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Aquaculture Effluents:

Overview of EPA Guidelines and Standards and BMPs for Ponds, Raceways, and Recycle Culture Systems

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Aquaculture Effluents

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Introduction

Robert C. Summerfelt

Aquaculture versus Hunt-and-Capture Fisheries

Aquaculture is the production of aquatic organisms, both plant and animal under controlled or semi-controlled conditions. The "controlled or semi-controlled conditions" distinguishes aquaculture from traditional "hunt-and-capture" fishing of wild stocks of marine and freshwater fish, shrimp, and shellfish. The combination of world aquaculture and commercial catches (wild stocks) have grown from 98.6 million metric tons (mmt) in 1990 to 126.2 mmt in 1999, but in 1990 aquaculture was only 13.2% of the total compared with 26.4% in 1999.

U.S. Aquaculture

In the U.S., individuals and public agencies have propagated fish for food and for stocking lakes and streams for recreational fishing for more than 130 years. "A Manual of Fish Culture, "published in 1897 by the United States Commission of Fish and Fisheries (CFF), described culture practices of 25 stations or hatcheries of the CFF for salmon, trout, lake trout, whitefish, black basses, crappies, rock bass, yellow perch, muskellunge, lake herring, American shad, edible frogs, cod, mackerel, lobster, oysters, and other species. The contents of the Manual of Fish Culture demonstrated practical techniques for spawning these species, but relatively little science or engineering based technology, and fish hatchery effluents were not a consideration.

In 1998, the first national census of fish culture in the U.S. reported the value of the aquaculture sector, both commercial and noncommercial at $978 million (USDA 2000). The noncommercial operations—Federal, State, or Tribal facilities—distributed their production for purposes of restoration or conservation; the value of their production was estimated. Culture systems include drainable and nondrainable ponds, raceways, recirculation ("closed re-circulation tanks") and cages. Most marine culture systems employ net pens for salmonids and prepared bottoms for shellfish, but oyster culture more often relies on a variety of off-bottom techniques (e.g., rafts, trays, containers). The food fish category accounted for the highest relative value at 70.7% of U.S. aquaculture sector, followed by mollusks 9.1%, ornamental fish 7.0%, baitfish 3.8%, crustaceans (crawfish and shrimp) 3.7%, sport or game fish 0.8%, and other fish and animal aquaculture 4.9%. The next census is scheduled for 2002, but probably not reported until 2004.

Per capita consumption

Because the value of the food fish category dominates aquaculture production, changes in U.S. population and per capita consumption are major forces driving production. Between 1990 and 2001, total fish and shellfish consumption (pounds per capita per year) in the U.S. ranged from 1.4.3 to 15.2. Between 1997 and 2000, there was a positive trend in per capita consumption, increasing each year, going from 14.3 in 1997 to 15.2 lbs/capita in 2000. However, after Federal Reserve Chair Alan Greenspan exposed the "irrational exuberance" that unduly escalated asset values of stocks and following the collapse of the exuberant "dotcoms", the per/capita consumption declined to 14.7 in 2001, demonstrating a close association between the economy and consumer response to the relative prices of seafood, poultry, pork and beef.

In spite of changes in consumption of all sources of fish and shellfish, the percentage of per capita consumption coming from aquaculture has been rising; e.g., catfish sales by processors had an increase of 7.1% in 2002. Also, the quantity and value of imported fish rose even more; e.g., tilapia rose 19 and 36%, respectively, and Atlantic salmon, which totaled 413 million pounds with a value of $818 million, showed a 15% increase in quantity and 6% in value over one year (Harvey 2003). The sum of the value of imported tilapia and salmon in 2002 ($174 and $818 million, respectively) was $992 million, which was greater than the $978 million for all of U.S. aquaculture production in 1998. Of course, the value in 2002 of all domestic and imported fish products were far less than the $3.4 billion value of imported wild-caught and farm-raised shrimp.

Environmental Concerns

The growth of aquaculture has not been without environmental impacts and critics, and at the extreme, there have been boycotts of net pen reared salmon. The publication by the Environmental Defense Fund of Murky Waters: Environmental Effects of Aquaculture in the United States (Goldburg and Triplett, 1997) was not the first, but it made a significant public impact. The report identified environmental problems caused by aquaculture, stating that aquaculture operations are a significant source of chemical (antibiotics) and biological pollutants (pathogens) and nutrient wastes. The report also considered aquaculture as a contributor to the "fishmeal dilemma," a major source for non-indigenous fish introductions (fish escapement), and noted the lethal control of predatory birds and marine mammals. Shrimp aquaculture has often been singled out for causing ecological and socioeconomic problems from destruction of mangrove forests and displacement of subsistence fishers.

Net pen culture of salmonids—i.e., farm-raised salmon in contrast to wild, hook-and-line or gill netted salmon—has been characterized as a fish feedlot that results in buildup of wastes around the net pens destroying benthos and a contributing to algal blooms. Fish escapement from net pens are considered potential threat to native salmon on both coasts, but special concern has been expressed about the impact of cultured Atlantic salmon on efforts to maintain and restore small stocks of native Atlantic salmon on the east coast. Salmonid culture, in net pens and raceway systems are also condemned for overuse of marine fish for fishmeal and oils for use in fish feeds. Fishmeal use in aquaculture feeds is said to consume more protein than it produces and to encourage excess harvest of pelagic marine fish (anchovy, menhaden, capelin, herring, and sardine), fish that are used by other organisms in the food web (Naylor et al. 1998).

Aquacultural effluents contain dissolved and suspended solids that have biochemical oxygen demand (BOD) and nutrients phosphorus (P) and nitrogen (N) that are derived from fish excretion, feces, and uneaten feed. Nutrients are the cause of eutrophication. The literature concerning aquaculture effluents shows great variability in reported waste loading and their environmental effects. This variability is a reflection of the differences in culture systems; production rates and timing; quantity and quality of source and recipient waters hydraulic retention time; fish species and age; feed types and feeding rates; and management procedures such as cleaning and effluent treatment.

The major focus of effluent issues has been on nitrogen compounds in marine environments that have caused hypoxia problems in the Gulf and eutrophication problems in freshwater from phosphorus compounds. All commercial animal production systems, including aquaculture, generate wastes, generally expressed as kg/day per 1,000 kg live weight for BOD, solids (TSS), nitrogen (TKN), and total phosphorus (TP). Although the production of these specific wastes in fish culture is usually much less than that for beef cattle, dairy cows, poultry, or swine (Chen et al. 1993), the volume of water used per unit production (m^3/kg production) pond and raceway systems is 10 to 100 times greater (Hargreaves et al. 2002). On the other hand, freshwater use in recycle aquaculture, systems (RAS) are typically less than 5% of total system volume per day, but RAS produce a concentrated waste.

Already, limitations on water supply and environment issues may constrain continued growth of certain segments of the aquaculture industry in the U.S. and Canada. The catfish industry, however, is in jeopardy due to drawdown of the once abundant groundwater resources in the Delta region (Tucker 1996) and expansion of the Idaho trout industry is challenged to meet a 40% reduction in phosphorus discharges (Goldberg and Triplett 1997). The image of aquaculture and its future may be in jeopardy unless it deals effectively with environmental issues.

Dilute, but large effluent volumes are discharged from traditional raceway systems used for salmonids (single pass and serial reuse), but they add up to high total daily loads (Westers 2000). Because of the high volume, effluents from raceway culture are extremely difficult to treat (Negroni 2000). Recycle aquaculture systems (RAS) use far less water, frequently less than 5% of system volume per day, and the effluent is concentrated.

Recently, in response to accusations and evidence of environmental pollution from aquaculture, both Canadian and U.S. environmental agencies have developed timelines for performance-based standards (effluent limitation guidelines) for aquaculture waste management. Eutrophication and related problems from fish hatchery effluents have been noted in freshwaters in both the U.S. and Europe, and in marine habitats affected by net pen culture (EPA 1974; Cowey and Cho 1991; Foy and Rosell 1991; Ketola 1991a; Ketola et al. 1991; Lall 1991; Ketola and Harland 1993; Ketola and Richmond 1994). In the North Central Region (NCR), environmental issues related to aquaculture effluents have already resulted in a mandated closure of a large salmonid net pen enterprise in Minnesota by the state Pollution Control Agency (Axler et al. 1998). Lawsuits by a homeowner association alleged that the phosphorus discharge from the Platte River Fish Hatchery, Beulah, Michigan caused eutrophication of their lake. Eutrophication issues from phosphorus are widely cited justification for reducing phosphorus content of fish feeds (Ketola 1991b; Ketola et al. 1991; Ketola and Harland 1993; Ketola and Richmond 1994). Similar concerns have been raised nearly everywhere salmonids are cultured (Cowey and Cho 1991; Foy and Rosell 1991; Persson 1991).

The diverse nature of the U.S. aquaculture industry will require an equally diverse array of strategies to deal effectively with environmental issues. The 1998 Census of Aquaculture indicates that U.S. fish production comes from a variety of cultural systems: 63% from ponds for catfish and minnows; 14% from flow through raceways for salmonids; 7% from closed/recycle systems for a variety of fish, but mainly hybrid striped bass and tilapia; 3% from cages and net pens (1%) for salmon; and others (12%). Most farms use groundwater (47.8%) or on-farm surface water (36.1%) sources for water supply. Aquaculture systems also represent various degrees of intensification (kg/unit of culture space), production (kg/yr), and concentration of waste components (solids, phosphorus, nitrogen) in their effluents. The diversity of aquaculture systems also results in a considerable diversity in waste characteristics. Engineering strategies to reduce nutrients in effluent and removal of suspended and dissolved solids will be different for catfish ponds, salmonid raceways, and recycle systems.

The recent concern over aquaculture waste in the U.S. is not really new. More than 25 years ago, the EPA sponsored studies to gather information on pollution from trout hatcheries (Hinshaw 1973) and intensive culture of catfish (Summerfelt and Yin 1974). These and other studies placed aquaculture low on the priority list and for this and other reasons—to focus resources on other industries that EPA regarded as higher priorities for the regulation of toxic pollutants—specific effluent guidelines for aquaculture were not developed (Keup 1989). Thus, in 1977, EPA policy was to rely on various provisions of the Clean Water Act to regulate the discharge of wastes from concentrated aquatic animal production facilities (CAAPF) under the general National Pollution Discharge Effluent System (NPDES) permit for point source pollutants. Under the Code of Federal Regulations, concentrated aquatic animal production facilities are considered point sources requiring NPDES permits for discharges into waters of the United States. EPA's guidance, however, was insufficient for many state-permitting efforts; it reflected neither the growth in the industry, nor the significant technological advances that have been made.

EPA's effort to develop pollutant controls in the form of nationally applicable discharge standards (known as effluent limitations guidelines and standards) for commercial and public aquatic animal production facilities were announced in the Federal Register Notice, September 14, 2000. This was required by a consent decree from an action filed against EPA on October 30, 1989 by the Natural Resources Defense Council, Inc., and Public Citizen, Inc in which they alleged, among other things, that EPA had failed to comply with CWA section 304(m) of the Clean Water Act. The action by EPA is the result of a settlement of that action in a consent decree entered on January 31, 1992. The consent decree established a schedule by which EPA is to propose and take final action for eleven point source categories identified by name in the decree.

The decree also established deadlines for EPA to complete studies of aquaculture. The last date for EPA action under the decree, as modified, is June 2004. The decree also required EPA to establish Effluent Guidelines. Several effluent guidelines are currently underway to help address siltation and nutrient problems, and, to a lesser extent, pathogens. In the proposed plan, EPA announced efforts that were initiated in late 1999 to develop new or revised regulations for aquatic animal production (i.e., aquaculture). (EPA had originally used the term Aquaculture to describe this industry. However, EPA has since recognized that the term Aquatic Animal Production better reflects the operations that EPA expects will be subject to the forthcoming effluent guidelines.) EPA is discussing the tasks and information necessary to develop an aquatic animal production rule with the Joint Subcommittee on Aquaculture's (JSA's) Aquaculture Effluents Task Force, which consists of representatives from trade associations, academia, federal and state agencies, professional societies, and non-governmental organizations. EPA has said that it will provide a number of opportunities for further involvement before developing the effluent guideline regulation.

EPA is planning release of final regulations by June 2004. In most cases, the EPA will delegate the job of enforcing the regulations to state pollution control (environmental quality) agencies. Based on what state agencies already require, effluents will need to be monitored and regulations may specify treatment technologies that are needed to bring the effluents into compliance with EPA effluent standards.

Whether aquaculture reaches its growth potential depends on how well producers are able to ameliorate these many issues with best management practices (BMPs) that reduce nutrient, chemical, and biological pollution. In part, these problems are growing pains of a relatively new and rapidly growing industry for which technology and management methods are being developed (Boyd 1999). The goal of this conference is to review the issues and provide science-based information that will help define the regulations and BMPs for fish farms with a focus on ponds, raceways and recycle systems. Net pen culture and cage culture are not considered because net pens are mainly used in marine environments and cage culture is a minor culture system. Good environmental stewardship requires that aquaculture effluents not have negative impact on the environment.

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Effluent Management, Water Quality Regulations and the Courts: The Platte Rive State Fish Hatchery Story – A Case Study

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Effluent Management, Water Quality Regulations and the Courts: The Platte River State Fish Hatchery Story – A Case History

Gary E. Whelan

Introduction

The Michigan Department of Natural Resources (Department) has operated a fish culture facility on the Platte River near Honor, Michigan since 1928. This facility has been involved in a long-term court case concerning the effects of the hatchery on the Platte River watershed, in particular Big Platte Lake. There are many lessons to be learned from this experience concerning: the effects of fish culture operations on aquatic systems in the Great Lakes; the operation of a facility; and how to deal with effluent problems from intensive culture facilities. The objectives of this case history paper are: 1) to discuss the history of the Platte River State Fish Hatchery effluent problem; 2) to discuss the effects of effluents, both real and perceived, on natural systems; and 3) to discuss the measures taken and proposed to correct this problem.

Site Description

The Platte River State Fish Hatchery is located near Honor, Michigan in the northwest part of the Lower Peninsula. Deep glacial outwash deposits and extensive groundwater resources characterize this area. The hatchery is located at River Km 29.0 upstream from Lake Michigan and is upstream of a large inland lake, Big Platte Lake. The hatchery uses strictly surface water from the Platte River (average of 11.4 million liters daily in 2002), Brundage Creek (average of 26.9 million liters daily in 2002), and Brundage Spring (average of 6.4 millions liters daily in 2002).

The facility was established as a trout rearing station in 1928 with an annual production of approximately 10,000 kg. During the period from 1966 to 1972, the facility was renovated to support the Department's Great Lake salmon program. Currently, the hatchery produces an average of 66,800 kg of coho and chinook salmon annually using mean annual food amounts of 67,757 kg (range 62,979 - 71,816 kg) using data from the period 1998 to 2002. The facility is currently the main coho salmon egg take location in the Great Lakes and produces most of the coho and chinook salmon needed by the Department's Great Lakes fishery management program. The current production targets for the facility are 1.5 million coho salmon at 36/kg and 4 million chinook salmon at 220/kg. Surplus salmon, beyond those needed for egg take purposes, are harvested at a weir in the lower river just above Lake Michigan.

The hatchery discharges into the Platte River after passing through a large treatment pond, 2 hectares in size. The facility is the only point source discharge in the watershed. The Platte River is a very stable river system because of the underlying glacial geology of the system with moderate natural productivity as measured by alkalinities between 100-200 mg/l. The river has a mean discharge of 3.4 m^3/sec, a 20% exceedence discharge of 3.8 m^3/sec and a 80% exceedence discharge of 2.8 m^3/sec. From the hatchery, the river flows 17.7 km to Big Platte Lake then on to Lake Michigan.

The water body that has been most effected by the operation of the Platte River State Fish Hatchery is Big Platte Lake, 18 km downstream of the hatchery. This lake is 10.6 km^2 natural lake with a 502 km^2 watershed that is 93% undeveloped. It has a mean depth of 7.7 meters with a maximum depth of 29 meters. The lake is classified as an oligo-mesotrophic lake with low nutrient concentrations, low algal productivity and low DO in bottom waters during the summer. The water residence time has been calculated at 5.9 months.

Big Platte Lake Water Quality Problem

Big Platte Lake has a recent history of seasonal transparency problems because of calcium carbonate (calcite) formation. These "whiting" events occur most dramatically during periods of hot calm weather in the late spring and result in high alkalinity concentrations that cause calcite formation, which drive down Secchi disk readings to less than 1 meter. Local residents, as represented by the Platte Lake Improvement Association (PLIA), have in court depositions stated that these events did not occur prior to the reconstruction of the Platte River State Fish Hatchery and transparencies were usually greater than 3 meters. They have also stated and supported with observational data that symptoms of eutrophication such as reductions in crayfish populations, sensitive vegetation disappearing (bulrushes), reductions in mayfly hatches, the occurrence of dark polluted matter on docks and boats, and fishing becoming worse have occurred because of the effluents from the hatchery. Unfortunately, qualitative scientific data on these charges is lacking to fully analyze and understand these observations and this case history really points to the need for more monitoring of surface waters near fish culture facilities.

Phosphorus has long been understood to be a limiting factor in plant growth in aquatic systems. It is also known that excessive algal blooms can produce major shifts in pH and can change the carbonate balance in lake systems. Thus, phosphorus loadings from the watershed are closely related to the above noted problems in Big Platte Lake. Watershed loadings to this lake were as high as 3260 kg annually in the late 1970's with the hatchery contributing 1360 kg of this load and this loading is capable of causing water chemistry changes.

Overall, there are four potential sources in the watershed: nonpoint sources; hatchery effluents; salmon smolts stocked by the hatchery that die in the outmigration; and returning unrecovered adult salmon that die in the river system. Nonpoint watershed inputs of P have decreased from 4100 kg annually in the 1970's to 2000 kg in the late 1990's. Hatchery loadings have declined to approximately 90.9 kg/year. From 1998 to 2003, the Department annually stocked an average of 810,453 coho salmon smolts that weighed approximately 23,000 kg into the Platte River. Some of these smolts die on their outmigration downstream or are eaten by predators. The estimated phosphorus loadings from this source range from 6.8 to 18.2 kg/year and the availability of this source to Big Platte Lake is not known at this time.

A number of adfluvial species return to the Platte River each year but the focus is on coho and chinook salmon. The total spawning run of chinook salmon to the Platte River averaged 5100 fish prior to 1988 and 3500 since 1988, with recent run sizes below 500 fish from 2000-2002. The total spawning run of coho salmon returning to the Platte River averaged 105,000 fish prior to 1988 and 47,000 since 1988, with recent runs between 80,000 to 120,000 fish. Only 20,000 of these fish are currently allowed to pass the lower weir facility annually with a total weight of approximately 60,000 kg (234 kg of P). Approximately 14,500 of these fish are annually harvested at the upper weir at the hatchery and angler harvest is estimated to be at least 80% of the unaccounted fish. The estimated phosphorus loadings from this source range from 19.3 to 100 kg/year and the availability of this source to Big Platte Lake is not known at this time.

Platte River State Fish Hatchery Court Case

By the 1980's, the local residents of Big Platte Lake came to the Department to express their concerns with the water quality of the lake. They pointed out that these problems did not occur prior to the reconstruction and expansion of the Platte River State Fish Hatchery. After meeting with the Department, the local residents did not see nor were they made aware of any major steps to improve the situation. Additionally, while this facility did have a National Pollution Discharge Elimination System (NPDES) Permit issued by the Department, it did not control phosphorus discharges until the 1980 permit and is the only controlled point source on the watershed. So there was a clear perception in the early 1980's that the Department ignored Platte Lake problems and did not adequately control effluents from the Platte River State Fish Hatchery.

Given the Department's lack of movement on the issue, the Platte Lake Improvement Association (PLIA) sued the Department under the Michigan Environmental Protection Act (MEPA) in 1986. PLIA made the following points: the draft 1985 NPDES permit level of 636 kg P annually not protective; not all sources of P were monitored or considered and that weirs, smolt stocking and hatchery discharge are all sources; and the Department was not actively taking steps to limit P inputs to the Platte River system. In 1988, the court agreed with the residents that the Department was polluting, impairing and destroying Platte Lake and would continue to do so, and required significant changes in the operation of the facility.

In the 1988 court opinion, the Department was required to: reduce the 1988 loading of 420 kg annually with the intent of maintaining a Big Platte Lake P standard of 8 ug/l; feed fish low phosphorus food (<1.0% P); deepen the treatment ponds and improve the waste removal system; hire a court master to oversee the court order; and stop the migration of salmon at the lower weir. The migration part of the order was later modified to allow the Department to pass at the lower weir the first 20,000 fish then 1,000 fish per week from August 15 to December 15. In response to the court order, the Department dredged the treatment pond in 1990; switched entirely to low phosphorus diets; installed a solids collection system in the indoor rearing building; operated the lower weir as required; is in the process of conducting a lower weir egg take facility feasibility study; funded a required experimental closed rearing system; and has funded an intensive watershed monitoring system.

In 2000 after 1 year of negotiations, the PLIA and the Department agreed to resolve the long-standing court case. A consent judgment was issued that contained the following stipulations: specific phosphorus discharge limitations that ultimately would require the facility to discharge no more than 79.5 kg/year and 34.0 kg of phosphorus in any 3 month period; limiting water use to no more than 75.7 million liters/day; no more than 20,000 coho salmon and 1,000 chinook salmon to be passed above the lower weir during weir operation (August 15 – November 14); all salmon would be harvested at the upper egg take weir during operational periods (August 15 – December 14); salmon harvest wastes to be removed from the watershed; phosphorus limit of 8 ug/l for Big Platte Lake that does not penalize the hatchery when operating within agreement limits; effluent and watershed monitoring that includes antibiotics and antiseptics; compliance audits; oversight group to include the parties and an implementation coordinator; and damage provisions of $500/violation with penalties for each 0.45 kg of phosphorus, each 1,000 coho salmon, each 100 chinook salmon or failure to sample any element of the program. This court settlement opened the way for a partial renovation of the Platte River State Fish Hatchery that includes the installation of new water monitoring equipment and state-of-the-art effluent monitoring equipment.

Results of Court Actions

Overall, watershed phosphorus loadings to Big Platte Lake have decreased since the 1970's highs of 4100 kg to a current value of approximately 2000 kg. The direct percentage contribution of the hatchery has gone from 33% to less than 5% of the annual P loading to Big Platte Lake with only slightly less fish production. This does not include the contribution of salmon smolt and adult mortality to phosphorus loadings which is uncertain at this time. Transparency during the warm water period (May to September) has improved from an average of 2 meters in the 1970's to 3.5 meters currently. However, severe whiting events with transparencies under a meter still occur although less frequently and with a lower duration. Maximum transparencies have increased from an average of 3.5 meters in the 1970's to 5 meters and greater currently. It is important to note that significant changes in water quality came in stages with notable changes occurring after 1988.

As noted above, the consent judgment cleared the way for a partial renovation of the Platte River State Fish Hatchery that will provide the necessary technical enhancements to meet the new effluent requirements for this facility. This includes the changing the way water is used in the hatchery from a 1.5 to a 3.5 pass system; providing 25-50% reuse capability in the outdoor raceway complex; covering the outdoor raceway system that will reduce stress, increase food utilization and decrease solids; screening all outdoor production water after each pass with disk screens; screening all indoor production water after use; reconfiguring the outdoor raceways to force the movement of solids to the screens instead of using settling areas in the raceways; adding a clarifier to settle and remove solids and a large sludge storage tank to effectively handle solids; and reconfiguring the finishing pond to allow for better treatment options. Additionally, new water monitoring and sampling devices have been installed to improve our data collection abilities. This $8.5 million dollar renovation project will be completed this winter.

While these changes have and will in the future improve Big Platte Lake water quality, the consent judgment requires consultation between the parties that has greatly improved the working climate for this watershed. All parties have full information on the activities of the other parties and a number of cooperative projects have occurred such as the installation of a fishway on a key barrier and the development of a watershed wide GIS based phosphorus model that will greatly enhance the abilities for watershed protection. Significant improvements have also been made in the field sampling and lab methodologies because of the combined efforts of all parties. The ability for the parties to be good neighbors and for the Department to be a good corporate citizen is absolutely critical and is perhaps the greatest accomplishment of the consent judgment.

Conclusions and Discussion

It is clear that effluents from intensive culture operations can have a measurable effect on receiving surface waters such as Big Platte Lake. The impact of the phosphorus loadings from Platte River State Fish Hatchery occurs in the spring or early summer when conditions are correct for "whiting" events. Reductions in nutrients from Platte River State Fish Hatchery and the watershed have had a measurable effect on Big Platte Lake. There are significant correlations between lake P and transparency because of influence of P on algal production, which in turn influences pH and calcite formation. It is also clear that rehabilitation takes time as Big Platte Lake phosphorus values were only reduced 9% because of internal P cycling in spite of overall loading reductions of 24% in the 1990's and early 2000's. With the current phosphorus loadings of hatchery (3-5 % of the watershed total), it will become increasingly difficult to detect any additional changes from effluent management at this facility. It should be noted that the availability of phosphorus from intensive culture operation could be higher than from watershed sources and this is a point of future analysis for the Implementation Team.

Many of the court ordered mitigative measures did work and major improvements in water quality in Big Platte Lake came because of requirements to limit P in 1988, improvements to solids collection in 1990, and after the switch to low P foods in 1988. The measures that did have positive impacts included switching to low phosphorus diets; capturing solids as close to the source as possible without fragmenting particles; reducing hatchery production which directly reduces food use; and intensive monitoring of the watershed which allowed better understanding of the problem. When these measures are combined with the new technology that the Department is installing, it is fully expected that the facility will meet the new effluent limitations.

Some of the control measures did not work and in fact increased P loading to the system. The Department dredged the treatment pond in 1990 to increase retention time and saw an immediate increase in P loadings to the Platte River as the littoral zone of the treatment pond was destroyed along with the plants that were tying up nutrients. This solution clearly overlooked the importance of the biological system in the pond and does lead one to actively manage the plant communities in these ponds to increase P uptake. An analysis of the effluent pond in 2001 and 2002 indicated that the pond was a net exporter of phosphorus during low loading periods but captured phosphorus during high loadings. Additional analysis of the pond operation will be needed to determine how best to operate the finishing pond and how to manage the vegetative community. Salmon migrations were stopped at the lower weir in 1992 and no changes in watershed loadings of P were seen, thus this measure did not provide answers on the role of salmon carcasses in P loadings in the system. The original court master concept did not work well because of a lack of clear direction and goals for the court master; a lack of knowledge about P cycling; and personality conflicts between the court master and the parties. Overall, the Department spent over $2 million dollars on the court case and the court master during the last ten years of the court case (1990-1999). This amount has been greatly reduced with the implementation of the consent judgment.

Current Status and the Future

The successful conclusion of the court case in 2002 cleared the way for joint efforts to improve the Platte River watershed. Currently, the parties are working on developing a new database that will allow improved analysis of new and existing data; a phosphorus budget for the hatchery to allow for targeting key sinks of potential loadings; and a watershed scale phosphorus budget. The consent judgment allowed the Department to finally apply for and receive an uncontested new NPDES permit from the Department of Environmental Quality in 2000 for the first time in 15 years. The permit mirrors the conditions in the consent judgment.

Where do we go from here? First, we need to determine if the renovated Platte River State Fish Hatchery will further reduce effluents. We to test whether the reuse system effectively reduces effluent volumes, whether rapid movement of solids to microscreening reduces escapement of solids, if improved fish culture techniques can reduce loadings, and if better vegetation management in the treatment pond using artificial wetlands and emergent plant processing can increase P capture. Second, we need to examine how phosphorus moves in this intensive culture system to refine how we can most effectively capture it. Third, we need to improve our quality control. We have examined and corrected problems in our lab phosphorus values and are improving the way we handle the large volumes of samples required to meet the monitoring requirements of the consent judgment. We now need to turn our attention to the rest of the laboratory and field procedures. Finally, the lessons learned from this case history have forced the Department to examine effluent treatment at all of our facilities to ensure that we do not impair the public trust resources we are charged to manage for the citizens of the State of Michigan.

NPDES Permits: The Pennsylvania Fish and Boat Commission Experience

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NPDES Permits: The Pennsylvania Fish and Boat Commission Experience

Andrew L. Shiels

The Pennsylvania Fish and Boat Commission currently operates 14 state fish hatcheries which are permitted to discharge hatchery effluents into waters of the Commonwealth via their National Pollution Discharge Elimination System (NPDES) permits. There are five cold water, two cool water/warm water and seven combination cold and cool/warm water hatcheries. The cold water hatcheries produce 5, 411,991 salmonids weighing 1,806,940 pounds per year. The largest hatchery (Bellefonte) produces 335,589 pounds and the smallest (Reynoldsdale) produces 133,754 pounds per year. The warm/cool water hatcheries produce 23 species numbering 109,621,761 fish annually. In addition, the Commission is in partnership with sportsmen's groups who operate 172 cooperative nurseries around the state. These Co-Ops produce 1,152,873 catchable salmonids and 119, 000 steelhead fingerlings annually with a total production of 719,657 pounds.

The Pennsylvania Department of Environmental Protection (PA DEP) conditions and issues NPDES permits individually for each facility and its specific outfalls. Permits range in duration from three to five years and may also contain interim limits, which may change after a designated number of years. Under Part "A", NPDES permits contain specific discharge parameters, which limit the concentrations and quantities of certain parameters or chemicals that can be discharged. Part A requirements provide definitions of terms and directions for sampling, reporting, quality control and compliance/noncompliance. Part "B" of the permit details Management Requirements, Penalties and Liabilities and Other Responsibilities. These sections clearly state the requirement for compliance schedules, a permittee's duty to report and the penalties associated with falsification of information and/or failure to report. The Part "C" requirements contain standard verbiage common to all permits plus additional conditions unique to the permitted facility. These conditions may include time frames for clarifier cleaning, guidelines for sludge handling, requirements for therapeutic chemical toxicity testing, and any other pertinent requirement not already covered in Parts "A" and "B". Once a final permit has been issued, all of the requirements and conditions must be followed. Failure to follow any condition is considered a violation of the permit and may result in significant fines or penalties.

In recent years, NPDES permits at Commission fish culture stations have become increasingly restrictive. The number of parameters and the frequency with which they are monitored has dramatically increased. Permit conditions have increased and become more complex. Permits are being issued with interim and final limits which requires short and long term adjustment of hatchery operations and upgrades to hatchery infrastructure. The Commission has requested net limits for Biochemical Oxygen Demand and Total Suspended Solids limits due to high background concentrations in influent water sources. Although net limits have not been granted, an opportunity for a justifiable exceedance has been allowed.

Increased sampling requirements, both in number of parameters and frequency of samples, have also been imposed. The number of water quality samples has increased from 1,783 to 3,837 annually during the current year. The new permits have included a requirement for acute and chronic toxicity testing of Diquat, Chloramine-t, Hydrogen Peroxide and Roccal II (Lysol).

Results of the toxicity tests will be used by PA DEP to calculate usage rates of these chemicals and amend existing permits. In 2002, the Commission received a final report from Fish Pro, a professional fish production facilities consultant. A through review of operations and infrastructure led to specific recommendations for upgrades and operational adjustments. Cost estimates for facility upgrades were provided on a three-tier level. Estimates for initial needed upgrades totaled approximately $45 million.

Facility improvements already undertaken include; new settling ponds and/or liners, nutrient management plans, baffles in raceways and settling ponds, and sludge storage tanks. Operational changes include vacuuming of raceways, adjustments of feed and feeding approaches, more thoughtful cleaning schedules and increased awareness of permit limits and issues.

Polychlorinated biphenyls (PCBs) have become a major issue at Pennsylvania's state fish hatcheries. Monitoring for PCBs in trout at all Commission hatcheries occurs annually. At one state fish hatchery, significant additional problems with PCBs have been identified. A number of investigative actions have taken place there to determine the source of ambient PCBs. Biotic and abiotic factors have been considered and evaluated. In addition, proposed permit conditions include a requirement for monitoring of PCBs using Water Quality Based Effluent Limits. This is a controversial approach to identifying PCB levels in hatchery effluents.

Progress in addressing effluent concerns is measured not only in a hatchery's ability to stay within permit limits but also via the PA DEPs analyses of impairment to aquatic benthic invertebrate communities. This approach has caused significant discussion and disagreement because objectives and goals are less tangible than numerical permit limits or pounds of biomass produced.

The PA Fish and Boat Commission remains committed to improving the quality of its hatchery discharges. Funding limitations for needed infrastructure improvements are proving to be problematic. The Commission receives no general tax monies and is supported almost solely on license fees and federal excise tax reimbursements. New funding sources will be needed if all of the proposed improvements are to occur on the schedule that has been proposed.

The future holds the potential for NPDES permits to be required of a heretofore unidentified number of the Co-Op nurseries, continual restrictions in permits limits and less room for error in hatchery operations. Commission facilities are under increased scrutiny by both the PA DEP and the public. Therefore, it is very important for managers to understand and ensure that NPDES permit requirements and conditions are being followed.

AQUACULTURAL EFFLUENTS: OVERVIEW OF EPA'S GUIDELINES AND STANDARDS

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AQUACULTURAL EFFLUENTS: OVERVIEW OF EPA'S GUIDELINES AND STANDARDS

John N. Hochheimer

Introduction

The intensive production of fish and other aquatic animals, or aquaculture, has many positive benefits such as:

- A variety of fish and shellfish produced as food
- Many different and unique species produced for the ornamental fish trade
- Bait produced for recreational fishing
- Sportfish produced for stocking into recreational fishing waters
- Jobs and income throughout the United States directly and indirectly as a result of the aquaculture industry

Like many other intensive animal production operations, some forms of intensive aquaculture produce waste products that must be carefully controlled to prevent polluting receiving waters. The Clean Water Act designated animal aquaculture (specifically concentrated aquatic animal production) as a point source when effluents from these facilities are discharged to waters of the United States. As such, some aquaculture facilities are required by the Clean Water Act to have a National Pollutant Discharge Elimination System (NPDES) permit if they discharge water from the facility directly to receiving waters.[1] Effluent Limitations Guidelines are an integral component of the NPDES permit development process because they establish minimum effluent standards that facilities should be able to achieve before water used in an aquaculture facility is discharged to receiving waters.

The goal of this presentation is to:

- Provide some background information on the effluent issues associated with aquaculture facilities
- Describe some of the potential environmental impacts of these effluents
- Provide an update on EPA's proposed Effluent Limitations Guidelines for the Aquatic Animal Production Industry
- Describe how BMPs can be integrated into operations at aquaculture facilities
- Outline the next steps in EPA's process

Characteristics of Aquacultural Effluents

There are four groupings of "pollutants" in effluents from aquaculture facilities:

1. Solids discharged from the facilities in the form of fish feces and uneaten food
2. Nutrients in dissolved and solid forms that result from fish metabolites and uneaten food

[1] This discussion is not meant to be a complete summary of the NPDES program, rather it is meant to broadly introduce the reader to the context of the Effluent Limitations Guidelines program. For more detailed information on the NPDES program and the regulatory background, see Chapter 1 of the technical development document and the proposed rule. See http://epa.gov/guide/aquaculture/tdd/tdd.html for the document.

3. Chemicals used in maintaining the process water (culture water), treating diseases, and cleaning various parts of the culture system
4. In some cases, the release of living organisms (including the cultured aquatic animals) when they are considered non-native or invasive, and disease organisms.

Feed and aquatic animal metabolites are the primary source of pollutants in the effluents. Feeding the fish results in the release of solids, which can be high in biochemical oxygen demand, ammonia, nutrients, and some partially or non-metabolized ingredients in the feed. For example, trace metals that are essential for growth and survival of the growing fish can be released in small concentrations. The amount of potential pollutants released will be a function of the percent of the food consumed by the aquatic animals and the digestibility of the food. Modern feed formulations, which are targeted to a particular species, are generally more palatable and digestible to that particular species.

Small amounts of uneaten food can result in a significant increase in the pollutants that are in effluents and potentially released from facilities. Since the fish does not "process" uneaten food, all of it will be present in the effluent unless it is somehow removed prior to discharge. The type of aquacultural system will have a significant impact on the amount of uneaten food that is potentially available for discharge. For example, in a closed pond with infrequent discharges, in-pond processes break down the uneaten food. In a net pen system, the uneaten food falls through the net and directly into the surrounding environment. Flow-through and recirculating systems may have solids removal processes (such as settling basins) that capture some of the solids resulting from uneaten food.

It is also important to remember that fish manure (i.e., collected solids in a settling basin) contains significant amounts of nitrogen and phosphorus. There are several factors that will contribute to the amount of nitrogen and phosphorus in collected fish manure including the constituents of the feed, the digestibility of the feed for the species of fish being grown, and the age of the manure. For example, older manures will tend to leach or lose nutrients and have lower levels of nitrogen and phosphorus than fresh manures. It is important for the facility operators to correctly store and dispose of collected solids (fish manure) to prevent supernatants with potentially high levels of nutrients and oxygen demanding substances, in addition to the collected solids, from entering receiving waters.

The amount of chemicals (used for cleaning or maintaining process waters) and therapeutics (such as antibiotics, antifungals, or hormone treatments) that are in aquacultural effluents will be proportional to the amounts used at a facility. Analysis of the industry found large differences in the amounts of chemicals used at individual facilities.

There is continued concern about the escape of non-native species that have the potentials to become invasive. In its proposed regulation, EPA has deferred the definition of these non-native species of concern to the states. There is also some concern about the potential for aquatic animal pathogens to be spread to wild species through aquatic animal production facilities. Both of these issues remain controversial.

Potential Impacts of Effluents from Aquatic Animal Production Facilities

The potential water quality impacts of effluents from aquatic animal production facilities include eutrophication, sedimentation, increased oxygen demand, toxicity, and ecological changes. Excess nutrients can lead to eutrophication, especially in smaller streams or in areas with minimal water exchange rates (e.g., lakes or reservoirs). Since most of the solids found in aquacultural effluents tend to settle quickly, localized areas of sedimentation can occur downstream from aquacultural system outfalls. The solids can be highly organic and lead to increased sediment and water column oxygen demand. Toxic substances, including ammonia and chemicals such as formalin, hydrogen peroxide, and copper, have the potential to be discharged from aquacultural facilities. There are many factors that lead to toxic impacts of effluents including:

- Concentration and duration of the toxicant in the effluent
- Dilution in the receiving water
- Exposure time to organisms in the receiving water
- Sensitivity of the organisms to the toxic substance

Effluents can also have longer-term ecological impacts in receiving waters. For example, excessive sedimentation may change the structure and make-up of benthic communities from diverse, balanced benthic communities to communities that are primarily pollutant tolerant and low in diversity.

Drugs and chemicals in effluents, particularly antibiotics, are of concern due to an increased awareness of antibiotic resistance and because of possible uptake by non-targeted species. Other possible environmental problems from drugs and chemicals are toxicity, water quality changes, and ecological impacts. Non-native species could have the potential to establish and become invasive, hinder the recovery of endangered species, or introduce new diseases.

The degree of receiving water impacts from aquatic animal production facilities depends on the ability of the receiving water to assimilate the different pollutant loads in the effluent, as well as the loads from other sources. For example, smaller streams with low flows, reservoirs and lakes with little flushing, and some coastal embayments might not have sufficient flushing or dispersion capabilities to adequately assimilate the nutrients and oxygen demanding substances in an aquacultural effluent.

As facilities intensify production, they concentrate more wastes into a smaller area. In some systems, this intensification becomes self-limiting. For example, ponds, flow-through, and net pen operators may not be able to increase production above a certain threshold because sufficient water is not available to maintain process water quality. Recirculating systems may not have available, cost-effective technology solutions to continually increase production levels.

EPA's Proposed Regulations

In September 2002, EPA proposed Effluent Limitations Guidelines to cover a subset of the concentrated aquatic animal production industry currently subject to NPDES regulation. The following types of facilities were targeted in the proposed rule:

- Flow- through systems
    - 100,000 – 475,000 lbs of aquatic animals produced annually
    - 475,000 lbs of aquatic animals produced annually
- Recirculating (100,000 lbs and above annually)
- Net pens (100,000 lbs and above annually)

The proposed regulation would not change the NPDES requirements for facilities producing more than 20,000 pounds but less than 100,000 pounds annually.
EPA did not propose regulations for some facilities (but is still evaluating these facilities) including:

- Ponds
- Lobster pounds
- Crawfish ponds
- Open water production of molluscan shellfish
- Aquariums
- Alligators

Tables 1-3 summarize the regulatory requirements proposed in September 2002.

Table 1. Proposed requirements for flow-through systems with 100,000 to 450,000 pounds annual production.

	Maximum Daily Net TSS	**Monthly Average Net TSS**	**Alternate Compliance**	**O&M BMP**	**Solids Control BMP**	**Drugs & Chemicals Reporting**	**Practices to Minimize Escapes**
Full-flow or Recombined Effluent	11 mg/L	6 mg/L	BMP plan in lieu of monitoring for TSS limits	Yes	N/A	No	No
Segregated Waste Stream	87 mg/L	67 mg/L	BMP plan in lieu of monitoring for TSS limits	Yes	Yes (bulk discharge)	No	No

Tables 2. Proposed requirements for flow-through systems with greater than 450,000 pounds annual production.

	Maximum Daily Net TSS	**Monthly Average Net TSS**	**Alternate Compliance**	**O&M BMP**	**Solids Control BMP**	**Drugs & Chemicals Reporting**	**Practices to Minimize Escapes**
Full-flow or Recombined Effluent	10 mg/L	6 mg/L	BMP plan in lieu of monitoring for TSS limits	Yes	N/A	Yes	Yes
Segregated Waste Stream	69 mg/L	55 mg/L	BMP plan in lieu of monitoring for TSS limits	Yes	Yes (bulk discharge)	Yes	Yes

Table 3. Proposed requirements for recirculating systems with greater than 100,000 pounds annual production.

	Maximum Daily Net TSS	Monthly Average Net TSS	Alternate Compliance	O&M BMP	Solids Control BMP	Drugs & Chemicals Reporting	Practices to Minimize Escapes
All Facilities	50 mg/L	30 mg/L	BMP plan in lieu of monitoring for TSS limits	Yes	N/A	Yes	Yes

Proposed requirements for net pen facilities with greater than 100,000 pounds annual production.

- Feed management via real-time monitoring
- Develop and implement a BMP plan that:
  - Minimizes the discharge of net fouling organisms
  - Avoids the discharge of blood viscera, fish carcasses or transport water
  - Prohibits the discharges of solid waste, cleaning chemicals, and tributyltin compounds
- Practices that minimize potential for escapes

Best Management Practices

EPA has proposed that Best Management Practices (BMPs) are an integral means to accomplish the effluent limits for aquatic animal production facilities. Many aspects of the operation of an aquacultural facility are uniquely tailored to the individual facility and the personnel that operate the facility on a daily basis. By evaluating these operations, the facility operators can often develop cost-effective ways to improve effluent quality, while often reducing operating costs. For example, developing a routine maintenance program for mechanical feeders can lead to more accurate feeding and less wasted feed. EPA's proposed regulations contain provisions for the use of BMPs in the areas of solids (TSS) reduction in discharges, operation and maintenance of certain activities, and prevention of escapes when non-native species are a concern.

When aquacultural facilities were evaluated to determine the existing practices and infrastructure, a wide range of activities were observed. There are many similarities in the general culture practices among comparable facilities (e.g., like species, system type, and ownership combinations). For example, many government-owned trout production facilities:

- Use raceways
- Have quiescent zones to capture solids
- Routinely clean the raceways and quiescent zones
- Regularly inspect the fish for signs of disease
- Have comprehensive feed management programs to manage fish growth
- Keep records
- Have settling basins for solids
- Have NPDES permits

Within this group of similar facilities, there are, however, many unique practices and configurations of equipment. This group of facilities may use different feed management programs and keep different records. Some of the facilities may have mechanical feeders. Some may use demand and hand feeding. Others may have a truck-mounted blower to deliver feed several times per day. This uniqueness requires site-specific analysis and solutions to improve effluent quality.

The BMP plan provides a framework for the facility to organize various operational and management tasks to specifically address reductions in pollutants being discharged. There is clearly more than one way to accomplish the goals of the effluent guidelines. The general approach to establishing a BMP plan involves:

- Analysis of the facility infrastructure, practices, and personnel to determine its unique characteristics and how to work with the existing facility and personnel to improve key practices
- Planning to develop the necessary changes, including developing a written plan
- Implementation of the plan by training the appropriate personnel and modifying actions
- Review of the progress and adjusting as necessary

After observing many different facilities throughout the country, it is clearly evident that many facilities are currently doing many of these steps, often informally. The following are some examples that were commonly seen at facilities.

- Feed management
  - Observing fish feeding, even when automatic or demand feeders are used
  - Buying high quality feeds and demanding accountability from feed vendors for quality
  - Adjusting feeding rates based on amounts being eaten
  - Record keeping to enable better decision-making
  - Regularly maintaining feeding equipment and calibrating the equipment
- Solids removal in culture units
  - Quiescent zones and baffles in raceways
  - Self-cleaning tanks
  - Routinely cleaning solids collection units
- Biosecurity
  - Limiting access – both human and other (predators, other fish, etc.)
  - Foot baths
  - Segregation of tools and equipment
  - Protected water supplies
  - Regular inspection of biosecurity devises
  - Quarantine new fish
  - Health management programs
- Predator Control
  - Netting and covers to exclude birds and animals
  - Removal of mortalities and preventing access to mortalities
- Operation and Maintenance

    - Regular inspection of critical components
    - Routine operation and maintenance of equipment
    - Incentives to employees
    - Development of innovative solutions
    - Elimination of over-engineered components
- Good Housekeeping
    - Litter control
    - Spill containment
    - Safe storage of chemicals and drugs
    - Routine maintenance and inspection
    - Employee training and incentives

Next Steps

EPA plans to release additional data and analyses in October 2003. This release is called a Notice of Data Availability and will be published in the *Federal Register*. After release of the Notice of Data Availability, there will be a comment period for the public to submit comments and concerns. EPA has been evaluating the detailed industry surveys, developing revised cost and benefits analyses, and reevaluating the proposed regulatory options. After the review and consideration of the public comments and completion of any additional analyses, EPA will prepare the final regulation package. The final regulation will be completed in June 2004.

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The HACCP Approach To Prevent The Spread Of Aquatic Nuisance Species By Aquaculture And Baitfish Operations

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The HACCP Approach To Prevent The Spread Of Aquatic Nuisance Species By Aquaculture And Baitfish Operations

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Abstract

The potential exists for aquatic nuisance species (ANS) to spread to uninfested waters through the transport of wild harvested baitfish and aquacultured fish. Baitfish and aquaculture industries are, however, diverse and complex, as are their risks of spreading ANS. Most industry segments pose no or very low risk of spreading ANS. To deal effectively and fairly with this potential vector, it is important to characterize the industry according to their risks of spreading ANS. Without adequate risk assessment of individual operations, regulations could be imposed which would unnecessarily negatively impact the economy of these industries and still not effectively reduce the risk of spreading ANS. One approach to this problem is to apply the Hazard Analysis and Critical Control Point (HACCP) concept similar to that used by the seafood industry to minimize seafood consumption health risks. The advantages of this system are that it can effectively deal with a diverse industry, it has proven to be a good partnership between industry and government regulators, and, if properly applied, it is effective. The HACCP approach concentrates on the points in the process that are critical to the safety of the product, minimizes risks, and stresses communication between regulators and the industry.

Introduction

Baitfish wild harvest and aquaculture have been identified as vectors for the spread of ANS (Litvak and Mandrak 1993; Ludwig and Leitch1996; Litvak and Mandrak 1999; Goodchild 1999). In fact, some management agencies have closed ANS infested areas to harvest and culture, some states have banned the importation of live bait, and others only allow certified ANS-free bait into their state (Kinnunen 1994). Other regulations restricting the economic viability of the baitfish and aquaculture industries have been proposed. The baitfish industry and aquaculture industries are extremely diverse in the species produced, the market forms of the species, the production systems used, and the water source used (Gunderson and Tucker 2000, U.S. Department of Agriculture 2000). Most industry segments pose no or very low risk of spreading ANS. To deal effectively and fairly with this potential vector, it is important to characterize the industry according to their risks of spreading ANS. Without adequate risk assessment of individual operations, regulations could be imposed which would unnecessarily negatively impact the economy of these industries and still not effectively reduce the risk of spreading ANS. One approach to this problem is to apply the Hazard Analysis and Critical Control Point (HACCP – pronounced has-sip) concept similar to that used by the seafood industry to minimize seafood consumption human health risks.

In December 1995, the Food and Drug Administration (FDA) issued seafood regulations based on the principles of HACCP (National Seafood HACCP Alliance 1997). The FDA issued these regulations to ensure safe processing and importing of fish and fishery products. These regulations specify that someone trained in HACCP perform certain critical jobs in seafood processing. Just as HACCP is used to ensure safe seafood, it can be applied to other business processes to ensure product safety. The Seafood HACCP approach was modified to address the risk that wild harvested baitfish and private and public cultured fish could spread ANS.

The goal of the ANS-HACCP approach is to prevent the spread of ANS while maintaining viable baitfish and aquaculture industries. The ANS-HACCP approach can also be used to certify ANS-free products for those businesses that choose to seek this certification.

Because industry pioneered the HACCP approach and it stresses communication between the industry and resource managers, the approach attempts to strike a balance between over-regulation and ignoring the potential for moving ANS. For the ANS-HACCP concept to be adopted as a tool, it must be accepted by both the industry and resource management agencies.

Methods: The HACCP Approach

HACCP is neither a new term nor a new concept. The Pillsbury Co. pioneered the application of the HACCP concept to food production during its efforts to supply food for the U.S. space program in the early 1960s. Pillsbury decided that their existing quality control techniques did not provide adequate assurance against contamination during food production. The company found that end-product testing necessary to provide such assurance would be so extensive that little food would be available for space flights. The only way to ensure safety, Pillsbury concluded, would be to develop a preventive system that kept hazards from occurring during production. Since then, Pillsbury's system has been recognized worldwide as an effective hazard control. It is not a zero risk system, but it is designed to minimize the risk of hazards (National Seafood HACCP Alliance 1997).

The seven HACCP principles have since been developed and include:

1) Conduct a hazard analysis. Prepare a list of steps in the process where significant hazards occur and describe the control measures.
2) Identify the critical control points (CCP) in the process.
3) Establish controls for each CCP identified.
4) Establish CCP monitoring requirements. Establish procedures for using monitoring results to adjust the process and maintain control.
5) Establish corrective actions to be taken when monitoring indicates that there is a deviation from an established critical limit.
6) Establish procedures to verify that the HACCP system is working correctly.
7) Establish effective record-keeping procedures that document the HACCP system.

The ANS-HACCP concept, if adopted by the industry and resource management agencies, can be used to focus attention on the segments of the baitfish and aquaculture processes that are most likely to pose a risk of spreading ANS. The HACCP approach allows regulators to assess what happens in various baitfish/aquaculture operations and evaluate how potential hazards are being handled. With HACCP, the emphasis is to understand the entire process. This requires the regulator and industry to communicate and work with one another. HACCP is most effective when regulators take the opportunity to review the HACCP plan and evaluate if critical hazards have been properly identified and that individual businesses are consistently controlling these hazards. It is therefore, a shared responsibility of the baitfish/aquaculture businesses and the resource management agencies to develop and implement ANS-HACCP plans.

Hazard Analysis — Principle 1

To perform a hazard analysis for the development of an ANS-HACCP plan, baitfish harvesters and fish farmers must gain a working knowledge of potential hazards. The ANSHACCP plan is designed to control all reasonable ANS hazards. Such hazards are categorized into three classes: 1) plants, 2) invertebrates, and 3) fish and other aquatic vertebrates.

Species considered ANS will vary from state to state. Consult with state resource management agencies to determine which species are considered ANS hazards. Aquatic nuisance plant hazards may include plants such as Eurasian water milfoil (*Myriophyllum spicatum*), water chestnut (*Trapa natans*), hydrilla (*Hydrilla verticillata*), curly leaf pondweed (*Potamogeton crispus*), and purple loosestrife (*Lythrum salicaria*).

Aquatic nuisance invertebrate hazards may include zebra (*Dreissena polymorpha*) and quagga (*Dreissena bugensis*) mussels, Asiatic clam (*Corbicula fluminea*), spiny (*Bythotrephes cederstroemi*) and fishhook (*Cercopagis pengoi*) waterfleas, lumholtzi waterflea (*Daphnia lumholtzi)*, rusty crayfish (*Orconectes rusticus*), Chinese mitten crab (*Eriocheir sinensis*), and green crab (*Carcinus maenas*).

Aquatic nuisance fish hazards may include ruffe (*Gymnocephalus cernuus*), round goby (*Neogobius melanostomus*), white perch (*Morone americana*), rudd (*Scardinius erythrophthalamus*), threespine and fourspine stickleback (*Gasterosteus aculeatus* and *Apeltes quadracus*), smelt (*Osmerus mordax*), and Asian carps - black (*Mylopharyngodon piceus*), grass (*Ctenopharyngodon idella)*, silver (*Hypophthalmichthys molitrix)*, and bighead (*Hypophthalmicthys nobilis*). Other aquatic vertebrates could include amphibians or reptiles that may be identified as nuisance species.

Each ANS has a unique life history and characteristics that cause them to be an environmental and economic concern and determines how they can be spread via baitfish and fish raised for stocking. These unique life histories and characteristics must be considered when developing control strategies. The following is a brief description of some of these unique characteristics of plants, invertebrates, and fish that must be considered.

When live fish are harvested from infested waters, there is a risk that ANS can be moved to uninfested waters. These hazards can be transported with the fish, the water, or cling to equipment used in infested waters. Many aquatic nuisance plant species reproduce by plant fragmentation. Small pieces of the plant can settle to the bottom, take root and grow even after being out of water for many days or even weeks in moist, cool conditions. Care must be taken to prevent the transport of viable plant fragments to uninfested waters. In addition, many plants can produce seeds or tubers that can survive long periods before germinating. Movement of dredged material could move viable seeds, tubers, zhizomes, or turions.

Some aquatic invertebrates can produce resting eggs that are resistant to freezing and drying (i.e. spiny and fish hook waterfleas) or produce eggs and larvae that are too small to see without aid of a microscope (i.e., zebra and quagga mussels). Other invertebrates, like zebra and quagga mussels, can attach to boats, equipment, and vegetation and survive out of the water long enough to be moved to other waters. Female crayfish may be able to establish a population even without the presence of a male, because they can carry viable sperm for many months before fertilizing eggs. As a result of these characteristics, aquatic nuisance invertebrates present different challenges for preventing their spread from infested waters.

ANS fish may be found in the waters where other fish are harvested or ANS fish may be cultured. Separating fish or other vertebrate ANS after harvest is difficult and is best accomplished by preventing an infestation in your ponds or facility. Other options include harvesting during times of the year or times of the day when the ANS fish or other vertebrates are spatially segregated. Because fish and other vertebrates may have different body shapes or sizes than targeted species, grading or sorting techniques may be able to reduce the risk of contamination to acceptable levels. ANS fish that are cultured for food (or other purposes) must be contained in the culture environment and prevented from escaping into the wild.

The hazard-analysis step is fundamental to the ANS-HACCP system. To establish a plan that effectively prevents the spread of ANS, it is crucial that all significant ANS hazards and the measures to control them be identified. During hazard analysis, the potential significance of each hazard should be assessed by considering risk (likelihood of occurrence) and severity of environmental impact. Estimation of risk is usually based upon a combination of experience, ANS infestation data, state policies, and information from the technical literature. Severity is the seriousness of a hazard. Assessment of ANS risk and severity will require close communication with resource management agencies and university experts.

It is important to remember that ANS-HACCP should focus solely on significant hazards that are reasonably likely to occur and may result in an unacceptable movement to new waterbodies. Without this focus, it would be tempting to try to control too much and lose sight of the truly relevant hazards. First-time HACCP plan writers, more often than not, identify too many hazards! This is a problem because it can dilute your ability to focus efforts and control the truly significant hazards. The dilemma is finding out and deciding what is significant. A hazard must be controlled if it is: 1) reasonably likely to occur and 2) if not properly controlled, it is likely to result in an unacceptable risk of spreading ANS to new waterbodies.

Before beginning the hazard analysis, a flow diagram (Appendix A) must be completed that shows the steps required to grow, harvest, handle, and distribute live baitfish or aquaculture products. This step provides an important visual tool that the ANS-HACCP team can use to complete the remaining steps of the ANS-HACCP plan. The flow diagram should be clear and complete enough so that people unfamiliar with the process can quickly comprehend the operational procedures. Since the accuracy of the flow diagram is critical to conduct a hazard analysis, the steps outlined in the flow diagram must be verified for the baitfish/aquaculture operation. If a step is missed, a significant hazard may not be addressed.

A hazard-analysis worksheet (Appendix B) can be used to organize and document the considerations in identifying ANS hazards. Each step in the process flow diagram should be first listed in column 1. Results of the hazard identification process are recorded in column 2. The risk assessment should be recorded in column 3, with the justification for accepting or rejecting the listed potential hazards stated in column 4. In column 5, list any control measures that can be applied to prevent the significant hazards. Control measures are actions and strategies that can be used to prevent or eliminate an ANS hazard or reduce it to an acceptable level.

An important difference between seafood HACCP and this program is that there are few science-based controls currently available. As a result, control measures are best determined with the help of resource management agencies, Sea Grant, university, college, or other local experts.

Critical Control Points — Principle 2

For every significant hazard identified during the hazard analysis there must be one or more critical control points (CCPs) where the hazard is controlled. CCPs are points in the process where HACCP control activities will occur. A CCP should be a specific point in the process where application of a control measure effectively prevents, eliminates, or reduces the hazard to an acceptable level. It may not be possible to fully eliminate or prevent a hazard. In some cases and with some ANS hazards, minimization may be the only reasonable goal of the ANS-HACCP plan. Although hazard minimization is acceptable in some instances, it is unacceptable in others. It is important that all ANS hazards be addressed and that any limitations of the ANS-HACCP plan to control those hazards be understood by resource management agencies and the fish farmer or baitfish harvester. When ANS-HACCP plans cannot satisfactorily control ANS hazards, other approaches to prevent the spread will be required.

Many points in the flow diagram not identified as CCPs may be considered control points. A HACCP plan can lose focus if points are unnecessarily identified as CCPs. Only points at which significant ANS hazards can be controlled are considered CCPs. A CCP should be limited to that point or those points at which control of the significant hazards can best be achieved. For example, an ANS plant fragment hazard may be controlled by attempting to avoid infested areas of the lake, by trying to pick each fragment off of a net before leaving the lake, by using equipment only in the infested waters, or by freezing the net for 48 hours before going to uninfested waters. However, trying to avoid infested areas, trying to pick off plant fragments, or freezing the net for 48 hours would not necessarily be considered CCPs if using equipment only in the infested waters best controlled the hazard. Differentiating between CCPs and control points will vary from business to business and depend on their unique operation. When designating CCPs, it is important to consider any applicable state statutes or rules that may dictate the identification of a CCP. For example, if it is illegal to transport an ANS overland, then CCPs must be developed to comply.

Establish Controls — Principle *3*

Controls must be established for each CCP identified in the hazard analysis on the ANSHACCP plan form (Appendix C). A control represents the boundaries that are used to ensure that a baitfish or aquaculture operation produces ANS-free products. Each CCP must have one or more controls for each significant ANS hazard. When the process deviates from the control limits, corrective action must be taken to ensure an ANS- free product. Examples of controls might be a minimum flow rate and time that baitfish are held in the holding tank to ensure that aquatic nuisance plant fragments are trapped in the outlet filters.

In this case, a minimum flow rate and time must be adhered to in order to control the aquatic plant hazard. In many cases, the appropriate control may not be readily apparent or available. Tests may need to be conducted or information gathered from sources such as scientific publications, regulatory guidelines, experts, or experimental studies. If the information needed to define controls is not available, a conservative value should be selected. The rationale and reference material used to establish controls should become part of the support documentation for the ANS-HACCP plan.

Monitoring — Principle 4

Monitoring is important to ensure that the controls designed to eliminate or minimize ANS hazards are consistently met. Monitoring is the process that the operator relies upon to maintain control at a CCP. Accurate monitoring indicates when there is a loss of control at a CCP and a deviation from a control limit. When a control limit is compromised, a corrective action is needed. Reviewing the monitoring records and finding the last recorded value that meets the control limit can determine the extent of the problem needing correction. Monitoring also provides a record that products were in compliance with the HACCP plan.

Control measures are intended to control the hazards at each CCP. Monitoring procedures are used to determine if the control measures are being enacted and the control limits are being met. Monitoring procedures must identify:
1) What will be monitored (Appendix C, column 4)
2) How the control limits and preventive measures will be monitored (Appendix C, column 5)
3) How frequently monitoring will be performed (Appendix C, column 6)
4) Who will perform the monitoring (Appendix C, column 7)

Monitoring must be designed to provide rapid results. There is no time for lengthy analytical testing because control limit failures must be detected quickly and an appropriate corrective action instituted before distribution occurs.

Physical and chemical measurements are preferred monitoring methods because testing can be done rapidly. Physical measurements (e.g., time, flow, current speed, temperature, and direct observation) can often be applied to ANS control. Examples of physical measurement monitoring at a CCP are:

1) Time and temperature: This combination of measurements is often used to monitor the effectiveness for destroying or controlling ANS contamination of traps, nets, and other equipment. For example, nets used in Eurasian water milfoil- infested waters in Minnesota must be frozen for 48 hours or dried for 10 days before using in other waters.
2) Water flow rate: Because plant fragments, eggs, and many invertebrates cannot swim against water currents, holding fish in flowing water to separate them from ANS is one way to control the hazard. Measuring flow rate, current speed, and the time it takes for one complete water exchange are examples of physical measurements that may be monitored.
3) Sensory examination: Observations for the presence of ANS contamination in baitfish or fish for stocking or continued observation for the establishment of ANS in waters

considered to be uninfested is one way to monitor ANS hazards.

Monitoring instruments that produce a continuous record of the measured value will not control the hazard on their own. Continuous records need to be observed periodically and action taken when needed. The length of time between checks will directly affect the amount of product loss when a critical limit deviation is found. In all cases, the checks must be performed in time to ensure that the contaminated product is isolated before shipment. When it is not possible to monitor a CCP on a continuous basis, it is necessary for the monitoring interval to be short enough to detect possible deviations from control limits.

Corrective Action — Principle 5

Corrective actions must be taken when controls at a CCP have been compromised. These actions must be predetermined when developing the HACCP plan. When controls are violated at a CCP, the predetermined, documented corrective actions should be immediately instituted. There are two components of corrective actions. First, corrective actions should state procedures to restore control at the CCP and second, they must determine the appropriate disposition of the affected product.

Corrective action options include: 1) isolating and holding fish for safety evaluation, 2) diverting the affected fish to another use where ANS contamination would not be considered critical, 3) using some method to separate ANS from the fish, 4) rejecting fish, or 5) destroying fish. Corrective actions are implemented when monitoring results indicate a deviation from control limits. Effective corrective actions depend heavily on an adequate monitoring program.

All corrective actions taken should be documented. Documentation will assist in identifying recurring problems so that the ANS-HACCP plan can be modified. Additionally, corrective action records provide proof of product disposition.

Verification — Principle 6

The purpose of verification is to provide a level of confidence that the plan is based on solid scientific principles, is adequate to control the hazards associated with producing and selling the harvested or cultured product, and is being followed.

There are several elements associated with this principle, including validation and reviews. Confusion sometime arises because the HACCP plan must include verification procedures for individual CCPs and for the overall plan.

Validation is an essential component of verification and requires substantiation that the HACCP plan, if implemented effectively, is sufficient to control the ANS hazards that are likely to occur. Validation of the plan occurs before the plan is actually implemented. The purpose of validation is to provide objective evidence that all essential elements of the plan have a scientific basis and represent a valid approach to controlling the ANS hazards associated with baitfish harvest and fish culture. There are several approaches to validating the HACCP plan; among them are incorporation of fundamental scientific principles, use of scientific data, reliance on expert opinion, or conducting specific observations or tests.

Actual components of the ANS-HACCP plan should be validated before relying on it and when factors warrant such as: 1) harvesting fish from a new lake, 2) changing the harvest techniques or culture methods, 3) new scientific information about potential hazards or their control, or 4) infestation of new ANS. Validation involves a scientific and technical review of the rationale behind each part of the HACCP plan from hazard analysis through each CCP verification strategy.

Verification activities developed for CCPs are essential to ensure that the control procedures used are properly functioning and that they are operating and calibrated within appropriate ranges for ANS control. CCP verification may also include targeted sampling and testing. Calibration is conducted to provide assurance that monitoring results are accurate.

In addition to the verification activities for CCPs, strategies should be developed for scheduled verification of the complete HACCP system. The frequency of the system-wide verification should be yearly or whenever there is a system failure or a significant change in the product or process. Systematic verification activities include on-site observations and record reviews. An unbiased person who is not responsible for performing the monitoring activities should perform reviews.

Until the ANS-HACCP approach is accepted and used by industry and resource management agencies, there is no official role of the resource management agencies in reviewing ANS-HACCP plans. The major role of resource management agencies in an ANS-HACCP system can be to verify that the plans are effective and are being followed. Verification normally will occur at the facility or at the water body that is being harvested.

ANS-HACCP plan reviewers must have access to records that pertain to CCPs, deviations, corrective actions, and other information pertinent to the HACCP plan that may be needed for verification. Because plans may contain proprietary information, the regulatory agency or other plan reviewers must appropriately protect them.

ANS-HACCP Records — Principle 7

Accurate record keeping is an essential part of a successful HACCP program. Records provide documentation that control limits have been met or that appropriate corrective actions were taken when limits were exceeded. Likewise, they provide a means of monitoring so that adjustments can be made to prevent ANS contamination. The four types of records needed are described below.

1) ANS-HACCP Plan and Support Documents:

It is advisable to maintain ANS-HACCP plan supporting documentation. ANS-HACCP support documents include the information and data used to develop the plan. This includes written hazard-analysis worksheets, records of any information used in performing the hazard analyses, and information used to establish controls actions and strategies.

Support documents may include the current geographic range of ANS infestation or sufficient data used to establish the adequacy of any barriers to prevent ANS release. In addition to data, support documents may also include correspondence with resource management agency personnel, consultants, or other experts.

2) Monitoring Records:

ANS-HACCP monitoring records are primarily kept to demonstrate control at CCPs. ANS-HACCP records provide a useful way to determine if control limits have been violated. Timely record review by a management representative ensures that the CCPs are being controlled in accordance with the ANS-HACCP plan. Monitoring records also provide a means by which regulators can determine whether a firm is in compliance with its HACCP plan.

3) Corrective Action Records:

Corrective action records are important to document procedures used to restore control if critical control measures were violated and to document the appropriate disposition of the affected product.

4) Verification Records:

Verification records should include modifications to the HACCP plan, operator records verifying supplier compliance with guarantees or certifications, verification of the accuracy and calibration of all monitoring equipment, results of on-site inspections, and results of equipment evaluation tests.

All records should be signed or initialed and dated by the reviewer.

Results and Discussion

The ANS-HACCP approach has been designed for three primary purposes. The first is to restrict the spread of ANS via the culture or transfer of live fish while maintaining the economic viability of baitfish and aquaculture industries. Many organizations and resource management agencies have recommended that baitfish/aquaculture operations be eliminated if they use ANS infested waters or are raising ANS. This is certainly the most effective approach to prevent the spread of ANS, but it is also potentially unnecessarily restrictive to important segments of the baitfish/aquaculture industry. It may also be short sighted. ANS may continue to spread despite our best efforts, and by eliminating businesses lake-by-lake and river-by-river as ANS continue their spread, there may not be a significant short-term impact, but cumulatively over many years it may have a large negative economic impact. We should anticipate the possibility of continued ANS spread and attempt to minimize the cumulative impact on the industry, while protecting the environment, by initiating an ANS-HACCP approach soon.

Of course, if the risk and economic damage caused by the baitfish/aquaculture industry is significant, then shutting down segments of the industry or preventing the culture of ANS is appropriate. The risk, however, is often small and depends on the ANS and the control strategies used. The risk is especially small compared to the risk associated with recreational boating and commercial shipping. Because of the relatively small size of the impacted baitfish/aquaculture industry, they are frequently held to a zero risk standard, while the extremely large and powerful recreational boating and commercial shipping industries are not held to that same standard. The fact that the baitfish/aquaculture industry is rather small is advantageous because less effort is needed to encourage them to change their behavior to reduce the risk of spreading ANS than is needed to change the behavior of recreational boaters or commercial shippers. The ANS-HACCP approach is one way in which resource management agencies can work with the baitfish/aquaculture industries to change, monitor, record, and verify their efforts to reduce the risk of spreading ANS.

The second purpose of the ANS-HACCP approach is to provide state and federal hatcheries with a means to satisfy public concerns regarding their role in the spread of ANS. State and federal hatcheries must also change their behavior for raising and stocking fish to ensure that they are not responsible for the spread of unwanted species when the waters the y use become ANS infested. Public hatcheries have been implicated in the unintentional spread of fish. An example is the U.S. Fish and Wildlife Service Inks Dam, Texas hatchery, which was identified as the source of a gizzard shad introduction to Morgan Lake, New Mexico via a shipment of largemouth bass. Gizzard shad have subsequently appeared to move downstream into the San Juan arm of Lake Powell, Utah (Bob Pitman, U.S. FWS, Albuquerque, NM pers. com.). Gizzard shad are not native to this region. State and federal hatcheries have a responsibility to instill confidence in the public that they are addressing ANS risks when they raise and stock fish. The ANS-HACCP approach provides a mechanism by which state and federal hatcheries can assure the public that they are conducting their fish stocking efforts in an environmentally responsible manner.

The third purpose for developing the ANS-HACCP approach is to provide a mechanism by which private aquaculturists can certify their product as ANS-free. Some states and watersheds require certified ANS-free bait. In addition, some organizations, agencies, and private buyers would like to purchase certified ANS- free fish for stocking. Currently, there is no certification program available. The ANS-HACCP approach could serve this purpose.

The ANS-HACCP approach has been pilot tested with the Michigan Wholesale Bait Association and the U.S. Fish and Wildlife Service hatchery managers and ecological services personnel in the southwest region. During these two training sessions, each were taught the basic principles of ANS-HACCP, how the principles apply to preventing the spread of aquatic nuisance species with the movement of live fish, and the development specific ANS-HACCP plans. These ANS-HACCP plans were developed in both training sessions by dividing participants into small working groups that focused on real situations involving the transfer of live fish from areas that contained ANS. Results of these pilot tests were very positive. Both groups appropriately applied the principles of ANS-HACCP, and each felt that the approach was workable from a business/public hatchery management perspective and that it could significantly reduce the risk of spreading ANS. Pilot project participants also provided suggestions to modify the draft manual. Comments from agency, industry, and university reviewers were also incorporated into the training manual (Gunderson and Kinnunen 2001).

Summary

The ANS-HACCP approach has many advantages. It can effectively deal with a diverse industry and diverse risk factors associated with a variety of plant, invertebrate, and vertebrate ANS. If it develops as it has in the seafood industry, it should prove to be a good partnership between industry and government regulators. It can help avoid overly restrictive regulations, and, if properly applied, can be effective at reducing the risk of spreading ANS via baitfish and fish stocking.

The HACCP approach concentrates on the points in the process that are critical to the environmental safety of the product, minimizes risks, and stresses communication between regulators and the industry. With proper cooperation between industry representatives, resource management agencies, and other ANS experts, the ANS-HACCP approach will reduce the risk that ANS will be established in new locations while maintaining the economic viability of the baitfish and aquaculture industries. It can provide a mechanism for ANS-free certification, and it can instill confidence in the public that state and federal fish stocking programs are conducting their activities in an environmentally responsible manner.

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Appendix A. Example of a flow diagram – Shiner wild harvest

Step 1	Shiners are seined in the fall from Lake XXX.
	⇓
Step 2	Harvested shiners are dip-netted from the seine and moved to the transport truck in 5 gallon buckets with lake water.
	⇓
Step 3	Buckets of shiners and lake water are dumped into transport truck. Truck also contains well water from facility to which salt has been added.
	⇓
Step 4	Shiners are transported to holding facility where the water and shiners are drained from the truck directly into holding tanks.
	⇓
Step 5	Shiners at the holding facility are held in flow through, aerated well water until sold.
	⇓
Step 6.	More shiners are brought into the facility periodically for holding
	⇓
Step 7	Shiners for sale to retail bait shops are put into 5 gallon buckets and loaded onto trucks and delivered in salted, aerated, well water.
	⇓
Step 8	Shiners are dip-netted from the truck and placed in 5 gallon buckets filled with well water for measuring volume and for moving them into the retail bait shop.
	⇓
Step 9	Shiners for sale to another wholesaler are dip-netted from tanks, placed in 5 gallon buckets to measure volume, and then loaded onto trucks containing salted, aerated, well water.
	⇓
Step 10	The whole truckload of water and shiners is drained directly into a wholesaler's holding tanks.

Appendix B. Hazard Analysis Worksheet

(1) Harvest or Aquaculture Step	(2) Identify potential ANS hazards introduced or controlled at this step (1)	(3) Are any potential ANS hazards significant? (Yes/No)	(4) Justify your decisions for column 3.	(5) What control measures can be applied to prevent the significant hazards?	(6) Is this step a critical control point? (Yes/No)

Appendix C. HACCP Plan Form

HACCP Plan Form									
			Monitoring						
(1) Critical Control Point (CCP)	(2) Significant Hazard(s)	(3) Limits for each Control Measure	(4) What	(5) How	(6) Frequency	(7) Who	(8) Corrective Action(s)	(9) Records	(10) Verification

Strategies and Tactics for Management of Swine Manure

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Strategies and Tactics for Management of Swine Manure

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Introduction

Manure management is a time-consuming activity. In the past, producers treated it almost as an afterthought. However, due to public outcry and resulting regulations and lawsuits, most swine producers in Iowa would tell you that addressing environmental concerns and managing manure in an acceptable manner is first or second priority on their list of challenges. Manure management decisions are based on the objectives of the operation. In some cases, the objective may be to simply store manure until it can be land applied (fall and/or spring). Other producers not only want to store the manure, but also want to retain valuable nutrients in order to provide those nutrients to crops. Another set of producers want to treat the manure during storage, possibly to address odor and/or water quality issues. And there is yet another group who want complete treatment so that they can then discharge the nutrients if allowed. The objectives determine the investment needed and the structure of the manure management system. To date, regulations have not directed specific management practices but do, indirectly, influence manure management decisions.

Current and Pending Regulations Affecting the Swine Industry

A summary of the more prominent regulations that must be addressed by swine producers ensues. Additional information can be obtained from the Department of Natural Resources' Office of Water Quality webpage.

Manure Applicator Certification Program

A number of states, including Iowa, now require that manure applicators become certified. In Iowa there are separate programs and requirements for producers who apply their own manure from a confinement facility and those who professionally apply manure for clients. An outline of the program, including who is required to become certified and what is entailed in certification is available in Appendix 1. This information was obtained from the Iowa Manure Management Action Group's website and can be located at http://extension.agron.iastate.edu/immag/maccsa.html. In summary, the 3-year certification for confinement site producers with more than 500 animal units (more than 1250 head of finishing, lactating, or gestating pigs, or more than 5,000 nursery pigs) requires that producers receive 2 hours of annual training or pass a test once every 3 years, plus pay a $100 3-year certification fee.

Manure Application

March 1, 2003 marked the effective date for changes in required separation distances for land application of manure. In general, distance from buildings and public use areas and designated areas (sinkholes, surface waters, ag drainage wells) were increased as a result of Senate File 2293. Appendix 2 outlines the new distances in a fact sheet developed by the Department of Natural Resources (http://www.state.ia.us/dnr/organiza/epd/wastewtr/feedlot/sepdstb4.pdf).

As a result of both state (Senate File 2293) and federal legislation (Clean Water Act, December 16, 2002) manure plans will soon be developed based on phosphorus application rates. Typically, this will require approximately twice the land base needed to apply manure on a nitrogen basis. However, opportunities exist to reduce phosphorus content of manure by reducing the formulated dietary concentration of P. While many producers and consultants believe that reproductive performance can be significantly influenced by P status, and as a result include a safety margin in diets, there is absolutely no research to support this claim. In fact, the work often cited, involved a 1940's study where animals were fed diets grossly deficient in many nutrients. Removal of the unnecessary safety margins from diet formulation is a necessary step if a producer is land limited. To avoid the concern that book values of nutrients for feed ingredients are greater than actual values, a routine feed sampling program should be initiated. The result will be fewer nutrients excreted and likely a cost savings from not including unnecessary nutrients. Sometime in 2006, plans will be developed on based on phosphorus application rates. So now is the time to develop good nutritional practices.

More detailed information on manure management plans can be found at http://www.state.ia.us/epd/wastewtr/feedlot/manure.htm.

The Master Matrix

Senate File 2293 brought on the creation of the Master Matrix, an evaluation tool that may be used by counties as part of the approval process for new and expanding operations. Counties determine, annually, if they want to incorporate the Master Matrix as part of the permitting process. As of July 14, 2003, all but 15 counties had chosen to adopt the Master Matrix. Appendix 3 depicts each county's status as of July 2003. Requirements that determine whether or not an operation must complete the Master Matrix are outline in Appendix 4. The Master Matrix consists of three sections: air, water, and community. Applicants must receive an overall total score of 50% across all three sections and a score of 25% in the three respective sections in order to receive a passing score. If the applicant receives an unsatisfactory score from the county, the Department of Natural Resources will conduct an independent evaluation with the Master Matrix and may determine that a satisfactory score is achieved. In this case, a preliminary approval is granted. Counties and applicants can appeal the Department of Natural Resources' decisions directly with the director of the Department of Natural Resources. To date, the validity of the Master Matrix is untested in the courts. An online version of the Master Matrix is available at: http://www.state.ia.us/epd/wastewtr/feedlot/mminter.htm. Example questions are provided in Appendix 5. The advantage of knowing the questions upfront is that producers can plan their operational changes such that a passing score is obtained.

Air Quality Regulations

Controversy over air quality issues surrounding livestock production continues nationwide. In 1997, the California South Coast Air Quality Management District (SCAQMD) established emission reduction goals for animal agriculture within their area in response to non-attainment of PM_{10} and ozone standards (CM#99WST-01 Appendix B: New and Revised Stationary Source Control Measures). The SCAQMD has set a goal of 30% reduction of volatile organic carbon emissions from livestock waste by 2006 and 50% reduction of ammonia emissions from dairy operations by 2006. One of the primary mechanisms for reaching the stated ammonia goal is relocation of the dairy industry out of the area. However, if the targets are not met by January 1, 2004, dairy and other livestock facilities still located in the Basin will be subject to ammonia controls.

In Iowa, we know we will see air quality regulations in effect as a result of Senate File 2293. However, we don't know what the rules will look like. In 2002 the state of Iowa adopted standards for hydrogen sulfide and ammonia from a CAFO. Odor standards were considered but not adopted because of a tenuous association in the literature between exposure to livestock odors and negative health impacts. Under Senate File 2293 the state Department of Natural Resources will conduct a comprehensive field study to monitor the level of airborne pollutants, particularly hydrogen sulfide, ammonia, and odor, emitted from animal feeding operations in the state. Following, the department may develop comprehensive plans and programs for the abatement, control, and prevention of airborne pollutants if the baseline data from the field study demonstrate, to a reasonable degree, that airborne pollutants emitted by an animal feeding operation are present downwind, at levels commonly known to cause a material and verifiable adverse health effect. Enforcement of an air quality standard will not occur before December 1, 2004. This regulation is based on human health impacts of emissions from animal feeding operations and should therefore reflect exposure levels consistent with negative impacts under chronic exposure (> 365 d). A report released by the University of Iowa and Iowa State University in February 2002 adopts the Agency for Toxic Substances Disease Registry's (ATSDR) recommendations for hydrogen sulfide and ammonia chronic (> 365 d) exposures. These numbers correspond to 15 ppb hydrogen sulfide and 150 ppb ammonia. The committee did not reach consensus on an odor recommendation. In order to appropriately apply the findings of the committee report, measurements must be taken where chronic exposure conditions will occur. In April 2003, the Iowa Legislature nullified the standards and the sampling manual. However, the Department of Natural Resources has until December 2004 to have something in place and still meet the original timeline. A chronology of the events that have taken place to date as well as the proposed standards is found in Appendix 6.

Managing Manure for Compliance and Beyond

The Department of Natural Resources has no specific guidelines as to how manure must be stored as long as there is no discharge from storage facilities. This does mean that there are concrete standards for construction and requirements for size of storage depending on the type and size of the operation. Recently the concrete standards were revised and there is some controversy over the new standards. However, with today's scrutiny of the swine industry most producers are looking for manure storage methods that will keep their operations out of the firing line. This means managing to minimize odor complaints. The remainder of this paper will focus on odor reduction strategies, with emphasis on liquid manure systems. Methods to decrease or alter the stored manure are one strategy employed to reduce odors from manure storage facilities. Such methods include dietary manipulation to influence manure characteristics as excreted or addition of additives to stored manure to alter manure characteristics. Additional methods include use of solids separation to remove recalcitrant material and decrease nutrient concentration going into the storage facility, and composting or anaerobic digestion to provide an opportunity for some biological processing of a portion of the collected manure thereby reducing the source concentration. A number of these techniques have demonstrated some success in reducing odor intensity.

A second strategy seeks to reduce the surface area from which odorous compounds can be volatilized. Methods include sizing of manure storage areas, orientation of manure storage areas with respect to frequency of wind direction, and the use of permeable and impermeable covers that reduce the amount of surface area directly exposed to outside air.

A third strategy involves reducing the volatilization of odorous compounds by reducing the net radiation on a manure storage facility. Methods to implement this strategy commonly involve the use of permeable and impermeable covers.

Malodor is the result of the incomplete anaerobic decomposition of stored manure. During the decomposition process malodorous intermediate compounds are produced and can accumulate if insufficient populations of bacteria that degrade these compounds are present. It is these accumulations that result in odor nuisance. Complete decomposition would produce odorless gases, carbon dioxide and methane, as well as some odorous gases, ammonia and hydrogen sulfide, that contribute little to overall odor intensity (Powers et al., 1999). Some manure storage facilities are designed and sized to allow for biological treatment and complete decomposition and would be considered low-load systems while others serve the purpose of storage only. The latter, high-load systems, are more prone to accumulation of the odorous compounds and, thus, odor concerns. Odor control strategies between high- and low-load systems must be fundamentally different.

Strategies for low-load systems

In a system where the nutrient load is low relative to the biological processing capability of the system, such as a lagoon, further reduction of the nutrient load on the system is a plausible strategy for reducing odors. This can be accomplished through an increase in the rate of processing of manure in the system or via a reduction in the loading rate of nutrients introduced to the system. Decoupling of the solution/air interface is another means of reducing odorous emissions from low-load systems.

Solids Separation

Solids separation by sedimentation, screening, filtration, or centrifugation allows for the removal of material that exceeds the screen opening size. Often, in the case of ruminant manures, this is fibrous material that is resistant to decomposition during storage. By removing larger-sized material, thereby decreasing the loading rate, the life of the storage area can be extended. Decomposition of remaining stored material may benefit from removal of the poorly digestible material. Reduced odor emissions from the storage facility, in terms of odor intensity and concentration of odorants, ensues improved decomposition. A 50% reduction in odor threshold from swine housing air samples was observed when a filter net was installed under the floor slats with daily removal of solids collected on the net (Kroodsma, 1986). Solids separation prior to anaerobic digestion of dairy flushwater modestly, but nonsignificantly, reduced odor intensity pre- and postdigestion (Powers et al., 1997).

Anaerobic Digestion

Anaerobic digestion enhances a naturally occurring process by providing conditions suitable for complete decomposition of organic matter to low-odor end products. During the process, manure is contained in a closed system, preventing release of odorous emissions to the atmosphere. The use of anaerobic digestion has proven to be a very effective means of reducing manure odors during storage and during land application (Pain et al., 1990, Powers et al., 1997). As much as a 50% reduction in dairy manure odor intensity was observed using 20-d HRT conventional laboratory-scale digesters. Anaerobic digestion can be a capital-intensive venture. Efforts to enhance the biological processing of a digester, and hence reduce the HRT and necessary volume storage requirement, have resulted in modifications to a conventional digester. Fixed-film digestion with a 3-d HRT performed similarly to a 10-d conventional digester in terms of odor control (Powers et al., 1997). While generally thought to be a capital-intensive system, some estimates illustrate that anaerobic digestion is economically feasible for larger operations. One example budget shows that a positive net income per cow of $31/y can be realized if the methane is captured and used as an energy source (Wright and Perschke, 1998). The following economic information is provided based on a 3,000-head finishing facility: $1.10 (20-year life) to $4.00 per head (10-year life) for initial construction minus gas harvesting equipment; $40 per head capacity to install and purchase gas harvesting equipment; $3.00 per head capacity recaptured as income from energy produced (Lorimor, 1998d).

Additives

In a low-load system bacterial populations are more likely to occur in quantities sufficient to provide a balanced production and utilization of intermediate degradation compounds. The storage facility is not overloaded. Whereas in a high-load system where addition of supplemental bacteria to a failing system would be futile due to environmental conditions, addition of supplemental bacteria to a low-load system may enhance the rate of processing because conditions are suitable for bacterial growth and function. Unpublished field reports indicate a direct relationship between decreased odor reduction and occurrence of anaerobic photosynthetic bacterial populations in lagoons. The anaerobic photosynthetic bacteria utilize hydrogen sulfide, hydrogen, and organic compounds such as volatile fatty acids and aromatic compounds to provide needed reducing equivalents and carbon. Reduced odor from lagoons where the pink-rose color, indicative of the populations, is present is likely the result of degradation and utilization of such odorous intermediates. Purple nonsulfur phototrophic bacteria, a predominate population in many lagoons, have demonstrated efficient degradation of highly odorous compounds such as organic acids, p-cresol, methyl mercaptan, ethyl mercaptan, and propyl mercaptan (Kobayashi and Kobayashi, 1995).

Enzymatic or chemical additions are more likely to have a greater benefit on odor intensity in a low-load system than a high-load system due to the stability of the environment. Mode of action of many commercially available products remains unknown, but it is plausible that some enzymes could enhance biological decomposition of odorous compounds to less odorous end products.

Impermeable Covers

By covering a manure storage area with an impermeable cover the air and solution interfaces are completely decoupled, thereby preventing the release of odorous gases from the manure storage into the atmosphere. Wind and radiation effects on emission rates are eliminated. Polyethylene covers typically range in price from $.40 to $.85 per square foot with the average price near $.50 (Freese, 1997). Additional costs for installation approximate $.60 per square foot (Lorimor, 1998a). Odor reduction efficiencies of 70 to 85% have been observed when surfaces are completely covered by these impermeable covers (Mannebeck, 1986). Dilution-to-threshold concentrations have been reduced from 340 to 30 by covering a storage area with an impermeable plastic cover; meaning that without the cover, the odorous air sample requires 340 dilutions with odor-free air in order to be imperceptible, whereas with the cover only 30 dilutions are required before the odor cannot be detected (Lorimor, 1998a). More intense odors require a greater number of dilutions.

Permeable Covers

Permeable covers, or biocovers, act as biofilters on the top of manure storage areas. Materials often used as covers include straws, cornstalks, peat moss, foam, and Leka rock. Permeable biocovers reduce odor, in part, by reducing the radiation onto the manure storage surface and reducing the wind velocity over the surface of the storage area. Covers act as a barrier to these forces. Humidity at the solution/air interface is relatively high, which creates a stabilized boundary thus slowing the emission rate of odorous volatiles at this interface. An aerobic zone exists within the biocover allowing the growth of aerobic microorganisms that utilize the carbon, nitrogen, and sulfur from the odorous emissions for growth. By further degrading and making use of these compounds prior to exiting the biocover, odors emitted above the biocover are altered and reduced. Mannebeck (1986) reported a 40 to 50% reduction in odor when straw was used, 45 to 55% reduction when foam pellets were used, and up to 85% reduction efficiency with the use of a floating mat or corrugated materials. In an Iowa State University Extension odor demonstration field evaluation, use of a biocover reduced the odor intensity of stored hog manure from 2.2 to 1.2, on a scale of 0-3 (Lorimor, 1998b). Costs for biocovers vary widely depending on material used and method of application. Straws and cornstalks cost approximately $.01 per square foot, peat moss and foam cost about $.26 per square foot, and Leka rock is approximately $.90 per square foot. Leka rock is a product of Norway thereby requiring considerable shipping costs ($5-$6/cubic foot) (Freese, 1997). Most recommendations suggest a minimum of 8 inches depth, preferably 10-12 inches depth of coverage on a manure storage surface. New covers may need to be applied annually.

Strategies for high-load systems

In a high-load system biological processing is incomplete due to an imbalance in microbial populations. Strategies to increase the processing rate are therefore futile. Successful odor reduction strategies focus on decoupling the solution and air interfaces. Examples of high-load systems are deep pits, holding ponds, and earthen or aboveground storage tanks. In each of these systems less biological processing takes place. Loading rate exceeds the microbial ability to utilize the waste to an extent necessary to prevent the accumulation of odorous intermediate compounds. Odors emanating from high-load systems such as deep pits or in-house manure storage facilities can be controlled through biofiltration as discussed above.

Use of impermeable covers is perhaps the most effective means of reducing odorous emissions from an outdoor high-load system. Similar to low-load systems, the air and solution interfaces are decoupled preventing escape of odorous emissions. The biological function of a permeable cover is greatly hindered in a high-load system due to the unbalanced microbial populations. Some odor reduction may still be achieved, however, by reducing wind and temperature effects on volatility of emissions.

Landscaping also will be of benefit in a high-load system by acting as a natural biofilter. Aesthetic value of landscaping is difficult to assess but can contribute to a reduction in 'perceived' odors.

Dietary manipulation potentially can be effective regardless of manure storage system. Perhaps a greater benefit can be observed under high-load than low-load systems due to the greater accumulation of odorous intermediate compounds that form under the unbalanced conditions present with a high-load system.

Conclusions

The incentive to creatively manage manure is not economic. Therefore, most producers do so to maintain compliance or to maintain a low profile with the neighbors. While novel systems, such as wetlands or anaerobic digesters are out there, they are few in number. By and large, most of the liquid swine manure in Iowa is managed in 6-12 month storage facilities (concrete or earthen) where little or no biological processing takes place. This decision is dictated as much by climate. Contrast this system to those in the southeastern U.S. where most of the manure is managed as a much more dilute liquid and stored in earthen lagoons where, because of the warmer climate, processing does occur. Until the economics change or until regulations mandate that manure be stored differently, the current systems will continue to predominate the industry.

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Appendix 1

MANURE APPLICATOR CERTIFICATION PROGRAM
- Confinement Site Applicators

A confinement site manure applicator is “a person who applies manure stored at a confinement site, other than a commercial manure applicator.” A confinement site contains a manure storage structure which is part of a confinement feeding operation as defined by “ an animal feeding operation in which animals are confined to areas which are totally roofed.” Confinement site applicators applying manure from a small animal feeding operation (SAFO) are exempt from being certified.
Until 2002, the law defined a SAFO as an animal feeding operation that has an animal weight capacity of 200,000 pounds or less for animals other than bovine, or 400,000 pounds or less for bovine. In 2002, the definition of a SAFO changed under Senate File 2293. The new definition of a SAFO is related to animal unit (a.u.) capacity and is defined as an operation with 500 or less a. u. If a confinement livestock operation has more than a 500 a.u. capacity, the operator must be certified to apply manure, see Table 1 for a.u. equivalents. To determine your a.u. capacity, multiply the number of animals you have by species and size by the corresponding factor in column 4. If the product is greater than 500, you must be certified to apply manure.
Confinement site applicators may include people who are part-time employees of, or who trade work with, other active farmers. The following people are exempt from a commercial manure applicator certification, but must still be certified as a confinement site applicator:

- Someone actively engaged in farming and trades work with another active farmer,
- Someone employed by an active farmer and applies manure only as in incidental part of the job,
- Someone who applies manure as an incidental part of a custom farming operation, or
- Someone who applies manure as an incidental part of their job duties.

Exemptions: Confinement site applicators are exempt from certification if they are:

- Part-time employees or family members of a confinement site applicator and are under the direct instruction and control of a certified confinement site manure applicator who is physically present and can physically observe and communicate with the supervised person at all times.

Becoming Certified and Maintaining Your Certification

Confinement site manure applicator certification is good for 3 calendar years, starting the year the applicator is certified. Confinement site manure applicators can become certified initially or renew their 3-year certification in one of three ways:

- Take and pass the 50-question, multiple-choice, true-false exam offered at Department of Natural Resources (DNR) field offices;
- Attend a two-hour training course offered in January through February annually at County Extension offices, or
- Watch a 2-hour training video offered by County Extension offices

Each of these options requires that the appropriate paperwork and fee be submitted to the DNR in order to complete the certification process. Beginning in January 2003, the fee is $100 for 3 calendar years.

Confinement site applicators that missed a two-hour training workshop during their 3-year certification will receive a letter from DNR stating they need to take the exam to be eligible to recertify. A list of exam dates and locations offered by the DNR is linked below.

Study Guides are available for Confinement Site Manure Applicators and may be purchased through Extension Publications Distribution at (515) 294-5247. When ordering materials ask for PM-1779, *Confinement Site Manure Applicator Certification Study Guide*. Cost for the publication is $20. **NOTE:** Study guides are currently being updated to reflect new laws.

Confinement Site Applicator Study Guides are now available to download from the web at: http://www.extension.iastate.edu/pubs/PM1779/homepage.html

Uniform Certification Deadline

Due to changes in the law, a uniform certification deadline policy was instituted in 2002. The uniform certification deadline states that confinement site manure applicator certifications will expire on December 31st of the third year of the license. Confinement site applicators will then have until March 1 of the following year to apply manure without being certified. After March 1 confinement site applicators cannot apply manure until they pass the exam or watch the video and send in the required form and fee for renewal. Any renewal that is postmarked after March 1 of the year following the expiration date will be charged a late fee of $12.50 by the DNR and applicators will not receive their certificates until all fees are paid.

NOTICE: Effective 3/27/03, in a decision made at DNR, the DNR will not be enforcing the late fees for the Manure Applicator Certification program for this year only. All commercial manure applicators and any confinement site applicator renewing their certificates for this year (through December 31st, 2003) will not be required to submit the late fee of $12.50 for applications postmarked after March 1, 2003. The department felt that since the late fees were not specifically identified on the application forms they could not enforce the payment of late fees.

Family Member Exemption

In 2000 the Legislature passed a law that allows family members to be certified under one manure applicator certificate of certified family member. This means that if you are a "spouse, parent, grandparent, child, grandchild or sibling", you can be certified under an existing certified family member's certification. The family will only have to pay one fee every three years. The provisions include: 1) family members must apply for the certification within one year of the date of primary family member certification or renewal, 2) family members must still attend training or pass exam, 3) must provide a notarized statement that you meet family member definition. The family member exemption only applies to Confinement Site Manure Applicators.

New Confinement Site Applicators
Confinement site applicators that have never been certified can become certified at any time of year by completing one of the options listed above, and submitting the appropriate form and fee. Certificates will expire on December 31st of the third year of the certification.

Additional Resources
For additional information regarding the Confinement Site Manure Applicator Certification program please see these resources:

- Confinement Site Manure Applicator Workshops – Dates and Locations offered by ISUE
- Confinement Site Manure Applicator Exams – Dates and Locations offered by DNR
- Questions and Answers about Manure Applicator Certification
- Separation Distances for Land Application of Manure from Open Feedlots & Confinement Feeding Operations, including SAFOs (pdf)
- Confinement Site Manure Applicator Certification (pdf)

Table 1: Equivalent number of confinement animals to define a small animal feeding operation (SAFO) under the new law and previous law.

Col. 1	Col. 2	Col. 3	Col. 4	Col. 5 New Law	Col. 6 Previous Law
	Animal Types/ Production Phases	IA Ave. Weight (lbs.)	A.U. factor	SAFO = ≤ 500 animal units (# of animals)	SAFO = ≤ 200,000 lbs. for non-cattle and ≤ 400,000 for cattle (# of animals)
Cattle	Veal Calves	150	1	500	2,667
	Beef/Dairy Feeder Cattle	500	1	500	800
	Beef/Dairy Fat Cattle	900	1	500	444
	Beef/Dairy Replacement Cattle	900	1	500	444
	Mature Beef Cattle	1200	1	500	333
	Mature Dairy Cattle	1300	1.4	357	308
Swine	Nursery Swine	25	0.1	5,000	8,000
	Grower Swine	70	0.4	1,250	2,857
	Wean-Finish Swine	135	0.4	1,250	1,481
	Grow-Finish Swine	150	0.4	1,250	1,333
	Breeding Replacement Swine	150	0.4	1,250	1,333
	Gestation Swine	400	0.4	1,250	500
	Lactation Swine with Piglets	450	0.4	1,250	444
Poultry	Brooder Turkey	2	0.018	27,778	100,000
	Finishing Turkey	14	0.018	27,778	14,286
	Breeding Turkey	14	0.018	27,778	14,286
	Broiler-Finishing Chicken	10	0.01	50,000	20,000
	Layer Chicken	10	0.01	50,000	20,000
Sheep	Sheep or Lambs	75	0.1	5,000	2,667

Livestock producers with animal feeding operations that have an animal unit capacity greater than 500 animal units must be certified to apply manure and must have a DNR approved manure management plan.

Appendix 2

Separation Distances for Land Application of Manure

from Open Feedlots & Confinement Feeding Operations, including SAFOs

Revised
October 2002
Effective 3/1/03

Iowa law requires that all manure from an animal feeding operation must be land applied in a manner that will not cause surface or groundwater pollution. Chapter 65 of the Iowa Administrative Code (IAC) contains rules that govern land application of manure, including the separation distances summarized in Tables 1, 2 and 3 below. The separation distances are required by law and must be maintained between the protected area and the area where manure is applied. Distances apply to the type of manure and the method of application that is used.

In 2002, changes in Iowa Law added water sources (see definition) and protected wetlands as designated areas. Other changes required incorporation to occur on the same date as application (see Table 2).

<u>**CAUTION**</u>**:** This document is only a summary of administrative rules contained in 567 IAC chapter 65; it is a guidance document and should not be used as replacement for the administrative rules. While every effort has been made to assure the accuracy of this information, the administrative rules will prevail in the event of a conflict between this document and the administrative rules.

Table 1: Required separation distances (in feet) for **buildings or public use areas** by type of manure and method of manure application

Buildings or Public Use Areas	**Dry Manure** – **Surface Application**: Incorporated within 24 hours	**Dry Manure** – **Surface Application**: Incorporated after 24 hrs. or not incorporated	**Liquid Manure** (except irrigated): **Direct Injection**	**Liquid Manure** (except irrigated) – **Surface Application**: Incorporated within 24 hrs.	**Liquid Manure** (except irrigated) – **Surface Application**: Incorporated after 24 hrs. or not incorporated
• residence • business • church • school • public use area	0	0	0	0	750 ft. [1]

1. a) This separation distance applies only to liquid manure from confinement feeding operations. It does not apply to manure from open feed lots or dry manure. The required 750-foot separation distance also <u>does not apply</u> if any of the following exist:
   1) manure is injected or incorporated <u>within 24 hours</u>,
   2) a written waiver is issued by owner of the building or public use area benefiting from the required separation distance,
   3) manure comes from a small animal feeding operation (SAFO), or
   4) manure is applied by low pressure spray irrigation equipment (a 250-foot separation distance applies—see Table 3).

   b) <u>Measure</u> the separation distance <u>from the applied manure</u> to the <u>closest point of buildings</u>; and to the <u>facilities where people congregate</u> (for public use areas).

Table 2: Required separation distances (in feet) for **designated areas** by type of manure and method of manure application

Designated Areas	**Dry Manure** – **Surface Application**: Incorporated on same date	**Dry Manure** – **Surface Application**: Not incorporated	**Liquid Manure** (except irrigated): **Direct Injection**	**Liquid Manure** (except irrigated) – **Surface Application**: Incorporated on same date	**Liquid Manure** (except irrigated) – **Surface Application**: Not incorporated
• sinkhole • abandoned well • cistern • drinking water well • designated wetland • water source	0	200 ft.[2] (50 ft. with buffer[3])	0	0	200 ft.[2] (50 ft. with buffer[3])
• high quality water resource	0	800 ft. [2, 4] (50 ft. with buffer[3])	0	0	800 ft. [2, 4] (50 ft. with buffer[3])
• unplugged ag drainage well • ag drainage well surface inlet	0	200 [5]	0	0	200 [5]

2. The separation distance applies to both open feedlots and confinement feeding operations, regardless of size. The 200-foot or 800-foot separation distance does not apply if either of the following exist:
   a) if manure is injected or incorporated on <u>the same date as the manure was land applied</u>, it can be applied up to the edge of the designated area, or
   b) if a 50-foot buffer is established around a designated area, manure can be applied up to the edge of the buffer (except a 200-foot separation distance must be maintained around an unplugged ag drainage well or an unplugged ag drainage well surface inlet).
3. Do not apply manure in the vegetative buffer.
4. <u>Check with the DNR</u> if you are adjacent to a <u>high quality water resource</u>, because an 800-foot separation distance may apply pending a <u>proposed</u> rule change.
5. Manure shall not be applied within 200 feet of an unplugged ag drainage well or unplugged ag drainage well surface inlet, unless injected or incorporated on the same date.

Table 3: Required separation distances (in feet) for land application of **irrigated liquid manure**

Protected Areas	**Irrigated Liquid Manure** Low Pressure (≤ 25 psi)	**Irrigated Liquid Manure** High Pressure (> 25 psi)
Property Boundary Line	100 ft. [1]	100 ft. [1]
Buildings or Public Use Areas • residence • business • church • school • public use area	250 ft. [2]	750 ft. [3]
Designated Areas • sinkhole • abandoned well • designated wetlands • cistern • drinking water well • water source	200 ft. (50 ft. with buffer [4])	200 ft. (50 ft. with buffer [4])
• high quality water resource	800 ft. [5]	800 ft. [5]
• unplugged ag drainage well • ag drainage well surface inlet • agricultural drainage well area (watershed)	No Irrigation Allowed [6]	No Irrigation Allowed [6]

1. a) Maintain at least 100 feet between the wetted perimeter (per manufacturer's specifications) and the property boundary line where irrigation is being used, and the actual wetted perimeter shall not exceed the property boundary line.
   b) If property includes a road right-of-way (ROW), a railroad ROW or an access easement, use the boundary of the ROW or easement as the property boundary line.
2. a) This separation distance applies to liquid manure applied by low pressure spray irrigation equipment as defined below.
   b) Measure the separation distance from the actual wetted perimeter of the manure to the closest point of buildings; and to the facilities where people congregate (for public use areas).
3. a) This separation distance applies to liquid manure from a confinement feeding operation. It does not apply to manure from open feed lots or dry manure. The required 750-foot separation distance does not apply if any of the following exist:
      1) manure is incorporated within 24 hours,
      2) a written waiver is issued by the owner of the building or public use area benefiting from the required separation distance,
      3) manure comes from a small animal feeding operation (SAFO), or
      4) manure is applied by low pressure spray irrigation (a 250-foot separation distance applies).
   b) Measure the separation distance from the actual wetted perimeter of the manure to the closest point of buildings; and to the facilities where people congregate (for public use areas).
4. Do not apply manure in the vegetative buffer.
5. Check with the DNR if you are adjacent to a high quality water resource, because an 800-foot separation distance may apply pending a proposed rule change.
6. No manure can be applied by spray irrigation equipment within an ag drainage well area. An ag drainage well area includes all land where surface or subsurface water drain to the well directly or through a drainage system connected to the well.

Recommended separation distance for land application of manure

Recommended, but not required: avoid application within 200 feet of (and draining into) a surface intake for a tile line.

Definitions

Buffer: consists of an area of permanent vegetation cover, including filter strips and riparian forest buffers, which exists for 50 feet surrounding the designated area other than an unplugged ag drainage well or surface intake to an unplugged ag drainage well. Do not apply manure in the vegetative buffer.

Designated area: includes a known sinkhole, or a cistern, abandoned well, unplugged agricultural drainage well, agricultural drainage well surface inlet, drinking water well, designated wetland, or water source. Designated areas do not include terrace tile inlets.

Designated wetland: means land owned by the U.S. Government or DNR and designated as a protected wetland by the Department of Interior or the DNR. It does not include land where an ag drainage well has been plugged causing a temporary wetland or land within a drainage or levee district.

High Quality Water Resource: means a high quality water or high quality resource water according Chapter 61 of the Iowa Administrative Code or a protected water area system as defined in Iowa Protected Water Areas General Plan (See list of high quality water resources by county.)

Low pressure spray irrigation equipment: discharges at a maximum pressure of 25 pounds per square inch (psi) and downward from a maximum height of nine feet.

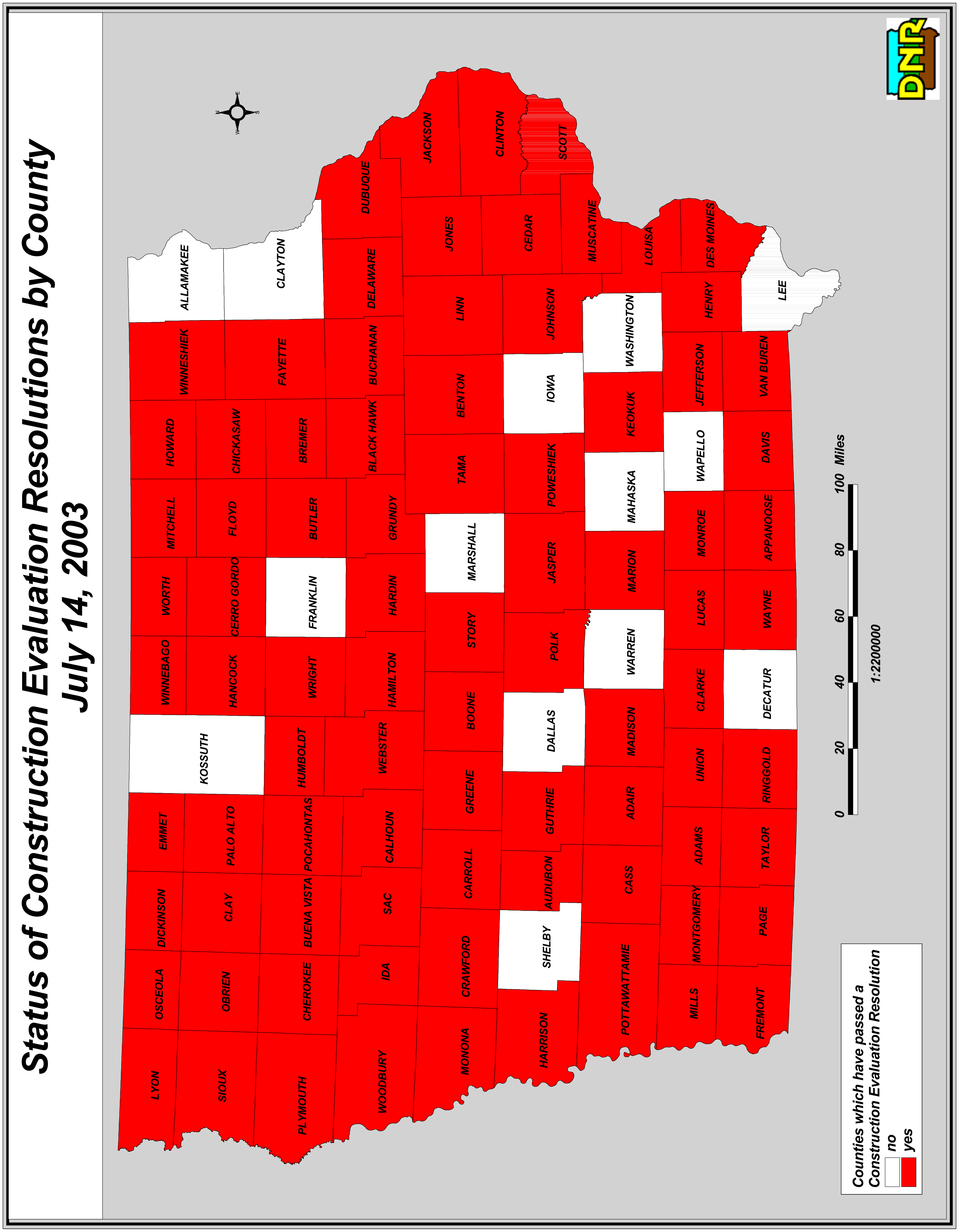
Public use area: government-owned land (local, state or federal) with facilities that attract people for significant amounts of time (i.e. picnic grounds, campgrounds, shelters, lakes, etc.). Public use areas do not include highways, road right-of-ways, parking areas, recreational trails or similar areas that people pass through but do not congregate in. Note: cemeteries are included in public use areas, but may be privately owned or managed.

Small Animal Feeding Operation (SAFO): an animal feeding operation that has an animal unit capacity of 500 or fewer animal units.

Water source: a lake, river, reservoir, creek, stream, ditch, or other body of water or channel having definite banks and a bed with water flow, except lakes or ponds without outlet to which only one landowner is riparian.

DNR 113: Rev. 10/2002

Appendix 3


Status of Construction Evaluation Resolutions by County
July 14, 2003
LYON
OSCEOLA
DICKINSON
EMMET
KOSSUTH
WINNEBAGO
WORTH
MITCHELL
HOWARD
WINNESHIEK
ALLAMAKEE
SIOUX
OBRIEN
CLAY
PALO ALTO
HANCOCK
CERRO GORDO
FLOYD
CHICKASAW
FAYETTE
CLAYTON
PLYMOUTH
CHEROKEE
BUENA VISTA
POCAHONTAS
HUMBOLDT
WRIGHT
FRANKLIN
BUTLER
BREMER
WOODBURY
IDA
SAC
CALHOUN
WEBSTER
HAMILTON
HARDIN
GRUNDY
BLACK HAWK
BUCHANAN
DELAWARE
DUBUQUE
MONONA
CRAWFORD
CARROLL
GREENE
BOONE
STORY
MARSHALL
TAMA
BENTON
LINN
JONES
JACKSON
HARRISON
SHELBY
AUDUBON
GUTHRIE
DALLAS
POLK
JASPER
POWESHIEK
IOWA
JOHNSON
CEDAR
CLINTON
SCOTT
MUSCATINE
POTTAWATTAMIE
CASS
ADAIR
MADISON
WARREN
MARION
MAHASKA
KEOKUK
WASHINGTON
LOUISA
MILLS
MONTGOMERY
ADAMS
UNION
CLARKE
LUCAS
MONROE
WAPELLO
JEFFERSON
HENRY
DES MOINES
FREMONT
PAGE
TAYLOR
RINGGOLD
DECATUR
WAYNE
APPANOOSE
DAVIS
VAN BUREN
LEE
0 20 40 60 80 100 Miles
1:2200000
Counties which have passed a Construction Evaluation Resolution
no
yes
DNR

Appendix 4

IOWA Water Quality Bureau
DEPARTMENT OF NATURAL RESOURCES

Animal Feeding Operations
Who Needs the Master Matrix?

The Master Matrix is required for the construction or expansion of confinement feeding operations, if all of the following applies:

1. The county, where the confinement feeding operation is or will be located, has adopted a Construction Evaluation Resolution (CER), and as long as the county's enrollment on the CER is valid at the time a construction application is submitted.
2. The confinement feeding operation is required to apply for a construction permit for the construction or expansion of a confinement feeding operation structure or modification in the volume or manner in which manure is stored.
3. Either of the following applies:
   a) The confinement feeding operation was constructed on or after April 1, 2002, including the expansion of these operations, regardless of the animal unit capacity (AUC); or
   b) The confinement feeding operation was constructed prior to April 1, 2002 and is expanding, and after expansion the AUC is 1,667 AU or more.
4. The construction permit application for the construction or expansion of a confinement feeding operation is received by the DNR on or after March 1, 2003.

If the answer was "yes" to all of the four questions above, then the county must use the Master Matrix to evaluate the construction permit application must be evaluated by the county with the Master Matrix .

CAUTION: This document is only a summary of Iowa Code chapter 459 (2003), 2002 Iowa Acts, Chapter 1137, (Senate File 2293) and the DNR's amended administrative rules of the Iowa Code 455B. It is a guidance document and should not be used as replacement for the statutory provisions and administrative rules (collectively, the law). While every effort has been made to assure the accuracy of this information, the law and administrative rules will prevail in the event of a conflict between this document and the law and administrative rules.

Appendix 5

APPENDIX C
MASTER MATRIX

Proposed Site Characteristics

The following scoring criteria apply to the site of the proposed confinement feeding operation. Mark one score under each criterion selected by the applicant. The proposed site must obtain a minimum overall score of 440 and a score of 53.38 in the "air" subcategory, a score of 67.75 in the "water" subcategory and a score of 101.13 in the "community impacts" subcateogry.

1 Additional separation distance, above minimum requirements, from proposed confinement structure to the closest:
* Residence not owned by the owner of the confinement feeding operation,
* Hospital,
* Nursing home, or
* Licensed or registered child care facility.

	Score	Air	Water	Community
250 feet to 500 feet	25	16.25		8.75
501 feet to 750 feet	45	29.25		17.50
751 feet to 1,000 feet	65	42.25		22.75
1,001 feet to 1,250 feet	85	55.25		29.75
1,251 feet or more	100	65.00		35.00

(A) Refer to the construction permit application package to determine the animal unit capacity (or animal weight capacity if an expansion) of the proposed confinement feeding operation. Then refer to Table 6 of 567--Chapter 65 to determine minimum required separation distances.
(B) The department will award points only for the single building, of the four listed above, closest to the proposed confinement feeding operation.
(C) "Licensed child care center" – a facility licensed by the department of human services providing child care or preschool services for seven or more children, except when the facility is registered as a child care home.
(D) "Registered child development homes" - child care providers certify that they comply with rules adopted by the department of human services. This process is voluntary for providers caring for five or fewer children and mandatory for providers caring for six or more children.
(E) A full listing of licensed and registered child care facilities is available at county offices of the department of human services.

2 Additional separation distance, above minimum requirements, from proposed confinement structure to the closest public use area.

	Score	Air	Water	Community
250 feet to 500 feet	5	2.00		3.00
501 feet to 750 feet	10	4.00		6.00
751 feet to 1,000 feet	15	6.00		9.00
1,001 feet to 1,250 feet	20	8.00		12.00
1,251 feet to 1,500 feet	25	10.00		15.00

1,501 feet or more	30	12.00		18.00

(A) Refer to the construction permit application package to determine the animal unit capacity (or animal weight capacity if an expansion) of the proposed confinement feeding operation. Then refer to Table 6 of 567--Chapter 65 to determine minimum required separation distances.
(B) "Public use area" - a portion of land owned by the United States, the state, or a political subdivision with facilities which attract the public to congregate and remain in the area for significant periods of time. Facilities include, but are not limited to, picnic grounds, campgrounds, cemeteries, lodges, shelter houses, playground equipment, lakes as listed in Table 2 of 567--Chapter 65, and swimming beaches. It does not include a highway, road right-of-way, parking areas, recreational trails or other areas where the public passes through, but does not congregate or remain in the area for significant periods of time.

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3 Additional separation distance, above minimum requirements, from proposed confinement structure to the closest:
* Educational institution,
* Religious institution, or
* Commercial enterprise.

	Score	Air	Water	Community
250 feet to 500 feet	5	2.00		3.00
501 feet to 750 feet	10	4.00		6.00
751 feet to 1,000 feet	15	6.00		9.00
1,001 feet to 1,250 feet	20	8.00		12.00
1,251 feet to 1,500 feet	25	10.00		15.00
1,501 feet or more	30	12.00		18.00

(A) Refer to the construction permit application package to determine the animal unit capacity (or animal weight capacity if an expansion) of the proposed confinement feeding operation. Then refer to Table 6 of 567--Chapter 65 to determine minimum required separation distances.
(B) The department will award points only for the single building, of the three listed above, closest to the proposed confinement feeding operation.
(C) "Educational institution" - a building in which an organized course of study or training is offered to students enrolled in kindergarten through grade 12 and served by local school districts, accredited or approved nonpublic schools, area educational agencies, community colleges, institutions of higher education under the control of the state board of regents, and accredited independent colleges and universities.
(D) "Religious institution" - a building in which an active congregation is devoted to worship.
(E) "Commercial enterprise" - a building which is used as a part of a business that manufactures goods, delivers services, or sells goods or services, which is customarily and regularly used by the general public during the entire calendar year and which is connected to electric, water, and sewer systems. A commercial enterprise does not include a farm operation.

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4 Additional separation distance, above minimum requirement of 500 feet, from proposed confinement structure to the closest water source.

	Score	Air	Water	Community
250 feet to 500 feet	5		5.00	
501 feet to 750 feet	10		10.00	
751 feet to 1,000 feet	15		15.00	
1,001 feet to 1,250 feet	20		20.00	
1,251 feet to 1,500 feet	25		25.00	
1,501 feet or more	30		30.00	

"Water source" - a lake, river, reservoir, creek, stream, ditch, or other body of water or channel having definite banks and a bed with water flow, except lakes or ponds without an outlet to which only one landowner is riparian.

5 Separation distance of 300 feet or more from the proposed confinement structure to the nearest thoroughfare.

	Score	Air	Water	Community
300 feet or more	30	9.00		21.00

(A) "Thoroughfare" - a road, street, bridge, or highway open to the public and constructed or maintained by the state or a political subdivision.
(B) The 300-foot distance includes the 100-foot minimum setback plus additional 200 feet.

6 Additional separation distance, above minimum requirements, from proposed confinement structure to the closest critical public area.

	Score	Air	Water	Community
500 feet or more	10	4.00		6.00

(A) All critical public areas as defined in 567--65.1(455B), are public use areas, and therefore subject to public use area minimum separation distances.
(B) Refer to the construction permit application package to determine the animal unit capacity (or animal weight capacity if an expansion) of the proposed confinement feeding operation. Then refer to Table 6 of 567--Chapter 65 to determine minimum required separation distances.

7 Proposed confinement structure is at least two times the minimum required separation distance from all private and public water wells.

	Score	Air	Water	Community
Two times the minimum separation distance	30		24.00	6.00

Refer to Table 6 of 567--Chapter 65 for minimum required separation distances to wells.

8 Additional separation distance, above the minimum requirement of 1,000 feet, from proposed confinement structure to the closest:
* Agricultural drainage well,
* Known sinkhole, or
* Major water source.

	Score	Air	Water	Community
250 feet to 500 feet	5	0.50	2.50	2.00
501 feet to 750 feet	10	1.00	5.00	4.00
751 feet to 1,000 feet	15	1.50	7.50	6.00
1,001 feet to 1,250 feet	20	2.00	10.00	8.00
1,251 feet to 1,500 feet	25	2.50	12.50	10.00
1,501 feet to 1,750 feet	30	3.00	15.00	12.00
1,751 feet to 2,000 feet	35	3.50	17.50	14.00
2,001 feet to 2,250 feet	40	4.00	20.00	16.00
2,251 feet to 2,500 feet	45	4.50	22.50	18.00
2,501 feet or more	50	5.00	25.00	20.00

(A) The department will award points only for the single item, of the three listed above, that is closest to the proposed confinement feeding operation.
(B) "Agricultural drainage wells" - include surface intakes, cisterns and wellheads of agricultural drainage wells.
(C) "Major water source" - a lake, reservoir, river or stream located within the territorial limits of the state, or any marginal river area adjacent to the state which can support a floating vessel capable of carrying one or more persons during a total of a six-month period in one out of ten years, excluding periods of flooding. Major water sources in the state are listed in Tables 1 and 2 in 567--Chapter 65.

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9 Distance between the proposed confinement structure and the nearest confinement facility that has a submitted department manure management plan.

	Score	Air	Water	Community
Three-quarter of a mile or more (3,960 feet)	25	7.50	7.50	10.00

Confinement facilities include swine, poultry, and dairy and beef cattle.

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10 Separation distance from proposed confinement structure to closest:
*High quality (HQ) waters,
* High quality resource (HQR) waters, or
* Protected water areas (PWA)
is at least two times the minimum required separation distance

	Score	Air	Water	Community
Two times the minimum separation distance	30		22.50	7.50

(A) The department will award points only for the single item, of the three listed above, closest to the proposed confinement feeding operation.
(B) HQ waters are identified in 567--Chapter 61.
(C) HQR waters are identified in 567--Chapter 61.
(D) A listing of PWAs is available at http://www.state.ia.us/government/dnr/organiza/ppd/prowater.htm#Location%20of%20PWA's%20in.

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11 Air quality modeling results demonstrating an annoyance level less than 2 percent of the time for residences within two times the minimum separation distance.

	Score	Air	Water	Community
University of Minnesota OFFSET model results demonstrating an annoyance level less than 2 percent of the time	10	6.00		4.00

(A) OFFSET can be found at http://www.extension.umn.edu/distribution/livestocksystems/DI7680.html . For more information, contact Dr. Larry Jacobson, University of Minnesota, (612) 625-8288, jacob007@tc.umn.edu .
(B) A residence that has a signed waiver for the minimum separation distance cannot be included in the model.
(C) Only the OFFSET model is acceptable until the department recognizes other air quality models.

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12 Liquid manure storage structure is covered.

	Score	Air	Water	Community
Covered liquid manure storage	30	27.00		3.00

(A) "Covered" - organic or inorganic material, placed upon an animal feeding operation structure used to store manure, which significantly reduces the exchange of gases between the stored manure and the outside air. Organic materials include, but are not limited to, a layer of chopped straw, other crop residue, or a naturally occurring crust on the surface of the stored manure. Inorganic materials include, but are not limited to, wood, steel, aluminum, rubber, plastic, or Styrofoam. The materials shall shield at least 90 percent of the surface area of the stored manure from the outside air. Cover shall include an organic or inorganic material which current scientific research shows reduces detectable odor by at least 75 percent. A formed manure storage structure directly beneath a floor where animals are housed in a confinement feeding operation is deemed to be covered.
(B) The design, operation and maintenance plan for the manure cover must be in the construction permit application and made a condition in the approved construction permit.

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13 Construction permit application contains design, construction, operation and maintenance plan for emergency containment area at manure storage structure pump-out area.

	Score	Air	Water	Community
Emergency containment	20		18.00	2.00

(A) The emergency containment area must be able to contain at least 5 percent of the total volume capacity of the manure storage structure.
(B) The emergency containment area must be constructed on soils that are fine-grained and have low permeability.
(C) If manure is spilled into the emergency containment area, the spill must be reported to the department within six hours of onset or discovery.
(D) The design, construction, operation and maintenance plan for the emergency containment area must be in the construction permit application and made a condition in the approved construction permit.

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14 Installation of a filter(s) designed to reduce odors from confinement building(s) exhaust fan(s).

	Score	Air	Water	Community
Installation of filter(s)	10	8.00		2.00

The design, operation and maintenance plan for the filter(s) must be in the construction permit application and made a condition in the approved construction permit.

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15 Utilization of landscaping around confinement structure.

	Score	Air	Water	Community
Utilization of landscaping	20	10.00		10.00

The design, operation and maintenance plan for the landscaping must be in the construction permit application and made a condition in the approved construction permit. The design should contain at least three rows of trees and shrubs, of both fast and slow-growing species that are well suited for the site.

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16 Enhancement, above minimum requirements, of structures used in stockpiling and composting activities, such as an impermeable pad and a roof or cover.

	Score	Air	Water	Community
Stockpile and compost facility enhancements	30	9.00	18.00	3.00

(A) The design, operation and maintenance plan for the stockpile or compost structure enhancements must be in the construction permit application and made a condition in the approved construction permit.
(B) The stockpile or compost structures must be located on land adjacent or contiguous to the confinement building.

---

17 Proposed manure storage structure is formed

	Score	Air	Water	Community

	Score	Air	Water	Community
Formed manure storage structure	30		27.00	3.00

(A) "Formed manure storage structure" - a covered or uncovered impoundment used to store manure from an animal feeding operation, which has walls and a floor constructed of concrete, concrete block, wood, steel, or similar materials. Similar materials may include, but are not limited to, plastic, rubber, fiberglass, or other synthetic materials. Materials used in a formed manure storage structure shall have the structural integrity to withstand expected internal and external load pressures.
(B) The design, operation and maintenance plan for the formed manure storage structure must be in the construction permit application and made a condition in the approved construction permit.

---

18 Manure storage structure is aerated to meet departmental standards as an aerobic structure, if aeration is not already required by the department.

	Score	Air	Water	Community
Aerated manure storage structure(s)	10	8.00		2.00

(A) Aerobic structure - an animal feeding operation structure other than an egg washwater storage structure which relies on aerobic bacterial action which is maintained by the utilization of air or oxygen and which includes aeration equipment to digest organic matter. Aeration equipment shall be used and shall be capable of providing oxygen at a rate sufficient to maintain an average of 2 milligrams per liter dissolved oxygen concentration in the upper 30 percent of the depth of manure in the structure at all times.
(B) The design, operation and maintenance plan for the aeration equipment must be in the construction permit application and made a condition in the approved construction permit.

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19 Proposed confinement site has a suitable truck turnaround area so that semitrailers do not have to back into the facility from the road

	Score	Air	Water	Community
Truck turnaround	20			20.00

(A) The design, operation and maintenance plan for the truck turn around area must be in the construction permit application and made a condition in the approved construction permit.
(B) The turnaround area should be at least 120 feet in diameter and be adequately surfaced for traffic in inclement weather.

---

20 Construction permit applicant's animal feeding operation environmental and worker protection violation history for the last five years at all facilites in which the applicant has an interest.

	Score	Air	Water	Community
No history of Administrative Orders in last five years	30			30.00

(A) "Interest" - means ownership of a confinement feeding operation as a sole proprietor or a 10 percent or more ownership interest held by a person in a confinement feeding operation as a joint tenant, tenant in common, shareholder, partner, member, beneficiary or other equity interest holder. Ownership interest is an interest when it is held either directly, indirectly through a spouse or dependent child, or both.
(B) An environmental violation is a final Administrative Order (AO) from the department of natural resources or final court ruling against the construction permit applicant for environmental violations related to an animal feeding operation. A Notice of Violation (NOV) does not constitute a violation.

---

21 Construction permit applicant waives the right to claim a Pollution Control Tax Exemption for the life of the proposed confinement feeding operation structure.

	Score	Air	Water	Community

	Score	Air	Water	Community
Permanent waiver of Pollution Control Tax Exemption	5			5.00

(A) Waiver of Pollution Control Tax Exemption is limited to the proposed structure(s) in the construction permit application.
(B) The department and county assessor will maintain a record of this waiver, and it must be in the construction permit application and made a condition in the approved construction permit.

22 Construction permit applicant can lawfully claim a Homestead Tax Exemption on the site where the proposed confinement structure is to be constructed
- OR -
the construction permit applicant is the closest resident to the proposed confinement structure.

	Score	Air	Water	Community
Site qualifies for Homestead Tax Exemption or permit applicant is closest resident to proposed structure	25			25.00

Proof of Homestead Tax Exemption is required as part of the construction permit application.
(A) Applicant include persons who have ownership interests."Interest" - means ownership of a confinement feeding operation as a sole proprietor or a 10 percent or more ownership interest held by a person in a confinement feeding operation as a joint tenant, tenant in common, shareholder, partner, member, beneficiary or other equity interest holder. Ownership interest is an interest when it is held either directly, indirectly through a spouse or dependent child, or both.

23 Construction permit applicant can lawfully claim a Family Farm Tax Credit for agricultural land where the proposed confinement feeding operation is to be located pursuant to Iowa Code chapter 425A.

	Score	Air	Water	Community
Family Farm Tax Credit qualification	25			25.00

(A) Applicant include persons who have ownership interests. "Interest" - means ownership of a confinement feeding operation as a sole proprietor or a 10 percent or more ownership interest held by a person in a confinement feeding operation as a joint tenant, tenant in common, shareholder, partner, member, beneficiary or other equity interest holder. Ownership interest is an interest when it is held either directly, indirectly through a spouse or dependent child, or both.

24 Facility size.

	Score	Air	Water	Community
1 to 2,000 animal unit capacity	20			20.00
2,001 to 3,000 animal unit capacity	10			10.00
3,001 animal unit capacity or more	0			0.00

(A) Refer to the construction permit application package to determine the animal unit capacity of the proposed confinement structure at the completion of construction.
(B) If the proposed structure is part of an expansion, animal unit capacity (or animal weight capacity) must include all animals confined in adjacent confinement structures.
(C) Two or more animal feeding operations under common ownership or management are deemed to be a single animal feeding operation if they are adjacent or utilize a common area or system for manure disposal. In addition, for purposes of determining whether two or more confinement feeding operations are adjacent, all of the following must apply:
(a) At least one confinement feeding operation structure must be constructed on and after May 21, 1998.
(b) A confinement feeding operation structure which is part of one confinement feeding operation is separated by less than a minimum required distance from a confinement feeding operation structure which is part of the other confinement feeding operation. The minimum required distance shall be as follows:
(1) 1,250 feet for confinement feeding operations having a combined animal unit capacity of less than 1,000 animal units.
(2) 2,500 feet for confinement feeding operations having a combined animal unit capacity of 1,000 animal units or more.

25 Construction permit application includes livestock feeding and watering systems that significantly reduce manure volume.

	Score	Air	Water	Community
Wet/dry feeders or other feeding and watering systems that significantly reduce manure volume	25		12.50	12.50

The design, operation and maintenance plan for the feeding system must be in the construction permit application and made a condition in the approved construction permit.

Proposed Site Operation and Manure Management Practices

The following scoring criteria apply to the operation and manure management characteristics of the proposed confinement feeding operation. Mark one score under each criterion that best reflects the characteristics of the submitted manure management plan.

26 Liquid or dry manure *(choose only one subsection from subsections "a" - "e" and mark one*

		Score	Air	Water	Community
a.	Bulk dry manure is sold under Iowa Code chapter 200A and surface-applied	15		15.00	
	Bulk dry manure is sold under Iowa Code chapter 200A and incorporated on the same date it is land-applied	30	12.00	12.00	6.00

		Score	Air	Water	Community
b.	Dry manure is composted and land-applied under the requirements of a department manure management plan	10	4.00	4.00	2.00
	Dry manure is composted and sold so that no manure is applied under the requirements of a department manure management plan	30	12.00	12.00	6.00

		Score	Air	Water	Community
c.	Methane digester is used to generate energy from manure and remaining manure is surface-applied under the requirements of an approved department manure management plan	10	3.00	3.00	4.00
	After methane digestion is complete, manure is injected or incorporated on the same date it is land-applied under the requirements of an approved department manure management plan	30	12.00	12.00	6.00
d.	Dry manure is completely burned to generate energy and no remaining manure is applied under the requirements of a manure management plan	30	9.00	9.00	12.00
	Some dry manure is burned to generate energy, but remaining manure is land-applied and incorporated on the same date it is land-applied	30	12.00	12.00	6.00
e.	Injection or incorporation of manure on the same date it is land-applied	30	12.00	12.00	6.00

(A) Choose only ONE line from subsection "a", "b," "c," "d," or "e" above and mark only one score in that subsection.
(B) The injection or incorporation of manure must be in the construction permit application and made a condition in the approved construction permit.
(C) If an emergency arises and injection or incorporation is not feasible, prior to land application of manure the applicant must receive a written approval for an emergency waiver from a department field office to surface-apply manure.
(D) Requirements pertaining to the sale of bulk dry manure under pursuant to Iowa Code chapter 200A must be incorporated into the construction permit application and made a condition of the approved construction permit.
(E) The design, operation and maintenance plan for utilization of manure as an energy source must be in the construction permit application and made a condition in the approved construction permit.
(F) The design, operation and maintenance plan for composting facilities must be in the construction permit application and made a condition in the approved construction permit.

27 Land application of manure is based on a two-year crop rotation phosphorus uptake level.

	Score	Air	Water	Community
Two-year phosphorus crop uptake application rate	10		10.00	

(A) Land application of manure cannot exceed phosphorus crop usage levels for a two-year crop rotation cycle.
(B) The phosphorus uptake application rates must be in the construction permit application and made a condition in the approved construction permit.

28 Land application of manure to farmland that has USDA Natural Resources Conservation Service (NRCS) approved buffer strips contiguous to all water sources traversing or adjacent to the fields listed in the manure management plan.

	Score	Air	Water	Community
Manure application on farmland with buffer strips	10		8.00	2.00

(A) The department may request NRCS maintenance agreements to ensure proper design, installation and maintenance of filter strips. If a filter strip is present but not designed by NRCS, it must meet NRCS standard specifications.
(B) The application field does not need to be owned by the confinement facility owner to receive points.
(C) On current and future manure management plans, the requirement for buffer strips on all land application areas must be in the construction permit application and made a condition in the approved construction permit.

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29 Land application of manure does not occur on highly erodible land (HEL), as classified by the USDA NRCS.

	Score	Air	Water	Community
No manure application on HEL farmland	10		10.00	

Manure application on non-HEL farmland must be in the construction permit application and made a condition in the approved construction permit.

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30 Additional separation distance, above minimum requirements (0 or 750 feet, see below), for the land application of manure to the closest:
*Residence not owned by the owner of the confinement feeding operation,
* Hospital,
* Nursing home, or
*Licensed or registered child care facility.

	Score	Air	Water	Community
Additional separation distance of 200 feet	5	3.25		1.75
Additional separation distance of 500 feet	10	6.50		3.50

(A) The department will award points only for the single building, of the four listed above, closest to the proposed confinement feeding operation.
(B) Minimum separation distance for land application of manure injected or incorporated on the same date as application: 0 feet.
(C) Minimum separation distance for land application of manure broadcast on soil surface: 750 feet.
(D) The additional separation distances must be in the construction permit application and made a condition in the approved construction permit.
(E) "Licensed child care center" – a facility licensed by the department of human services providing child care or preschool services for seven or more children, except when the facility is registered as a child care home.
(F) "Registered child development homes" - child care providers certify that they comply with rules adopted by the department of human services. This process is voluntary for providers caring for five or fewer children and mandatory for providers caring for six or more children.
(G) A full listing of licensed and registered child care facilities is available at county offices of the department of huma

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31 Additional separation distance, above minimum requirements (0 or 750 feet, see below), for land application of manure to closest public use area.

	Score	Air	Water	Community
Additional separation distance of 200 feet	5	2.00		3.00

(A) "Public use area" - a portion of land owned by the United States, the state, or a political subdivision with facilities which attract the public to congregate and remain in the area for significant periods of time. Facilities include, but are not limited to, picnic grounds, campgrounds, cemeteries, lodges, shelter houses, playground equipment, lakes as listed in Table 2 in 567--Dhapter 65, and swimming beaches. It does not include a highway, road right-of-way, parking areas, recreational trails or other areas where the public passes through, but does not congregate or remain in the area for significant periods of time.
(B) Minimum separation distance for land application of manure injected or incorporated on the same date as application: 0 feet.
(C) Minimum separation distance for land application of manure broadcast on soil surface: 750 feet.
(D) The additional separation distances must be in the construction permit application and made a condition in the approved construction permit.

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32 Additional separation distance, above minimum requirements (0 or 750 feet, see below), for the land application of manure to the closest:
* Educational institution,
* Religious institution, or
* Commercial enterprise.

	Score	Air	Water	Community
Additional separation distance of 200 feet	5	2.00		3.00

(A) Minimum separation distance for land application of manure broadcast on soil surface: 750 feet.
(B) Minimum separation distance for land application of manure injected or incorporated on same date as application: 0 feet.
(C) The additional separation distances must be in the construction permit application and made a condition in the approved construction permit.
(D) "Educational institution" - a building in which an organized course of study or training is offered to students enrolled in kindergarten through grade 12 and served by local school districts, accredited or approved nonpublic schools, area educational agencies, community colleges, institutions of higher education under the control of the state board of regents, and accredited independent colleges and universities.
(E) "Religious institution" - a building in which an active congregation is devoted to worship.
(F) "Commercial enterprise" - a building which is used as a part of a business that manufactures goods, delivers services, or sells goods or services, which is customarily and regularly used by the general public during the entire calendar year and which is connected to electric, water, and sewer systems. A commercial enterprise does not include a farm operation.

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33 Additional separation distance of 50 feet, above minimum requirements (0 or 200 feet, see below), for the land application of manure to the closest private drinking water well or public drinking water well
- OR -
well is properly closed under supervision of county health officials.

	Score	Air	Water	Community
Additional separation distance of 50 feet or well is properly closed	10		8.00	2.00

(A) Minimum separation distance for land application of manure injected or incorporated on the same date as application or 50-foot vegetation buffer exists around well and manure is not applied to the buffer: 0 feet.
(B) Minimum separation distance for land application of manure broadcast on soil surface: 200 feet.
(C) If applicant chooses to close the well, the well closure must be incorporated into the construction permit application and made a condition in the approved construction permit.

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34 Additional separation distance, above minimum requirements, for the land application of manure to the closest:
* Agricultural drainage well,
* Known sinkhole,
* Major water source, or
* Water source.

	Score	Air	Water	Community
Additional separation distance of 200 feet	5	0.50	2.50	2.00
Additional separation distance of 400 feet	10	1.00	5.00	4.00

(A) "Agricultural drainage wells" - include surface intakes, cisterns and wellheads of agricultiral drainage wells.
(B) "Major water source" - a lake, reservoir, river or stream located within the territorial limits of the state, or any marginal river area adjacent to the state, which can support a floating vessel capable of carrying one or more persons during a total of a six-month period in one out of ten years, excluding periods of flooding. Major water sources in the state are listed in Tables 1 and 2 in 567--Chapter 65.
(C) "Water source" - a lake, river, reservoir, creek, stream, ditch, or other body of water or channel having definite banks and a bed with water flow, except lakes or ponds without an outlet to which only one landowner is riparian.
(D) The additional separation distances must be in the construction permit application and made a condition in the approved construction permit.

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35 Additional separation distance above minimum requirements, for the land application of manure, to the closest:
* High quality (HQ) water,
* High quality resource (HQR) water, or
* Protected water area (PWA).

	Score	Air	Water	Community
Additional separation distance of 200 feet	5		3.75	1.25
Additional separation distance of 400 feet	10		7.50	2.50

(A) HQ waters are identified in 567--Chapter 61.
(B) HQR waters are identified in 567--Chapter 61.
(C) A listing of PWAs is available at
http://www.state.ia.us/government/dnr/organiza/ppd/prowater.htm#Location%20of%20PWA's%20in

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36 Demonstrated community support.

	Score	Air	Water	Community
Written approval of 100% of the property oweners within a one mile radius.	20			20.00

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37 Worker safety and protection plan is submitted with the construction permit application.

	Score	Air	Water	Community
Submission of worker safety and protection plan	10			10.00

(A) The worker safety and protection plan must be in the construction permit application and made a condition in the approved construction permit.
(B) The worker safety and protection plan and subsequent records must be kept on site with the manure management plan records.

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38 Applicant signs a waiver of confidentiality allowing public to view confidential manure management plan land application records

	Score	Air	Water	Community
Manure management plan confidentiality waiver	5			5.00

The waiver of confidentiality must be in the construction permit application and made a condition in the approved construction permit. The applicant may limit public inspection to reasonable times and places.

39 Added economic value based on quality job development (number of full time equivalent (FTE) positions), and salary equal to or above Iowa department of workforce development median (45-2093)

- OR -

the proposed structure increases commercial property tax base in the county.

	Score	Air	Water	Community
Economic value to local community	10			10.00

The Iowa department of workforce development regional profiles are available at http://www.iowaworkforce.org/centers/regionalsites.htm. Select the appropriate region and then select "Regional Profile."

40 Construction permit application contains an emergency action plan.

	Score	Air	Water	Community
Emergency action plan	5		2.50	2.50

(A) Iowa State University Extension publication PM 1859 lists the components of an emergency action plan. The emergency action plan submitted should parallel the components listed in the publication.
(B) The posting and implementation of an emergency action plan must be in the construction permit application and made a condition in the approved construction permit.
(C) The emergency action plan and subsequent records must be kept on site with the manure management plan records.

41 Construction permit application contains a closure plan.

	Score	Air	Water	Community
Closure plan	5		2.50	2.50

(A) The closure plan must be in the construction permit application and made a condition in the approved construction permit.
(B) The closure plan must be kept on site with the manure management plan records.

42 Adoption and implementation of an environmental management system (EMS) recognized by the department.

	Score	Air	Water	Community
EMS	15	4.50	4.50	6.00

(A) The EMS must be in the construction permit application and made a condition in the approved construction permit.
(B) The EMS must be recognized by the department as an acceptable EMS for use with confinement operations.

43 Adoption and implementation of NRCS approved Comprehensive Nutrient Management Plan (CNMP).

	Score	Air	Water	Community
CNMP	10	3.00	3.00	4.00

The implementation and continuation of a CNMP must be in the construction permit application and made a condition in the approved construction permit.

44 Groundwater monitoring wells installed near manure storage structure), and applicant agrees to provide data to the department.

	Score	Air	Water	Community
Groundwater monitoring	15		10.50	4.50

(A) Monitoring well location, sampling and data submission must meet department requirements.
(B) The design, operation and maintenance plan for the groundwater monitoring wells, and data transfer to the department, must be in the construction permit application and made a condition in the approved construction permit.

	Total Score	Air	Water	Community
	880	213.50	271.00	404.50
Score to pass	440	53.38	67.75	101.13

Appendix 6

IOWA Air Quality Bureau
DEPARTMENT OF NATURAL RESOURCES

Ambient Air Quality Standards for Ammonia and Hydrogen Sulfide Nullified

In April 2003, the Iowa Department of Natural Resources (DNR) brought forth a plan to the Environmental Protection Commission to establish Iowa Ambient Air Quality Standards for hydrogen sulfide and ammonia. These standards, based on university recommendations found in the Iowa Concentrated Animal Feeding Operations Air Quality Study, would apply to both animal feeding operations (regardless of size) as well as non-agricultural industries that emit hydrogen sulfide or ammonia.
To implement these standards, the department developed an ambient air sampling manual which contained monitor siting requirements, data handling procedures, approved monitoring methods and equipment, quality assurance requirements, and requirements for public availability of data.

The Commission approved both the ambient standards and the sampling manual in April. However, on April 30, 2003, the standards and the sampling manual were nullified by the Iowa Legislature.
Public comments on the proposed standards and sampling manual were gathered during an extended public comment period and at meetings held across the state. All comments are listed in a "responsiveness summary" document, which also contains the DNR responses. The complete responsiveness summary is posted below.

- DNR Response to Public Comments for the Ambient Air Quality Standards (DOC File).
- DNR Response to Public Comments for the Ambient Air Sampling Manual (DOC File).
- A Chronology of the History and Development of the Iowa Ambient Air Standards (DOC File).

Chronology of Iowa Ambient Air Standards

April 21, 2003

- **January 16, 2001.** Iowa Citizens for Community Improvement (Iowa CCI) filed a petition for rulemaking before the Iowa Environmental Protection Commission. The petition requested that the department adopt specific fence line and ambient air quality standards for hydrogen sulfide, ammonia and odor applicable to confined animal feeding operations.
- **February 2002.** In response to a request by Governor Tom Vilsack, Iowa State University and the University of Iowa Study Group issued a report, the Iowa Concentrated Animal Feeding Operations Air Quality Study (University Study), recommending that health standards for hydrogen sulfide and ammonia be established to protect the health of rural Iowans. (See Appendix A for specific language.)
- **March 2002.** The department prepared a draft rulemaking to be incorporated in a Notice of Intended Action (NOIA) at the April Environmental Protection Commission (EPC) meeting. The draft rule proposed ambient air quality standards for ammonia and hydrogen sulfide at the levels recommended in the University Study.
- Senate File (SF) 2293, a bill relating to animal agriculture regulation, including the development of comprehensive plans and programs for air quality, was under negotiation in the Iowa legislature.
- **April 29, 2002.** SF 2293 was signed into law. The law instructs the department to conduct a comprehensive field study to measure ambient concentrations of hydrogen sulfide, ammonia and odors near confined animal feeding operations (CAFOs). SF 2293 specifies that the department may develop plans or programs to control air pollution near CAFO's if pollution levels at "separated locations" exceed levels known to cause health problems. Section 23 of Senate File 2293, "Development of Comprehensive Plans and Programs for Air Quality" is now located in Iowa Code section 459.207 (see Appendix B for specific language.)
- **June 11, 2002.** The Technical Advisory Group on CAFO Air Monitoring held its first meeting. These meetings were held to assist the department in determining the best available ambient air monitoring methods for implementation of the hydrogen sulfide and ammonia standards, including the siting of ambient air monitoring stations. Discussions centered on equipment accuracy and monitor portability during the study.
- **June 25, 2002.** The Technical Advisory Group held its second meeting to provide additional recommendations on ambient air monitoring methodologies, particularly odor measurement, for the comprehensive field study and the proposed standards. The group also provided recommendations on siting locations and strategies for placement of monitors for the study at each type of confinement feeding operation structure as defined in SF 2293.
- **July 22, 2002.** EPC approved the NOIA for the ambient air quality standards. The rule recommended adoption of the following ambient air quality standards as recommended in the University Study:

Pollutant	Standards	Averaging Time	Not to be exceeded
Hydrogen Sulfide	0.015 ppm	1 hour	more than 7 times per year
Ammonia	0.150 ppm	1 hour	more than 7 times per year

- DNR presented to the EPC the draft ambient air sampling manual for information. This manual contained monitor siting requirements, data handling procedures, approved monitoring methods and equipment, and quality assurance requirements for determining compliance with the proposed hydrogen sulfide and ammonia standards. The methodology and monitoring equipment found in the manual are based on the recommendations of the Technical Advisory Group.
- The EPC denied the petition for rulemaking put forward by Iowa CCI in January of 2001.
- **August 19, 2002.** The EPC approved the NOIA for the ambient air sampling manual presented the previous month.
- **August 21, 2002.** NOIA was published in the Iowa Administrative Bulletin Notice for the ambient air quality standards. The public comment period would run through October 4, 2002.

An informational meeting and four public hearings were held from mid September through early October.

- **September 10, 2002**. Administrative Rules Review Committee reviewed the NOIA on the proposed ambient air quality standards.
- **September 18, 2002.** NOIA published in the Iowa Administrative Bulletin Notice for the ambient air sampling manual. The public comment period would run through November 1, 2002. Four public hearings are held during October.
- **October 2, 2002.** Amended NOIA published in the Iowa Administrative Bulletin to add another public hearing date for the ambient air quality standards and the ambient air sampling manual. The public comment period for both rules is extended until November 6, 2002.
- **October 8, 2002.** Administrative Rules Review Committee reviewed the NOIA on the ambient air sampling manual.
- **November 6, 2002.** The department held a combined public hearing in Davenport on the proposed ambient air quality standards and proposed ambient air sampling manual.
- Close of public comment period on ambient air sampling manual.
- **December 11, 2002.** Amended NOIA published in the Iowa Administrative Bulletin to extend the public comment period for the ambient air quality standards until January 6, 2003.
- **January 6, 2003.** Close of public comment period on ambient air quality standards. A total of 47 written comments and 50 oral comments were received on the ambient standards, and a total of 6 written comments and 5 oral comments were received on the ambient air sampling manual.

- DNR compiled oral and written comments and began preparation of responsiveness summaries.
- **April 2, 2003.** The department finalized its response to public comments for both the ambient air quality standards and the ambient air sampling manual. The comments and the departmental response to comments are located in the responsiveness summaries with each rule.
    - In response to public comment, the department made the following additional modifications to the draft rule for ambient air quality standards presented in the NOIA to obtain the current form of the rule:
    - Removed the definition of "community-oriented monitoring site."
    - Formulated the standards as a three-year average of the annual eighth-highest daily maximum hourly average concentration.
    - Established an earliest implementation date (instead of enforcement date) of December 1, 2004 based on Iowa Code section 459.207.
    - Changed the units of the standards from parts per million (ppm) to parts per billion (ppb).

Pollutant	Standards	Averaging Time	Not to be exceeded
Hydrogen Sulfide	15 ppb	1 hour	more than 7 times per year, averaged over 3 years
Ammonia	150 ppb	1 hour	more than 7 times per year, averaged over 3 years

- In response to public comment, the department made the following modifications to the draft sampling manual presented in the NOIA to obtain the current form of the sampling manual:
    - Added the common molecular abbreviations NH_3 (ammonia) and H_2S (hydrogen sulfide).
    - Reworded the "Flow Obstructions" paragraph.
    - Added a requirement that monitors be sited at a specified minimum distance away from roadways.
    - Added a section defining the level of the standards.
    - Reworded the "Computation of a Daily Maximum One-hour Average" paragraph.
    - Added a section "Computation of the Three-year Average" and deleted the section "Rounding Conventions".
    - Removed the section "Relationship between Exceedances and a Violation".
    - Removed the requirement that compliance measurements must be performed at a "community-oriented monitoring site".
    - Deleted the "Data Capture Requirements" paragraph and replaced it with an expanded "Data Completeness Requirements" section.
    - Added a provision to allow additional monitoring methods for hydrogen sulfide and ammonia to be used for determining attainment with ambient standards for hydrogen sulfide and ammonia, if approved by the Director or the Director's designee.
    - Added a provision that requires that the precision and accuracy of the ammonia and hydrogen sulfide monitoring network be assessed using procedures similar to those

established by the United States Environmental Protection Agency (EPA) for federally regulated pollutants.
    - Added a provision that provides for the public availability of monitoring data.

- **April 21, 2003**. The EPC adopted the final version of ambient standards and sampling manual.
- **April 30, 2003.** The Iowa Legislature nullified the ambient standards and sampling manual.

APPENDIX A

Excerpt taken from the executive summary of the Iowa Concentrated Animal Feeding Operations Air Quality Study, by the University of Iowa and Iowa State University Study Group.

Response to Question 3

Question 3: Based on an analysis of peer-reviewed, duplicated, legitimate, and published scientific research, what would you recommend as Iowa or National consensus standards for any proposed substances to be regulated as emissions from CFOs?

The study group recommends that ambient air quality standards be developed to regulate the concentration of hydrogen sulfide, ammonia and odor. There has been considerable discussion on what standard levels should be established for each pollutant as well as where the measurement should take place. Some states measure concentration at the property line of the source while others measure at the residence or public use area. The U.S. EPA has determined that simultaneous exposure of two substances such as hydrogen sulfide and ammonia (both pulmonary irritants) results in an additive effect. Thus, in order to protect against the adverse effects of such binary mixtures the exposure limit for each should be reduced accordingly. While emissions from CAFOs fluctuate over time, they produce chronic rather than acute exposures. Rather than representing single doses, these exposures are recurring and may persist for days with each episode.

The study group reached consensus that measurements for hydrogen sulfide and ammonia should be taken at the CAFO property line and residence or public use area. Measurements for odor should be taken at a residence or public use area and one proposal includes measurements at the CAFO property line. The study group recommends that measurements for hydrogen sulfide and ammonia should be time weighted rather that instantaneous to allow for atmospheric variability. With current animal production practices, stored manure must be removed and land-applied. During these times hydrogen sulfide, ammonia and odor levels at or near production facilities may be significantly higher than during normal conditions. Therefore, it is also recommended that provisions be made for allowable times to exceed the established standards to allow for proper manure application to land. Notification must be given to the Iowa DNR and nearby residents, at least 48 hours in advance when the operation expects to exceed the standards

The study group provides the following recommendations on the regulation of hydrogen sulfide, ammonia, and odor from CAFOs:

Hydrogen Sulfide
It is recommended that hydrogen sulfide, measured at the CAFO property line, not exceed 70 parts per billion (ppb) for a 1-hour time-weighted average (TWA) period. In addition, the concentration at a residence or public use area shall not exceed 15 ppb, measured in the same manner as the property line measurement. It is recommended that each CAFO have up to seven days (with 48-hour notice) each calendar year when they are allowed to exceed the concentration for hydrogen sulfide.

Ammonia
It is recommended that ammonia, measured at the CAFO property line, not exceed 500 ppb for a 1-hour TWA period. In addition, the concentration at a residence or public use area shall not exceed 150 ppb, measured in the same manner as the property line measurement. It is recommended that each CAFO have up to seven days (with 48-hour notice) each calendar year when they are allowed to exceed the concentration for ammonia.

Odor
The study group was unable to reach consensus on the regulation of odors. Thus, the following two opinions for odor are presented:

Opinion 1:
It is recommended that odor, measured at the residence or public use area, shall not exceed 7:1 dilutions with an exceedance defined as two excessive measurements separated by 4 hours, in any day. It is recommended that each CAFO have up to seven days (with 48-hour notice) each calendar year when they are allowed to exceed the concentration for odor. At the CAFO property line, odor shall not exceed a 15:1 dilution, with an exceedence defined as one excessive two-hour time averaged sample, in any day. It is recommended that each CAFO have up to 14 days (with 48-hour notice) each calendar year when they are allowed to exceed the property line concentration for odor. Exceedence of a CAFO ambient air quality standard should result in regulatory action similar to that which would be required in regulatory action exceedence of a National Ambient Air Quality Standard. The IDNR should be granted the power to develop an implementation plan to reduce the emissions that led to the violation.

Opinion 2:
Odor recommendations are more difficult to establish because studies relating health impacts to odor exposure have not measured odor concentrations. However, odor concentrations related to annoyance impacts have been established. Measurements for odor should be taken at a residence or public use area. Using sampling events at the source, the frequency, duration, and concentration of exposure to odor at the residence

can be modeled using tools currently available, thereby avoiding extensive monitoring. Polls indicate that residents are willing to tolerate nuisance odors for only up to a reasonable amount of time (see Iowa Rural Life Poll, Chapter 7 in the full report). Thus, the reported odor concentration represents tolerable continuous exposure, above which, concentrations are tolerated only in relation to their frequency and duration. An odor concentration of 7:1 dilutions at a residence is a tolerable odor providing it is not exceeded for periods that extend beyond that considered reasonable.

APPENDIX B

Iowa Code section 459.207 (formerly section 23 of Senate File 2293, "Development of Comprehensive Plans and Programs for Air Quality")

459.207 Animal feeding operations -- airborne pollutants control.
1. As used in this section, unless the context otherwise requires:
a. "Airborne pollutant" means hydrogen sulfide, ammonia, or odor.
b. "Separated location" means a location or object from which a separation distance is required under section 459.202 or 459.204, other than a public thoroughfare.
2. The department shall conduct a comprehensive field study to monitor the level of airborne pollutants emitted from animal feeding operations in this state, including but not limited to each type of confinement feeding operation structure.
3. *a.* After the completion of the field study, the department may develop comprehensive plans and programs for the abatement, control, and prevention of airborne pollutants originating from animal feeding operations in accordance with this section. The comprehensive plans and programs may be developed if the baseline data from the field study demonstrates to a reasonable degree of scientific certainty that airborne pollutants emitted by an animal feeding operation are present at a separated location at levels commonly known to cause a material and verifiable adverse health effect. The department may adopt any comprehensive plans or programs in accordance with chapter 17A prior to implementation or enforcement of an air quality standard but in no event shall the plans and programs provide for the enforcement of an air quality standard prior to December 1, 2004.
b. Any air quality standard established by the department for animal feeding operations shall be based on and enforced at distances measured from a confinement feeding operation structure to a separated location. In providing for the enforcement of the standards, the department shall take all initial measurements at the separated location. If the department determines that a violation of the standards exists, the department may conduct an investigation to trace the source of the airborne pollutant. This section does not prohibit the department from entering the premises of an animal feeding operation in compliance with section 455B.103. The department shall comply with standard biosecurity requirements customarily required by the animal feeding operation which are necessary in order to control the spread of disease among an animal population.

c. The department shall establish recommended best management practices, mechanisms, processes, or infrastructure under the comprehensive plans and programs in order to reduce the airborne pollutants emitted from an animal feeding operation.
d. The department shall provide a procedure for the approval and monitoring of alternative or experimental practices, mechanisms, processes, or infrastructure to reduce the airborne pollutants emitted from an animal feeding operation, which may be incorporated as part of the comprehensive plans and programs developed under this section.

BEST MANAGEMENT PRACTICES FOR RACEWAY CULTURE SYSTEMS

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BEST MANAGEMENT PRACTICES FOR RACEWAY CULTURE SYSTEMS

Harry Westers

Introduction

Trout production typically occurs in raceways which are, more often than not, arranged in a serial reuse fashion, with water moving from pond to pond. This may repeat itself many times over. The ponds can be arranged linearly or parallel to each other with the flow traveling zigzag, i.e. back and forth, and from pond to pond (Figure 1).

There are many variations in pond design with respect to size, dimensions, and structure. Older facilities may still use earthen ponds. An example of this is shown with Figure 2.

Pond design, structure and operational mode can significantly affect the capability, and efficiency, to manage waste components, particularly the solids fraction (feces and waste food).

Waste Management Principles

Preventative measures

Prevention is always the best strategy to consider first. For aquaculture there are two main approaches, as well as a long-term strategy.

1. *Responsible feed management.*— In intensive fish production feed is the sole source of pollution. Feed waste must be avoided as much as possible. Although zero waste may not be practical, this waste should not exceed 3.0-5.0%. Feed losses as high as 20 to 50% have been reported (Cho, et al. 1991). All of the waste feed contributes to pollution, and directly affects the economics. The following should be considered in efforts to reduce feed waste to a minimum.

   a) Avoid overfeeding; observe the response of the fish, match feeding rates to response (Wong and Piedrahita, 2003).
   b) Feed where the fish are located.
   c) Handle feed with care; prevent fines/remove fines.
   d) Know the feed requirements of the fish (%BW/d), based on fish size, water temperature and dietary energy.
   e) Know the biomass – amount of feed to feed per day.
   f) Feed no more than 0.5 to 1% BW per feeding. Feed should be consumed within 15 minutes.
   g) Establish records: growth rates and feed conversion ratios.

2. *Use low-polluting diets.*— These are diets which are highly digestible, of high nutrient density and have a well-balanced protein-to-energy ratio. Of course, they must be economical as well, but the unit cost can be greater if feed conversions are lower. By way of

illustration, high energy diets, with up to 30% fat, 40% protein and 13% carbohydrates (nitrogen-free extract) when fed to Atlantic salmon, demonstrated reductions in nitrogen output by 35%, phosphorous by 20% and solids by at least 20% due to a feed intake reduction of 20% versus diets with a fat level of 22% or less (Johnson and Wandsrik, 1991).

3. Genetic selection and/or genetic engineering.— As new species enter aquaculture, there is a need for domestication, but there is also a continuing need for improvements in growth rates and feed utilization of traditional species. The traditional approach, genetic selection, has been largely ignored, but, according to Doupé and Lymbery (2003) holds promise and should be pursued. A "shortcut" in this process is the technology of genetic engineering, the "creation" of genetically modified organisms (GMO). GMO's are extremely controversial. There is much opposition to the use of genetically modified foods. Genetically modified fish (salmon) have been produced, but opposition has been expressed by anglers, the wild fish lobby, conservationists, and even fish farmers and breeders, because they know that GMO is unacceptable as food, and that includes farmed salmon (Roberts, 2000). However, Roberts also points out that research into this technology should not be choked off outright, but ought to be allowed to proceed with all needed precautions in place.

Corrective measures

Feeding fish is synonymous to polluting the water. Solids (feces and waste feed), nitrogen and phosphorus are the main components of concern. Solids can be reported as settleable, suspended, dissolved, BOD and COD, nitrogen as inorganic, ammonia, nitrite, nitrate, and organic nitrogen, and total nitrogen, phosphorus as inorganic ortho-phosphate and as organic phosphorus in the solids fraction of the waste. Values for each of these sub-components have been reported, showing considerable variation (Axler et al. 1997). This is not surprising, because within flow-through systems much variation can be expected due to management practices, source water quality, monitoring methods (timing, frequency, etc), system design and operational modes. This problem was pointed out by Cho, et al (1991). They compared the nutritional mass-balance method (biological) with the water chemistry method (limnological), and found significant differences in outcome between these two approaches. Higher than projected TSS values are most likely the result of feed waste. Facility design and management practices can also be responsible for significant variations in concentrations of aquaculture waste components in the effluent. Successful best management practices are, to a large extent, driven by facility design.

System Design Factors

Earthen pond systems

It is always difficult to apply corrective action without a good diagnosis of the problem and an intimate knowledge of the characteristics of the production system. All flow-through raceway systems are not equal. The “simplest” ones are earthen ponds, "down to earth" in construction but complex when it comes to identifying what is happening to the waste and how to manage it. Earthen raceways function as settling basins, because of low water velocities. In reality, this is a characteristic of all raceways, a truth not always recognized, especially when large flows are used through such rearing vessels. To illustrate, a raceway with these dimensions, length (l) is 30 m (≈ 98') width (w) is 3.0 m (≈ 9.8') and a depth (d) of 0.66 m (≈ 2.2') has a rearing volume of

60 m^3 (2200 ft^3). To create a velocity of 15 cm/s (0.5'), a velocity that would keep solids in suspension, long enough, would require a flow rate of 18,000 lpm (4755 gpm), the water turn-over time would be a short 3.33 minutes, the exchange rate 18 x per hour (R = 18). Normal turn-over rates for most raceways range from 1.0 to 4.0 per hour. The velocity (v) at 4 changes per hour (R = 4.0) would be 3.3 cm/s (0.11 ft/s). Velocity can be determined with: v = (l x R)/36

Where v is velocity in cm/s, 36 is from 3600 s/h divided by 100 because the velocity is expressed as cm/s, the length (l) in m (1.0 m = 100 cm)

For English equivalents: v (as ft/s) = (l (in ft) x R)/3600. In this case the units used for velocity and length are the same, namely feet.

It is an indisputable fact that raceways function as settling basins. Every fish culturist who has worked with raceways has observed the buildup of solid waste within raceways.

This fact, that raceways function as settling ponds, creates several problems with respect to managing the solids fraction of the waste.

As solids settle and build up, they are often resuspended by fish and human activity. This destroys the integrity of the solids (fecal material and wasted feed) and changes relatively large particles (>100 µ*m*) into many smaller particles. It has been reported that a high proportion (80%) of TSS may end up in size ranges from 5.0 to 20.0 µ*m* (Boardman, et al. 1998). Such sizes take a long time to settle, they are difficult to remove, and even micro-screens are ineffective because these devises are not very efficient in capturing particles smaller than 80 µ*m* (Boardman, et al. 1998). Also, the finer the particles the easier they leach nutrients (N and P). Their surface area to volume ratio is very large. For example, it takes 64,000 5.0-µ*m* particles to achieve the same volume as one 200-µ*m* particle.

In serial reuse arrangements, such fine solids are passed from pond to pond, degrading the water quality. Although the concentrations are relatively low (< 10.0 mg/l) under normal conditions, they can reach concentrations in excess of 100 mg/l whenever there is activity within the pond, through heavy feeding when fish densities are high and through in-pond activities such as harvesting, sorting, inventorying, cleaning, etc.

In an earthen pond system much of the waste seems to "disappear." Some of it is converted to new biomass (bacterial, algal, and higher organisms), these generate their own waste components, such as BOD; COD; CO_2; dead organic matter, and, under anoxic and anaerobic conditions, release phosphorus, and can generate hydrogen sulfide or methane gas. It is therefore difficult, if not impossible, to determine final effluent end products from earthen ponds. The within system dynamics are too complex.

For instance, the BOD, TSS, and TAN concentrations reported (NPDES) for the facility shown as Figure 2, were 5.0, 3.0, and 1.1 mg/l respectively. As for the 1.1 mg/l TAN, this concentration, according to the manager, is the highest on record. Average concentrations have been in the 0.7 to 0.8 mg/l range.

This facility produces about 240,000 pounds of food-sized rainbow trout per year. Daily feed input ranges from 600 to 800 pound per day. The flow rate through the system is about 1200 gpm measured as the discharge flow rate. Assuming the following values per pound of feed:

Solids: 140 g; TAN: 13 g; BOD: 150 g.

Then the daily totals, based on 800 pounds of feed, are 112 kg TSS (247 lbs); 10.4 kg TAN (23 lbs); and 120 kg BOD (264 lbs).

If these compounds were distributed evenly over a 24-hour period in the flow rate of 1200 gpm, concentrations would be 17.1 mg/l TSS; 1.59 mg/l TAN and 18.3 mg/l BOD. Compared to the measured concentrations, about 82% of TSS, 40% of TAN, and 73% of BOD is unaccounted for.

Trout production in earthen ponds presents a difficult challenge for waste management. Neither full-flow settling ponds nor micro-screening can be effective, because routine effluent concentrations are very low and consist, predominantly, of very small particles.

There also is the problem of high TSS concentrations released during pond activities, with concentrations in excess of 100 mg/l. This flow should be diverted to a settling pond. This can be a problem where these flows are needed to supply other ponds in the series. Provisions must be made to bypass some, or all, of the water.

Over time, accumulated sludge may have to be removed from the pond. This is best accomplished by having the ability to drain the pond down to the level of the sludge and then pump this material to sludge drying beds, constructed wetlands or land apply. For this, all fish must have been removed and, in most cases, there must be the ability to by-pass the normal flow.

Concrete raceways

Concrete raceways for salmonid culture are common with state and federal public fish hatcheries. They are also popular with the large Idaho trout industry and other, relatively large trout production systems throughout the USA and Europe.

Concrete raceways have a distinct advantage over earthen ones. They can accept greater flows of water and are easier to manage.

Nevertheless, even with higher flow-rates, these raceways still function as settling basins. Velocities of 15 cm/s or more are required to make the raceway self-cleaning, but velocities hardly ever exceed 3.0 cm/s. Even at this velocity the flow rate through the 30 m x 3.0 x 0.66 m dimension raceway mentioned earlier, must be as great as 3600 lpm (951 gpm).

As solids settle and accumulate in raceways, fish activity will, from time to time, resuspend them into the water column, breaking them down into smaller particles which take longer to settle. Eventually some will drift out of the raceway. In general, the TSS concentration in the raceway effluent varies from 1.0 to 6.0 mg/l (Tables 1 and 2). Such concentrations depend on the amount of feed, the fish size and rearing density and the amount of waste accumulated, i.e., how frequently the pond is cleaned.

Whenever fish stir up solids, in-pond TSS concentrations may reach 60 mg/l, but these are of short duration, most will resettle rather quickly (Boardman et al. 1998). Eventually some of these short-duration spikes exit the raceway. Batch sampling seldom "catch" these, and with 24 hour composite sampling, these short-duration spikes do not significantly contribute to the overall concentration.

Things are different with raceway cleaning, harvesting, sorting or any other activity requiring people to walk in the raceway. Shock loading can easily exceed TSS concentrations of 100 mg/l

(Boardman, et al. 1998). Table 1 shows concentrations during cleaning for seven State of Michigan facilities. These range from 54 up to 145 mg/l TSS, they involve cleaning activities lasting 2 to 6 hours (MWRC, 1973).

The 1998 studies by Boardman et al. agree well with Michigan's data. Tables 1 and 2 also show much agreement for TSS concentrations under normal, routine operations, showing average values of 2.88 mg/l and 3.00 mg/l, respectively. Mean values for TSS for the three trout farms evaluated by Boardman et al were 3.9, 3.9 and 6.1 mg/l respectively. The ranges for the Michigan facilities are 1.0 to 6.1 mg/l (Table 1), for the Pennsylvania facility 0.6 to 5.7 mg/l (Table 2).

The negative TSS value of -0.9 mg/l in Table 1 for Baldwin, indicates that the raceways trap solids from the source (river) water. In this case, incoming TSS concentrations are greater than effluent concentrations (river velocities are greater than raceway velocities). This phenomenon has been reported elsewhere.

Table 2 lists the monthly NPDES monitoring values for BOD, TSS, TAN, and TP for 1999 and 2000, from the Big Spring fish culture facility operated by the Pennsylvania Fish and Boat Commission. The facility operates two groups of 40 concrete raceways, each group consisting of 8 parallel raceways, arranged in a 5-pass fashion. The flow from the upper 40 units can be directed to the lower block of 40 units for another 5 passes. The first column of Table 2 lists the NPDES monitored values for BOD, TSS, TAN, and TP, the second column gives the projected values based on the following generated values per kg feed:

BOD - 0.340 kg (340 g)
TSS - 0.300 kg (300 g)
TAN - 0.030 kg (30 g)
TP - 0.005 kg (5 g)

The third column lists the percent differences between NPDES and the theoretical values. Phosphorus shows a somewhat higher average NPDES concentration then the theoretical value, but the NPDES report for BOD, TSS, and TAN are, on average, 64, 53 and 50% less than the theoretical, feed-based values. This is not that surprising for BOD and TSS but difficult to explain for total ammonia nitrogen in solution. Both effluent BOD and TSS concentrations can be expected to be less than predicted because of the settling characteristics of raceways. As a matter of fact, it appears that at least 50% of the solids end up at the bottom of the raceway and, if it was not for fish activity stirring these up, nearly 100% could be intercepted. It is a matter of knowledge among fish culturists familiar with raceways that these units can be almost self-cleaning if occupied by many large fish constantly stirring up the solids, at the same time destroying the integrity to the point where re-settling would require a very large settling basin. Full-flow settling basins are difficult to manage as far as solids removal is concerned.

Studies by Cho et al. (1991), compared theoretical feed based values for TSS, TAN and TP with effluent water quality monitoring values. They found TSS values to be greater for the water chemistry analysis than the theoretical feed based value. The difference was 16%. The study was conducted with 4 m x 4 m square fiberglass tanks with rounded corners and a center bottom drain; in other words with a circulating fish rearing unit. Very different from plug-flow units.

Obviously there are major differences between plug-flow and circulating rearing units. Findings by Cho et al. are opposite to those reported for raceways, i.e. higher TSS values versus lower values when predicted based on feed input. Routine monitoring of raceway effluents for

TSS range, most of the time, from about 2.0 to 4.0 mg/l (tables 1 and 2), most often well below maximum NPDES values. Concentrations for TAN range from 0.05 to 1.00 mg/l (tables 1 and 2). Similar values for TSS and TAN for three raceway flow-through trout production systems have been reported by Boardman, et al. (1998). Again, these values are well below theoretical ones based on feed. Raceways require periodic cleaning to remove the accumulated waste. Removing these solids also help in reducing nutrient loadings. Raceways must be designed to include the capability to divert cleaning flows to sludge collection systems for storage and future processing.

Self-cleaning raceway

Westers (1991), describes the use of baffles in concrete raceways to make them self-cleaning. Baffles are thin plates or heavy curtains positioned throughout the length of a raceway spaced apart at distances equal to the width of the raceway. They extend to, or above, the water surface and leave a gap between the bottom edge of the baffle and the raceway floor of 6 to 10 cm. As the bulk of the water passes through this narrow gap, the velocity increases. The goal is to create velocities from 15 to 30 cm/s, sufficient to move solids to the next baffle. Settled solids are continuously moved along to the fish retaining screen. Once there, they pass through the screen. As the water passes through the screen, the waste particles are separated and, subsequently, settle very rapidly in the quiescent zone. This zone, the sediment trap, is no longer than the width of the raceway (Figures 3 and 4). Detention time is only a few minutes, yet the bulk of the solids (75 to 85%) settle out and is deposited immediately behind the screen. The presence of these screens helps in creating a quiescent (non-turbulent) area within the trap, thus optimizing the settling of suspended solids. Because of the trap's limited storage capacity, solids may have to be removed as often as weekly, but, of course, this depends entirely on the feed input. Baffles do work and they work well in concrete raceways, but not in earthen ones. An overall raceway velocity of 3.0 cm/s (0.10') is desirable. This method of waste management has not caught on for these reasons:

- Baffles interfere with managing the facility, in particular where frequent harvesting is practiced from the raceway. This requires removal of these structures, which is viewed as very labor intensive.
- Baffles provide surface areas for nuisance growth, bacterial and algal.

In countering these objections to baffles, it is very important to understand the function of the baffles and their basic construction and installation requirements. Baffles are intended to make the raceway "self-cleaning" of fecal matter and waste feed. Baffles do not prevent biological growth on the raceway floor and sides. This growth will also occur on the baffles themselves. Raceways without baffles are routinely cleaned to remove accumulated waste. At the same time the brooms are often used to remove the growth from the bottom and the walls as well..."while we are at it." Fish culturists have been conditioned to keep raceways clean. Baffles will not perform that function, they will only "sweep" out the loose solids, not the attached growth. For most fish culturists this means that baffles really are not self-cleaning because they still have to go in with brooms to remove nuisance growth, not only attached to the floor and sides, but to the baffles as well. Thus, instead of baffles saving labor, they add labor for cleaning. In addition, baffles interfere with harvesting and handling fish as well. Conclusion, baffles are too labor intensive.

Is it important to remove the algal and bacterial growth? This biological activity uses some of the dissolved nutrients and aid in purifying the water, rather than degrading it. Water-quality-wise, such growth is not harmful, rather the opposite. In a sense, the baffles function as a biofilter. But without brushing the raceways look dirty, and this is a poor reflection on the fish culturist. So what! Fish culturists produce fish. Why waste time on removing such growth. The practice with Michigan's state hatcheries is to operate a full, one-year production cycle without ever putting a broom into the raceway. They are only cleaned before the next cycle starts. A pressure washer can quickly clean the baffles.

Baffles do interfere with operations such as harvesting, sorting of fish, etc. Construction and installation of baffles must allow for easy and quick removal and re-installation. Baffles are not much more than heavy curtains hanging in the raceway. They can be constructed of very thin aluminum sheets or possibly even from heavy pond liner material. One person can easily and quickly remove and re-install a light baffle, but if too bulky, two persons can perform this task very quickly. Weight should be no issue.

The benefits of baffles in managing solids are too great to be ignored. Culturists have to make some adjustments in their raceway cleaning habits. This means no brooms, no fish disturbance, no labor required for cleaning. Fish too, need some time to adjust to baffles. Baffles, so managed, result in a net saving of labor while performing an important task in managing solids, the most critical waste component in fish production.

The waste collected in the sediment trap at the end of the raceway can either be pumped or drained to an offline basin, or directly land-applied.

Discussion

Effluent water quality measurements (such as NPDES records) for BOD, TSS, TAN, and TP from most flow-through fish production systems do not present reliable quantitative information about such waste components. In most cases such data does not match up with projected values based on feed input. As was stated earlier, in intensive aquaculture systems, feed can be considered the sole source of all waste. The lower the FCR, the less waste.

It has been estimated that a feed conversion increase from 1.0 to 1.5 increases the COD by 186%, the TN by 70%, and the TP by 86% (Bergheim, et al. 1991). Feed loss can be, and probably often is, a major contributor to aquaculture waste under farm conditions. But, in raceways where ponds function as settling basins, effluent concentrations of TSS, under routine conditions, underestimate the production of this waste component.

Summary

The best available technology for waste management in raceways depends on design and management flexibility. The following BMP recommendations are offered:

1) Earthen ponds should have the ability to drain down to the level of the accumulated sludge. This should be pumped to an appropriate sludge storage or processing facility. In case of serial reuse, water bypass must be provided.

2) Concrete raceways must have the flexibility to divert cleaning flows, as well as similar "shock loadings," to appropriate settling basins. They should be equipped with a quiescent zone as well.

3) Concrete raceways should be operated at a minimum, overall, velocity of 0.1'/s. These can be equipped with baffles, a preferred method to make raceways self-cleaning. Requires only small quiescent zone (QZ).

4) Solids from QZ should be diverted to an offline settling basin, and, ideally, its overflow should pass through a "polishing" pond.

5) Full-flow settling ponds are not ideal but preferred over no solids interception provisions.

6) Micro-screening does not appear to be economically practical.

All systems: Feed and health management.

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Table 1. Net effluent concentrations in mg/l for five parameters for seven state of Michigan salmonid flow-through production facilities.

Facility	TSS *N	TSS **CL	BOD N	BOD CL	TAN N	TAN CL	ORG. N N	ORG. N CL	TOTAL P N	TOTAL P CL
ODEN	6.1	145	1.9	7.5	0.19	0.28	0.21	9.3	0.12	2.4
MARQUETTE	5.4		-0.3		0.02		0.19		0.04	
THOMPSO	5.0		0.6		0.12		0.13		0.07	
HARRIETT A	1.2	87	1.6	3.5	0.08	0.18	0.02	3.2	0.07	1.00
WOLF LAKE	2.4	59	2.0	9.8	0.07	0.21	0.05	3.8	0.03	0.98
BALDWIN	-0.9		0.5		0.04		0.05		0.01	
STURGEO N	1.0	54	-1.7	5.8	0.07	0.14	0.11	5.2	0.03	1.6
AVERAGE	2.88	86	1.20	26.6	0.084	0.20	0.108	5.4	0.053	1.50

*N represents normal (routine) operations

**CL represents raceway cleaning activities of 2 to 6 hour duration

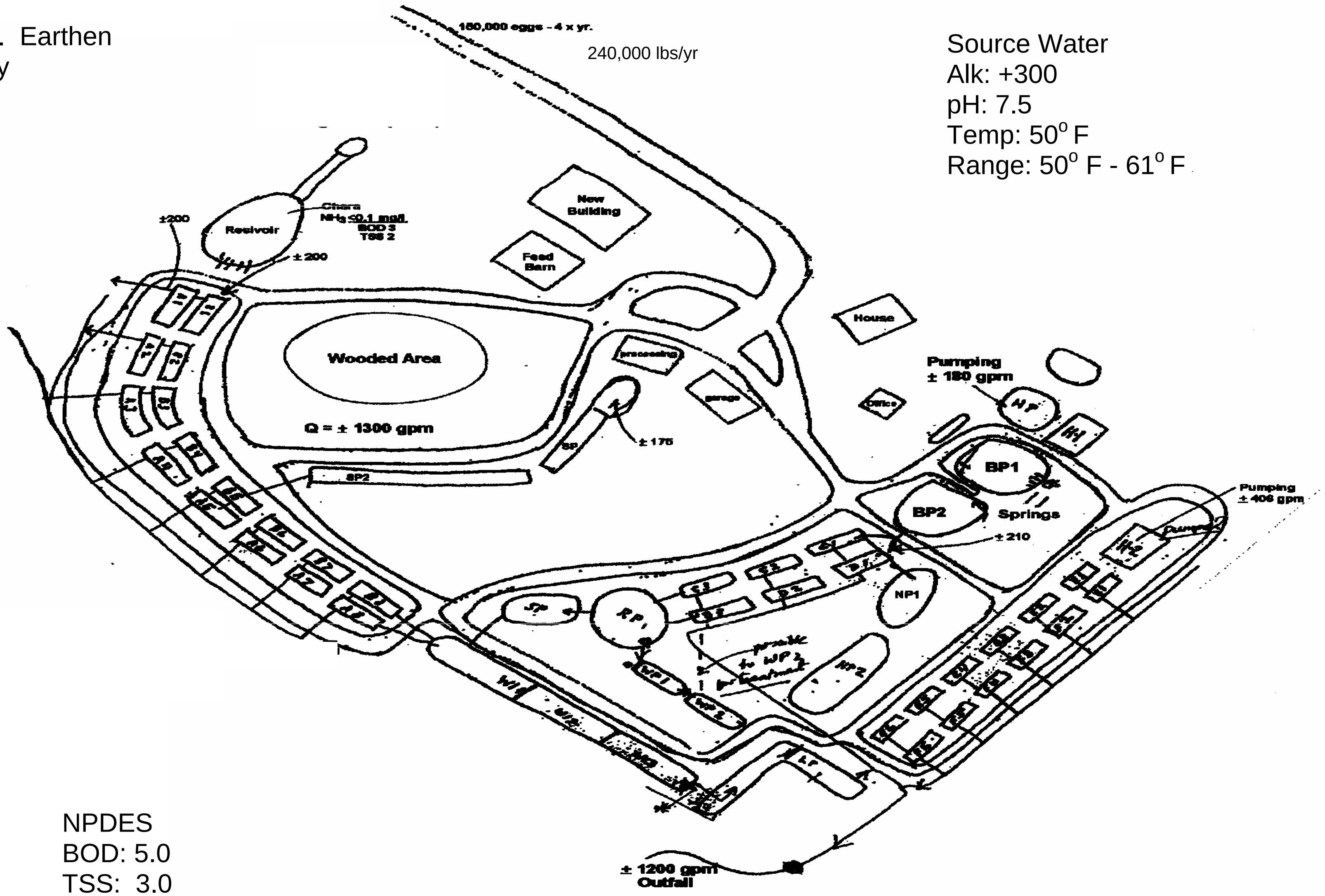
All Samples: 24 hour composite

Table 2. NPDES monitoring data from Big Spring, PA state fish hatchery, a concrete raceway flow-through salmonid production system. NPDES values are compared with theoretical values based on feed input (Fd for feed). Differences are expressed in percent (see text).

MONTH/YR	BOD			TSS			TAN			T-PHOSP		
	NPDES	Fd	%	NPDES	Fd	%	NPDES	Fd	%	NPDES	Fd	%
1/99	2.9	9.5	69	2.0	8.4	76	0.38	0.84	55	0.10	0.14	29
2/99	4.0	8.6	53	3.0	7.5	60	0.56	0.75	13	0.13	0.13	0.0
3/99	4.5	7.3	38	1.0	6.4	84	0.59	0.64	8	0.15	0.11	-27
4/99	2.8	5.8	52	3.0	5.1	41	0.36	0.51	29	0.09	0.09	0.0
5/99	2.2	3.2	31	2.0	2.8	29	0.26	0.28	7	0.04	0.05	20
6/99	1.5	4.6	67	2.0	4.1	51	0.22	0.41	46	0.03	0.07	57
7/99	1.6	5.2	69	0.0	4.6	>100	0.23	0.46	50	0.05	0.08	38
8/99	0.6	5.3	89	3.0	4.7	36	0.32	0.47	32	0.07	0.08	12
9/99	2.5	6.7	63	2.0	5.9	66	0.34	0.59	42	0.09	0.10	10
10/99	2.6	7.6	66	3.0	6.7	55	0.37	0.67	45	0.09	0.11	18
11/99	2.9	8.5	66	4.0	7.5	46	0.49	0.75	35	0.06	0.13	54
12/99	4.3	8.6	50	1.0	7.6	87	0.47	0.76	38	0.19	0.13	-31
1/00	2.3	12.5	82	4.0	9.4	57	0.43	0.94	54	0.22	0.16	-37
2/00	4.7	9.6	51	4.0	7.2	44	0.49	0.72	32	0.24	0.12	-100
3/00	4.6	9.1	49	5.0	6.8	26	0.47	0.68	31	0.21	0.11	-91
4/00	1.8	8.5	79	1.0	6.4	84	0.25	0.64	61	0.05	0.11	55
5/00	1.4	5.5	75	2.0	4.1	51	0.31	0.41	24	0.11	0.07	-57
6/00	1.2	5.7	79	2.0	4.3	53	0.12	0.43	72	0.05	0.07	28
7/00	1.5	6.5	77	2.0	4.8	58	0.20	0.48	58	0.06	0.08	25
8/00	3.1	7.4	58	4.0	5.6	29	0.35	0.56	38	0.14	0.09	-56
9/00	3.2	9.0	64	7.0	6.7	-	0.52	0.67	22	0.12	0.11	-9
10/00	5.2	11.9	56	5.0	8.9	44	0.50	0.89	44	0.27	0.15	-93
11/00	5.7	10.9	48	4.0	8.2	51	0.79	0.82	4	0.20	0.14	-38
12/00	3.6	13.7	74	6.0	10.3	42	0.65	1.03	37	0.30	0.17	-76
* Average	2.9	8.0	+64	3.0	6.4	+53	0.32	0.64	+50	0.13	0.11	-18

*The plus sign for average values indicate theoretical, feed based, values are greater than NPDES values. The negative sign is the opposite and is only true for TP.

Figure 2. Earthen Raceway



Source Water
Alk: +300
pH: 7.5
Temp: 50° F
Range: 50° F - 61° F

NPDES
BOD: 5.0
TSS: 3.0
TAN: 0.7 – 0.8
all mg/l

Best Management Practices For Pond Aquaculture

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Best Management Practices For Pond Aquaculture

Craig S. Tucker

Regulatory Status of Pond Aquaculture Systems

Although the United States Environmental Protection Agency (EPA) will not publish the final rule on effluent limitations guidelines for aquaculture until July, 2004, it appears likely that EPA will not propose nationally applicable regulations for pond effluents. In September, 2002, EPA published the proposed rule (United State Federal Register, Vol. 67, No. 177, pages 57872-57926), and the proposal specifically excludes ponds from new regulations (found at Federal Register 67(177):57884-57885. Part V.B. "Facilities Not Subject to 40 CFR Part 451").

The proposed rule also states (at Federal Register 67(177): 57875. Part III.A. "Concentrated Aquatic Animal Production Effluent Guideline Rulemaking History") that EPA does not propose to revise the existing language regarding aquaculture in the National Pollutant Discharge Elimination System (NPDES) permitting program. The proposal to leave the existing NPDES language (found at 40 CFR Part 122, Appendix C) intact is important because it defines which aquaculture facilities constitute "concentrated aquatic animal production facilities" and are therefore subject to the NPDES permit program. Presumably, the criteria in 40 CFR Part 122, Appendix C attempts to identify facilities or production systems whose discharge represents a significant threat to the environment (and would therefore be subject to NPDES permitting) and to distinguish those facilities or production systems from those that do not pose a significant environmental threat.

With respect to warmwater aquaculture in ponds, 40 CFR 122 Appendix C states that

"A hatchery, fish farm, or other facility is a concentrated aquatic animal production facility for the purposes of 122.24 if it contains, grows or holds . . . warm water fish species or other warm water animals in ponds, raceways, or similar structures which discharge water at least 30 days per year, but does not include: Closed ponds which discharge only during periods of excess runoff; or facilities which produce less than 45,454 harvest weight kilograms (approximately 100,000 pounds) of aquatic animals."

Nearly all aquaculture ponds are operated with limited intentional discharge and are therefore excluded from the NPDES permitting system. Note, however, that 40 CFR 122 also states that any aquatic animal production facility can be declared a concentrated aquatic animal production facility subject to the NPDES permitting if so declared by the Director of the United States Environmental Protection Agency on a case-by-case basis.

Improving Environmental Performance

Although EPA apparently will not propose nationally applicable effluent limitation guidelines for pond culture systems, the Agency does plan to promulgate "guidance" for pond aquaculture, probably in the form of "best management practices." Regardless of future regulatory activities, it is in the best interest of farmers to adopt sound management practices that reduce, to the extent economically feasible, the environmental impacts of fish farming.

Most farmers are aware that environmental protection is in their best interest due to practical concerns related to marketing and the public perception of aquaculture products. The current marketing appeal of farm-raised fish is based on the production of a high-quality product that can be differentiated from the quality uncertainties associated with other seafood. Maintaining the marketing appeal of farm-raised fish should be ample incentive for farmers to adopt responsible production and management practices. In addition, certain environmental management practices may also have collateral economic benefits by improving operational and production efficiency. For example, managing ponds to maintain some capacity to store rainfall reduces the requirement for groundwater, thereby reducing costs associated with operation of well pumps, simultaneously reducing the volume of effluent discharged. In another example, improving feeding practices will reduce waste loading to ponds, thereby improving water quality, and will increase the efficiency of feed utilization, thereby improving economic performance.

Four general approaches can be used in efforts to reduce quantities of substances discharged from ponds:

1) Decrease waste production within the pond by reducing the feeding rate, increasing the retention of feed nutrients by fish, or by optimizing the amount of nitrogen and phosphorus in the feed;
2) Increase the rate of in-pond biological and physicochemical loss processes for nitrogen, phosphorus, and organic matter to reduce concentrations of those substances in the pond before water is discharged;
3) Treat effluents to remove potential pollutants; or
4) Reduce discharge volume.

All four approaches to management of aquaculture pond effluents have been the subject of research, but the practical applicability of most options under commercial conditions is questionable.

Reduce Waste Production within Ponds

Despite the use of high quality manufactured feeds, relatively little of the nutrient content of the feed is ultimately converted to fish flesh and removed from the pond at harvest. Under commercial conditions, only about 10-20% of the carbon, 15-25% of the nitrogen, and 20-30% of the phosphorus in the feed is removed in fish at harvest. The remainder represents the nutrient load to the ponds. Reducing the waste load in ponds can be accomplished by decreasing the amount of feed added to the pond or by maintaining high feeding rates but increasing the efficiency of food utilization.

It is, however, critical to note that reducing waste loading to ponds may not translate to reduced waste discharge. The "disconnection" of system loading from mass discharge clearly differentiates ponds from open aquaculture systems, such as net pens and raceways, where the hydraulic retention time is so short that waste discharge is a simple function of waste loading to the system. In ponds, wastes produced by fish are not immediately discharged into the environment but rather eliminated or transformed within the pond by a variety of internal biological, chemical, and physical processes. The degree to which the wastes are eliminated depends primarily on hydraulic retention time and temperature, both of which vary considerably depending on pond hydrological type, culture species, individual farm management practices, season, and geographical location. For example, well over 90% of the nitrogen, phosphorus, and organic matter added to ponds as fish waste is removed from water prior to discharge from warmwater fish ponds with long hydraulic retention times (hundreds of days, or more). Lower removal efficiencies would be expected in coolwater ponds operated with shorter retention times.

Discharge frequency (which is related to hydraulic retention time) is another factor that "disconnects" waste loading from discharge. Modeling of mass discharge from catfish ponds operated over a broad range of pond draining frequencies resulted in a wide range of mass discharge estimates (John Hargreaves, Louisiana State University, unpublished data). To illustrate this point, one can envision two theoretical extreme cases. At one end of the spectrum, a pond that continuously discharges a large volume of water (essentially a flow-through system) will have a very short hydraulic retention time (minutes), a very high discharge frequency (infinity), and a waste treatment efficiency of 0% (all the waste produced by fish is discharged). On the other hand, a pond that never discharges has a very long hydraulic retention time (infinity), a very low discharge frequency (zero), and a waste treatment efficiency of 100% (none of the waste produced by fish is discharged).

The key point to made here is that certain physical factors, such as hydraulic retention time and discharge frequency, have greater effect on mass discharge than manipulating internal waste loading in ponds—at least for warmwater fish ponds managed to achieve economically viable production levels. As such, feed management probably offers limited opportunities for control of potential pollution from ponds, unless ponds are managed with relatively short hydraulic retention times (on the order of a few days, or less). Feed management does, however, provide benefits other than environmental protection. Feed represents the largest single variable cost of fish production and efficient use of feeds can improve farm profitability. Also, operating ponds within the assimilative capacity of the pond ecosystem will improve water quality inside the pond and provide a better environment for fish growth. Feed management is therefore one of the most important aspects of pond aquaculture, independent of potentially beneficial environmental effects.

Reduced feeding rates

Nutrients derived from fish wastes stimulate phytoplankton growth, and phytoplankton and phytoplankton-derived detritus constitute the overwhelming majority of solids in warmwater fish ponds. At low feeding rates, phytoplankton abundance is regulated by plant nutrient availability (derived from fish wastes) and the relationship between feed input rate and phytoplankton abundance is linear to a certain point. This point represents the transition between limitation of phytoplankton growth by nutrient availability and limitation of phytoplankton growth by light. Experimental evidence (Cole and Boyd 1986) and practical experience indicate that this first critical point (the transition between nutrient and light limitation of phytoplankton growth) occurs when mid-summer, long-term feeding rates exceed 30 to 50 pound/acre per day. Beyond that point, phytoplankton communities achieve a more or less steady-state maximum density and increases in feed input will not result in further increases in solids concentration.

At maximum sustained feeding rates of 30 to 50 pounds/acre per day, fish production can be no greater than 2,000 to 3,000 pounds/acre per year assuming a 150- to 180-day growing season and a feed conversion ratio of about 2.0. In the case of large-scale commercial catfish culture, annual yields this low are generally considered unprofitable. To achieve greater production and, presumably, profitability, farmers stock more fish and provide more feed.

As feeding rates increase past 30 to 50 pounds/acre per day, a point is eventually reached where the capacity of the pond to assimilate and process fish waste products is exceeded, and fish growth rate decreases markedly due to deterioration of water quality. That point is not well defined because the waste assimilation capacity of ponds is affected by many variables. Published information, field observations, and summertime feeding records from catfish farms using good fish culture practices indicate that fish growth rapidly decreases when feeding rates during the growing season exceed 100 to 150 pound/acre per day for prolonged periods. Presumably, the waste assimilation capacity of the pond is exceeded when higher feeding rates are used because water quality deterioration suppresses fish appetite. Thus, feed loading rates during the growing season within the range of 100 to 150 pounds/acre per day correspond to an upper critical limit for static-water aquaculture ponds under current management conditions.

Most catfish farmers in the southeastern United States manage ponds at a level of intensity between the two critical feeding rates described above. Within this middle range, pond water quality is optimized in relation to feed inputs and fish production. Pond water quality (and, therefore, effluent quality) could be improved by reducing feeding rates, but based on the available data, truly significant improvement in water quality appears possible only by reducing average daily feeding rates to less than about 30 to 50 pounds/acre per day.

The effect on effluent quality of managing feeding rates under commercial conditions has been studied for 3 years at the National Warmwater Aquaculture Center, in Stoneville, Mississippi. One set of ponds has been stocked with 7,500 catfish/acre and managed with a maximum daily feeding rate of 100 pounds of feed/acre per day. The other set of ponds has been stocked with 10,000 fish/acre with no daily feed limit. After 3 years of biweekly measurements, there are no significant treatment-related differences in concentrations of total nitrogen, total phosphorus, 5-day BOD, total suspended solids, and total volatile suspended solids.

Improved feed utilization efficiency

Considerable research has been conducted on methods of improving nutrient utilization in fish feeds with the goal of reducing waste production per unit of feed consumed. Most of the effort has concentrated on improving utilization of phosphorus, which is considered the most important potential nutrient pollutant released from fish culture facilities. There are obvious benefits of reduced waste phosphorus generation from fish cultured in facilities, such as raceways or net-cages, that discharge directly to the environment. However, the benefits of improved phosphorus utilization in static-water ponds with high fish densities are less clear. It appears that the reduction in phosphorus loading to the water possible by diet modification is overwhelmed by the complex fates of phosphorus within the pond ecosystem. As such, modest improvements in feed phosphorus utilization have not resulted in improved quality of potential pond effluents.

A series of unpublished studies have been conducted at the National Warmwater Aquaculture Center, Stoneville Mississippi, to evaluate the effect of improving phosphorus utilization by catfish on water quality and phytoplankton abundance in ponds. Three approaches were evaluated: 1) use feeds with the lowest possible phosphorus supplementation to meet the dietary requirements; 2) use a water-insoluble phosphorus supplementation (deflourinated rock phosphate); and 3) use microbial phytase to improve the bioavailability of plant phytate phosphorus. No differences in concentrations of soluble or total phosphorus or in phytoplankton abundance were found in ponds, regardless of approach used to reduce waste phosphorus loading in ponds by modifying practical diets.

In another study, Gross et al. (1997) measured phosphorus concentrations in channel catfish ponds receiving equal amounts of feed with phosphorus concentrations of 0.60, 0.68, 0.75, 0.81, and 1.03%. At the end of the grow-out period when feeding rates were highest, there were about the same amounts of phosphorus in waters of all ponds regardless of diet. However, more phosphorus was adsorbed by bottom soils in ponds with high phosphorus diets than in those with low phosphorus diets. Bottom soil adsorption and sediment oxidation-reduction potential largely control phosphorus concentrations in pond water, so lowering phosphorus concentrations in diets is beneficial, even if it does not result in direct reduction of water-borne phosphorus levels. Long-term reduction in phosphorus loading reduces the input of phosphorus to bottom soils and conserves the capacity of soils to adsorb phosphorus.

The efficiency of feed utilization can be increased by using careful feeding practices. Feeding fish more than they can consume in a relatively short period (20-30 minutes) is wasteful and results in poor feed conversion. Because feed typically represents about 50% of production costs, inefficient feeding practices can have a profound effect on profitability. In addition, decomposition of uneaten feed exerts an oxygen demand and releases nutrients that contribute to the development of high phytoplankton abundance in the pond.

Enhance Within-Pond Removal of Nutrients and Organic Matter

Natural biological and physicochemical processes within ponds act to reduce nutrient and organic matter levels in potential effluents far below the levels expected from the calculated mass balance of inputs and outputs. In effect, ponds act as their own water treatment system. Effluent quality could therefore be further improved if rates of these natural processes could be enhanced. Some approaches that have been examined include

1) Aeration or circulation to enhance the dissolved oxygen supply;
2) Precipitation of inorganic phosphorus from water using soluble calcium or aluminum salts; and
3) Use of bacterial or enzyme amendments (bioaugmentation).

Aeration and circulation

Mechanical aeration is usually the most important procedure for improving water quality in ponds. Aeration provides a zone of dissolved oxygen sufficiently large to maintain the cultured fish biomass. It also prevents thermal stratification and reduces the development of anaerobic conditions in deeper water and at the soil-water interface. By enhancing dissolved oxygen concentrations, aeration increases the capacity of ponds to assimilate organic matter by aerobic processes. Higher dissolved oxygen concentrations also increase the nitrification rate of ammonia to nitrate, which is then lost from the pond through denitrification in the large volume of anoxic sediment.

Aeration and water circulation also affect rates of phosphorus loss from pond water. Formation of oxidized ferric phosphates and phosphorus occluded in ferric oxyhydroxide coatings on soil particles in the surface layers of sediment are important sinks for orthophosphate from the overlying water. The thin layer of oxidized surface sediment also functions as a barrier preventing prevents the release of orthophosphate from deeper, anaerobic layers of mud into the overlying water. In the absence of an oxidized surface layer, soluble reactive phosphorus will be released from the sediment in response to a concentration gradient between sediment porewater and the overlying water column. This was demonstrated under field conditions by Masuda and Boyd (1994), who showed that soluble reactive phosphorus concentrations were higher in unaerated ponds than in aerated ponds. Apparently, the sediment-water interface in aerated ponds was sufficiently oxidized to function as an effective barrier to the diffusion of porewater soluble reactive phosphorus. So, adequate aeration and circulation can enhance rates of inorganic phosphorus removal from pond water, with the overall effect of reducing phosphorus availability to phytoplankton as well as reducing concentrations of soluble reactive phosphorus.

Despite the clear benefits of aeration, application of excessive aeration and circulation can have deleterious effects. Erosion of pond bottoms and levees by strong water currents produced by certain types of aerators can suspend large amounts of particles and potentially increase the suspended solid concentration in pond effluents.

Phosphorus removal using chemical precipitation

Alum (aluminum sulfate) has a long history of use in potable water supplies to reduce particulate turbidity. Treatment of water with alum also quickly reduces the amount of phosphorus in water by precipitation. Alum treatment increases the Al^{3+} concentration in water, and Al^{3+} quickly hydrolyzes to form aluminum hydroxide complexes of low solubility. The flocs of aluminum hydroxide formed after alum treatment act as ligands to adsorb phosphate ions. Phosphate is also removed by direct precipitation as sparingly soluble aluminum phosphate compounds.

Masuda and Boyd (1994) found that treatment of channel catfish culture ponds with 20 mg/L alum (about 1.8 mg Al/L) reduced soluble reactive phosphorus concentrations by about 50% and total phosphorus concentrations by about 80%. Much of the phosphorus removal from treated water was attributable to precipitation of phosphorus-containing suspended matter. The major limitation to the use of alum is that it has no residual activity and phosphorus concentrations quickly increase in aquaculture ponds in response to continuing inputs in feed. Frequent treatment would be needed for long-term control of phosphorus levels.

In naturally soft-water ponds, phosphate can be removed by increasing the concentrations of calcium, which forms poorly soluble calcium phosphates at pH values above neutrality. Gypsum is a relatively inexpensive and highly soluble source of calcium that has an advantage over alum as a phosphorus-precipitating ligand because calcium is only slowly lost from pond waters (unless the water is rapidly diluted with low-calcium water). As such, treatment of pond waters with gypsum should influence phosphorus levels for a longer period of time than alum treatment.

Wu and Boyd (1990) used gypsum to increase calcium concentrations of fertilized fish ponds from 2-3 mg/L to about 50-60 mg/L. Concentrations of soluble reactive phosphorus in gypsum-treated ponds were reduced by about 95% relative to those in control ponds. It should be noted, however, that most of the phosphorus in catfish pond waters is present in the particulate organic fraction, principally in living phytoplankton or phytoplankton-derived detritus. Increasing the water hardness using gypsum will have little effect on phytoplankton abundance (and, by extension, total phosphorus concentrations) as evidenced by the fact that phytoplankton are abundant in nutrient-enriched waters with extremely high calcium concentrations.

Bioaugmentation

Static pond aquaculture is possible because the natural pond microbial community performs many of the functions required to maintain adequate environmental conditions for fish growth. These functions include the decomposition of organic wastes and the transformation and eventual loss of waste nitrogen from the pond. The central role of the microbiological community in pond ecology has led to the belief that water quality can be improved by augmenting the native microbial community with microorganisms produced in culture. The theory is that the inoculum increases the total microbial biomass or the abundance of certain kinds of microbes in the pond (either directly or through subsequent growth of the inoculum) and thereby increases the rate at which certain processes are performed. This approach to ecosystem manipulation is called “bioaugmentation.” Another approach involves circumventing the role of microorganisms by adding enzymes directly to the water.

Numerous studies of aquaculture pond bioaugmentation have been conducted at Auburn University, in Alabama, and at the National Warmwater Aquaculture Center, in Stoneville, Mississippi. In one study (Queiroz and Boyd, 1998) application of a bacterial inoculum improved catfish survival but the difference in survival could not directly linked to the inoculum. In no study conducted at either location (published or unpublished) has bioaugmentation significantly improved water quality.

These results are not surprising given the current level of understanding of aquatic microbial ecology. The addition of large quantities of organic matter promotes the development of a dense and diverse microbial assemblage. The activity of the microbial community, and the resulting enhancement of organic matter decomposition, is more likely limited by the availability of oxygen or water temperature than by the population level of a particular group of organisms.

Treat Effluents to Remove Potential Pollutants

Many schemes for treating pond effluents or using the water discharged from ponds for a beneficial purpose have been proposed. These waste-management practices include nutrient and organic matter removal by traditional wastewater treatment processes, use of water in hydroponics or to grow another crop of aquatic animal, use of water for irrigation of row crops or rice, treatment by wetlands and settling basins, and water reuse. It is important to emphasize that the extremely intermittent nature of discharge and the winter-early spring peak in discharge volume strongly impacts the cost and potential effectiveness of nearly all treatment options

Wastewater treatment procedures such as mechanical or biological filtration and activated-sludge processes are not economically feasible because the nutrient and organic matter concentrations in pond effluents are too dilute to make these treatment procedures effective. Another complicating factor is that average annual hydraulic loading to a treatment system will be low, but when discharge occurs, the volume will be large for a brief period. This is a difficult engineering problem because the system must be designed to rapidly treat a large volume of dilute wastewater. The intermittent nature of pond discharges will also affect the economic performance of the system because the system will be idle for many more days than it is used. In short, conventional wastewater treatment technologies are too expensive to use with pond effluents.

Nutrients in fish pond effluents are not concentrated enough for use in hydroponics unless they are supplemented, which defeats the purpose of using this procedure to "treat" effluents. Also, it is difficult to visualize hydroponics being developed to the scale where any significant proportion of the discharge from a large aquaculture industry can be treated in that manner. Filter-feeding fish and mollusks and certain plants have been successfully cultured in effluents, but this practice has seldom been economical (in part because of limited markets for the "second" crop), and it does not greatly improve effluent quality. Again, a significant limitation is the intermittent and seasonal nature of discharge.

The three procedures that have been considered for the treatment of pond effluents are wetlands settling basins, wetlands, and irrigation. Each of these three procedures has serious drawbacks.

Wetlands

Using wetlands to treat wastewaters is based on removal of nutrients and solids as the water is slowly passed through a shallow, vegetated impoundment. Nutrients are assimilated by wetland plants, removed by physicochemical processes, such as precipitation and adsorption reactions in the soil, and transformed and removed by biological reactions associated with the vast surface area provided by plant roots and above-ground plant biomass. Solids are removed by filtration and settling as water slowly passes through the system.

Schwartz and Boyd (1995) designed a system where water from a single catfish pond was passed through a constructed wetland consisting of two cells planted with emergent aquatic vegetation. Concentrations of potential pollutants were much lower in effluent from the wetland than in influent from the catfish pond. Overall performance of the wetland was best when operated with a 4-day hydraulic retention time in the vegetative season, but good removal of potential pollutants was achieved for shorter retention times. The wetland was relatively efficient in improving water quality even in late fall and winter when vegetation was dormant.

The disadvantage of constructed wetlands for treating wastes from channel catfish ponds is the large area necessary to provide adequate hydraulic retention time when the process is used on large farms. In particular, the relationship between the pond area and wetland area needed for effective effluent treatment during the high-discharge winter periods is not known. Also, the usefulness of wetlands to treat pond effluents in more northerly locations is suspect.

Two studies have been conducted on the economics of using wetlands for treating effluents from ponds (Casado 1993; Kouka and Engle 1996). Both studies found constructed wetlands to be the most costly of the treatment options considered. Generally, the costs associated with the use of constructed wetlands are such that they are not a feasible option for treating all of the discharge from fish farms unless taxation rates per unit of discharge are high. Given the current small margins with which most catfish farms are operated, effluent taxation would seriously impact the potential profitability of pond aquaculture. Investment tax credits or other incentives would be required for wetlands to be an economically feasible effluent management system.

An alternative to using wetlands designed to treat all effluents from a farm would be to construct a small wetland to treat only the most concentrated effluents released when ponds are drained in the drier seasons—the time of greatest potential environmental impact because of low rates of dilution in effluent-receiving streams. In other words, effluents released during peak discharge would not be treated because of the large wetland area needed to provide an effective hydraulic retention time and the great dilution provided by high receiving stream flows. This approach would minimize the land needed for constructed wetlands and significantly improve effluent quality during dry periods. However, the overall reduction in mass discharge of nutrients and organic matter, and the costs associated with this scaled-down approach are unknown.

Settling basins

Settling basins are easier to construct and operate than wetlands because they do not have to be seeded with plants. More important, Boyd et al. (1998) showed that settling basins may be nearly as effective as constructed wetlands at removing potential pollutants from effluents discharged during pond draining, which often contain high concentrations of solids dislodged from the pond bottom by fish harvest activities (Boyd, 1978; Schwartz and Boyd, 1994). Sedimentation of synthetic pond effluents (designed to simulate waters released during the final stages of pond draining) for 8 hours removed more than 75% of suspended solids and total phosphorus and more than 40% of the 5-day biochemical oxygen demand (BOD_5) and turbidity. Removal of these substances is rapid because much of the phosphorus and organic matter in this particular kind of pond effluent is associated with inorganic suspended solids, primarily suspended soil particles, which settle quickly. Unfortunately, sedimentation may not be effective at removing potential pollutants from pond overflow because most of the solids, nutrients, and oxygen demand in those effluents is associated with phytoplankton that does not settle readily.

Boyd and Queiroz (2001) studied the feasibility of using settling ponds to treat effluent from pond draining alone or effluent from pond draining and storm overflow. Their calculations used data on Alabama climatology, land-use, and soil types, and were based on a settling pond with mean depth of 4 feet and an 8-hour hydraulic retention time. Average settling basin areas to treat effluents from pond draining alone are 0.25 acres per acre of levee pond and 0.28 acres per acre of watershed pond. Watershed ponds tend to be slightly deeper than levee ponds, which accounts for the need for a larger settling pond on a per-acre of production pond basis. Because of the effect of watershed area on runoff volume, settling pond areas required to retain and treat overflow from storms are much greater for watershed ponds than for levee ponds. For levee ponds, settling pond areas (per acre of production pond area) are 0.07 acres for rainfall from a 25-year storm, 0.08 acres for a 50-year storm, and 0.09 acres for a 100-year storm. Settling pond areas (per acre of production pond area) for watershed ponds are 0.43 acre for rainfall from a 25-year storm, 0.50 acre for a 50-year storm, and 0.57 acre for a 100-year storm.

Estimates of settling pond size were used by Boyd and Queiroz (2001) to calculate settling pond areas needed to treat draining effluent or draining effluent plus storm overflow for catfish farms of various sizes. Percentages of the farm area devoted to settling ponds for draining effluent from levee ponds ranged from 0.7% for a 500-acre farm to 14% for a 25-acre farm. The corresponding range for watershed ponds is 0.8% to 15%. To treat overflow from a 25-year storm on farms greater than 60 acres, settling ponds would constitute 7% of the farm area for levee ponds and 43% of the farm area for watershed ponds.

Boyd et al. (2000) observed that most catfish farms in Alabama extend downslope on watersheds to streams or property lines, which precludes installation of settling ponds unless existing ponds are taken out of production and reconfigured as settling ponds. Even where space is available, Boyd and Queiroz (2001) believe that land and construction costs for settling ponds large enough to treat draining and overflow effluents would be prohibitive.

In a recent study, Engle and Valderrama (2003) used economic engineering modeling to estimate investments and annual costs for 160 design scenarios using settling basins to treat catfish pond effluents. Investment and operating costs varied greatly with factors such as complexity of farm drainage patterns, pond size, effluent treatment requirement (whether to treat all effluents or just the most concentrated effluent), and farm size. Overall, it was concluded that the increased costs of using settling basins are prohibitive for nearly all scenarios and that requiring their use would impose a disproportionate burden on small farms.

For watershed ponds that must be partially drained to facilitate fish harvest, another possible approach, and one that does not require additional investment, is simply using the production pond as its own settling basin. When ponds are drained during fish harvest, most of the solids, organic matter, and nutrients are released in the last 20% of water discharged from ponds. So, when ponds are drained, the final volume of water may be held in the pond for 2 to 3 days to allow solids to settle before draining completely. Holding this last portion of water without discharge is even more desirable and can further minimize the potential environmental impacts of fish pond effluents. Alternatively, the last 20% of water discharged from ponds can be held in farm drainage ditches for settling prior to final discharge.

Crop irrigation

Most pond aquaculture is practiced in areas already used for intensive row-crop or rice agriculture. As such, it appears logical that pond effluents could be used to irrigate terrestrial crops. The primary goal of integrating aquaculture and terrestrial agriculture would be to make productive use of pond effluents by supplementing the water supply for irrigation. Nutrients in the pond effluent might also be beneficial to the crop.

Problems with using aquaculture pond waters for irrigation are as follows: 1) peak water demand for irrigation occurs at the time when there is little or no overflow from most fish ponds, 2) many fish farmers object to draining ponds during the summer growing season, and 3) total evaporation and seepage losses for irrigation water derived from ponds would be greater than that if the water were directly applied to fields. Also, in some types of irrigation (such as flooding of rice fields) water is needed quickly, in relatively large volumes, and at a specific time—which may or may not correspond to the availability of water from fish ponds. For example, a crop of rice requires about 3 to 4 feet of water, which corresponds to nearly the entire volume of most fish ponds for an equivalent area of rice. Low rates of water exchange do not improve water quality in fish ponds (McGee and Boyd, 1983), so using pond water for irrigation would not benefit fish production. Further, the need for large water volumes delivered quickly means that gravity flow from pond discharge devices may not be sufficient to provide the flow rates that are needed. Rapid delivery of large water volumes would require installation of large pumps and water distribution systems to convey water where it is to be applied in the required amounts.

The benefit of the "nutrient load" in pond effluents to the irrigated crop is largely an illusion because effluents from aquaculture ponds are, in fact, quite dilute with respect to major plant nutrients. For example, nitrogen is usually applied to rice as a top dressing at 25 to 50 pounds/acre. Assuming an ammonia-nitrogen concentration of 0.5 mg/L in pond water, roughly 20 to 40 feet of water would be needed to supply the amount of nitrogen usually applied to rice as fertilizer. Thus, the contribution of nutrients in catfish pond water to the irrigated crop is small. The lack of benefit of the nutrients in catfish pond water to the irrigated crop was verified in an unpublished study conducted at Stoneville, Mississippi, where rice fields were irrigated over a 3-year period using water pumped from a catfish pond. Rice yield across several nitrogen fertilization practices did not differ when using catfish pond water or ground water as a source of irrigation water.

Reduce Effluent Volume

Effluent regulations often place limits on concentrations of potential pollutants that can be discharged. A serious problem with concentration-based rules is that highly concentrated pollutants may be harmless if the volume of effluent is very small, whereas dilute pollutants might be harmful if large volumes are discharged. In that respect, mass discharge—the product of concentration and volume discharged over time—is usually more important than concentration alone in determining the impact of an effluent on the environment. The effect of concentration tends to have localized impacts near the point of discharge, whereas the effect of mass discharge tends to have impacts that have large temporal and spatial displacement from the point of discharge.

When considering the environmental effects of pond effluents, research has shown that changes in discharge volume are much more important than changes in nutrient and organic matter concentrations in controlling mass discharge from ponds (Tucker et al., 1996). Also, discharge volume is also easier to manipulate than effluent quality.

As outlined above, total effluent volume consists of water discharged during intentional water exchange, water that overflows unintentionally during periods of excess rainfall, and water discharged when ponds are drained. All three sources of effluent can be controlled to some extent.

Reducing overflow during water exchange

Water exchange is a common practice in many aquaculture ponds and water lost during "flushing" can constitute a substantial percentage of overall effluent volume. However, it may be possible to reduce water exchange, simultaneously conserving water and reducing discharge volume. For example, prior to about 1985, pumped water was used liberally in catfish ponds as a panacea for water quality and fish health problems. Catfish farmers believed that "flushing" the pond with pumped water from the well would substantially improve environmental conditions and benefit the fish population. Research (McGee and Boyd, 1983) and practical experience have demonstrated, however, that water exchange at rates possible in most commercial culture ponds (less than 5% of total pond volume per day) is generally not beneficial. Catfish ponds in northwest Mississippi are now managed as static systems with no intentional water exchange. Natural biological activity and mechanical aeration maintain adequate environmental conditions for culture and pumped water is used only to fill ponds and replace evaporation and seepage losses.

Reducing overflow caused by excessive rainfall

Although rainfall cannot be influenced by fish farmers, a surprising degree of control can be exerted on the volume of overflow released from ponds as a result of rainfall. Overflow volume can be dramatically reduced simply by not refilling ponds completely when water is added to replace evaporation and seepage losses. This leaves some storage capacity in the pond so that rainfall is captured rather than allowed to overflow. This method of conserving water and reducing effluents, originally modeled for catfish ponds by Pote et al. (1988) and Pote and Wax (1993), has become known as the "drop-fill scheme."

In drop-fill schemes, water is not added to the pond until the water level falls to a certain level below the level of the pond overflow device. Then the pond is not refilled completely, but water is added to allow the maintenance of some rainfall storage capacity. For example, a "10-6 drop-fill scheme" means that water would not be added to the pond until the water level fell to 10 inches below the level of the overflow device. Then, 6 inches of water would be added, bringing the water level to 4 inches below the overflow level. This 4 inches of storage will capture a large proportion of rainfall events, most of which are less than 4 inches. The basic idea is to manage pond water levels to maintain some capacity for the capture and storage of rainfall. By capturing as much rainfall as possible, the future need for pumped water is partially offset and the loss of rainfall through overflow is minimized.

Tucker et al. (1996) used a 30-year climatological record for northwest Mississippi to model the reduction in overflow volume possible by using a 6-3 drop-fill scheme. Pond overflow volumes for the average year were greatest in the winter and spring when rainfall was highest and pond evaporation rates were lowest. Use of the 6-3 drop-fill scheme greatly reduced overflow volumes compared to ponds managed without surplus storage. In an average year, use of the 6-3 scheme reduced annual overflow to about 30% of that from ponds managed without surplus storage. The reduction in pond overflow volume was greatest in the summer because the climatic conditions in the summer (high evaporation rates and brief, sporadic rainfall events) are such that ponds usually have sufficient storage to capture nearly all rainfall. The predicted overflow in the average summer was only about 8% of that from ponds managed without storage, and the model indicated that there would have been no overflow from ponds managed to maintain storage potential in exceptionally dry summers.

Hargreaves et al. (2001) extended the results of Tucker et al. (1996) by evaluating drop-fill schemes for embankment ponds with drops ranging from 2 to 18 inches and fills ranging from 2 to 6 inches. Overflow was greatest for the 2-2, 3-3, and 4-4 schemes (essentially refilling the pond completely each time the water level dropped to a predetermined level). Overflow was minimum for the 18-2 scheme. In general, overflow decreased as the water storage capacity in the pond increased. This may seem intuitively obvious but the magnitude of the effect was quite large.

For example, in an average climatological year in Mississippi, effluent discharge with the 2-2 scheme was about 29 inches/year, but was only about 18 inches/year with the 6-2 scheme, a reduction of 38%. Further reductions in discharge were achieved by additional increases in pond storage capacity: effluent discharge averaged 8 to 10 inches/year for any of the 18-inch drop schemes evaluated. There are, however, limits to the amount of storage capacity that can be maintained in commercial fish ponds because allowing large variation in storage requires the use of deeper ponds (which are much more expensive to build) so that an acceptable water depth for fish culture can be maintained. Most fish ponds are 3- to 4-feet deep, and can easily be operated with 6- to 12- inch drops without affecting fish growth or culture practices.

Another approach to reducing effluent volume is based on the use of some ponds on a farm for both fish production and water storage (Cathcart et al., 1999). The production/storage ponds are 1-3 feet deeper than typical production ponds to provide additional volume for storage of rainfall. The production/storage ponds are linked via culverts to 1 to 3 production ponds so that overflow from all ponds in the linked system drains into the production/storage pond. Overflow occurs only when the storage capacity of the linked system is exceeded. Mathematical modeling using a 26-year climatological record for northwest Mississippi showed that the effluent discharge from linked ponds can be reduced by 40-90% (depending upon rainfall) relative to single ponds refilled to the top of the overflow device every time the water level drops 3 inches. A field study to validate the model and identify any practical limitations to this approach is currently being conducted at the National Warmwater Aquaculture Center in Stoneville, Mississippi.

Reducing water discharged during pond draining

It is impossible to conduct pond aquaculture without occasionally draining the pond. Most commonly, ponds are drained to facilitate complete harvest of the aquaculture crop. Production schemes have, however, been developed for some species that allow multiple crops to be grown without draining the pond. Using such systems dramatically reduces effluent volume

The use of ponds for several years without draining and refilling is possible, in large part, because natural microbial and physicochemical processes continually remove nutrients and organic matter from pond water. The rate at which these processes act is such that fish ponds (at least in the southeastern United States) can be used for many years without significant long-term accumulation of nutrients and organic matter in the water column, despite large inputs of metabolic waste resulting from fish feeding practices.

When natural microbial and physicochemical processes act over the long hydraulic retention time that is characteristic of fish ponds, a large proportion of the total waste loading to the pond is removed before water is discharged. For example, Boyd (1985) estimated that in-pond processes removed 90% of the waste N and P, and 95% of the organic matter added to catfish ponds over 1 year. If water is retained in ponds for multiple years, further increases in waste treatment efficiency can be realized. In fact, Zimba et al. (2003) showed that catfish ponds can be operated continuously for 15 years, or longer, without year-to-year accumulation of nutrients and organic matter in the water column. So, if it is possible to use ponds for longer interval between drawdowns, fuller use is made of the "waste treatment" capability of the pond ecosystem because natural processes are allowed to remove more wastes from the water before it is discharged when the pond is drained. For example, compared to ponds drained each year, annualized waste discharge is reduced by approximately 30% when ponds are used for 3 years before draining and by 45% when ponds are not drained for 5 years (Tucker et al., 1996).

When it is necessary to completely drain ponds, it is may be possible to pump or drain water into adjacent ponds and store it. The water could then be drained or pumped back into an empty pond for reuse. On large farms, it may be possible to transfer water to a storage reservoir. Water quality would improve over time in the storage reservoir through natural water purification processes, and the water could then be reused.

Management Practices to Reduce Environmental Impacts

The unique nature of pond aquaculture poses challenges for effluent management. Overall, adoption of management practices that minimize environmental impacts may be a more effective means of implementing environmental management for the pond aquaculture than monitoring and post-discharge treatment. These practices, taken as a whole, will optimize mass discharge relative to fish yield by reducing effluent volume or by improving nutrient utilization within ponds.

Reduction of discharge volume must be the centerpiece of any set of best management practices for pond aquaculture because it is technologically difficult to achieve significant reductions in the concentrations of potential pollutants prior to discharge and most post-discharge treatment options are economically impractical. Aside from the obvious benefit of decreasing overall mass discharge, reducing discharge volume also increases hydraulic retention time. Given a longer retention time, natural biological, chemical, and physical processes are provided a greater period of time in which to remove nutrients and organic matter from water before it is discharged. As such, a smaller percentage of the waste loading to ponds enters is actually discharged.

Below is a list of recommended management practices that will make farm operations more efficient and provide environmental protection. The list is based on practices described by Schwartz and Boyd (1996), Brunson (1997), Boyd and Tucker (1998), Boyd (1999), Boyd et al. (2000), and Tucker et al. (2002). A wide variety of culture techniques and culture facilities are used in fish farming, so some practices may not be applicable, or economically justified, in all situations.

Pond Operation and Management

1) Operate food-fish production ponds for several years without draining
2) Capture rainfall to reduce effluent volume.
3) Eliminate or reduce water exchange.
4) Use high quality feeds and efficient feeding practices.
5) Manage within the pond assimilative capacity.
6) Provide adequate aeration and circulation of pond water.
7) Position mechanical aerators to minimize erosion.

Harvest and Draining Practices

1) Allow solids to settle before discharging water.
2) Reuse water that is drained from ponds.

3) Treat pond effluents in constructed wetlands or settling basins prior to discharge.
4) Use effluents to irrigate terrestrial crops.

Pond Construction and Renovation Practices

1) Optimize the ratio of watershed to pond area.
2) Divert excess runoff from large watersheds away from ponds.
3) Construct ditches to minimize erosion and establish plant cover on banks.
4) Protect embankments in drainage ditches from erosion.
5) Maintain plant cover on pond watersheds.
6) Avoid leaving ponds drained in winter, and close valves once ponds are drained.
7) Close drain valves when renovating ponds.
8) Use sediment from within the pond to repair levees rather than disposing it outside of ponds.
9) During pond renovation, excavate to increase operational depth, permitting increased water storage and greater fluctuation in water level.

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Best Management Practices for Recycle Systems

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Introduction

Recirculating aquaculture systems use flowing water to intensively culture fish and, by definition, they must treat and reuse a high percentage of the water to maintain water quality in the fish culture units. Recirculating systems use unit treatment processes designed to reduce fish metabolites, such as suspended and settleable solids, dissolved nitrogen compounds (ammonia and ammonium), and BOD, as well as processes for removing dissolved carbon dioxide and adding dissolved oxygen. These systems typically use tanks for confining the cultured fish, clarifiers or filters to remove particulate solids, biological filters to reduce dissolved wastes, strippers/aerators to add oxygen and decrease carbon dioxide levels, and oxygenation units to increase oxygen concentrations above saturation (Tables 1 and 2). Processes to provide advanced oxidation and pH control may also be required (Tables 1 and 2).

Recirculating aquaculture systems are used because they allow for greater control of the rearing environment, especially water temperature, than is possible in conventional flow-through, pond, or net pen applications. Recirculating aquaculture systems minimize water use and place the wastes into a concentrated and relatively small volume effluent. The reduced volume and concentrated effluent discharged from recirculating systems significantly reduces the size and thus the cost of wastewater treatment. The concentrating effect from recycling the water also can (in some instances) make it practical for recirculating aquaculture systems to discharge directly to publicly owned treatment works (POTWs). The increased waste capture efficiency created when treating a more concentrated effluent can also significantly reduce the daily waste load discharged in the farm effluent, sometimes allowing recirculating aquaculture systems to produce fish in locations that contend with strict environmental regulations. In addition, recirculating aquaculture systems are more amenable to implementation of biosecurity, or "hazard reduction through environmental manipulation," measures than outdoor systems because of a smaller facility footprint, smaller makeup water supplies that are either from a ground water source or can be disinfected, and higher level of management.

Table 1. Unit processes are used in intensive aquaculture systems to control water quality at levels sufficient for fish health (from Noble and Summerfelt, 1996).

Component: Purpose	Significant conditions and the units action on water quality	Importance to fish health
Culture unit: To contain fish during grow-out, allow fish to feed, and flush feces	• Fish respiration reduces levels of dissolved oxygen and increases levels of ammonia and carbon dioxide, which reduces pH. • Acid-base equilibrium (i.e., pH) controls the fraction of unionized ammonia and carbon dioxide present. • Feed introduces solids into the system. • Excretion produces particulate and dissolved solids. • High fish densities. • Fish may or may not carry pathogens. • Tank cleaning and fish handling or grading may occur that involve physical interaction with the fish.	• High fish densities and the deterioration in water quality (low dissolved oxygen and elevated carbon dioxide, ammonia, nitrite, and solids levels) may stress fish. • Physical interactions with the fish may produce fish stress or physical damage. • Horizontal pathogen transmission.
Clarification: To remove solids via settling, sieving, flotation, or filtration.	• Most conventional clarifiers do not remove fine solids (<20 µm). • Some clarifiers store organic solids, which can produce anoxic or anaerobic conditions, exert an oxygen demand, support microbes, and leach nutrients.	• Fish pathogens may be associated with solids. • Elevated levels of solids and ammonia may induce gill pathology.
Biofiltration: To provide surface area where micro-organisms can establish; when the reused flow passes across these surfaces, the microbes remove a portion of the dissolved wastes.	• Microorganism metabolism lowers oxygen levels and produces carbon dioxide, which reduces pH. • Oxygen must be present for bacteria to oxidize ammonia and nitrite. • Increased levels of nitrite leaving the biofilter can occur if the biofilter is overloaded. • Biofilters may take 3-6 weeks to develop the population of bacteria to convert ammonia to nitrite and an additional 2-4 weeks to develop the population of bacteria required to convert the nitrite to nitrate. • Microbial growth produces solids within the biofilter. • Biofilm and biosolids produced in the biofilter may slough and be carried out with the recirculating flow, which contributes to the microbial counts and the concentration of fine solids in the water.	• Biofilms may support certain fish pathogens, which may be passed to fish in the culture tank with sloughed biofilm carried in the reused flow. • Certain anaerobic by-products (e.g., sulfides) are toxic to fish. • Improved water quality reduces fish stress, which makes fish more resistance to disease. • Certain anaerobic by-products (e.g., sulfides) are toxic to fish.
Stripping/aeration: To contact water with air at near atmospheric pressures.	• Shifts concentrations of dissolved carbon dioxide, nitrogen, oxygen, and ozone towards equilibrium (i.e., adds oxygen, removes carbon dioxide, nitrogen, ozone, and gas supersaturations). • Strips little ammonia at typical pH levels (pH < 9.0).	• Elevated carbon dioxide reduces the capacity of blood to transport oxygen and may induce nephrocalcinosis.
Oxygenation: To contact water with purified oxygen at pressures ≥ atmospheric.	• Generally used to create supersaturations of oxygen. • High gas pressures can be produced when off-gas not vented. • Little carbon dioxide is removed due to insufficient gas exchange with respect to the volume of water treated.	• Gas supersaturations can produce gas bubble disease. • Increased oxygen levels can support much higher fish loadings in the culture tank, which adds stress.
Ozonation: To oxidize constituents in the water.	• Oxidation can reduce levels of nitrite, organic matter, microbes, water color, odor, or off-flavor compounds. • Organic matter and nitrite react with ozone, which makes sustaining an ozone residual difficult.	• Disinfection reduces risk from infectious diseases. • Improves water quality. • Ozone and certain of its by-products are toxic.

Table 2. Recirculating systems use some of the following unit processes to control accumulations of waste metabolites (from Summerfelt, 1996).

Unit process	Example types
Solids removal	• microscreen filters (drum, Triangel™, and disk) • settling basins • tube/plate settlers • roughing filters (packed with random rock or plastic, and with structured plastic) • swirl separators • pressurized filters (sand, activated carbon, and plastic bead) • gravity filters (high rate sand and slow sand) • flotation/foam fractionation
Biofiltration	• fluidized-media reactors (sand and plastic bead) • rotating biological contactors • trickling filters • submerged large media reactors • pressurized bead filters
Stripping/aeration	• mechanical-surface mixers • diffusers • columns (open to atmosphere or enclosed with forced ventilation) a. packed or tray b. spray • shallow air-lifts • corrugated inclined plane • stair-type drops
Ozone contactors	• U-tubes • columns (atmospheric pressure and pressurized) a. multistaged (e.g., low head oxygenators) b. packed or tray c. spray • oxygenation cones • oxygen aspirators • diffusers • enclosed mechanical-surface mixers

The costs associated with construction and operating the additional water treatment equipment can increase the cost of producing fish in recirculating systems to the point that they do not compete economically against less costly technologies. For example, recirculating systems are not typically used to grow out channel catfish. Likewise, the production of food-size rainbow trout or salmon in commercial recirculating systems is still minor compared to the biomass commercially cultured in flow-through systems and net pen systems, respectively. Commercial recirculating aquaculture systems are being used to produce relatively higher value fish or fish that can be effectively niche marketed for a higher price, such as: salmon smolts, certain ornamental and tropical fish, tilapia, hybrid striped bass, sturgeon, yellow perch, rainbow trout, walleye, arctic char, flounder, cod, and halibut in North America and sea bass, turbot, eel, and African catfish in Europe. Additionally, recirculating aquaculture systems in North America are being used at public hatcheries to produce trout, char and salmon for recreational stock enhancement or restoration of threatened and endangered aquatic species.

Although there are a number of widely diverse recirculating aquaculture systems, only a few recirculating aquaculture systems discharging wastewater directly to a receiving water body (and not to a POTW) have an annual production rate exceeding 100,000 pounds (45 metric tons). Taking tilapia for example, according to the American Tilapia Association (Charles Town, West Virginia) recirculating systems accounted for more than 75% of the more than 8,000 metric tons of annual tilapia production in the United States by the end of the 1990s. Presently, several of the largest tilapia producers in the United States have zero discharge to receiving waters, as they discharge to POTW and sometimes apply a slurry of their thickened manure to fields at agronomic rates. Some of the larger commercial recirculating aquaculture systems that produce tilapia also agronomically apply their concentrated wastes on fields or treat these wastes within constructed wetlands before discharge.

There is great heterogeneity between recirculating systems, in part due to the wide variety of species being cultured and the broad range of conditions under which the fish must be grown. There is even heterogeneity in the type of recirculating system used to culture the same species, especially in different regions of the continent. Continuing with the tilapia production example, some recirculating tilapia systems rely completely on more traditional physical/chemical and fixed-film biological treatment processes while others use a 'green water' or organic detrital algae soup (an activated sludge-type treatment) treatment process and others include an aquaponic component to treat the water using plants that are also marketed as produce. Total suspended solids concentrations in these different systems can range from less than 10 mg/L to greater than 150 mg/L. Thus, the many types of recirculating systems can have distinctly different water quality and volumes of water discharged. Therefore, the associated waste management systems must consider the specifics of each recirculating aquaculture system in order to successfully achieve waste collection, transfer, storage, treatment, and utilization. And, a waste management system that works specifically with a given recirculating system cannot be automatically assumed to be appropriate for a different type of recirculating system.

Although most larger recirculating aquaculture systems require a continuous but relatively small flow of make-up water, recirculating systems are clearly distinguishable from flow-through systems in that they require biological treatment within the system to prevent ammonia from accumulating to harmful levels and they have distinctly different hydraulic residence times (HRTs). Flow-through systems will typically operate with an overall HRT of < 1–3 hours. However, a recirculating system with an HRT of at least 12 hours would be considered an 'open' system, but this system would still likely capture and remove > 90% of the particulate solids produced while controlling culture tank water quality. A longer HRT is indicative of a higher degree of water reuse and particulate waste capture efficiencies will approach 100% as recirculating system HRT approaches or exceeds 10 days. Therefore, in order to maintain suitable water quality, recirculating systems must assume the treatment burden for 90–100 percent of the ammonia and particulate waste that they produce. This waste treatment burden is similar to the waste treatment burden that catfish pond systems carry, and both of these systems carry a much higher waste treatment burden than flow-through or net pen systems.

Waste management first requires removal of the wastes produced within the fish culture system (Figures 1 and 2). To remove the wastes requires either capture (e.g., microscreen filters capture suspended solids) or treatment (e.g., biofilters remove ammonia when they convert it to nitrate). Captured wastes must then be transferred to further processes for storage, treatment, or some form of utilization (Figures 1 and 2).

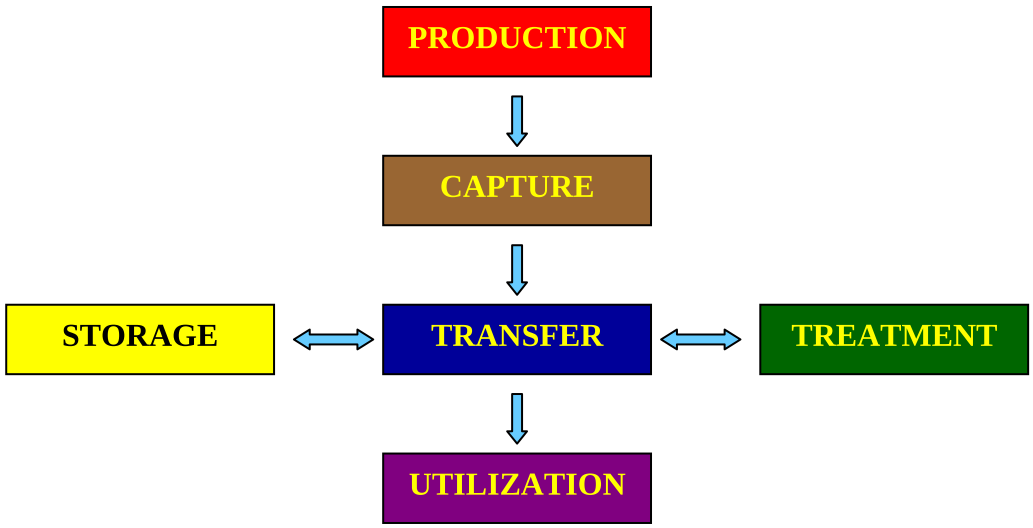

Figure 1. Waste management first requires capture of the wastes produced and then transfer to storage, treatment, or some form of utilization.

All recirculating aquaculture systems ultimately must use an on-site treatment or disposal option to be rid of a relatively small but concentrated slurry of captured biosolids and in some cases to treat a more dilute but relatively larger volume system overflow (Figure 2). As an alternate to on site treatment, either of these wastes flows could be discharged to a POTW.

Best waste management practices (BMPs) can be used to reduce pollution discharged from recirculating systems and to promote water quality within these same systems. This paper describes BMP's to (1) improve waste capture and promote better water quality within recirculating aquaculture systems, (2) reduce effluent volume and/or improve effluent water quality discharged from recirculating aquaculture systems, and (3) treat, store, utilize, and/or dispose of captured biosolids. To this end, BMP's are provided in the following areas:

- site selection,
- feed management,
- carrying capacity identification and management,
- solids removal from the recirculating aquaculture system,
- solids removal from recirculating system effluents before discharge,
- solids storage,
- solids treatment and disposal,
- nitrogen and phosphorus treatment,
- prevention of aquatic species escape,
- mortality removal,
- prevention of aquatic species escape, and facility operation and maintenance.

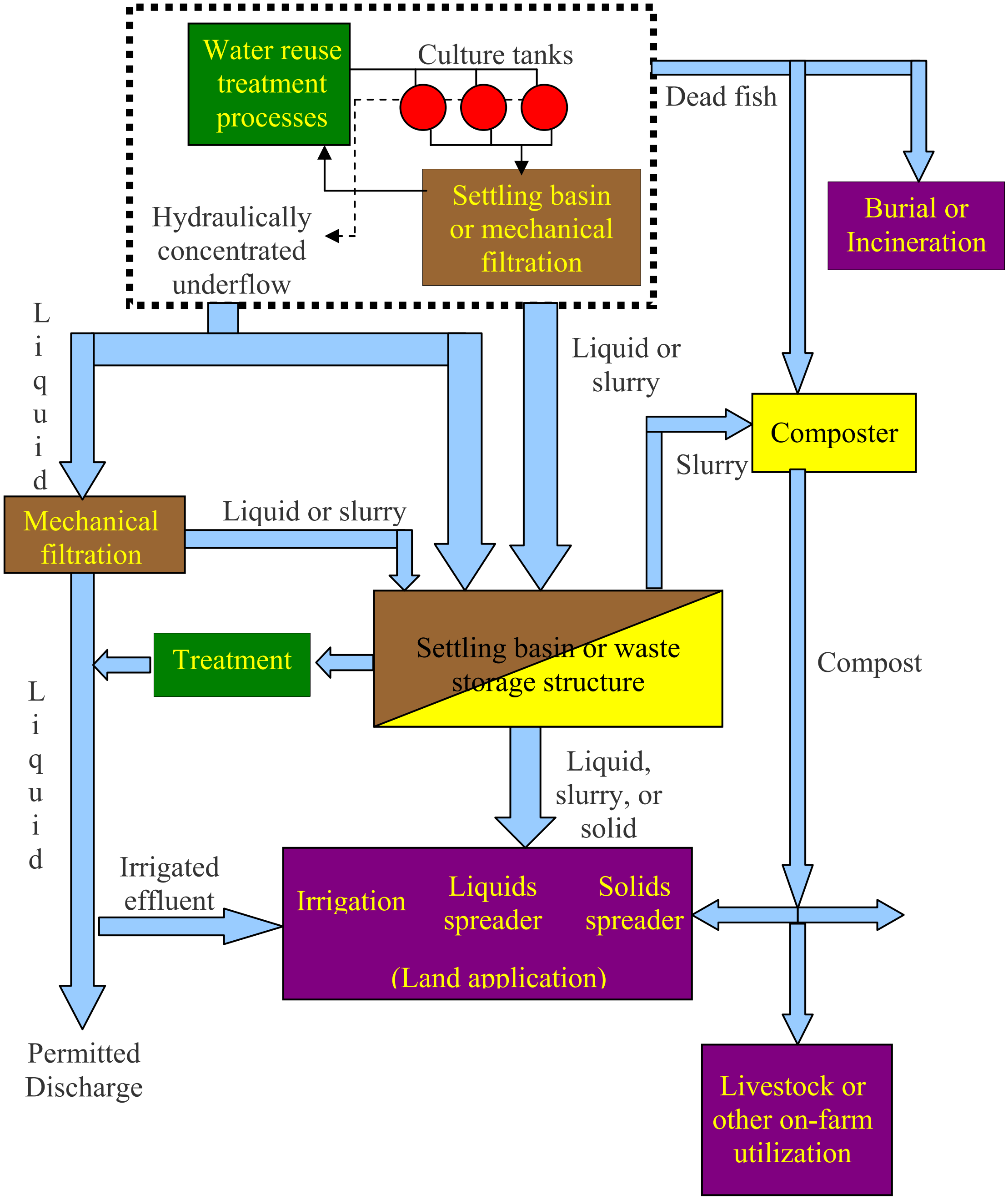

Figure 2. Possible waste management routes to first capture or treat the wastes and then transfer wastes to storage, treatment, or some form of utilization.

Site Selection

A site must be considered carefully before construction to identify all restrictions and regulations that may apply to the use of the land and water for aquaculture. City and county zoning and building restrictions are widely different between locations and can seriously effect construction requirements and costs. Local, state or federal agencies may have authority over land use, water use (including discharge into waters of the United States) and building construction. For guidance, contact the local state office of environmental quality and the local state office of the USDA Natural Resources Conservation Service. A National Pollution Discharge Elimination System (NPDES) Permit administered under the federal Clean Water Act may be required. Additional site review may be required by the United States Army Corps of Engineers.

When selecting a site to build a recirculating system, avoid flood prone areas in order to prevent contaminating the recirculating system with surface water or even catastrophic loss of fish or damage to equipment. Site topography should allow for discharge into receiving waters at an elevation above flood level. Site topography should also allow construction of pump sumps, culture tanks, and any required treatment vessels in a manner that considers water table depth, to avoid floating an empty vessel if the ground below becomes saturated with water. Construction of facilities and access roads should not alter natural water flows needed to maintain surrounding habitats.

Unit processes used for wastewater treatment (such as tanks, ponds or wetlands) should not be located where containment failure could result in loss of life or damage to residences, industrial buildings, highways, public utilities, or environmentally sensitive areas.

Identify a site with a reliable makeup water supply that has sufficient volume to meet the requirements of the recirculating system. When possible, asses historical records of the water supply to check its reliability. The makeup water supply must also be clean and uncontaminated so that it cannot harm fish or cause poor water quality in the culture system and its effluents. The makeup water supply should also be free of chemicals that can accumulate in fish tissues and affect product quality or food safety. In general, a ground water source is considered better than a surface water source for use in recirculating systems because ground water, if concentrations of iron or other contaminants are not a problem, usually has a relatively constant temperature and contains fewer solids, few or no potential fish pathogens, and few or no vertebrates or invertebrates (such as snails) that might create problems in the recirculating system. Surface waters typically do not meet the same criteria as ground water and surface waters are prone to unsuspected pollution or fish pathogens. If used, surface water may require filtration and disinfection prior to use. Chlorinated tap water can be used by relatively small recirculating system, but the chlorine must first be removed from the water and the cost of this water may be cost prohibitive.

Feed Management

Feed is the major input of solids, biochemical oxygen demand (BOD), nitrogen, and phosphorus in recirculating aquaculture systems. Therefore, feed management is one factor among many in the control of potential pollution from recirculating aquaculture systems. However, feed management does provide benefits other than environmental protection. Feed represents the largest single variable cost of fish production and feeding methods that minimize waste feed and maximize productivity will improve production efficiency and farm profitability. Minimizing waste feed will minimize the wastes that must be treated in the recirculating system and ultimately the amount of waste released to the environment. Feed management is therefore one of the most important aspects of recirculating aquaculture systems.

Feeds should meet the nutritional requirements of the fish under culture, and should be formulated to optimize digestibility, improve efficiency, and reduce waste output. Feed pellets should be water stable and should be shipped and handled at the farm to minimize pellet breakage and production of fine particles. Stored feed should be secure from contamination, vermin, moisture and excessive heat. Long term storage of feed can affect feed quality.

Feed size should be appropriate for the size of fish in each rearing unit.

Feeding levels should maximize feed conversion rates and be sufficient to produce maximum growth, depending upon production objectives. Feeding levels are influenced by species being fed and its size, feed formulation, water temperature, dissolved oxygen and carbon dioxide concentrations, fish health status, and management goals.

Feed can be delivered by hand, by demand feeders, or by mechanical and automatic feeders. Whenever possible, feed utilization should be monitored by observing feeding behavior or by looking for trends in waste feed collecting within the culture unit or waste feed exiting the culture unit. Use of multiple feeding events distributed over a 24-hours period can provide more uniform water quality within a recirculating system than a feeding schedule only offering meals once or twice daily. Feeding equipment improperly adjusted or malfunctioning can over or under feed a population of cultured species, which can diminish feed and production efficiency. Therefore, feeding equipment should be checked periodically to ensure efficient operation.

For recirculating aquaculture systems, the loading of potential pollutants to a receiving body of water is not entirely related to feed input, but is dependent upon the effectiveness of waste capture and treatment processes within the recirculating system and on any additional effluent treatment processes used to clean the water before discharge. However, increased waste production and waste discharge can be a direct consequence of operating at feed levels in excess of the recirculating system's carrying capacity.

Carrying Capacity Identification and Management

Water quality criteria required to maintain a healthy and fast growing fish are the basis for designing water reuse processes. The parameters of primary concern are dissolved ammonia, nitrite, oxygen, carbon dioxide, nitrogen and solids. These parameters are important because their production or reduction can lead to concentrations that affect fish growth and health.

Certain species (e.g., salmonids) require excellent water quality to support their healthy and sustainable production within recirculating systems. Achieving high water quality standards within recirculating systems requires effective treatment of all waste metabolites that could compromise fish health (Noble and Summerfelt, 1996). Therefore, the following factors should be considered when designing recirculating systems to achieve high water quality:

- selection of unit processes that achieve high removal efficiencies;

- specification of culture tank exchange rates that are rapid enough to adequately supply dissolved oxygen and also prevent the waste produced during one pass through the culture system from degrading water quality; and
- a system design that allows for relatively simple cleaning routines to remove sediment and biological growth from all pipes, sumps, channels and unit processes within the recirculating system.

Fish respiration, i.e., the consumption of dissolved oxygen, and the production of waste metabolites are proportional to feeding levels. Therefore, to maintain water quality inside the recirculating system that promotes fish health and growth, recirculating aquaculture systems should be operated at feeding levels that are within the assimilative capacity of the system's water treatment processes and water flows. Dissolved oxygen is usually the first water quality parameter to limit culture tank carrying capacity (Colt et al., 1991), which, in simplistic terms, is the maximum fish biomass that can be supported at a selected feeding rate. In most tank-based recirculating aquaculture systems, in-tank aeration or flowing water determines the carrying capacity of the system, not the volume of culture units in the system. Flowing water carries dissolved oxygen to the culture units, receives the waste produced in the culture unit, and carries these wastes away from the culture unit to treatment units before the wastes can accumulate to harmful and undesirable levels. The water flow requirements through the culture units within a recirculating system can be much greater than the make-up water flow requirements that flush the system, because recirculating systems will by definition treat and reuse large portions of the system make-up water flow. Of primary importance is the removal of the waste metabolites: ammonia, carbon dioxide, and total suspended solids (TSS), whose production is directly proportional to feed load. Biofilters, aeration columns, and filters/clarifiers are unit processes used to control ammonia, carbon dioxide and TSS accumulations within recirculating systems. Therefore, the concentration of wastes within the fish culture water are much lower than expected based on waste loading produced from feed, because the water quality is also dependent upon the unit process treatment efficiencies and the flows of the recirculating and makeup waters (Liao and Mayo, 1974). Aquacultural engineering texts and many other publications provide the methodology to design biofilters, aeration columns, and filters/clarifiers to treat a given flow or the waste metabolites produced by a given feeding rate (Timmons and Losordo, 1994; Summerfelt, 1996; Summerfelt et al., 2001; Timmons et al., 2002).

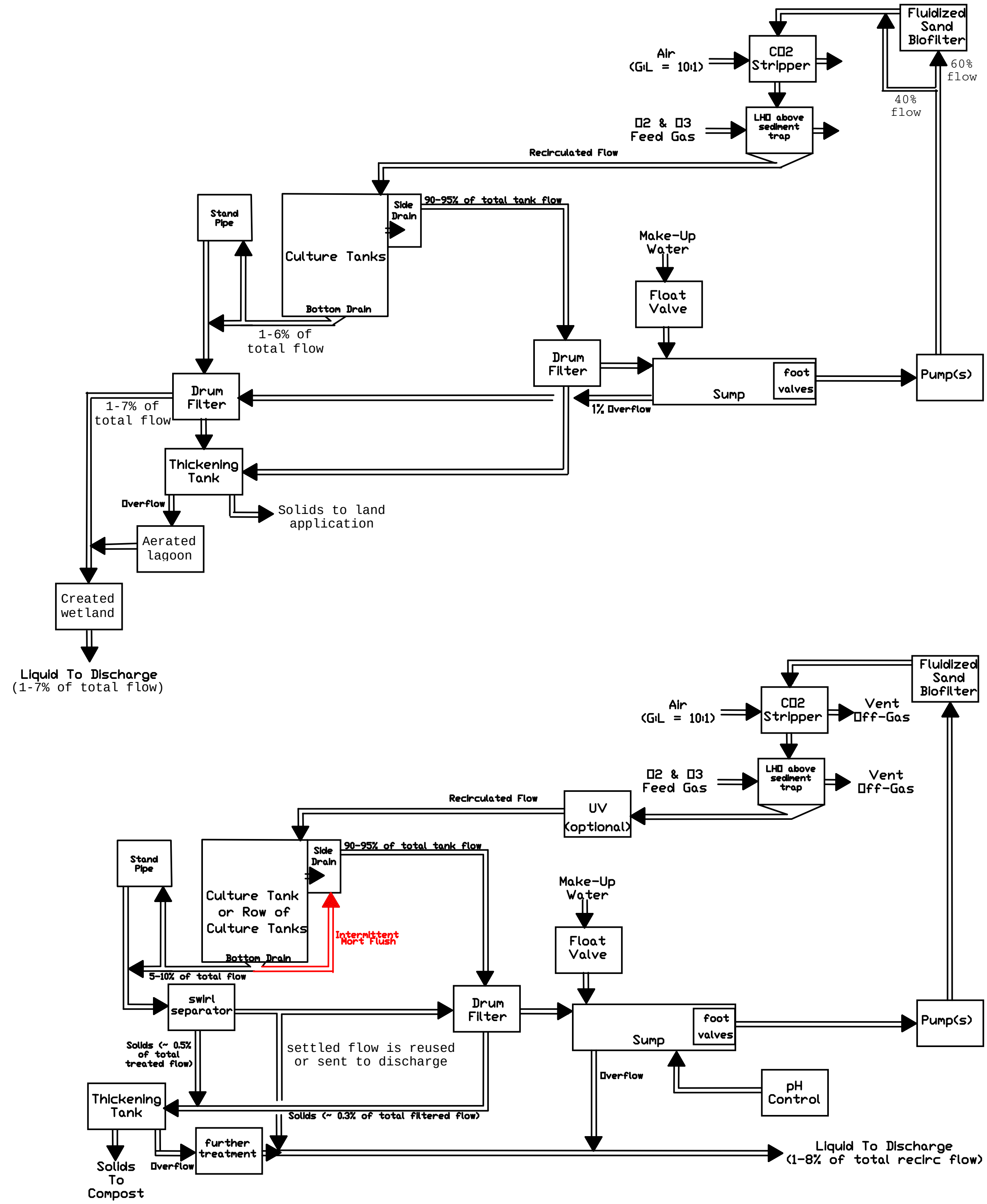

Figure 3. Two sample process flow drawing illustrates the waste management processes used at West Virginia Aqua's Rockhouse Springs Growout Farm in Man, West Virginia (top) and at the Conservation Fund Freshwater Institute (bottom) (Summerfelt et al., In Press).

When a unit treatment process (e.g., biofilter or aeration column) is designed, the designer should use a steady-state mass balance – as first described by Liao and Mayo (1974) – to predict the expected water quality exiting a culture tank within a recirculating system, which depends upon the treatment efficiency of the unit processes, the production rate of the waste (which is proportional to feed loading), and the recirculating system water flow rate and make-up water flow rate. This calculation helps to ensure that the design will provide safe water quality for the fish when they are reared at maximum carrying capacity, i.e., feed loading.

Significant progress has been made in the development of recirculating systems over the past 30 years. As pointed out in the introduction to this paper, many different types of recirculating systems are used and these different systems can produce distinctly different water quality within the system and in their discharge. Figure 3 provides an example of several of the recirculating system designs that have been used in North America for the culture of coldwater salmonid species. These types of process flow drawings are useful for tracking water and waste flows within and discharged from recirculating aquaculture systems.

Solids Removal from the Recirculating Aquaculture System

Wastes produced within recirculating systems include uneaten feed, dissolved metabolites, and fish feces. Waste feed and fish fecal matter are waterborne and require separation for efficient management of water quality within the recirculating system. The solids treatment processes in a recirculating system remove a portion of the feed derived waste solids in the recirculating water. Higher solids removal efficiencies result in cleaner water within the recirculating system. Therefore, the concentration of particulate wastes within the fish culture water is much lower than would be predicted based on the waste loading from feed, because it also depends upon the capture efficiency of the solids treatment process and the recirculating and makeup water flow rates (Liao and Mayo, 1974).

Culture tanks should be designed and operated to flush solids from the culture unit

Circular tanks can rapidly concentrate and remove settleable solids. Circular tanks are designed to promote a primary rotating flow that creates a secondary radial flow that carries settleable solids to the bottom center of the tank, making the tank self-cleaning. The self-cleaning attribute of the circular tank depends on the overall rate of flow leaving the bottom-center drain, the strength of the bottom radial flow towards the center drain, and the swimming motion of fish re-suspending the settled materials. The factors that affect self-cleaning within circular tanks are also influenced by the water inlet and outlet design, tank diameter-to-depth ratio, water rotational period, size and density of fish, size and specific gravity of fish feed and fecal material, and water exchange rate through the culture tank. However, in a well designed circular tank, only about 5 to 20% of the total flow passed through a circular tank may be all that is required to concentrate settleable solids at their bottom and center, which in some instances allows circular culture tanks to be managed as “swirl settlers”. Concentrating solids into a relatively small bottom-drain flow will increase the solids removal efficiency at the ‘down stream’ solids removal process in comparison to those removed from an un-concentrated flow.

If used, raceways should be designed to prevent the settling of solids within the rearing unit. Solids flushed from the fish culture areas of raceways can be captured in quiescent zones, other settling basins, or mechanical filters. Solids that settle and decompose in rearing units can degrade water quality, which may irritate fish gills and lead to fish disease.

Solids should be removed rapidly and gently

Waste solids exiting the rearing tank can be removed from the bulk flow leaving the culture tank using a treatment unit such as a settling basins (e.g., full-flow settlers, off-line settlers, quiescent zones, inclined [tube or plate] settlers, and swirl separators), microscreen filters (e.g., drum, disk, or belt filters), and granular media filters (e.g., bead or sand filters). In addition, ozone and foam fractionation are water treatment processes that can be used to remove extremely fine organic particulates, so they complement solids removal via settling or filtration. Conventional sedimentation and microscreen filtration processes are often used to remove solids larger than 40-100µm. However, few processes used in aquaculture can remove dissolved solids or fine solids smaller than 20-30µm. Depending on the particle size distribution and the concentration of solids, conventional sedimentation and microscreen filtration processes typically remove anywhere from 30-80% of the solids in the treated flow. The best solids removal processes remove solids from the system as soon as possible and exposes solids to the least turbulence, mechanical shear, or micro-biological degradation. Note that microscreen filters and swirl separators (with a continuous underflow) do not store solids for an appreciable period, unlike settling basins and most granular media filters. Significant degradation or re-suspension/flotation of the solids matter should be avoided, but can occur in treatment units such as settling basins and granular media filters because of their relatively infrequent backwash. If unit processes are not installed to remove fresh and intact solids rapidly, then solids decomposition within recirculating systems can degrade water quality and thus directly affect fish health and the performance of other unit processes. Also, products of solid decomposition are more difficult to remove from aquacultural effluents.

It is important to note that not all recirculating aquaculture systems maintain low levels of suspended solids, as is typically the goal in a recirculating systems used for sensitive species such as trout and salmon. Other species may tolerate elevated levels of suspended solids and may actually consume the algae or micro-organisms found in these solids. Such is the case for some recirculating systems used for tilapia and shrimp (or other species). Some of these recirculating systems rely on a combination of what is generically called ‘green water’ or sometimes called an organic detrital algae soup (ODAS; an activated sludge-type treatment process) and settling basins or granular media filters to treat the water. In these instances, the rapid removal of waste solids is not a goal because the ‘green water’ and ‘ODAS’ growing in situ within the recirculating systems may be reliant upon the solids degradation to drive heterotrophic treatment of the dissolved wastes. Total suspended solids concentrations in these recirculating systems can exceed 150 mg/L. Thus, the associated waste management systems must consider the specifics of each recirculating aquaculture system in order to successfully achieve waste collection, transfer, storage, treatment, and utilization (Figures 1 and 2).

Backwash of the solids capture unit will create an intermittent solids laden flow that will require treatment before discharge (Figure 3), unless discharged to a POTW.

Solids Removal from Recirculating System Effluents Before Discharge

Solids can impact the aquatic environment. In addition, phosphorus and BOD wastes are largely distributed among the settleable and filterable solid fractions, making rapid suspended solids concentration, removal from the system, and disposal a primary objective of aquaculture effluent treatment. Therefore, many recirculating aquaculture systems ultimately must use an on-site treatment or disposal option to be rid of the relatively small but concentrated slurry of captured biosolids. In some cases, it may also be necessary to treat the more dilute but relatively larger volume system overflow before this flow is discharged. As an alternate to on site treatment, either of these wastes flows could be discharged to a POTW.

In practice, nearly all recirculating systems will require make-up water and will produce an effluent of some volume. Recirculating systems will often have two separate discharges (Figures 2 and 3): the system primary flow, which is relatively large in volume and has dilute waste concentrations; and, the system solids flow, which is a relatively small flow containing the concentrated solids backwashed from the solids removal unit, flushed from quiescent zones, or flowing continuously from the bottom drain of a dual-drain culture tank or swirl separator. The more continuous primary flow of displaced water (such as an overtopping flow from a pump sump that is water that has been displaced by makeup water addition) may have a concentration of solids similar to that found in the fish culture tanks. The primary flow discharged from recirculating systems may or may not contain concentrations of wastes that would require treatment in order to meet effluent standards. The recirculating aquaculture system's relatively small volume but more concentrated solids flow will likely require solid capture before discharge. However, even though the waste concentrations may be relatively high, the cumulative waste load discharged to receiving watersheds from recirculating systems are generally much lower in TSS, BOD, total ammonia nitrogen, and total phosphorus than would be discharged from a similar sized single-pass or serial reuse production facility.

Remove solids from concentrated backwash flows before to they are discharged

Solids backwashed from solids removal processes tend to be dilute at less 0.1–2% total solids content. However, these solids must be removed by further concentration and thickening, which typically occurs in settling basins and can produce solids concentrations of up to 5–10% total solids content. Other sludge thickening methods include sand beds, wedgewire sieves, inclined belt filters, bag filters, filter presses, centrifuges, vacuum filters, and created wetland drying beds. All of these techniques have specific advantages and disadvantages, but solids thickening within a settling basin is the most frequently applied technology.

Thickening basins operate according to discrete particle settling principles. However, because thickening basins are often receiving water with elevated solids content and are concentrating these solids, they are also subject to compression settling within the layer of captured solids at the bottom of the basin. The particles in this region begin to form a structure of particle-particle contact and the slurry is concentrated further. In general, the overflow rate for sludge thickening basins used to treat intermittent backwash flows should be approximately 0.0009 ft^3/s per square foot (0.00027 m^3/s per square meter) of settling area with hydraulic retention times of between 20 to 100 minutes. Overflow rate is defined as the volume of water flow per unit time per square foot of settling area and is commonly expressed as cubic feet per second of flow per square foot of settling area.

Settling basins can be rectangular or circular. Water flows from one end of a rectangular vessel to the opposite end in a linear manner. In a radial-flow settling tank, water is gently introduced within the center of the circular vessel and it then flows radially to a collection launder located around the perimeter of the vessel.

A settling basin used to treat the backwash flows from a recirculating system will be relatively small compared to the settling basins used in flow-through systems, because the backwash flows from recirculating systems are relatively small. For example, the backwash flow from a microscreen filter is only 0.2-2.0% of the bulk flow that it treats. Therefore, achieving a conservative hydraulic loading rate may not require a large settling basin.

Solids thickening and storage tanks will often discharge a supernatant/overflow, which will be a relatively small volume discharge but one that contains the highest concentration of wastes leaving a recirculating system. Therefore, treating the thickening tank overflow before discharge can reduce the mass load of wastes discharged from the recirculating system. Treatment can be relatively simple and inexpensive (compared to the recirculating system processes) due to the extremely low volumes that must be treated. Further removal of soluble BOD and ammonia may be required, and can be accomplished with properly designed aerated basins, aerobic lagoons, created wetlands, anaerobic filters, or other suitable technologies. Alternatively, the thickening tank overflow could be reused beneficially for irrigation or hydroponics.

Remove solids from the recirculating aquaculture system's overtopping flow before it is discharged

Depending upon their makeup water requirements, some recirculating systems will have an overtopping flow in addition to a concentrated backwash flow. The concentration of solids in the overtopping flow is typically similar to that found in the fish culture tanks. Depending upon the specifics of the recirculating aquaculture system, the suspended solids in the flow overtopping this system may require further treatment. Waste solids can be removed from the overtopping flow using a treatment unit such as a settling basins (e.g., full-flow settlers, inclined [tube or plate] settlers, and swirl separators), microscreen filters (e.g., drum, disk, or belt filters), granular media filters (e.g., bead or sand filters), or dissolved air flotation systems.

Solids Storage

Concentrated aquaculture solids can be stored in thickening basins that have been designed to accommodate the build-up of solids and hence provide some temporary solids storage capacity. However, solid-liquid separation becomes less effective as sludge accumulates within these basins. Increasing sludge depths can compromise settling basin hydraulics and the solids stored can rapidly ferment leading to solids flotation and dissolution of nutrients and organic matter. In many cases the thickened sludge from thickening basins is transferred to larger sludge storage structures capable of holding months of captured and thickened solids. These off-line storage structures typically have zero overtopping flow and store their manure slurry contents until they can be removed for disposal.

Sludge storage structures include earthen ponds, above-ground tanks, and below-ground tanks. Earthen ponds are generally rectangular basins with inside slopes (horizontal:vertical) of 1.5:1 to 3:1. Depending on site geology and hydrology, earthen ponds can have liners of concrete, geomembrane, or clay. Because they are uncovered, earthen pond design will include the capacity for storage of rain water as well as a method for removing solids. In the case where solids will be removed via pumping, the solids must be agitated to provide a uniform consistency. Pond agitation may be accomplished with hitch-type propeller agitators that are powered by tractors or by agitation pumps. Propeller agitators work well for large ponds, while chopper-agitator pumps work well for smaller ponds. Solids removal may also be done with heavy equipment, in which case pond design should include ramp access (maximum slope of 8:1) and suitable load capacity in the unloading work area.

Sludge may also be stored in tank structures, above and below ground. Storage tanks are primarily constructed of reinforced concrete, metal, and wood. Reinforced concrete tanks may be cast-in-place, walls, foundation, and floor slab, or they may be constructed of pre-cast wall panels, bolted together, and set on a cast-in-place foundation and floor slab. Metal tanks are also widely used, with the majority being constructed of glass-fused steel panels that are bolted together. There are many manufactured, modular tanks commercially available in both reinforced concrete and metal, as well as wood.

Design of all structures, earthen or manufactured, should include considerations for internal and external hydrostatic pressure, flotation and drainage, live loads from equipment, and dead loads from covers and supports.

Solids degradation during storage can produce dangerous levels of hydrogen sulfide gas, methane and hydrogen gases, and in tanks with little air exchange can contain an atmosphere that includes the aforementioned gases and is also depleted in oxygen. Use OSHA confined space guidelines when considering all aspects of the human interface with a solids storage structure and take every practical precaution to prevent harm to those working around these structures.

State and local regulations regarding odors from the manure storage vessels must be followed.

Solids Treatment and Disposal

Fish manure should be defined as an agricultural waste. Fish feces contains nitrogen and phosphorus and can be used as a soil amendment. The composition of solids removed from a recirculating aquaculture system will vary according to feed formulation fed to the fish, biosolids age, and treatment of solids inside and outside of the recirculating system. It is unlikely that these solids will contain toxic concentrations of contaminants, however, the concentration of salts and heavy metals in the solids must be taken into account when considering long term application of aquacultural solids on agricultural crops. Certain state or local government authorities may consider the fish manure captured in an aquaculture systems wastewater treatment processes an industrial or municipal waste (i.e., not an agricultural waste). This designation by local or state authorities can limit waste disposal options.

Disposal of solids should comply with all applicable local regulations. Solids disposal should be conducted in a manner that prevents the material from entering surface or ground waters. This will be a site-specific practice according to local regulations, soil types, topography, land availability, climate, crops grown, etc. Disposal options include land application on agricultural lands, long-term storage lagoons, composting, reed drying beds, and contract hauling.

Land application

The most common form of aquacultural waste utilization is land application. Proper application of fish waste provides a safe method for waste utilization while fertilizing crops and amending the soil. Fish manure in liquid form may be spray irrigated directly onto agricultural land. In slurry form, fish waste may be pumped into a tank truck/liquids spreader and then applied to agricultural land. Finished compost generated from aquacultural waste solids may also be applied onto agricultural land at agronomic rates. In some instances, supernatant or leachate from slurry treatment processes with high nutrient concentrations can be irrigated at agronomic rates.

Lagoons

Manure slurries from aquaculture operations may be treated in waste treatment lagoons, which can both thicken and stabilize the manure.

Composting

Thickened and dewatered manure may be composted. Composting stabilizes the waste solids and produces a valuable soil amendment. Aerobic static pile composting is the most common method for composting dewatered manure. Any excess supernatant, leachate, or filtrate leftover from slurry treatment processes may contain elevated TSS, COD, and nutrient concentrations that will require a suitable disposal plan. State and local regulations regarding composting should be considered.

Reed drying beds

Depending on location and the local regulations, an aquaculture facility may have only limited and costly options available for disposal of the thickened manure, especially if transportation costs make sludge disposal on crop land uneconomical. Disposing of the sludge on-site within created wetlands may be an attractive alternative. A constructed reed drying bed can provide on-site treatment of a concentrated solids discharge with an uncomplicated, low-maintenance, plant-based system. Reed drying beds are vertical-flow wetland systems that have been used over the past 20 years to treat thickened sludge (1-7% solids) produced in the clarifier underflow at wastewater treatment plants and have been recently used to treat manure from commercial recirculating systems. Manure is loaded in sequential batches onto the reed drying bed every 7-21 days. Only 7-10 cm of manure is applied during a given application. The 1-3 week intervals between manure applications allow for dewatering and drying, which is facilitated by the vegetation growing on the sand bed. Reed beds have a useful lifetime of up to 10 years.

Contract hauling

A licensed contract hauler can also be paid to come and remove the thickened manure.

Nitrogen and Phosphorus Treatment

Discharge of ammonia-nitrogen may or may not be regulated, but nearly all recirculating systems will use biological nitrification to convert the total ammonia nitrogen (because it unionized form is toxic) to nitrate (relatively non-toxic), so total ammonia nitrogen concentrations may be relatively low in the water discharged from these systems. Nitrate typically makes up the largest fraction of dissolved nitrogen discharged from a recirculating aquaculture system that uses a nitrification process. When required, nitrate can be removed by biological denitrification. However, nitrate removal with denitrification is a more complex and costly process than solids control and is infrequently used.

Phosphorus is distributed primarily among the settleable and filterable solid fractions, making rapid suspended solids concentration, removal from the system, and disposal a primary objective of aquaculture effluent treatment. The removal of dissolved phosphorus is more complex and expensive and its complexity and cost increases as the required effluent phosphorus concentration decreases. When required, phosphorus removal can be accomplished by fine mechanical or granular filtration, biological treatment, or chemical precipitation. However, these options may be too costly for a fish farm to support.

Prevention of Aquatic Species Escape

Before importing or transporting an aquatic species, follow all local, state, and federal regulations that govern type of species allowed for aquaculture, importation, holding, and transport. Contact appropriate state and federal agencies for regulations governing aquaculture, importation, holding, and transport, because most states tightly regulate the type of species allowed for aquaculture.

Design the facility to provide secure containment of the cultured species. To prevent escape or loss of cultured species, barriers of appropriate size and strength should be installed on the facility discharge and on the makeup water entry into the facility. A procedure or mechanism should also be identified to prevent debris from plugging the barriers, thus preventing water from overflowing or by-passing the screens.

Avoid areas prone to flooding when siting facilities. Waters that flood a recirculating system could allow cultured animals to escape.

Mortality Removal and Disposal

Fish mortalities in aquaculture are unpredictable and highly variable. Depending on water temperature and species, dead fish either float or sink after dying, with fish in warm water typically floating and fish in cold water typically sinking. Dead or moribund fish are transported by flowing water to a tank drain, where they can accumulate against screens and restrict the water flow out of the culture unit. In recirculating systems, sinking fish mortalities tend to accumulate on the exclusion screen on the bottom center drain of circular tanks or on the outlet screen of linear raceways. Floating fish will accumulate on the surface of circular tanks, where they are relatively easy to see. Dead fish should be removed from recirculating systems as soon as possible to maintain water level in the culture tank, to reduce the spread of fish disease, and to reduce water quality deterioration that would be produced if dead fish were allowed to decay within the recirculating system. Dead fish that sink may be difficult to detect at the bottom center of large circular culture tanks that are deep or contain turbid water. A procedure or mechanisms should be identified for detecting and removing dead fish from the culture tanks under all circumstances.

Do not discharge mortalities into receiving waters. Appropriate barriers on the outlet to receiving waters will prevent discharge of fish mortalities into receiving waters.

Use only approved methods of mortality disposal. Disposal methods may be site-specific and usually governed by state or local regulations. Disposal options include composting, rendering, use as a soil amendment, incineration, or landfill.

As much as possible, prevent mortalities by following recommended aquatic animal health management practices. Most states offer diagnostic services and treatment recommendations for disease problems.

Facility Operation and Maintenance

Operating recirculating aquaculture systems in a sustainable fashion can protect the environment and protect the farm investment. Long-term economic performance is enhanced and environmental impacts are reduced when recirculating aquaculture facilities are well-maintained, managed efficiently, and operated in compliance with all applicable laws and regulations. As such, the following management practices should be implemented.

Store and use petroleum products in a manner that prevents them from contaminating the fish culture systems or the environment. Information on petroleum storage regulations can be obtained from State Departments of Commerce, State Departments of Environmental Quality or Protection, or from regional EPA offices. Used oil should be disposed of according to state or federal regulations.

Store and use chemicals in a manner that prevents them from contaminating the environment. Water treatments and disinfectants are the most common chemicals used in recirculating aquaculture. Chemical use is regulated by federal and state agencies and individuals are responsible for using products according to label instructions and disposing of containers and unused chemicals according to applicable state and federal regulations. Chemicals should be used only when needed and only for the specific use indicated on the label. All chemicals should be stored in secure, well-ventilated, water tight buildings.

Develop a response plan for spills of petroleum products, pesticides, and other hazardous materials. State and federal law requires reporting significant spills of petroleum and pesticides. The plan should be developed specifying response procedures, key staff, and regulatory authority phone numbers and all facility employees should be aware of the plan.

Collect and dispose of solid waste on a regular basis and in a responsible manner according to all applicable state and federal regulations.

Develop a record-keeping system on parameters such as feeding, chemical use, water quality, significant changes in conditions or events, fish culture operations, and inventory. Good record keeping can facilitate improvements in the efficiency of farm input use. Paper copies of records should be maintained for archival purposes; computerized record-keeping tools can be used for trend analysis and forecasting. Records should be reviewed periodically to determine if they are useful and to provide insight into opportunities for improvement of farm operation.

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