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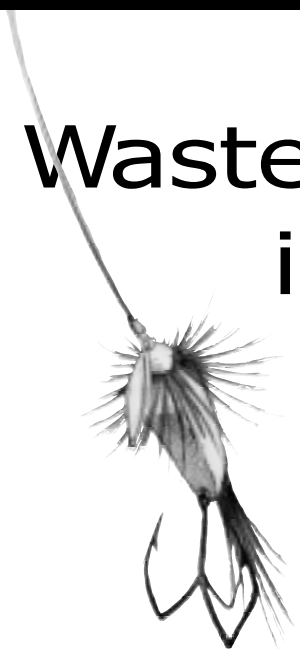
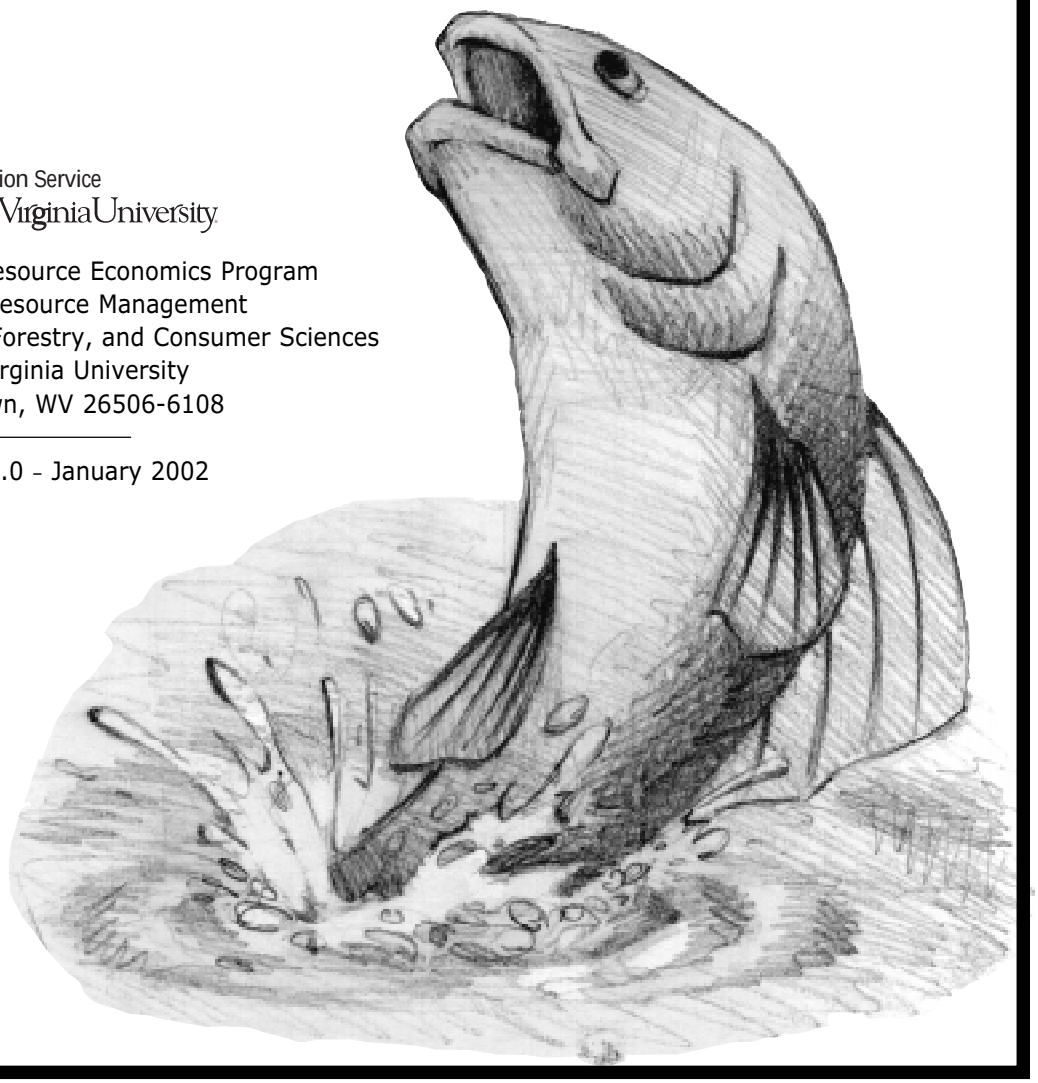
Waste Management in Aquaculture

Dan Miller and Ken Semmens





Extension Service
West Virginia University

Agricultural and Resource Economics Program
Division of Resource Management
College of Agriculture, Forestry, and Consumer Sciences
West Virginia University
Morgantown, WV 26506-6108

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The authors are respectively, Dan Miller, Senior Project Coordinator-Aquaculture, and Ken Semmens, Aquaculture Extension Specialist, West Virginia University, Morgantown, WV.

WVU Extension Service Communications
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WASTE MANAGEMENT IN AQUACULTURE

Best management practices to reduce aquaculture waste

The growth in aquaculture has led to an increase in the use of feeds applied to water for improved production. The wastes that result from the use of aquaculture feeds are the focus of this paper. In West Virginia the annual production of trout and char in commercial operations is approaching 700,000 pounds. Compared to beef production this level is insignificant; however, as the industry grows we must consider that our water resources are limited and efforts must be made to sustain or improve the quality of the aquatic resources in the state.

With increased interest in environmentally friendly farming practices, and the potential for regulatory action by the EPA and other agencies, the aquaculture industry has been focusing on ways to reduce the wastes (environmental impact) from aquaculture facilities. By choosing the appropriate feeds during the production cycle, and paying close attention to the feeding methods and the resulting solids production, the manager can greatly reduce the wastes. For example research shows that combining quality feeds with careful management in a well designed culture system and solids collection area, can reduce nutrient discharges by as much as 50% (Hulbert, 2000). If the facility is going to be built or modified, greater reductions can be made.

The Federal Clean Water Act requires the industrial discharge of water to meet Federal standards. Enforcement of this law in West Virginia has been delegated to the state of West Virginia's Department of Environmental Protection. This law is not similarly enforced in all states because the classification of aquaculture varies from state to state (Ewart, 1995). Agricultural wastes have less stringent restrictions than industrial based wastes. Some states have classified aquaculture as an agricultural activity. Presently, in West Virginia the laws categorize aquaculture waste as an industrial waste. A discharge permit (NPDES) is required if a facility is discharging more than 30 days per year or producing above 20,000 lbs. per year[1].

Many of the fish farms operating in West Virginia do not use filters or ponds to reduce the amount of waste that leaves the farm. This results in negative externalities that are often more costly than if the farmer were to treat the waste on the farm. New regulations by the EPA are expected, and these regulations may be based on Total Maximum Daily Load (TMDL's) rather than concentration limits (mg/l). MDL permits are used in Europe and Idaho and have been shown to be effective. Idaho's Division of Environmental Quality has published useful information on aquaculture waste management (Idaho Waste Management Guidelines for Aquaculture Operations). Each watershed can have different levels of nutrients or water uses, and therefore regulations may vary, depending on the ambient levels of nutrients in the watershed. Another factor influencing the discharge regulations is the intended use of the water in the watershed. Public water supply, trout waters, recreational, and industrial uses will have an impact on the permitted discharge limitations.

Point source treatment is also known as "cost internalization" to economists. If the industry is to be sustainable, the cost of waste treatment must be internalized.The best management practices referred to in this paper can help reduce the cost outlay to accomplish this. These costs will be addressed after defining different types of waste. Wastes from a fish farm come in three general forms: metabolic, chemical, and pathogenic.

Feed Management

During the past decade, feed and nutrition research has shown the importance of ingredients in trout feed. By selecting grains low in phytate for the formulation of trout feeds, less phosphorus will be

[1] Chief of Water Resources phone: 304-558-2107

released by the fish. The majority of the phosphorus in plant proteins is not absorbed by trout because it is not digested in animals with only one stomach (Hardy, 1999). Another approach, to increase the bioavailability and utilization of phosphorus in feeds, is to increase the level of phytase in the feed (Baker et al., 2001; Papatryphon, 1999; Jackson et al., 1996). This approach is more effective in warm water species. The lower water temperatures associated with trout culture reduce the impact of phytase supplementation (Rodehutscord and Pfeffer, 1995). The relationship in trout between increasing phosphorus retention and 3-phytase in trout feeds was shown to be most effective with levels of phytase between 500 and 2000 FTU/kg (Baker et al., 2001).

The selection of extruded, high-energy feeds is another management tool that can be used to reduce waste. Recently the high-energy extruded pellet has been shown to reduce feed conversions in trout without a reduction in growth, thereby reducing waste (Bender et al., 1999). The fat content can be increased without using the coating method, which allows the fat to be introduced before the pellet is formed, thereby giving a more homogeneous mix. Extruded feeds can be made to sink or float. Floating feeds provide another tool that the manager can use to avoid overfeeding. Uneaten feed will remain visible as evidence of overfeeding. The higher cost of these feeds is the main reason that more farmers do not use them. When the reduction in the cost of waste management is considered, along with the reduced feed conversion ratios, high energy extruded feeds have proven to be more economical than regular pelleted feed.

By minimizing feed handling and storage time feed conversions can be improved. Excessive handling results in a greater percentage of fines that are generally not eaten by the fish. Regular deliveries and a good inventory system will keep the feed fresh. This is especially important in the hot summer months when the storage life of feed is reduced.

Solids Removal and Metabolic Waste

Metabolic waste comes in two forms: dissolved and suspended. When determining the amount of waste a system will generate, the amount of feed used in a system is the most important factor. In a properly managed farm, approximately 30% of the feed used will become solid waste. Feeding rates tend to increase with temperature, so the amount of waste is often greatest in the summer months when feeding rates are highest. Besides choosing a high energy extruded feed for greater assimilation, waste management efforts will be most effective if focused on the quick removal of solids. Primary treatment, or solid waste removal, should be done as soon as possible to reduce waste fragmentation. Fragmentation causes leaching of nutrients into the water. Excessive waste accumulation has been known to cause disease in fish culture operations. Water flow patterns in production units are important for waste management because a proper flow will minimize the fragmentation of fish feces and allow for rapid settling and concentration of the settleable solids. This can be critical because a high percentage of nonfragmented feces can be quickly captured which will greatly reduce the dissolved organic waste (Mathieu and Timmons, 1993). A reduction in downstream pollution is best achieved by the rapid removal of solids in the settleable form before discharge to public waters. By settling out downstream, solid wastes cover benthic animals and reduce oxygen levels, which reduce the biodiversity of a stream.

Dissolved Waste

Dissolved waste is another component of metabolic waste. It comes in the form of biological oxygen demand (BOD), and chemical oxygen demand (COD). BOD is considered a long-term measure of the consumption of oxygen because it may not occur until long after the water leaves the farm. On the other hand COD is a short-term measure because the loss of oxygen occurs, for the most part, within the farm.

Dissolved waste occurs in many forms: ammonia, nitrite, nitrate (i.e.; nitrogen), phosphorus and organic matter. Ammonia, which is excreted through the gills, is the most toxic form

of nitrogen when in the un-ionized form. Naturally occurring bacteria convert ammonia into less toxic forms that are utilized by plants and algae for growth. Providing a large surface area for autotrophic bacteria to grow is the best way to convert the ammonia to less toxic forms.

An increase in suspended solids will result in an increase of BOD (Alabaster, 1982). That is why a higher portion of settleable solids, quickly removed, will reduce the dissolved portion (BOD and COD) of waste from the farm. Generally, the smaller a particle is, the more leaching will take place. The majority of the solids produced in aquacultural operations are particles measuring 30 microns or less (Boardman et al., 1998; Chen et al., 1993). Small particles also take longer for settling to occur.

Phosphorus is found in fish feeds and is broken down into a more useable form (phosphate) through decomposition. In nutrient limited waters, phosphorus can be desirable for improving the benthic and planktonic community in a stream. In fresh waters, phosphorus is often the limiting nutrient for productivity. In most cases phosphorus and nitrogen contribute to eutrophication in a watershed by promoting growth of algae or plants. Watershed resource managers focus on reducing the amounts of phosphorus and nitrogen in a watershed when attempting to improve water quality.

Harvesting of fish occurs regularly on a farm. It is during the harvest and cleaning of tanks or ponds that elevated levels of waste are released. In particular, the final 25% that drains from a pond normally contains the majority of the metabolic and pathogenic waste. Frequent removal of solid wastes will reduce the dissolved wastes in the outflow from the farm.

Chemical Waste

The use of chemicals on fish farms is regulated by state and federal laws. Although there are few chemicals that are allowed to be used on food fish, a detoxification procedure should be followed, according to the manufacturer's label associated with the chemical treatment. Salt is a commonly used stress reducer in fish and has been approved for use in foodfish.

Pathogenic Waste

Water treatment plants often use some form of disinfection to reduce the parasitic, bacterial, and viral particles that flow from the plant. Fish farms can contribute to an increase in potentially pathogenic organisms. The three most common methods to reduce pathogens from water is chlorination, ultraviolet radiation and, ozonation. UV radiation occurs in a chamber and is not harmful to life downstream from the treatment. Both chlorine and ozone are strong oxidizers and have been responsible for fish kills due to excessive concentrations in the water.

West Virginia regulations do not require fish farms to treat for pathogenic wastes. The options listed above are available but generally are considered unnecessary and too costly to effectively treat all water discharged from most farms, especially if it is a flow through operation. Pathogens can be removed in wetlands via sedimentation and filtration. Macrophyte roots have been reported to have antibacterial properties (National Small Flows Clearinghouse). Bacteria are causes of numerous diseases in fish. *Pseudomonas* and *Aeromonas* are often present and can cause significant mortality in stressful conditions.

Methods for Waste Removal

Raceway and Tank Design

Proper engineering can be an economical means of controlling the wastes from a fish operation. By controlling the flow of water through a system, most solids can be collected and concentrated before fragmentation occurs. Round tanks can be designed with dual effluent areas. The high volume-low solids flow, can exit the tank from the upper perimeter while a low volume-high solids pipe, in the center of the tank, will remove most settleable material (Summerfelt and Timmons, 2000). Circular tanks with properly designed inlets, drains, and filters can remove the majority of solids with minimum labor. Centrifugal forces

will move settleable solids to the center drain when water velocity exceeds 20 cm/sec. (Burrows, 1970).

Vacuum removal of solids can be labor intensive. In raceways, if the flow is less than 3 cm/sec. non-fragmented trout feces will settle out if fish cannot stir the bottom. Figure 1 shows a typical raceway system with waste management options. Raceways should be designed with an optimum flow, which will allow an area at the end of each raceway, called the quiescent zone, to collect settleable solids for periodic removal by the operator.

Concrete raceways are difficult to modify once constructed. Research is planned to improve the waste collection abilities of raceways by inserting a device that will create a circular flow to collect the majority of the solids in the center. Like the round tanks, the concentrated waste can be removed by allowing 10-20% of the flow to exit from the center (Wong and Piedrahita, 2001). Research is underway at WVU to develop raceways made of alternative lighter materials, that will permit more flexibility in design. Rectangular raceways can be designed to channel water into a circular pattern before exiting the unit. This will allow most of the settleable solids to be concentrated and removed from the center while most of the water flows out the end, into the next rectangular raceway.

Transformation

Dissolved organic waste (phosphorus and nitrogen) is a nutrient for plants. Biofilters will transform a toxic form of nitrogen (ammonia) into a nontoxic form (nitrate), which is a nutrient for many algae. Artificial wetlands have also been used for waste treatment in aquaculture operations (Summerfelt et al., 1995). In a wetland, sediments are trapped and used for grass and aquatic plant growth. Various types of vegetables and herbs have been produced using hydroponics with recirculating water from fish operations. In order for the herbs or vegetables to significantly reduce the nutrient level in a commercial recirculating system, the time spent on fish culture can become secondary to the plant cultivation and marketing (Rakocy, 1999). In all of the above methods, nutrients are transformed or removed from the discharge with the help of common plants and bacteria.

Filtration

Drum, disk, bead, and sand filters are commonly used to trap and remove particles as small as 60 microns from the water. Cartridge filters will remove particles down to 1 micron but that level of purification is usually not necessary, and very costly. High volume flows require expensive filtration units. With flows of 1000 gpm and above, the maintenance and cost of mechanical filters become burdensome. That is why the dual drain design, mentioned earlier, works well. By treating only the low flow of concentrated solids, the cost of treatment can be greatly reduced by using smaller filters. If land is available a settling pond would be another inexpensive option.

Radiation / Ozone

Ultraviolet radiation is used for disinfection of water. Many pathogens, including viruses can be killed with relatively low levels of radiation. For UV treatment to be effective the solids must be removed before treatment. UV systems are a low maintenance, low risk method of disinfection.

Low levels of ozone dissolved in the water will also remove most pathogens. Ozone will improve particulate filtration and reduce the dissolved organic waste in the water. Low levels of ozone in the air are detrimental to human health. Residual ozone is toxic to fish at low levels and should be monitored.

Costs

Flow through systems

In a study published in 1997 the internalized cost, or pollution prevention cost, of flow through systems, was determined to be $.05/lb. of fish produced. This compared favorably with the pollution damage cost, or the external cost, which was estimated to be $.22/lb. (Smearman et al., 1997). If the industry approaches the waste

problem from a long-term sustainable path, the efficient and economical way to deal with the problem is to internalize the cost. According to the study, in a flow through system, the cost for a producer of 20,000 lbs./yr. would be about $1,000/yr. if it were internalized. The level at which a producer would need to address waste management is determined, in many states, by the annual pounds of production or the annual feed consumption for the operation. In West Virginia a producer is regulated if the annual production exceeds 20,000 lbs./year. There are few producers above the 20,000 lb./year level, however the state may inspect these sites.

Settling Basins

The Engineering Department at WVU has begun research using a new composite material for portable raceways that will investigate the quiescent zone design, and how efficiently different designs remove solid waste. The initial phase of this research should be completed in 2003. When this data becomes available an analysis of the economics can be conducted to determine the cost-effectiveness of modified in-raceway quiescent zones compared to settling ponds or basins.

Ponds can be a very efficient means of settling out wastes from an aquaculture operation. If an existing pond is located below the production facility, and has a residence time of at least a day, the cost for solid waste removal will remain low. It is difficult to predict the cost of a pond because every site is unique and existing infrastructure should be used to reduce costs.

Recirculating systems

In recirculating systems dissolved organics accumulate and can be removed with protein skimmers or foam fractionators. Ozone, which is a disinfectant, is also very effective for removal of dissolved organics. However, due to its cost, it is generally economical in intensive recirculating systems producing a high value (> $3/lb) product.

Biofilters can transform a limited amount of ammonia each day. This transformation rate is usually the first limiting factor for production in recirculating systems. The management of biosolids can have a great impact on all of the components in the system. For a recirculating system that produces 20,000 lbs./yr. the average daily feeding rate would be approximately 80 lbs./day. In a well-designed system the solids should be removed rapidly and only high quality feeds should be used.

The additional cost of tank design and filters that are necessary for proper waste management of a 20,000 lb./year system would be estimated at about $8,000. These expenses could be amortized over a 10-15 year period. The collected wastes could be used for field applications if laws permitted. With proper management, total solid waste for an operation of this size (from 25,000 lbs. of feed/yr.) should not exceed 8,000 lbs./yr. Assuming there is an adjacent field for the application of the concentrated solids, and labor costs of $500/year for transportation and field application, the annual cost for waste management per pound of production would be $.065/lb., similar to the cost in flow through systems. Field application rates are determined by the slope, soil type, precipitation, temperature, nutrient content, and plant type.

Constructed Wetlands

Constructed wetlands are artificial shallow wastewater treatment systems (ponds or channels) that have been planted with aquatic plants, and rely on natural processes to treat wastewater. Constructed wetlands have advantages over alternative treatment systems in that they require little or no energy to operate. If sufficient inexpensive land is available close to the aquaculture facility wetlands can be a cost effective alternative. Wetlands provide habitat for wildlife, and may be aesthetically pleasing to the eye. The disadvantages are that wetlands require more land area than alternative systems. Wetlands function best as a secondary treatment for water (after most solids are removed). They require a prolonged start-up period until vegetation is well

established, and seasonal efficiencies occur that result from a decrease in sunlight and temperature. It is important to control the hydraulic and solids loading rate so as not to overload the system. Substrate clogging is often a problem with constructed wetlands. For this reason the aquaculture effluents need to be monitored to know the suspended solid size and nutrient concentrations of the effluent before it enters the wetland. Standard methods can be used for this analysis.

Constructed wetlands for aquaculture waste treatments have been reported to be useful for from five to ten years (Reed et. al., 1995). An excellent publication on wetland design, maintenance, and treatment results is available from the Environmental Protection Agency (EPA Manual, 2000); on the web at: http://www.epa.gov/ORD/NRMRL). Simple methods can be used to construct a wetland. They have been shown to remove more than 95% of the total suspended solids and 80% - 90% of the nitrogen and phosphorus when application rates are about 30 kg. solids/sq. meter/ year (Summerfelt et.al., 1996).

Using constructed wetlands for primary treatment of wastewater is not recommended (EPA, 2000). For catfish production in Mississippi the additional cost of a constructed wetland per pound of production was $0.075/lb. (Posadas and LaSalle, 1997). However, over three quarters of the construction cost was in the purchase and planting of mature plants needed to conduct the experiment. Much of this expense could be avoided by planting seedlings and letting them mature before heavy loads are introduced into the wetland. For a well designed aquaculture operation of 20,000 lbs./yr. where the settleable solids could be field applied, a constructed wetland of 150 square meters should be sufficient to remove most of the suspended solids, phosphorus and nitrogen. The estimated cost for construction of a wetland for secondary treatment measuring 150 square meters is about $5,500 or $37/m^2 (see Appendix 1), and is estimated to last 5-10 years without major maintenance. Factors that impact the nutrient removal rate in wetlands are: hydraulic retention time, type of vegetation, solar radiation, microbial activity, and temperature (Hammer, 1993; Hammer and Bastian, 1989; Reed et al., 1995). A wetland design should be site specific, selecting local hardy plants (bulrushes or cattails).

There are two main types of constructed wetlands used for water treatment; surface flow and subsurface flow. Surface flow systems can treat large volumes, and subsurface flows generally are used for smaller flows. Because each system is highly site specific due to the slope, soil, shade, elevation, temperature, and other variables, the construction costs will vary considerably. The drain location will determine whether the flow is horizontal or vertical. Greater oxygenation can be achieved with parallel systems receiving intermittent flow. By alternating between wet and dry conditions within the substrate, BOD, ammonia, and phosphorus reduction is very good (Negroni, 2000).

Assuming that the constructed wetland would be used as a secondary treatment solely for a medium sized aquaculture facility in West Virginia, the subsurface design would probably work best. The subsurface flow also eliminates mosquitoes from breeding in the water. Plant selection is another important criterion for efficient water treatment. In the Northeastern U.S. some of the common plants used in constructed wetlands are cattails, bulrushes, rushes, and sedges. Selection of the media material is also crucial. System performance will depend on media size, uniformity, porosity, hydraulic conductivity and phosphorus binding capacity. Locally available media (river gravel) will reduce costs.

A subsurface constructed wetland in Emmitsburg, MD measuring 0.07 hectares (700 sq. meters.) cost less than $35,000 to build (National Small Flows Clearinghouse - WWBKDM38). This same source indicated another study in Arcata, CA, which had capital costs of $41,000/ha. for a 12.6 ha. wetland. The hydraulic surface loading, and influent nutrient load will determine the appropriate size of a wetland. Typical wastewater retention times in a constructed wetland range from two to six days. Wetlands can be designed to meet specific effluent

criteria if the influent characteristics including maximum TSS and BOD are known (EPA Manual).

Waste Utilization

Aquaculture waste can be utilized in much the same way that agriculture waste is used to amend the soil for crop production. State laws may not permit land application of aquaculture waste until aquaculture waste is clearly classified as an agricultural waste and not an industrial waste. Other options for waste utilization include the production of hydroponic plants or composting for garden applications.

Acute or chronic mortalities occur at some point in time and the dead fish need to be disposed of in a proper manner. Composting is a useful way of utilizing the dead fish, as a nitrogen source to be mixed with sawdust, or another carbon source, for the production of mulch. The process needs regular attention and aeration if it is to be done properly. Mortalities can be considered a solid waste and should be treated as such.

Composting is a sustainable option, and if done properly can generate a minor revenue for the farm. Fish carcasses, which are high in nitrogen, should be mixed with a material high in carbon such as wood chips in an attempt to attain a C:N ratio of 30:1. A few essential elements needed for successful composting are: a moisture content of 50-60%, porosity of 35-50%, pH should be 6.5-8.0, temperature between 130-150^{0}F, a C:N ratio of 25-35:1, and a particle size of ¼”-3/4”. Aerobic composting requires an oxygen concentration of >5%. Generally if these parameters are maintained a quality compost can be obtained in two to four months. Anaerobic composting can convert wastes into compost quicker than aerobic composting, however there are odors and methane production that can cause serious trouble. Temperature is a key process control factor and should be monitored closely. Pathogens and parasites can be controlled by maintaining the temperature above 131^{o}F (55^{o}C). Any one of these factors can delay the process and each carbon and nitrogen source has different qualities which can impact the composting process. Good record keeping with experiments can help develop an efficient compost process within the first year.

Conclusions

Sustainable growth of the aquaculture industry requires profitability, economic development, and waste management. Waste management decisions must be made on an individual basis due to site characteristics on the farm and within the watershed. Research has shown that round tanks can be more efficient at waste removal than rectangular or square tanks. Dual drains allow for continual removal of concentrated waste while the majority of the flow can be reused or discharged containing minimal waste. The circular flow principle has been used to retrofit existing raceways by modifying the flow in the quiescent zone. (Wong and Piedrahita, 2001)

Significant reductions in waste can be made by managerial decisions focusing on all aspects of the feed, including digestibility, ingredients, handling, storage, and presentation, without an interruption in production. Rapid solids removal will minimize shearing of solids which results in an increase of dissolved wastes which are more difficult to concentrate and remove from the system.

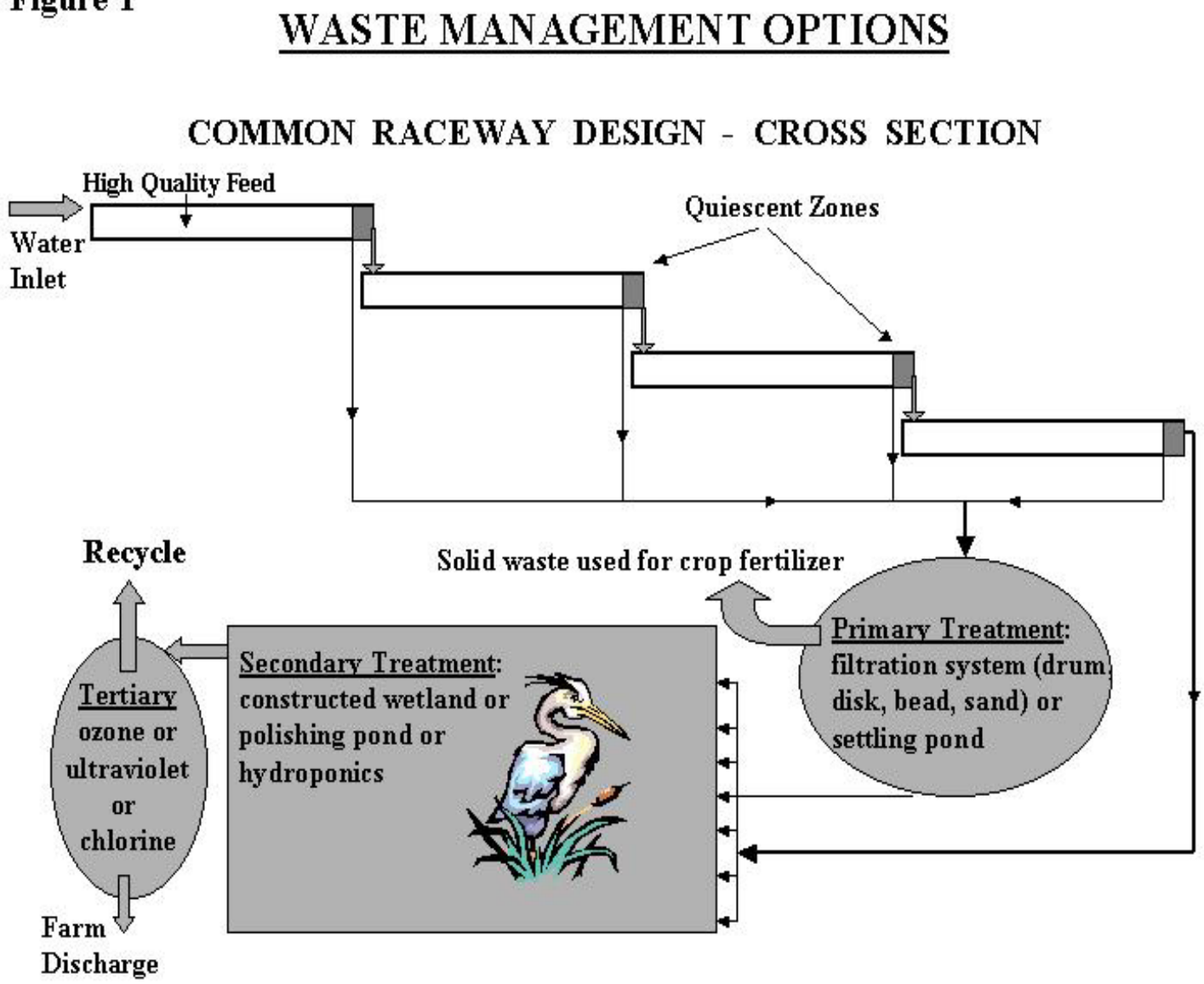
Understanding waste characteristics is important in the design of a waste management system. The NPDES permit application will require knowledge in this area. The first step in waste treatment is the removal of larger (settleable) solids. This is commonly done with filtration systems and settling basins or ponds. The second step is the removal of smaller (suspended) solids, those particles less than 60 microns, and dissolved nutrients. This is can be done using polishing ponds, constructed wetlands or hydroponics. The third step in waste treatment is disinfection. Ozone, chlorination, and ultraviolet radiation are all effective means of disinfection.

Although the costs incurred with waste management seem high, they are minor compared to the costs of controlling the pollution after it has left the farm and entered the environment.

Proper application of biosolids from an aquaculture operation requires knowledge on soil type, slope, crop development, seasonal rainfall and other issues.

Regulatory actions will need to consider the ultimate use of the water and the characteristics of the watershed, before being implemented. Policy options to address this issue include, cost-sharing, incentives, feed related taxes, education, and water quality testing that would be used to establish total maximum daily loads (TMDL).

Figure 1



APPENDIX 1

Estimated Wetland Construction Costs

Feeding level not to exceed 30,000 lbs. / year

With 30% sludge production: 10,000 lbs. sludge produced

Primary treatment: removes 70% of solids; 3,000 lbs. solids /yr. enter wetland

3,000lbs. solids / 150 sq. meters = 20 lbs. solids/ sq. meter/ yr.

Sludge application rate: 20 lbs. solids / square meter / year

150 square meter area with 10 cm of coarse sand over 40 cm of gravel.

$150m^2$ x 0.10m(deep) x $\$20/m^3$
(sand) = …….$300

$150m^2$ x 0.40m(deep) x $\$28/m^3$
(gravel) =……..$1,680

Backhoe $75/ hr x 16 hours = $1,200

Labor at $ 10/ hour (preparation)
x 60 hours = ……..$600

Estimated cost for plants:…$1,200

PVC pipe …….$300

Misc. ……..… $320

TOTAL: $5,600

$ 5600 / 150 m^2 = $ 37 / m^2 for construction costs.

With a 5 year estimated life span for secondary treatment, and fish production of 20,000 lbs. / year.

$5,600 / (5 years x 20,000 lbs./yr.) Cost per pound of production = $0.06 / lb.

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