off-line settling

Quiescent zones are screened-off areas below the rearing area at the tail end of raceways. The screen, constructed with PVC or aluminum pipe

mounted on a wood frame, prohibits fish from entering the quiescent zone, which allows the solids to settle undisturbed. Quiescent zones should be part of each pond, trough, or raceway. It is essential that last-use rearing units have quiescent zones to settle the solids prior to effluent discharge into receiving waters.



Picture 1. Quiescent zone in foreground with screen and standpipe

Full-flow settling is where the entire water flow of a facility passes through a settling basin or basins prior to discharge into receiving waters. The waste management system may or may not include quiescent zones and solids removal from the individual raceways. Full-flow settling basins are usually used where total facility flow is less than 10 cubic feet per second.

Off-line settling basins receive the solids removed from quiescent zones and rearing areas. Generally, the combination of quiescent zones and off-line settling basins is the most commonly used system for solids capture and removal. The quiescent zone is the primary collector of solids, which are either pumped, or moved by gravity flow, to off-line settling basins.

Aquaculture solids have varying settling velocity (V_s) values depending on their size and specific gravity. Trout fecal casts are large and heavy, and will have settling velocities ranging from 0.066 to 0.164 ft/s, but fine, lighter particles settle at much slower rates ranging from 0.0015 to 0.0030 ft/s. Smaller particles require a lower overflow rate, and hence more surface area for settling.

The Idaho Waste Management Guidelines For Aquaculture Operations recommends for trout raceway production systems different overflow rates based on the type of settling basin used and where the settling occurs on the facility. These recommendations take into account the change in particle size as the solids move through the facility.

Solids in raceways are large and relatively undisturbed, however, solids that pass from one raceway to another, or through vacuum heads, pumps and pipes break apart and become smaller.

The recommended overflow rates for the following settling basins are:

• Quiescent zones -	0.031 ft/s
• Full-flow basins -	0.013 ft/s
• Off-line basins -	0.0015 ft/s

It is these values that are used to determine settling basin area. If water flow varies, the settling basin must be sized to accommodate the highest flow rate. As an example, to determine the surface area required for a full-flow settling basin given a flow of 6 cfs:

- $V_o = 0.013 \text{ ft/s}$
- $Q = 6 \text{ ft}^3/\text{s}$
- $A = Q / V_o$
- $A = 6 \text{ ft}^3/\text{s} \div 0.013 \text{ ft/s}$
- $A = 462 \text{ ft}^2$

Therefore, 462 square feet of surface area are required for a full-flow settling basin with a flow of 6 cfs.

In many instances, it is relatively easy to upgrade an existing facility by installing quiescent zones or properly sizing existing ones. In addition to improving waste management capabilities, downstream water quality from raceway to raceway is improved benefiting fish health and performance.

For example, to calculate the required length for a quiescent zone given a raceway 10 feet wide and a flow of 2.5 cfs:

- $V_o = 0.031 \text{ ft/s}$
- $Q = 2.5 \text{ ft}^3/\text{s}$
- $A = 2.5 \text{ ft}^3/\text{s} \div 0.031 \text{ ft/s} = 81 \text{ ft}^2$
- Length = area/width
- Length = $81 \div 10 = 8.1 \text{ ft}$

In this example, the quiescent zone for a raceway 10 feet wide and with a flow of 2.5 cfs should be 8.1 feet long.

The above examples assume settling under ideal conditions, however, ideal conditions do not exist on aquaculture facilities. Several factors, including flow surges, wind shear, scour, short-circuiting, and turbulence reduce the effectiveness of settling

basins (figure 3). To compensate for these less than ideal conditions, the Idaho Waste Management Guidelines For Aquaculture Operations recommends doubling the calculated settling basin area. Thus for the examples above, the full-flow settling basin should be 924 square feet (462 x 2) and the quiescent zone length should be 16.2 feet (8.1 x 2). In addition, there are other design considerations that will minimize the effects of short-circuiting and turbulence on settling basin efficiency.

Inlet and Outlet Design

Flow evenly distributed across the cross-section of the basin is necessary for effective functioning of the settling basin. Proper design of inlet and outlet structures is important in achieving evenly distributed flow. It is very easy to just use a pipe at each end of the settling basin to introduce and discharge the water. However, this type of design produces extremely poor flow characteristics for sedimentation, causing short-circuiting at the inlet and scouring and upwelling at the outlet.

When designing inlet structures the following factors should be considered:

- The influent should be introduced evenly across the entire cross-section of the settling zone.
- The influent velocity to the settling zone should be reduced enough to prevent excessive turbulence and mixing.

A submerged weir extending across the entire width of the settling basin works well in meeting the above considerations. The height of the weir should be approximately 85% of the water depth, have chamfered edges, and be between 12-24 inches thick.

Outlet design is much simpler, only requiring a weir spanning the entire width of the basin. The weir should be level, ensuring a uniform discharge across the entire weir length.

Other considerations include, constructing rectangular settling basins and providing protection from wind. Irregular shaped basins will cause short-circuiting. Freeboard on basin walls in addition to shrub or tree windbreaks will provide protection from wind. If there are nearby neighbors, a tree line can also keep unsightly settling basins from view.

Management Practices

Quiescent zones should be cleaned as often as possible. The usual recommendation is to clean at a minimum at least once every two weeks, however, as long as effluent compliance limits are met, the frequency of solids removal is somewhat flexible. Other factors besides meeting regulatory effluent limits influence the frequency of solids removal. Typically, larger fish are reared in the lower portion of the facility, utilizing later and last use water. As such, larger fish consume the largest

THE EFFECTIVE SETTLING ZONE

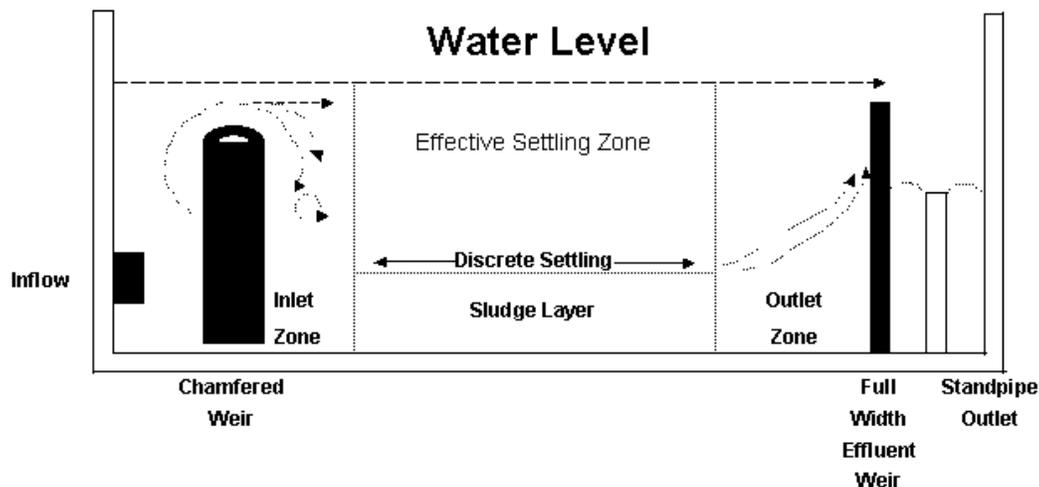


Figure 3. Turbulence is created even with good weir design. Long weirs help reduce the velocity of water entering and leaving the settling basin, which increases the effective settling zone. Flow surges, wind shear, scour, short-circuiting, and turbulence caused by inlet and outlet structures are all reasons for the doubling recommendation that increases the effective settling zone.

portion of feed fed and produce the majority of waste; last use quiescent zones should be cleaned more often compared to the other quiescent zones. Sludge left too long in a settling basin becomes sticky and viscous making it much more difficult to remove. Anaerobic conditions can also develop, causing resuspension of particles by gases and release of dissolved nutrients. Sludge also provides a medium for bacteria and frequent sludge removal can benefit fish health in downstream rearing units by reducing the available substrate for bacteria. Aerobic solubilization of dissolved nutrients, especially phosphorous, also occurs and is most rapid within a few days after excretion of the fecal material.

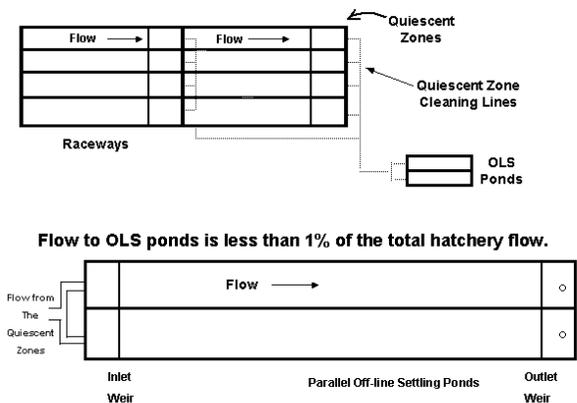
Vacuumsing the settled solids from quiescent zones is one of the most effective methods for removal. Similar to vacuuming debris from swimming pools, suction is provided by head pressure from the water depth of the raceway or by a pump. Usually, a standpipe in each quiescent zone connects to a common pipe that carries the slurry mixture to the off-line settling basin. A flexible hose and a swivel joint are used to connect the vacuum head to the standpipe. Vacuum heads are commercially available, but most designs are homemade. Designs include slotted pipes, triangular heads, open hoses, and rectangular vacuum heads mounted on wheels. Where lift is required, it's usually more efficient and cost effective to connect the pipes from the quiescent zones by gravity flow to a sump or lift station with a stationary pump, than to use a portable pump that is moved from one quiescent zone to another. Pump and pipe sales representatives can assist in proper sizing of pipes and pumps to ensure adequate suction at the vacuum head. Inadequate suction causes resuspension of the solids before they can be vacuumed and increases cleaning time.



Picture 2. Vacuum head mounted on wheels; notice the settled material in the foreground.

The off-line settling basin receives the solids and water mixture from the quiescent zones. Usually, the flow to the off-line settling pond is less than 1% of the total flow of the facility. Off-line settling basins are either earthen or concrete. Earthen basins are less expensive to build, but solids removal is more difficult. Typical depths range from 3.5 feet to over 6 feet. Depth provides storage for the solids and usually 4 feet is adequate for basins that are cleaned monthly. Minimum cleaning frequency should be every 6 months. Most concrete basins have a ramp at one end to allow access with a front-end loader and some have sumps at the deep end of the basin. To clean an off-line settling basin, the inflow is bypassed and the supernatant decanted into an adjacent settling basin or discharged. The solids are allowed to dry for several days and are then removed with a front-end loader or by backhoe from earthen basins. Or the slurry can be pumped directly from concrete basins onto a tank truck or manure spreader after decanting a portion of the supernatant. It's recommended to construct two off-line basins (figure 4). This will allow the removal of solids from one basin while continuing cleaning operations from the quiescent zones into the other basin. The two basins can be placed in series or side-by-side and operated simultaneously if so desired.

Figure 4. Off-Line Settling Ponds



Land application of aquaculture wastes is the most common disposal method. Confer with local regulatory agencies for applicable standards and regulations. Other handling options include composting and evaporation ponds to dry the solids. Evaporation ponds work well in the arid west.

Suggested Reading

State of Idaho, Division of Environmental Quality.
1997. Idaho Waste Management Guidelines for
Aquaculture Operations.

Stechey, D. and Y. Trudell. 1990. Aquaculture
Wastewater Treatment: Wastewater
Characterization and Development of Appropriate
Treatment Technologies for the Ontario Trout
Production Industry. Queen's Printer for Ontario.

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