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Aquaculture Effluents: A Guide for Water Quality Regulators and Aquaculturists

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Introduction

As aquaculture or the farming of aquatic organisms continues to expand and intensify, provisions for waste management become very important issues for both producers and environmental regulatory officials. There are a number of types of aquaculture and their environmental impacts are highly varied. For example intensive culture of finfish in tanks or netpens requires the addition of prepared feeds, with attendant waste management problems, but culture of filter feeding bivalve mollusks or seaweeds may actually cleanse or remove nutrients from effluent waters.

A proper waste management plan is needed to maintain the legality, profitability and environmental soundness of any aquaculture facility. Typical wastes from an aquaculture facility may include feces and nutrients from excretion by aquatic animals, as well as uneaten feeds and chemicals such as therapeutant and cleanser residues. If there is a significant discharge of waste into lakes, rivers, estuaries or any other receiving waters it may cause adverse environmental impacts. In order to prevent these adverse impacts from occurring, regulations on discharges into receiving waters have been or are in the process of being established. In most cases, aquaculture facilities are not given permits unless there is a waste management plan that meets applicable local, state and federal environmental regulations. The intent of this fact sheet is to: a) describe the waste effluents produced by aquaculture facilities, b) to serve as a guide for water quality regulators and aquaculturists interested in discharge permitting, and c) to provide information for using dilution models in freshwater and coastal water bodies.

Who Regulates Effluents?

Since the Water Pollution Control Act of 1972, which was revised as the Clean Waters Act in 1977, the U.S. Environmental Protection Agency (EPA) has been given responsibility of maintaining the chemical, physical, and biological integrity of the of the nations waters. This mandate includes promulgation of regulations aimed at achieving a level of water quality that provides for the protection and propagation of fish, shellfish, and wildlife, and for recreation in and on the water. The EPA regulates all discharges of point and non-point sources of water pollutants, which is achieved by the issuance of National Pollution Discharge Elimination System (NPDES) permits. The Clean Water Act also gives the EPA the ability to transfer or delegate effluent discharge permitting authority to individual states. For example, in the State of Rhode Island, the state water resources agency issues the Rhode Island Pollution Discharge Elimination System (RIPDES) permit in lieu of the NPDES permit. Other delegated states use a similar permitting procedure. In the Northeast Region, all states are EPA *delegated* states except for the states of Massachusetts, New Hampshire, Maine and the District of Columbia, which have *non-delegated* state status. Water quality regulations in delegated states must be equivalent or more stringent than the EPA's permitting requirements. Often times delegated states will incorporate the NPDES permit into their regulatory program through a joint state/ federal permit.

The NPDES permit regulations under section 40, Part 122, Subpart B, Section 122.24 and Subpart D, Appendix C of the Code of Federal Regulations consider "concentrated aquatic animal production facilities" to be sources requiring NPDES permits for discharges into United States waters. Permits are needed for:

1) Cold water fish (including trout but not limited to the family Salmonidae of fish, e.g., trout and salmon) in ponds, raceways or other similar structures that discharge at least 30 days per year. Facilities that produce less than 9090 harvest kgs (approximately 20,000 lbs.) of aquatic animals per year, or facilities which feed less than 2,272 kgs (approximately 5,000 lbs.) of feed during the calendar month of maximum feeding are not included.

2) Warm water aquatic animals (including but not limited to the Ameiuridae, Ictaluridae, Centrarchidae and Cyprinidae families of fish, e.g. catfish, sunfish and minnows) in ponds, raceways or other similar structures which discharge at least 30 days per year. Closed ponds are exempted that discharge only during periods of excess runoff, or facilities which produce less than 45,454 harvest kgs (approximately 100,000 lbs.) of aquatic animals per year.

3) Any aquaculture facility that the EPA determines is a significant contributor of pollution to waters of the U.S. based on an on-site inspection of the facility. In this determination, the EPA shall consider the following factors:

a) location and quality of the receiving waters,
b) capacity of the facility,
c) quantity and nature of pollutants discharged, and
d) relevant factors such as total maximum daily load (TMDL) determinations for watersheds.

The Army Corps of Engineers also regulates aquaculture permitting due to the Rivers and Harbors Act of 1899 which gives the ACOE authority over structures of facilities over or in navigable waters. This would include the siting of net pens and off-bottom shellfish culture that may affect water quality and impede navigation. The Clean Waters Act also encourages the use of Best Available Technology (BAT) and the Best Management Practices (BMP). A public hearing may also be needed for obtaining a permit. It is the responsibility of the aquaculturist to know the regulations that apply to their facility and apply for the necessary permits. For a more detailed explanation of the permitting process for aquaculture effluent discharge and waste disposal see NRAC Bulletin No. 300 - State Policies for Aquaculture Effluents and Solid Wastes in the Northeast Region by J.W. Ewart, J. Hankins, and D. Bullock.

On September 10, 1999 a general NPDES permit for aquaculture went into effect in the state of Idaho which contains effluent monitoring requirements that are not established in other states yet. This permit can serve as a template for future requirements in other states involved in aquaculture effluent regulation. Copies of the permit are available by contacting EPA Region 10 Public Environmental Resource Center at 1-800-424-4372. The documents can also be obtained from EPA Region 10's Office of Water Resources website at the EPA Region 10, Idaho office, 1435 North Orchard Street, Boise, Idaho 83706 or downloaded from their website under "Public Notices" http://www.epa.gov/r10earth/office/water/ow.htm.

What types of wastes are produced by aquaculture facilities?

There are three main types of pollutants that can be produced by aquaculture facilities: chemicals for maintaining facility cleanliness, drugs used for disease control, and metabolic products such as feces, ammonia and uneaten food.

The first two types of pollutants are usually sporadic and the best way to treat the chemicals and drugs used in treating disease is to follow the manufacturer's instructions or advice from qualified chemists. Procedures for detoxification or adequate dilution of a chemical should be in place before even using it.

The second type of waste is feed wastes and metabolic waste products. These waste products from metabolism, excretion, and uneaten food are in the forms of dissolved compounds and suspended solids. Waste from feeding the fish compose the bulk of aquaculture waste. This can be explained by the energy balance equation:

$$C = F + U + R + P$$

When, C is the energy in consumed food,
F is the energy content of feces,
U the nitrogenous wastes from the gills and in the urine,
R is the heat generated in respiratory metabolism, and
P is the energy available for body growth or reproduction.

Simply stated, feeds must be consumed, digested and assimilated, first, before utilization. The assimilated protein, lipids and carbohydrates (C minus F) are available for maintenance (U + R), growth or reproduction (P). Waste management terminology may use synonymous expressions such as solid waste (SW) for F, dissolved waste (DW) for U. Uneaten feed is termed feed waste or FW. Thus total aquaculture waste (TW) is:

$$TW = SW + DW + FW$$

Dissolved Compounds

Dissolved waste compounds include ammonia, nitrate, phosphate and organic matter. Many of the dissolved waste compounds can lead to eutrophication by virtue of the fact that they are nutrients or natural fertilizers. Eutrophication of receiving waters can lead to oxygen deficiencies (hypoxia) or anoxia, which in turn can lead to fish and shellfish mortalities. In most freshwater systems, phosphorus is usually the limiting nutrient, but nitrogen is usually limiting phytoplankton production in seawater.

The fish nutritionist has control over nitrogenous waste arising from the diet by way of manipulating feed formulation. Mainly, dissolved wastes are the nitrogenous wastes excreted by the fish as a result of amino acid degradation in the body. Although the endogenous nitrogenous waste (i.e. nitrogen resulting from body tissue degradation) is a fixed level for a given condition, nitrogen excretion arising from the diet can be minimized. This can be done by a) using a protein source that has a balanced amino acid profile in relation to the amino acid requirements of the fish; and b) decreasing dietary protein level by replacing it with lipid or carbohydrate. The first step ensures that protein is channeled solely to protein deposition (i.e. growth) and not to energy production where nitrogenous waste is a by-product. This does not imply that fishmeal should be the sole source of protein; in some feeds, complementary proteins from animal or plant sources could be incorporated. Plant protein sources should be used very sparingly, if at all, in most high protein diets for predatory species.

The second step of substituting lipids or carbohydrates ensures that the diet is lesser in protein but higher in energy. Dietary energy regulates feed intake. That is, a fish will consume less in weight of an energy-dense diet than one with a lower energy density to satisfy its energy requirements. Thus, a lesser amount of feed is consumed effecting practically the same growth rate (and thus an improved feed conversion ratio) producing less dissolved wastes.

Ammonia is a dissolved excretory compound from protein metabolism that is monitored often in aquaculture facilities because it is highly toxic to fish. When ammonia gas (NH_3) dissolves in the water, some of it reacts with the water to give ammonium ions NH_4^+ while some remains un-ionized as dissolved NH_3. Combined NH_3 and NH_4^+ make up total ammonia, which can be easily determined by commercially available test kits. [See NRAC Fact Sheet No. 170, An Introduction to Water Chemistry in Freshwater Aquaculture by J.K. Buttner, R.W. Soderberg and D.E. Terlizzi for a discussion of water quality testing]. Primarily the water's pH and temperature determine the amount of un-ionized ammonia (NH_3) in culture systems. As the pH increases, the amount of toxic NH_3 increases, which can be harmful to fish. For example, when ammonia (NH_3) exceeds levels of 0.0125 mg/L, trout will experience reduction in growth rate, as well as damage to the kidneys, gills and liver tissue. Fish have different tolerances, for example it takes 0.12 mg/L NH_3 to cause gill damage to channel catfish. Some ammonia can be removed from aquaculture systems by aeration, which strips off some of the NH_3 directly into the atmosphere. Alternatively, ammonia can be removed from water prior to discharge or reuse through ion exchange by passing the water through natural zeolites or cation exchange columns. However, these methods have limited utility in commercial scale production facilities.

Often, ammonia is treated in re-use or recirculation aquaculture systems by having it aerobically (requiring oxygen) converted to nitrate (NO_3^-) by nitrifying bacteria. The nitrifying bacteria (*Nitrosomonas* and *Nitrobacter*) can be promoted on surfaces of biological filters in recirculating or water reuse systems [for a discussion of biological filters, refer to SRAC Publication No. 452, Recirculating Aquaculture Tank Production Systems: Management of Recirculating Systems. By M.P. Masser, J. Rakocy and T.M. Losordo]. Conversion of ammonia to nitrate, however does not remove the total dissolved nitrogen from the aquaculture system, it simply makes the form of nitrogen less toxic to the cultured organisms.

Effluents from aquaculture systems employing nitrification systems are often rich in nitrate-N, so it may be desirable to further treat the effluent prior to discharge. Lagoons can remove 35-85% of the total nitrogen by microbial fermentation and through uptake by algae. Likewise, constructed wetlands using shallow lagoons with rooted vascular plants can remove nitrate through uptake by the plants or through soil processes such as denitrification that converts nitrate to simple nitrogen gas.

Removal of phosphate (PO_4^{3-}) from aquaculture effluents is problematic, and the best management strategy for phosphorus is to limit the amount of phosphorus in the feeds. A key problem with phosphorus is that most of it is not available to fish (i.e. not digestible). Some feed studies suggest that addition of enzymes to feeds such as phytase can improve phosphate availability. Typical dietary phosphorus requirements in most fish & crustacean feeds are 0.3-0.8% of the dry diet (Penaflorida, 1998)

The usual strategy is to optimize the amount of phosphorus in the feeds through experimental feeding trials. Typically in feeding experiments, nutritionists will vary the concentration of available phosphorous in the diets and monitor fish growth. Fish growth is plotted against phosphorus levels in the feed, and optimum phosphorus levels are found at the point where any additional phosphorus in the feed will not result in any additional growth. Often nutritionists will plot fish growth versus phosphorus levels in the feed and then define optimum level by mathematically determining the inflection point of a curve that fits the data. However, one simple way for aquaculture producers to optimumize phosphorus in diets is to calculate a Phosphorus Utilization Index (PUI) from feeding trial data. The PUI can be described by the equation:

$$PUI = (W_f - W_o/F \times p)$$

When, F is the weight of feed supplied over the test period,

W_f-W_o is the gain of weight of fish over the test period,

and, p is the percentage of percentage of phosphorus in the feed.

So for example, if the phosphorus in a feed were 5 g/kg of feed, p would be 0.005, and over a six-month feeding trial fish gained 600 kg when fed a total 1,200 kg of feed, the phosphorus utilization index would be:

$$PUI = (600kg/(1,200kg \times 0.005) = 100$$

The PUI values are reduced when the phosphorus in the feeds are either insufficient or in excess. Optimum phosphorus content in fish feeds is species specific and occurs when the PUI value is maximized.

This method of calculating optimum phosphorus in feeds closely follows the method of calculating the optimum amount of protein in prepared diets. See NRAC Fact Sheet No. 222 Evaluation of Artificial Diets for Cultured Fish by M.A. Rice, D.A. Bengtson and C. Jaworski for more information on calculating protein efficiency ratio (PER) in feeding trials. Similar to dietary phosphorus, optimizing protein in prepared diets can lower the amount of total nitrogen in effluents.

Phosphorus can be removed from aquaculture effluent waters in treatment lagoons and constructed wetlands primarily through incorporation of the nutrient into plant biomass.

Suspended solids

Uneaten food and fish feces are usually in the form of suspended solids, which is defined as all particles greater than 2 μm in size. Suspended solids can make natural waters more turbid and eventually form organic deposits on the bottom of water bodies. These organic deposits can reduce the oxygen content of the water through natural oxidation, which includes microbial respiration and aerobic decomposition.

The first step in determining a waste management plan is to calculate the amount of potential uneaten food and how much feces is being produced by the organism being cultured. A wide range of factors affect feed digestibility, but the nature and composition of the ingredients used in the diet and the processes involved in their preparation are the most important. The fish nutritionist has very little control on the digestibility of feed ingredients except to process them as to render them as physically small in particle or as less complex as possible to make them more vulnerable to digestive enzyme processes. Of course, aquaculturists are very interested in efficient food utilization by their livestock in the interest of cost of feeds.

Feces production is related to feeding rate. The food conversion ratio (FCR) is a very simple and convenient descriptor of feed utilization. FCR is defined as the weight of the food given divided by the weight gain of the cultured organism over the culture period. So, if a fish is fed 4 kg of food over a six-month period and gains two kilograms in that time, the FCR would be 4kg/2kg = 2. The FCR values factor in all fed utilization and waste, and lower FCR values indicate better feed utilization by the fish [for a more information on feed conversion see NRAC Fact Sheet No. 222 Evaluation of Artificial Diets for Cultured Fish by M.A. Rice, D.A. Bengtson and C. Jaworski]. A typical FCR of 2 usually leads to about 50% of feed input becoming waste products, most of which is in the solid form, including uneaten feed and feces. It should be noted that FCR is strictly calculated on the basis of food weight and fish weigh gain regardless moisture content. So a comparison of wastes from feeds of different moisture contents may require a correction for moisture.

The feed and fecal wastes also contribute to biological oxygen demand (BOD), which is used as an index of pollution by dissolved organic substances or suspended particulate matter. BOD_5 is a measure of the amount of oxygen consumed when aerobic microorganisms consume the organic material in effluent water within 5 days under standard

(20^oC) conditions. Units of BOD are mgO_2/L of wastewater.

One can get an initial estimation of the amount of BOD generated by decomposition of aquaculture wastes through some basic theoretical respiration calculations. Excess fish feeds in aquaculture wastes, for example, contain mixtures of complex carbohydrates, protein and lipids (fats). The complex carbohydrates like starches and cellulose have a general formula of $X(C_6H_{12}O_6)$, when X is an arbitrary number referring to the number of simple sugars polymerized to form the complex molecule. Full oxidation or respiration of the complex carbohydrate would be:

$$X(C_6H_{12}O_6) + X(6O_2) = X(6CO_2) + X(6H_2O)$$

So, full oxidation of each kg of carbohydrate would require the consumption of 1.07 kg of oxygen based on molar equivalents.

The ratio of CO_2 produced and O_2 consumed in respiration is called the Respiratory Quotient or RQ. In the case of carbohydrate respiration, one molecule of CO_2 is produced for every molecule of O_2 consumed, so:

$$RQ = X(6CO_2) / X(6O_2) = 1.0$$

In the case of respiration of protein and fatty wastes, RQ values are 0.8 and 0.7 respectively, because they require more oxygen for full oxidation. For example, if excess fish feed waste is a problem, and the proximate analysis of the feed is 30% crude protein, and 20% fat with the balance as complex carbohydrate, the RQ can be used to estimate total oxygen requirements. For each kg of feed waste:

Carbohydrate:
1.0kg-feed x 0.5 = 0.5kg-carbo x 1.07 kg-O_2/kg-carbo ÷ 1.0(RQ) = $\underline{0.535\ kg\text{-}O_2}$

Protein:
1.0kg-feed x 0.3 = 0.3kg-protein x 1.07 kg-O_2/kg-carbo ÷ 0.8(RQ) = $\underline{0.401\ kg\text{-}O_2}$

Lipid:
1.0kg-feed x 0.2 = 0.2kg-lipid x 1.07 kg-O_2/kg-carbo ÷ 0.7(RQ) = $\underline{0.306\ kg\text{-}O_2}$

So, the total oxygen required to fully oxidize this 1 kg of feed would be:

$$0.535\ kg\text{-}O_2 + 0.401\ kg\text{-}O_2 + 0.306\ kg\text{-}O_2$$

$$= 1.242\ kg\text{-}O_2$$

In the case of net pen or sea cage aquaculture, fish feces and excess feeds are deposited directly into the receiving water without treatment, so this calculation of potential oxygen requirements becomes relevant. Often in the case of net pen operations, organic carbon can be deposited below cages into the sediments. Measurement of total organic carbon (TOC) of sediments (Gross, 1972) under fishcages or netpens in comparison to adjacent control sites can be an excellent index of excess solid wastes. Estimates of BOD and measurements of TOC are useful for choosing suitable areas for siting aquaculture projects, especially when coupled with flushing and dispersion considerations to be discussed later in this fact sheet.

Most suspended solids can be removed from land-based aquaculture effluents before discharge by employing filtration screens and use of settling basins. Simple filtration screens can allow collection of solids for land disposal or use as fertilizer.

Suspended particles that are smaller than 2μm can be removed by collecting in settling basins. Settling basins try to spread effluent to slow it down and let the solids settle out by weight. Factors that affect the design and size of settling basins are retention time, density of waste solids, water flow and velocity and water depth. Concrete raceway or linear clarifiers and earthen ponds or lagoons are examples of settling basins that have been used in aquaculture applications, but in general the bigger the settling pond the more effluent that can be treated. The total nitrogen and phosphorus content of aquacultural sludge or settled solids has been found to be similar to or slightly more than that of common municipal sludge.

Before disposal of waste, a two-treatment process may be necessary for some applications, which includes thickening and stabilization. The purpose of thickening is to increase solid content of the sludge. Clarification in settling tanks or ponds is a common thickening process, because the settling process concentrates the sludge at the pond bottom where it can be removed. When solids are removed from the ponds the concentration of solids are typically 2 to 5%, with the bulk of the weight being water.

Storage and stabilization is necessary where waste application is limited to certain times per year and where odors need to be minimized. Stabilization helps in volume reduction and control of any odor due to the decay of organic materials. Frequently simple air-drying or composting of the sludge are means of stabilizing small quantities of sludge. Lagoons are usually the most feasible way of storing and stabilizing larger quantities sludge in large land-based operations. Wastes can be of value as a fertilizer and can be spread directly on the ground. It may also be possible to dispose of waste in the municipal system or dry it and sell it to fertilizer manufacturers. Of course, if aquacultural wastes generated in seawater systems may have residual salts that may limit its usefulness as a fertilizer for most terrestrial plants.

The feed manufacturing process itself may assist in waste reduction by creating feed pellets that resist disintegration in water, making collection easier. In the processing of most fish diets, extrusion pelleting offers an advantage over conventional steam pelleting in terms of lessening fecal waste. Extrusion pelleting involves processing of ingredients at higher temperatures and pressure. The extrusion of the hot mixture through dies results in the evaporation of water causing rapid increase of the volume of the pellets. By adjustments in the conditions of the extruder and in the proportion of the starch, one can develop a range of desired pellet density including buoyant pellets that allow convenient monitoring of fish feeding behavior. This can lead to better feed management by minimization of waste feed.

Keeping waste management planning appropriate for the aquaculture species and the culture system

Fish can be raised in many types of rearing facilities including circular tanks, raceways, earthen ponds, cages, and net-pens. So, it is important for the aquaculturist to consider what type of rearing facility to use to help minimize wastes that will be produced from the facility. However, other aquacultured species such as bivalve mollusks and seaweeds either filter natural particulates from the water or assimilate nitrogenous and phosphorus-rich nutrients from the water. So it is important to consider the species being cultured when developing wastewater plans [for an overview of aquaculture systems refer to NRAC Fact Sheet No. 120, Aquaculture Systems for the Northeast by J. Buttner, G. Flimlin and D. Webster].

Shellfish hatcheries, nurseries and grow-out facilities are distinctly different from fish facilities in that most shellfish aquaculture systems filter naturally occurring phytoplankton out of the water. Additionally, they do not have the large amount of feed going into the systems as in fish facilities. Shellfish will excrete feces, pseudofeces (filtered material such as silt that is not ingested) and ammonia into the water as a result of their filtering of particulates from the water. The amount of ammonia typically produced by a northern quahog or hard clam, *Mercenaria mercenaria* is 9.35 $mgNH_3/kg$ soft tissue per day and oyster *Crassostrea virginica* is 4.76 $mgNH_3/g$ soft tissue per day (Srna and Baggaley, 1976).

Shellfish aquaculture can be a beneficial form of waste treatment in that they improve water quality by the filtration of particles and act to stimulate decomposition and mineralization processes (e.g. Doering et al., 1986). For example, freshwater mussels, *Diplodon chilensis chilensis* are present in a lake in Chile where intensive salmon farming is occurring. Eutrophication has not occurred in the lake due to the nutrient cycling and mineralization by the uptake of particulate organic nitrogen and the release of ammonium.

The ammonium excretion in turn enhances primary production of phytoplankton, which is later removed by the mussels (Soto and Mena 1998). Bivalves can be established in high nutrient waters and can alleviate the adverse effects caused by effluents (Kaiser et al. 1998), and bivalves can improve water quality by filtering large volumes of water and can also regenerate nutrients back into the water column.

In most permitting jurisdictions, there is a distinction between land-based and field-based shellfish aquaculture. Effluents from land based facilities are monitored by state discharge programs and field-based, while not really considered to have a point-source discharge are still subject for environmental review for location of leasing sites and stocking densities and any environmental effect they might have on the local waters.

Use of Best Management Practices

Best Management Practices (BMPs) are approved industry standards of schedules of activities, prohibitions, maintenance procedures, and other management practices to prevent or reduce the pollution of the waters of the United States. BMPs are a set of formal written guidelines agreed upon by industry and regulatory agencies that help the permitting process by setting best agreed-upon standards.

At present there are no established aquaculture BMPs for aquaculture in the Northeastern States. Some potential BMPs include the use of aquaculture effluents as irrigation water, soil enrichment, fertilizer and animal feed. Other BMPs might encourage the use of nutritional strategies for the management of aquaculture waste (NSWAW) by minimizing waste outputs from the source. For example as discussed earlier, a BMP of reducing the amount of phosphorus, through the use of low phosphorus feed, may decrease the likelihood of eutrophication in freshwater habitats. The basic principals of waste reduction through feed management are formulation of high-nutrient diets and development of efficient feeding systems based on energetic or growth efficiency data (Cho et al. 1994). Another example of a BMP may be effluent treatment protocols like suspended solids filtration and separation as discussed previously.

Single-pass aquaculture systems only allow water to go through system once. Often wastes are dumped into the water and immediately discharged. Effluents can often be minimized through the use of recirculating or water reuse systems. In some aquaculture recirculating facilities, aquaculturists can reuse water as many as 10 times through a series of raceways, ponds or tanks. This reuse of water can reduce production costs as well as provide a more effective method to manage wastes. Water recirculation technologies might be employed because the quantity of water available could be low, the cost for pollution abatement post-discharge could be high, energy to heat the water may be high, or continuous water sterilization may be costly. During re-use of water, the fish will give off carbon dioxide, remove oxygen, and excrete urea, ammonia and feces. Uneaten food can also accumulate. Best management practices as applied to recirculation systems include all of the ammonia detoxification strategies and solids removal protocols previously discussed.

Best Management Practices as applied to lease sites for net pens may include locating culture sites in areas with proper tidal flushing. In a survey study performed on 57 salmon farms in Scotland, it was determined that salmon net pens should be sited in an area that has a minimum average current speed of 5-10 cm/sec. This is in order to reduce self-pollution and to assure adequate waste dispersal from the site (Lumb, 1989).

Discharges into Natural Waters

When applying for a permit a description of the outfall being used should be stated. This would include the diameter, discharge velocity and depth of the outfall relative to the mean low water depth. A general description of the aquaculture operation, which provides information of what species are being cultured, what medications or treatments would be used for any type of illness or disease should also be mentioned. Include the stocking density and the amount of food and type that are planned on being fed.

It is extremely important to submit what the ambient water quality is before the facility is in place. If there is discharge into a flowing stream, water quality data should be collected as close to 7Q10 flow conditions as practical. The term 7Q10 refers to the lowest stream flow for 7 consecutive days that would be expected to occur once in 10 years. In coastal tidal waters, data on tidal current speed and direction through a full tidal cycle should be reported preferably at both neap and spring tides.

Water quality parameters that should be included would be pH, flow, dissolved oxygen, ammonia, nitrate, phosphorus, turbidity, total suspended solids (TSS), and Biological Oxygen Demand (BOD). Next, submit what the expected concentrations of the parameters just mentioned would be as a result of the aquaculture facility. The types and quantities of chemicals used for disease treatment should also be mentioned. Include the engineering plans for the removal of pollutants such as settling basins or lagoons. Make sure to include Best Management Practices that will be used. Finally, include estimates of the water quality impacts by evaluating in stream dilution or an estuarine mixing model. Determine the dissolved oxygen and ammonia within the mixing zone as a first cut analysis. If this is determined to be unacceptable by the permitting agency, there are computer models that can be used [see the subsequent section on discharge modeling].

Mixing Zones

Mixing zones are areas where an effluent discharge undergoes initial dilution and these zones also cover the secondary mixing in the ambient water body. When wastewater is transported into a water body its transport may be divided into two stages. The first stage is mixing and dilution which are determined by the initial momentum and buoyancy of the discharge. The initial contact with the receiving water is where the concentration of the effluent will be greatest in the water column. The design of the discharge outfall should provide ample momentum to dilute the concentration as quickly as possible.

The second stage of mixing covers a more extensive area in which the momentum and buoyancy is diminished and the effluent is mixed by turbulence. The general definition for a completely mixed condition is when there is no measurable difference in the concentration of the pollutant. This exists across any transect of the water body.

Acceptable mixing zones do not impair the integrity of the water as a whole, and there is no lethality to organisms passing through the mixing zone. Hydraulic investigations of various wastewater discharges suggest that the use of a high-velocity discharges with an initial velocities of 3 meters per second or more can create a large enough turbulent mixing zone to dilute most pollutants. This should ensure that the criterion maximum concentrations (CMCs) of pollutants would be satisfied within a few minutes under practically all conditions. However for most aquaculture applications, effluents are not particularly noxious to marine organisms so such a rigorous discharge mixing protocol may not be necessary to achieve acceptable effluent dilution.

Recommendations for outfall design

The design of the effluent outfall is an important factor in maximizing the initial dilution of an effluent. There are three types of outfall designs: surface discharge from free flows in a pipe or canal, single-port submerged discharge, and multi-port submerged discharge. Of the three, the surface discharge type is the least favorable since it offers the least initial mixing. Submerged discharges offer more flexibility in meeting the design goals. Submerged diffusers allow the effluent to be directed at different angles to the ambient flow to maximize the initial dilution. Multi-port submerged diffusers provide more dilution than single outlets. In rivers the preferred arrangement is to direct the outlet into the current flow direction or vertically upwards. In coastal bays, the preferred offshore discharges are parallel diffuser alignment and perpendicular diffuser alignment. In lakes and reservoirs, the preferred arrangement for a negatively buoyant discharge is to direct the diffuser vertically upwards. A slight angle above the horizontal should be used for positively buoyant effluent and for ocean outfalls in which the initial dilution is improved by longer and deeper diffusers. A discharge plume is difficult to measure in marine systems due to conditions such as tides, river inputs, wind intensity and direction, and thermal and saline stratification. Models are often used to determine dilution of discharge. A minimum estimate of the initial dilution available in the outfall vicinity can be made by using the equation (EPA, 1991):

$$S = 0.3\ x/d$$

When:

S = flux-averaged dilution,
x = distance from outlet, and
d = diameter of outlet.

The coefficient of 0.3 represents the average of two values from the literature, 0.28 and 0.32, that were determined empirically from dye release studies. Assumed conditions of the formula are that the outlet velocity is zero and the discharge is neutrally buoyant. So for example, if the diameter discharge pipe is was 10 cm (or 0.10 m) and you wanted to know what the dilution value was at 2 meters away from the outlet the flux average dilution would be:

$$S = 0.3 \times (2\text{m}/0.10\text{m}) = 6.0.$$

Or a factor of 6 reduction in concentration compared to the effluent in the pipe.

Effluent Dilution Models

The simplest effluent dilution model may be a simple calculation of effluent dilution through dispersion into a large flowing receiving volume. For example, consider the case of a facility like a shellfish hatchery discharging effluent water containing 10 mg/L ammonia at a rate of 1000 gallons per hour into a 30 ft deep estuary with an average current of 0.5 knot (3,038 ft/hr). It is possible to get a first estimate of the incremental increase in ammonia concentration in the receiving waters using some estimates and the given data. The distance of an initial discharge plume is dependent upon diameter of the discharge pipe and the velocity of discharge (Fischer et al., 1979). If for example, you estimate that the discharge plume extends 10 feet beyond the discharge pipe, and assume that it is fully mixed throughout the water column, then the hourly volume of receiving water into which the effluent is mixing would be:

$$10\text{ft} \times 30\text{ft} \times 3038\ \text{ft/hr} = 911{,}000\ \text{cu ft/hr}$$
$$= 6.8\ \text{million gal/hr}$$

The effluent volume of 1000 gal/hr would fully disperse into the receiving water at a ratio of:

$$6.8\ \text{million gal/hr} \div 1000\ \text{gal/hr} = 6{,}800$$

So, the incremental increase of ammonia in the receiving water would be the effluent concentration of 10 mg/L divided by the dilution factor 6,800 to equal 1.5 µg/L or 1.5 parts per billion.

Computer models can be used to give a more detailed analysis of the mixing zone. Computer models are based on integral jet techniques. The models require the following data: discharge depth, effluent flow rates, density of effluent, density gradients in receiving waters, ambient current speed and direction, and outfall characteristics (port size, spacing, and orientation). Model outputs include the dimensions of the plume at each integration step, time of travel to points along the plume centerline, and the average dilution at each point. There are 6 mixing zone models that are available through the U.S. Environmental Protection Agency. All of these computer models require a user who is familiar with mixing concepts and the data necessary to run the models.

The first model, CORMIX may be the most useful to regulators since it is an expert system that guides the user in selecting an appropriate modeling strategy for rivers or estuaries. It is available from the National Technical Information Service (NTIS) and user support is available from the U.S. EPA. The CORMIX computer program is for the analysis and design of submerged buoyant or non-buoyant discharge containing conventional pollutants entering stratified or unstratified watercourses, with emphasis on the geometry and dilution characteristics of the initial mixing zone. Subsystem CORMIX 1 deals with the single-port discharges and subsystem CORMIX 2 addresses multi-port diffusers. The system operates on microcomputers with the MS-DOS operating system. CORMIX 1 can summarize dilution characteristics at specified boundaries and recommended design alterations to improve dilution characteristics (Donekar and Jirka, 1988).

The other five models are designed for submerged discharges in oceans. They all report dilution, and all terminate when the vertical ascent of the plume is zero and they all assume that there is a deep receiving stream (no bottom interference). UPLUME is an initial dilution model that can be used for stagnant water bodies, such as lakes and reservoirs, where the ambient current is assumed to be zero. Other models include:

UOUTPLM, which can be used in flowing and stagnant water bodies,

UMERGE, which can be used for both flowing and stagnant waters,

UDKHDEN, which is a three dimensional model that can be used for flowing and stagnant water bodies, and

ULINE, which models a vertical slot discharge into flowing water body.

Dynamic modeling techniques explicitly predict the effects of receiving waters and effluent flow and of concentration variability. Three techniques recommended by EPA are continuous simulation, Monte Carlo simulation and log-normal probability modeling. For a more detailed description of these models, refer to EPA (1991) and the references contained within.

Final Considerations

In brief, this fact sheet should provide some information on how to set up an aquaculture facility that minimizes the potential for environmental degradation. It is most often helpful to consult with staff of the regulatory agency in your state responsible for water quality permitting. Usually, agency staff biologists and engineers review applications for aquaculture effluent discharge permits. Frequently they have prepared information sheets available that are specific to your state that will guide you in developing your aquaculture effluent management plan.

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