Best Management Practices for Flow-Through, Net-Pen, Recirculating, and Pond Aquaculture Systems

Lead Editor

Craig Tucker
Mississippi State University

Contributing Editors

Sebastian Belle
Maine Aquaculture Association

Claude Boyd
Auburn University, Alabama

Gary Fornshell
University of Idaho

John Hargreaves
Louisiana State University

Scott LaPatra
Clear Springs Foods, Inc., Idaho

Steven Summerfelt
The Freshwater Institute, West Virginia

Paul Zajicek
Florida Department of Agriculture and Consumer Services

This document was prepared as part of an Interagency Agreement between the United States Environmental Protection Agency (EPA) and the United States Department of Agriculture Cooperative State Research, Education, and Extension Service (CSREES), and a Cooperative Agreement between CSREES and Mississippi State University. The editors acknowledge the input, technical assistance, and critical review of the document by members of the Aquaculture Effluents Task Force of the Joint Subcommittee on Aquaculture.

CONTENTS

SECTION 1

THE ROLE OF BMPS IN AQUACULTURE

1.1 BMPs and Environmental Management in Aquaculture

Best Management Practices (BMPs) combine sound science, common sense, economics, and site-specific management to reduce or prevent adverse environmental impacts of a particular activity. Environment management relies heavily on BMPs, and they often are applied in water quality regulations, land management programs, and product certification. They also are promoted worldwide by environmental advocacy groups, lending institutions, international development agencies, and others interested in better environmental stewardship and greater sustainability.

The benefits of BMPs are greatest for activities where pollution is the sum of effects of several activities separated in time and conducted over a relatively large area. This situation is characteristic of non-point source pollution from aquaculture. Application of BMPs also is ideal for activities such as aquaculture where various methods of production are used on sites with different characteristics. Moreover, BMPs are valuable in activities such as aquaculture where producers often do not realize that environmental impact may occur or do not know how to avoid this impact. Adoption of BMPs can standardize techniques, encourage better technology, and enhance environmental stewardship. Implementation of BMPs should, in the long term, increase profitability and sustainability as well as providing environmental protection.

Establishing numerical effluent limitations guidelines is difficult for most types of aquaculture. Discharge may be highly intermittent (such as from ponds) or diffuse (such as from net pens), which make treatment and monitoring for compliance difficult and expensive. It is therefore not surprising that BMPs have become key components of both voluntary and mandatory environmental programs in aquaculture.

There are at least five ways in which BMPs can be applied in aquaculture:

1) Regulatory agencies may prescribe BMPs instead of requiring numerical limits for water quality variables in effluent permits;

2) Facilities attempting to comply with numerical water quality limits in effluent permits may install BMPs to improve effluent quality;

3) Limitations on water quality variables in some effluent permits do not protect against certain events, and supplemental BMPs may address these situations;

4) Certifying bodies may require producers to implement BMPs to achieve certification status for products produced by environmentally-responsible methods; or

5) They can be adopted voluntarily by producers to improve environmental stewardship.

Some aquaculture facilities in the United States must comply with NPDES effluent permits, and pending federal effluent limitation guidelines for aquaculture will require more facilities to do so. Effluent permits often have numerical limits on water quality variables, but they usually do not prescribe practices for achieving compliance with the limits. Faced with this situation, producers may implement BMPs as a means of complying with effluent permits. This use of BMPs is similar to the use of BMPs in environmental management systems (EMS), but compliance with effluent permit conditions is mandatory while adoption of EMS and associated standards is voluntary. Also, effluent permits with water quality criteria are generated by the government, while in EMS, the limitations often are established by the EMS owner.

Aquaculture facilities in the United States that qualify as concentrated aquatic animal production facilities must comply with NPDES effluent permits. In instances where there are no federally-mandated effluent limitation guidelines, a state can require BMPs as the sole means of compliance with the NPDES program. State environmental management agencies are responsible for designing such BMPs. A specific set of BMPs could be prescribed for all producers, or BMPs could be tailored for each facility.

Sometimes, an effluent permit consisting only of numerical limits for water quality variables is not adequate for environmental protection. For example, suppose that a farm has installed a settling basin to assure compliance with an effluent permit. The settling basin must be cleaned occasionally, and when this event occurs, there may be a high probability of non-compliance with permit limitations on suspended solids or other variables. The permit may prescribe BMPs for settling basin operation in order to avoid non-compliance with the permit. Another example is that of fuel storage on watersheds to which effluent permits apply. Fuel tanks could overflow or rupture spilling into effluent. Secondary containment around fuel tanks may be considered a necessary BMP in the permit.

Voluntary adoption of BMPs, installation of BMPs to comply with product certification standards, and application of BMPs to meet requirements of effluent permits are straightforward processes over which producers have complete control. They can adopt BMPs according to individual discretion and site characteristics, or they may choose to operate without BMPs. Potential problems can arise if BMPs are mandatory, and especially if a specific suite of BMPs is prescribed for an entire industry.

1.2 BMPs as Part of the EPA Regulatory Process

Regulation of potential sources of pollution is accomplished by establishment of numerical limits, narrative statements, or best management practices. Title 40 of the Code of Federal Regulations Part 122.2 defines BMPs as schedules of activities, prohibitions of practices, maintenance procedures, and other management practices that prevent or reduce pollution. Although BMPs have traditionally focused on good housekeeping measures, BMPs may be used in a wide variety of pollution prevention activities. When used as part of a regulatory activity, BMPs are most often used

1) to reduce pollution from activities ancillary to industrial processes (such as runoff from a plant site, spillage or leaks, and so on);

2) in situations where numerical limits are not feasible or;

3) in situations where they are necessary or best suited to achieve numerical limits.

When used as part of the regulatory process, BMPs are developed into formalized plans that become an enforceable part of the National Pollutant Discharge Elimination System (NPDES) permit for the facility.

1.3 BMPs as Part of State Activities

A number of states have identified BMPs for aquaculture facilities to support environmental protection. The BMPs are being used as voluntary or required components in some state effluent regulations, and for guidance and education for producers and regulators. Some BMPs have been developed for specific species and associated production systems.

Additionally, numerous research studies are underway or planned at regional and state levels to identify technologies and practices that have measurable benefits for environmental protection and are affordable and practical for implementation at facilities. This research and development work is expected to continue and result in improved BMPs that support environmental protection and producer adoption. The following are examples of how some states are using BMPs related to aquaculture effluents and facilities.

Alabama

Auburn University aquaculture faculty, with funding from the Alabama Catfish Producers (a division of the Alabama Farmers Federation), have developed a set of BMPs for aquaculture facilities in Alabama. The BMPs are described in a series of guide sheets and a manual "Best Management Practices for Channel Catfish Farming in Alabama" (Boyd et al., 2003) that have been adopted by the USDA Natural Resources Conservation Service (NRCS) to supplement the Service's technical standards and guidelines. The NRCS technical standards are intended to be referenced in Alabama Department of Environmental Management rules or requirements promulgated for aquaculture in Alabama. The guide sheets address a variety of topics, including reducing storm runoff into ponds, managing ponds to reduce effluent volume, controlling erosion in watersheds and on pond embankments, using settling basins and wetlands, and implementing feed management practices.

Arizona

Arizona’s regulation for BMPs for feeding operations covers aquaculture facilities classified as feeding operations for purposes of regulation of discharge water quality (Statutory reference: ARS 49-245-47; CWA Section 318). The Arizona Department of Environmental Quality regulates aquaculture through three general, goal-oriented BMPs. These BMPs address manure handling, including harvesting, stockpiling, and disposal; treatment and discharge of aquaculture effluents containing nitrogenous wastes; and closing of aquaculture facilities when they cease operation (Fitzsimmons, 1999). Compliance with these BMPs is intended to minimize the discharge of nitrates from facilities without being too restrictive for farm operations. The draft document “Arizona Aquaculture BMPs” describes practices that can minimize nitrogen impacts from aquaculture facilities. A list of resources is also available for additional information about Arizona aquaculture and BMPs (Fitzsimmons, 1999).

Arkansas

The Arkansas Bait and Ornamental Fish Growers Association has developed a list of BMPs to help its members make their farms more environmentally friendly (Arkansas Bait and Ornamental Fish Growers Association, Undated). The manual “Best Management Practices (BMPs) for Bait and Ornamental Fish Farms” provides a set of BMPs that help to conserve water, reduce effluent, capture solids, and manage nutrients. Members may voluntarily agree to adopt the BMPs on their farms. For more information, contact the University of Arkansas at Pine Bluff.

Florida

Florida statutes require that any person engaging in aquaculture be certified by the Florida Department of Agriculture and Consumer Services and to follow BMPs (Chapter 597, Florida Aquaculture Policy Act, Florida Statutes). “Aquaculture Best Management Practices,” a manual prepared by the Department, establishes BMPs for aquaculture facilities (Chapter 5L-3, Aquaculture Best Management Practices, Florida Administrative Code). The practices in the manual are intended to preserve environmental integrity while eliminating cumbersome, duplicative, and confusing environmental permitting and licensing requirements. When these BMPs are followed, facilities meet the minimum standards necessary for protecting and maintaining offsite water quality and wildlife habitat. All certified aquaculturists are required to follow the BMPs in Chapters II through X of the manual, which address federal permitting; construction; compliance monitoring; shipment, transportation, and sale; water resources; nonnative and restricted nonnative species; health management; mortality removal; and chemical and drug handling (Florida Department of Agriculture and Consumer Services, 2000).

Hawaii

The USDA-CSREES Center for Tropical and Subtropical Aquaculture funded the development of a practical BMP manual to assist aquaculture farmers in managing their facilities more efficiently and complying with discharge regulations. The manual “Best Management Practices for Hawaiian Aquaculture” (Howerton, 2001), is available at:

<http://library.kcc.hawaii.edu/external/ctsa/publications/BMP_txt.htm>

The manual addresses topics related to site selection, farm operations and effluent management.

Idaho
In combination with site-specific information, “Idaho Waste Management Guidelines for Aquaculture Operations” can be used to develop a waste management plan to meet water quality goals. Such a waste management plan addresses Idaho’s water quality concerns associated with aquaculture in response to the Federal Clean Water Act and Idaho’s Water Quality Standards and Wastewater Treatment Requirements. The manual is also intended to assist aquaculture facility operators in developing BMPs to maintain discharge levels that do not violate the state’s water quality standards (Idaho Department of Environmental Quality, Undated)

Louisiana

The Louisiana State University Ag Center has published a manual of “Aquaculture Production Best Management Practices” (Louisiana State University Ag Center, 2003). The manual, available at

<www.lsuagcenter.com/Communications/pdfs_bak/pub2894aquaBMP.pdf>

was prepared in consultation with representatives of the Natural Resources Conservation Service, the Louisiana Department of Environmental Quality (DEQ), the Louisiana Department of Agriculture and Forestry, and the Louisiana Farm Bureau Federation. Reflecting the diversity of Louisiana aquaculture, the manual includes BMPs for finfish production in ponds, crawfish production in ponds, crawfish nutrient management, intensive production systems, soil and water management, pesticide management and pesticides, and general farm practices. Adoption of BMPs by producers is voluntary and the Louisiana DEQ has no current plans to make implementation of BMPs in aquaculture compulsory.

Maine

Both voluntary and mandatory BMPs are used in Maine. The Maine Aquaculture Association and its member farmers have developed a series of codes of practices and cooperative agreements designed to establish minimum operational standards, and BMPs are an integral part of these codes. Both the codes of practice and their attendant BMPs are regularly reviewed and updated by members of the Maine Aquaculture Association. Best management practices have been developed and implemented to address biosecurity, animal welfare, escape prevention, waste management, nutrient management, therapeutants and chemical use, production management, integrated pest management, coordinated bay management, community relations, visual impacts, and farm operation and maintenance.

In several cases such as biosecurity, fish containment, nutrient management, fish health and coordinated bay management programs, BMP compliance is a specific condition of the permits and leases necessary to operate an aquatic farm in Maine. These permits also require regular auditing of BMP implementation. Through onsite sampling state environmental monitoring programs routinely assess the efficacy of the BMPs in minimizing environmental impact. All permits and leases may be revoked if BMPs are not appropriately implemented or if environmental impacts exceed thresholds established by the relevant public agency.

Michigan

Michigan State University faculty, with industry and multi-governmental agency input, have developed "Generally Accepted Agricultural and Management Practices (GAAMPs) for the Care of Farm Animals" which includes aquaculture species. The GAAMPs are written to provide uniform, statewide standards and acceptable management practices based on sound science. These practices can serve producers in various sectors of the industry to compare or improve their own managerial routines. Agricultural producers who voluntarily follow these practices are provided protection from public or private nuisance litigation under the Right to Farm Act. The GAAMPs are reviewed annually and updated when new scientific discoveries, changing economic conditions, or regulatory actions may require revision of the practices.

The Aquaculture Species GAAMP contains an overview of the aquaculture industry in Michigan and information on stock procurement, transportation, handling, facilities and equipment, health care and medical procedures, and useful references. The Michigan Care of Animals GAAMP can be accessed through

<http://www.michigan.gov/documents/MDA_AnimalCareRedlineStrikeout2003_67612_7.pdf>

Missouri

The Missouri Department of Natural Resources Environmental Assistance Office has developed a publication, "Missouri Aquaculture Environmental and Regulatory Guide,"

<http://www.dnr.state.mo.us/oac/pub513.pdf>

that provides basic information and suggestions to protect the environment through pollution prevention. The individual guide sheets address specific topics including discharge permits, backflow prevention, dead fish disposal, proper drug use, prevention of fish diseases, solid waste disposal and recycling and wastewater disposal and permits. The publication also includes a checklist of practices to prevent pollution at aquaculture operations.

New Jersey

Rutgers University is finalizing "Recommended Management Practices for Aquaculture" that includes Agricultural Management Practices (AMPs) and an Aquatic Organism Health Management Plan. The document was developed by the New Jersey Departments of Agriculture, Environmental Protection and Health in cooperation with Rutgers University, the Haskin Shellfish Research Laboratory, the New Jersey Aquarium, Cumberland County College and the state aquaculture industry. Recommended practices are designed to assist potential aquaculturists in complying with appropriate environmental regulations and facilitate the permitting process while protecting environmental quality and wild stocks. Specific AMPs deal with effluent management and water quality treatment. To develop coherency among the various rules, regulations and practices impacting aquaculture, these practices are included in a general rule, Criteria and Standards for Animal Waste Management.

Oklahoma

Langston University and the Oklahoma Aquaculture Association in consultation with the Oklahoma Department of Environmental Quality have identified a series of BMPs for aquaculture facilities. The BMPs were developed for consideration as a component in the effluents permitting process for aquaculture facilities that require a discharge permit. Presently, official adoption of the BMPs in the permitting process is pending based on the outcome of EPA national effluent regulations. However, adoption of BMPs that support good environmental management is encouraged by all aquaculture producers regardless of the need for a discharge permit. Producers can also devise their own BMPs that are not already identified. BMPs are intended to minimize nutrient and sediment discharges from farms and support expansion with practical requirements that meet discharge regulations.

Washington

Net-pen fish farmers in Washington State have had an industry-sponsored "Best Management Practices Manual" since the 1980s. The most recent version was published in 1991, and addresses all aspects of facility operation, fish health management, emergency plans, safety, pollution monitoring, and other issues.

A voluntary Code of Conduct was completed in 2002 and can be viewed at

<http://www.wfga.net/conduct.asp>

The voluntary code addresses many overall concepts to complement a code of practice revision. Since 1996, fish culture BMPs have been intermeshed with Washington State issued NPDES permit requirements for marine net pens and were updated in the 2002 permit cycle. The extensive BMPs cover every conceivable aspect of net pen operation and possible problems and are periodically revised in response to changing conditions or findings.

Upland hatcheries (flow-through systems) in Washington State also utilize BMPs as part of their NPDES permit requirements that require a pollution prevention plan, an operating plan, a spill prevention plan as well as solid waste and stormwater plans. For more information on either type of facility contact the Washington Fish Growers Association

<http://www.wfga.net/contact.asp>

or the Washington Department of Ecology

<http://www.ecy.wa.gov/ecyhome.html>

Wisconsin

The National Sea Grant Program is funding the development of the publication, "Production of a Best Management Practices Manual for Aquaculture in Wisconsin and the Great Lakes Region." This manual is being prepared through a joint effort of experts from universities, fish farmers (Wisconsin Aquaculture Association), regulators (Wisconsin Department of Natural Resources and Wisconsin Department of Agriculture, Trade & Consumer Protection, Division of Animal Health), and an environmental group (Partners in Amphibian and Reptile Conservation). The Best Management Practices manual for aquaculture is intended for use in Wisconsin and throughout the Great Lakes Region and is expected to be completed in Spring, 2004. The manual will focus on pond, flow through, and recirculation systems and include discussions on aquaculture effluents and water discharge, and outline recommended practices to meet environmental protection goals. Other topics covered will be fish health, non-native species and strains, impacts on land and water resources, and impacts on non-fish wildlife and plants. The target audience will be current and prospective aquaculturists and personnel involved in regulation development. The manual will be primarily advisory in nature.

1.4 BMPs as Part of Voluntary Activities

Although BMPs have a defined role in the regulation of point sources of pollution, they are often used external to the regulatory process by private entities desiring to improve overall environmental stewardship.

Organizations promoting better practices typically craft statements, sometimes called guiding principles, to explain the objectives of their programs. Suggestions for improving environmental stewardship and food safety often are presented in codes of conduct and codes of practices.

A code of conduct is a system of principles or rules about how some activity, in this case aquaculture, should be conducted. Codes of conduct are general statements of policies and practices to assure a particular outcome. They do not provide details on how to implement programs of better management.

Codes of conduct usually are accompanied by codes of practices. Practices used to solve resource management problems often are called best management practices. A best management practice refers to structural or vegetative modifications and management activities needed to solve one aspect of a resource management problem. Rarely, a single practice may solve a problem, but usually a collection of practices must be adopted. A list of BMPs for solving resource management problems is called a code of practices. The practices are often presented in the form of short statements supplemented by notes or other guidance to assist in implementation.

Codes of practices usually are adopted voluntarily. Also, practices needed to prevent negative impacts at one farm may be different from those needed at another farm. Thus, producers should select practices most appropriate at a particular site. It usually is not intended for all practices given in a code of practices to be installed at a specific location.

Codes of conduct and codes of practices can provide the benefits of an EMS. An EMS is designed to maintain and improve compliance with environmental requirements. The requirements may be mandated by governmental agencies or certifying bodies, but they often are developed by the EMS owner. The typical components of an EMS follow: impact identification; development of standards; adoption of practices to comply with standards; identification of indicators; monitoring; review and correction for non-compliance; confirmation of compliance; and sanctions for non-compliance (Martin and Edgley, 1998). Environmental management systems are best suited for large organizations that can devote a staff of specialists to the task. However, aquaculture organizations can develop codes of practices with implementation instructions and monitoring and review procedures. Such programs can be designed by a process similar to the one used in EMS, and once adopted by producers, they will satisfy the intent of EMS.

Several organizations (Table 1.1) have developed codes of conduct for responsible aquaculture and members or clients of the organizations are encouraged to adopt them (Boyd 2003). These programs are voluntary and the extent of adoption by producers has not been determined.

A code of conduct is similar to guiding principles and the two can be interchangeable. For example, the "Guiding Principles of Responsible Aquaculture" of the Global Aquaculture Alliance (GAA) also doubles as the organization's code of conduct for enhancing environmentally responsible aquaculture (Boyd, 1999). The GAA's guiding principles (Table 1.2) were fashioned after the "Code of Conduct for Responsible Aquaculture" of the Food and Agriculture Organization (FAO) of the United Nations (FAO 1997). The FAO's code of conduct addresses nations, while the GAA's guiding principles are directed at producers and producer associations.

1.5 Development of BMPs for Aquaculture

A single suite of BMPs would not be optimum for a particular species across the United States or in a single state. The use of best management practices must be an iterative and evolving process to provide a flexible system of pollution abatement so that new approaches can be implemented as technology changes. The use of best management practices rather than numerical limits also recognizes that pollution abatement strategies must vary farm to farm because of their diverse range of aquaculture systems, species cultured, geographical location, farm size, financial situation, and production goals.

Because of the diversity of situations and production methods, BMPs should be selected carefully and adjusted for site-specific conditions. This does not imply that a list of BMPs cannot be prescribed as an alternative to numerical limits for water quality variables. However, prescriptive BMPs should be made through a broad, collaborative process involving all stakeholders. At a minimum, stakeholders involved in the process should include industry representatives, regulatory agency representatives, representatives from the USDA Natural Resources Conservation Service (NRCS), and technical experts, such as aquaculture Extension specialists. It is especially important to have options for different situations.

There are several approaches to effect reductions in different pollutants in effluents. Permit writers are not aquaculture experts, and they will not know which approach is best in terms of effectiveness, initial implementation, minimum disruption of day-to-day operations, and economical feasibility. A well-intentioned permit writer might choose a system of BMPs that could lower pollutant concentrations or loads to acceptable levels, but it might cause the producer more inconvenience and greater expense than another, equally-effective system of BMPs. Thus, development of BMPs, either for voluntary or mandatory adoption, should be done with the input of all stakeholders.

There are no guidelines for developing aquaculture BMPs. However, a system of BMPs for use in channel catfish farming has been prepared by the Alabama Catfish Producers, and can be seen at the Alabama NRCS website

<www.al.nrcs.usda.gov/about/so_sect/eng/aq_bmp.html>

The process by which these BMPs were designed illustrates the broad, collaborative, and technology-based effort that should be used. The effort began with an environmental impact assessment of catfish farming. This study documented production practices, investigated water use and effluent discharge patterns, determined concentrations and loads of pollutants, identified potential impacts, and suggested practices to lessen impacts (Boyd et al., 2000). The results of the assessment were presented in a general meeting of Alabama catfish farmers to obtain their input. An environmental audit form was prepared and used to obtain additional information on differences in sites and practices among farms and the feasibility of implementing various practices. Next, draft BMPs were developed and circulated to a selected group of farmers, University researchers, and extension workers. Reviewer's comments were considered, a second draft of BMPs was made, and another general meeting of farmers was convened. Comments from the meeting were incorporated into a third draft, and it was reviewed by scientists of the Alabama Department of Environmental Management (ADEM), NRCS, and EPA. There also was a tour of selected catfish farms by ADEM, NRCS, and EPA officials accompanied by University scientists and selected fish farmers. The EPA and ADEM officials made some suggestions for further data collection to substantiate assumptions for BMPs related to chemical treatments, and these studies were conducted. A fourth draft of BMPs was prepared to include the findings of the special studies and other inputs from those participating in the tour. This draft was presented at a general meeting of farmers, and their comments were incorporated into the final draft which was edited and posted on the NRCS website. The entire process took place over a 2-year period (Table 1.3).

Government agencies developing aquaculture BMPs should employ a process similar to the one used in Alabama. Under no circumstances should BMPs be developed by agency employees without consultation with other experts and stakeholders.

1.6 BMP Implementation and Verification

Logical development of BMP plans—with diverse stakeholder involvement as described above—is the first step in using BMPs for environmental protection. To be effective, however, the plan must be implemented. Implementation begins with educating producers about the goals and benefits of the plan, as well as training on how to implement specific practices. Education and training should be provided by an aquaculture industry association, third-party, or an appropriate public agency.

Implementation of voluntary BMPs seldom occurs spontaneously. The best incentive for implementation of voluntary practices is clear demonstration of ancillary economic benefits for the producer. These benefits may take the form of price differentiation for products produced using environmentally responsible practices, increased access to foreign markets, or, more commonly, cost-saving resulting from the relationship between environmental performance and production efficiency. The most obvious example of this relationship is the simultaneous effect of feed conversion efficiency on waste generation and economic returns. Feed is the ultimate source of most potential pollutants in aquaculture as well as the major variable cost. So, better feed conversion results in less waste generation and improved economic performance.

Verification of BMP compliance, when appropriate or mandated, should be achieved through independent audits or on-farm inspections. Only qualified personnel with formal training in aquaculture BMPs and their verification should serve as trainers, auditors, or compliance officers. If necessary, environmental monitoring should only be applied with a goal of minimizing impacts to farm operations and costs. Results should be periodically reviewed with the farmer and aquaculture Extension Specialists to revise sampling plans to achieve environmental protection goals. Record keeping should be kept to a minimum and designed to be congruent with farm management practices. Records should be stored and be easily accessed on the farm for specified periods of time.

1.7 Costs of BMP Implementation

There is a cost to implementing BMPs, and those that require structural modifications or additions to infrastructure will be the most expensive. For example, the following represents costs incurred for a flow-through facility recently constructed in Idaho. The facility consists of three decks of 12 raceways for a total of 36 raceways. Raceways are 130 feet long and 18 feet wide and include quiescent zones 22 feet long. Land area required for the 36 quiescent zones and two off-line settling basins is one acre, valued at $15,000 per acre. Excavation ($1,600), concrete including labor ($142,500), screens and catwalks ($25,200), plumbing and lift stations ($18,400), and engineering costs ($10,000) bring total costs of the waste treatment system to $212,700 or $5,908 per quiescent zone (data obtained from Clear Springs Foods, Inc., Buhl, Idaho).

Settling basins for pond effluents are also expensive to construct and require additional space or conversion of production area to sedimentation area. A study of Alabama catfish farms revealed that it would seldom be possible to build settling basins because of lack of space (Boyd and Queiroz 2001). Another study (Engle and Valderrama, 2003) showed that the increased costs associated with settling basins are too high to make their use economically feasible in pond aquaculture, and that requiring the use of settling basins would impose a disproportionately higher cost on smaller farms. This illustrates an important point: construction, maintenance, administration, monitoring and other costs associated with BMP implementation can be high for individual farmers and, therefore, BMP plans must be appropriate to the scale of the facility.

The use of BMPs may also have significant indirect costs through their impact on production capacity. For example, in Maine the use of individual identification tags on cultured fish is being examined as a method of assessing the efficacy of containment on salmon farms. While the direct cost of tagging is significant ($0.10 to $0.12 per fish; Hammer and Blankenship, 2001) the indirect cost of reduced production capacity is much higher. Production capacity is reduced by reduced growth due to handling stress and inefficient use of tank volumes due to a need to keep tagged lots separate. Current estimates suggest that production capacity may be reduced by as much as 30% and that the total costs to Maine salmon farmers may exceed $40 million (Pietrak et al., 2003).

1.8 Effectiveness of BMPs

As with BMPs developed for most other activities, it can be difficult to ensure *a priori* that BMPs will achieve expected benefits in a cost-effective manner, although many of the key BMPs listed in this document have been subject to research to verify effectiveness. The EPA and state environmental management agencies have the goal of reducing pollutant loads to waters of the nation, and this goal is advanced by the adoption of BMPs to improve aquaculture practices and reduce the loads of pollution from production facilities. Best management practices developed through a collaborative process should represent the best practical methods for managing aquaculture facilities in an efficient and environmentally responsible manner.

Effectiveness of BMPs will be maximized when strategies are tailored for specific sites, with consideration given to the diverse range of environmental impacts, aquaculture systems, species cultured, geographical location, farm size, financial situation, and production goals. Effective use of BMPs must also account for evolving technology—development and implementation of BMP plans must be an on-going process so that new approaches can be implemented as technology changes.

Table 1.1 Organizations which have developed codes of conduct and codes of practice for aquaculture. The following is not a complete list, but it contains the best-known codes. Source: Boyd (2003)

Fish Farming Codes of Conduct:
- Alabama Catfish Producers Association (USA)
- Australian Aquaculture Forum
- British Columbia Salmon Farmers Association
- British Trout Association
- Catfish Farmers of America
- Center for Tropical and Subtropical Aquaculture (Hawaii, USA)
- Florida Department of Agriculture and Consumer Service (USA)
- Irish Salmon Growers Association
- Missouri Department of Natural Resources (USA)
- Naturland (Germany)
- Ornamental Fish Industry (UK)
- Soil Association (UK)

Shrimp Farming Codes of Conduct:
- Aquaculture Foundation of India
- Australian Prawn Farmers Association
- Belize Shrimp Farmers Association
- Coastal Resources Center, University of Rhode Island (USA)
- Department of Fisheries of Malaysia
- Global Aquaculture Alliance (International)
- Industrial Shrimp Action Network (NGO)
- Marine Shrimp Culture Industry of Thailand
- Organic Aquaculture (Netherlands)
- Shrimp Farmers Association in Colombia
- World Wildlife Fund and Environmental Defense Fund (NGO)

Table 1.2 A typical code of conduct is the *Guiding Principles of Responsible Aquaculture* of the Global Aquaculture Alliance. Source: Boyd (1999).

Companies and individuals engaged in aquaculture, singularly and collectively:

1) Shall coordinate and collaborate with national, regional, and local governments in the development and implementation of policies, regulations, and procedures necessary and practical to achieve environmental, economic, and social sustainability of aquaculture operations.

2) Shall utilize only those sites for aquaculture facilities whose characteristics are compatible with long term sustainable operation with acceptable ecological effects, particularly avoiding unnecessary destruction of mangroves and other environmentally significant flora and fauna.

3) Shall design and operate aquaculture facilities in a manner that conserves water resources, including underground sources of freshwater.

4) Shall design and operate aquaculture facilities in a manner that minimizes effects of effluent on surface and ground water quality and sustains ecological diversity.

5) Shall strive for continuing improvements in feed use and shall use therapeutic agents judiciously in accordance with appropriate regulations and only when needed based on common sense and best scientific judgment.

6) Shall take all reasonable measures necessary to avoid disease outbreak among culture species, between local farm sites, and across geographic areas.

7) Shall take all reasonable steps to ascertain that permissible introductions of exotic species are done in a responsible and acceptable manner and in accordance with appropriate regulations.

8) Shall cooperate with others in the industry in research and technological and educational activities intended to improve the environmental compatibility of aquaculture.

9) Shall strive to benefit local economies and community life through diversification of the local economy, promotion of employment, contributions to the tax base and infrastructure, and respect for artisanal fisheries, forestry, and agriculture.

Table1.3 Activities leading up to formalization of Alabama Catfish Producers BMPs (Boyd et al., 2003).

Environmental assessment	1997-1999
Farmer meeting to discuss environmental assessment	October 1999
Environmental audit	1999-2000
First draft of BMPs	March-May 2000
Review of draft BMPs by selected farmers, extension agents, and researchers	May-July 2000
Revision to prepare second draft of BMPs	August-September 2000
Farmers meeting to review draft BMPs	October 2000
Revision to prepare third draft of BMPs	November-December 2000
Review of draft BMPs by employees of ADEM, NRCS, and EPA	January-April 2001
EPA/ADEM aquaculture site visit in Alabama	March 2001
Special studies related to chemical treatment BMPs	March-October 2001
Revision to prepare fourth draft of BMPs	April-August 2001
Farmers meeting to review draft BMPs	October 2001
Revision to prepare fifth draft of BMPs	November-December 2001
Final editing of BMPs and installation on NRCS website	January-February 2002
Publication of manual	2003

SECTION 2

BEST MANAGEMENT PRACTICES FOR FLOW-THROUGH AQUACULTURE SYSTEMS

Flow-through aquaculture systems are highly diverse in size, geographic location, species cultured, life stage cultured, water source quality and quantity, water temperature, and effluent characteristics. As such this diversity affects the amount and type of food fed, aquatic animal growth, feed efficiency, feces characteristics, particle settling velocity, and pollutants generated. Water source quality can vary greatly between regions and within individual states. These differences affect a number of uses, such as number of rearing units and serial water uses at particular sites, carrying capacities and total aquatic animal production. Flow-through systems are the most commonly used aquaculture production systems to produce trout and other salmonids. Trout and other salmonids are cultured under a range of water temperatures. In some areas of the country ground water sources are at constant temperatures such as 50 or 60EF, whereas in areas using surface water sources, temperatures may range from 32EF to over 70EF. Other species such as tilapia, catfish, sturgeon and ornamental fish are also produced in flow-through systems, but to a much lesser extent than trout. These warmwater and coolwater flow-through systems can range in water temperatures between 60 to 85EF. The distinguishing hydraulic characteristic of flow-through aquaculture systems compared to other aquaculture production systems is the continuous discharge of water during production as a result of a continuous supply of fresh water diverted into the rearing units. Flow-through systems include earthen and concrete raceways, and also tanks constructed from a variety of materials.

Rearing units in flow-through systems are typically linear but circular units are also used. The hydraulic pattern in linear units approximates plug flow where all elements of the water essentially move with the same horizontal water velocity. This results in a water quality gradient from the inflow to the outflow of the rearing unit during production. Circular rearing units have relatively uniform water quality throughout the rearing unit.

Flow-through systems can be classified as in series or parallel. A system is in series when the discharge of the upstream rearing unit is the inflow of the next one below. In parallel systems the rearing units are adjacent to each other and water flows through each rearing units and is discharged from the facility. Available water, water quality, space, and topography influence whether a flow-through system is constructed in series or parallel. Many flow-through aquaculture production facilities use a combination of series and parallel rearing units.

Functionally, flow-through systems maintain water quality for the cultured aquatic animals through the continuous supply of fresh water supplying oxygen and carrying away waste products. Concentrations of solids and nutrients in effluents from flow-through systems are considerably lower than in effluents from recirculating aquaculture systems or ponds. This is in part due to water quality requirements of species cultured in flow-through systems and typical feed conversion ratios of those species. Practical cost-effective treatment of a large continuous discharge of dilute effluent presents a difficult engineering challenge. Adoption of management practices that minimize environmental impacts through feed management and solids control is an effective approach to implementing environmental management of flow-through aquaculture systems.

Certain environmental practices may also provide economic benefits by increasing operational and production efficiency. For example, increasing feed efficiency through improved feed management results in greater yield per unit feed, which can improve profitability, but also results in a reduction of waste products generated.

This section provides a list of options that can be used to improve the environmental performance of flow-through aquaculture. Recommended practices are provided for site selection, feed management, solids management, solids disposal, management of escapees, mortality removal and disposal, and facility operation and maintenance. Although the guidance may appear to lack specificity, this is intentional. Flow-through systems are used to culture a variety of coldwater and warmwater species, and production practices vary widely among species and for different life stages of the same species. Culture methods also vary with geographical location, intended market, and other factors. The diversity of systems, species cultured, and culture methods used in flow-through systems make the development of generic environmental management practices challenging. A reasonable practice for one species or facility may be totally inappropriate for another. Furthermore, practices may be combined in unique ways to achieve the goal of pollutant reduction. As such, BMPs should never be developed without consultation with technical experts and all stakeholders.

2.1 Site Selection

Location on substandard sites is a frequent cause for failure of aquaculture projects. Most of the siting criteria important in reducing environmental impacts of flow-through aquaculture systems are also critical in assuring profitability of the operation. For example, selection of sites with suitable topography, particularly the amount of vertical relief available, will allow the use of gravity flow in lieu of pumps to remove and transport collected solids while also ensuring adequate drop between rearing units to reaerate the flow, thereby maximizing production potential in downstream rearing units. A site with sufficient slope can produce more fish per unit of water than a site without sufficient slope and eliminate pumping costs associated with the removal and transport of collected solids. A careful site evaluation should be made prior to investing in the venture. Identification of potential problems before construction and either addressing those problems or locating an alternative site is much less expensive than solving problems by implementing mitigation measures after construction or, in the extreme, having to abandon the operation.

Guidance

1) Before purchasing land or constructing a flow-through system, be aware of all restrictions and regulations that may apply to the use of the land and water for flow-through aquaculture.

Several state and federal agencies have jurisdiction over flow-through system construction and water use, including discharge into waters of the United States. Contact the local state office of environmental quality for guidance. A National Pollutant Discharge Elimination System (NPDES) Permit administered under the Federal Clean Water Act may be required.

2) Flow-through systems should not be sited where the discharge may impair protected water resources, at-risk water bodies, and special habitats.

These areas are generally excluded from coverage under an NPDES permit and typically are sensitive habitats for threatened and endangered species. At-risk water bodies may include areas in close proximity to downstream drinking water intakes for municipalities.

3) Avoid sites that are prone to frequent flooding.

Floods that overflow flow-through systems result in loss of cultured animals, contamination of rearing units with wild fish, and mixing of flood waters with rearing unit waters. Aside from the possible escape of farmed species, floods are usually catastrophic for the farmer. Generally rearing unit waters will have better water quality than flood waters.

4) Site topography should be suitable for flow-through system development.

Selection of sites with suitable topography will allow the use of gravity flow in lieu of pumps to remove and transport collected solids.

5) Water quantity and quality should be suitable for the proposed operation.

The water supply for flow-through systems may be from springs, wells, or surface waters (rivers, lakes, and reservoirs). The water quality and quantity from a given source will depend strongly on local climatic and hydrological conditions and can be highly variable even within a relatively small geographic area. Some ground and surface waters may require pretreatment to remove excess gases and to add dissolved oxygen. Surface waters tend to have greater seasonal variations in water temperature.

The quality and quantity of water available determine the size and type of flow-through system suitable for the proposed site. Fish farmers depend on high water quality and sufficient quantity to sustain optimal fish health and productivity. Water supplies for flow-through systems should be free of substances that may affect product quality or safety. Quality of water supplies should meet the biological needs of the cultured animals. Ground waters are typically free of contaminants and fish pathogens, although it is prudent to have a water analysis conducted or ask local and state water agencies if there is cause for concern. Surface waters while suitable for flow-through systems are more prone to variable water quality and contamination from upstream sources. An assessment of upstream land activities and water uses can determine if a surface water supply is suitable. If upstream activities can potentially degrade water quality or contaminate product quality, an alternate site may be required. Ground and surface water quantity may vary considerably throughout the year. In addition to reasonably estimating the flow of the water source, it would be prudent to obtain historical flows from agencies or well-drilling companies.

6) Avoid sites where previous land use could have contaminated soils.

If earthen raceways are proposed, soils previously exposed to industrial or agricultural activities may be contaminated with chemicals that affect health of cultured species, product quality or food safety. The history of the site should be investigated to determine if soil testing is warranted.

2.2 Feed Management

Feed is effectively the only major source of aquaculture-derived nutrients, such as nitrogen and phosphorus, and solids in flow-through systems. Due to the relatively short hydraulic residence time of flow-through systems and the continuous discharge of water, feed management is an important component in controlling the amount of nutrients and solids discharged into receiving waters. Optimizing feed management through feed quality and ingestion and minimizing feed waste can minimize the nutrients and solids generated and released to the environment. Feed also represents the largest single variable cost of production and efficient use of feeds can improve profitability. Accurate feeding systems and appropriate feeding levels are essential for productivity, economic efficiency, and protection of the environment. As such, feed management is one of the most important aspects of flow-through aquaculture.

Fish nutrition and feeding practices are active areas of research, and technology is constantly evolving. An important research goal is to improve the efficiency of nutrient utilization by fish, thereby enhancing economic returns and reducing waste production. Because technology is rapidly changing, BMPs for feed management should be flexible so that newer and better practices can be implemented as they become available.

Guidance

1) Use high quality feeds.

Feeds should be formulated to meet the nutritional requirements of the cultured species. Feeds should be formulated using feed ingredients that have high dry matter and protein apparent digestibility coefficients. Formulations should be designed to enhance nitrogen and phosphorus retention efficiency, and reduce metabolic waste output. Feeds should contain sufficient dietary energy to spare dietary protein (amino acids) for tissue synthesis. Available phosphorus levels should be slightly in excess of the dietary requirements of the species of fish for each life-history stage, and formulation should be designed to minimize the difference between total feed phosphorus levels and available feed phosphorus levels. Consult a qualified fish nutritionist or feed manufacturer for information regarding feed formulation. Feeds should be water stable for sufficient periods such that pellets remain intact until eaten by fish. Feeds should be manufactured, stored, shipped, and handled at the farm such that they contain a minimum amount of fine particles.

2) Use efficient feeding practices.

Feed can be delivered by hand, demand feeders, automatic feeders or by mechanical feeders. Regardless of the delivery method or system, the amount of feed offered should optimize the balance between maximum growth and maximum feed efficiency. The appropriate quantity of feed for a given species is influenced by fish size, water temperature, dissolved oxygen levels, health status, and management goals. Feed particle size should be appropriate for the size of fish in each rearing unit. Feeding behavior should be observed to monitor feed utilization and evaluate health status.

3) Manage within the carrying capacity of the flow-through production system.

Impaired water quality due to high loading and high feeding rates stresses fish and reduces feed efficiency and production. High loading and high feeding rates also lead to higher levels of nutrients and solids in the effluent. Loading and feeding rates within the carrying capacity of the production system are more efficient, and minimize the discharge of pollutants. Carrying capacity is determined by incoming water quality and quantity, production goals, facility design, site characteristics, and species cultured. As such, there is no single carrying capacity value applicable to flow-through systems. Carrying capacity will vary within and between facilities due to the factors previously stated.

.

4) Feed should be properly stored.

Feed storage should be secure from contamination, vermin, moisture and excessive heat. Long term storage of feed can affect feed quality. Feed should be rotated (use oldest feed first) and not stored beyond the manufacturer's recommended use date.

5) Feeding equipment should be checked to ensure efficient operation.

Improperly adjusted or malfunctioning feeding equipment can over or under feed a tank or raceway of fish and lower feed and production efficiency.

2.3 Solids Management

Fish fecal matter and waste feed are the major constituents of total suspended solids from culture practices in flow-through systems. Solids can impact the aquatic environment and should be intercepted and removed as thoroughly as possible prior to discharge. Flow-through system effluent is characterized as high volume with low solids concentration. This effluent characteristic generally limits practical and economical solids management to the capture and removal of solids using settling basins. Solids found in flow-through systems readily settle and can be managed with practices that rely on gravitational settling before water is discharged. Practices that increase solid particle fragmentation decrease settling efficiency. These particles are much smaller and have poor settling characteristics. Fish grading, harvesting, and other activities within raceways or ponds should be conducted in a manner that minimizes the disturbance and possible discharge of accumulated solids.

Guidance

1) Rearing units should be designed for efficient and rapid capture of solids from the water column, incorporating fish-free settling basins where practical.

   Linear rearing units designed to promote plug flow and sufficient water velocity to prevent the settling of solids within the rearing unit allow the efficient capture of solids using quiescent zones or other settling basins. Solids allowed to settle in rearing units degrade water quality and may irritate fish gills leading to disease. Proper facility design and construction can be an economical means of managing solids through settling in designated areas which allows for efficient removal.

2) Settling basin area should be based on overflow rate.

   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. For practical purposes overflow rate is expressed as a velocity (ft/s). Cubic feet per second of flow per square foot of settling area ($ft^3/s/ft^2$) can be reduced to feet/second (ft/s). In general, any particle with a settling velocity greater than or equal to the overflow rate will settle within the settling basin. As such, overflow rate is the settling velocity of the smallest particle to be removed.

   Settling basin area in square feet is calculated by dividing the influent settling basin water flow rate (ft^3/s) by the settling velocity (ft/s) of the smallest particle to be removed (overflow rate). Aquaculture derived solids have varying settling velocities depending on particle size and specific gravity. Larger particles readily settle and require smaller settling basin area relative to smaller particles that have slower settling velocities. Overflow rate also varies with type and location of settling basin used. The three types of settling basins used for solids management in flow-through systems are quiescent zones, full-flow settling, and off-line settling. In general, quiescent zones capture relatively larger and intact particles at the end of raceways compared to off-line settling basins where particles are typically smaller and fragmented, thereby requiring less settling basin area than off-line settling basins.

There is no single overflow rate appropriate for all flow-through system settling basins. Several factors determine the appropriate overflow rate for a settling basin, including settling basin type, species cultured, feed fed, particle settling velocities, end of pipe objective, and local water quality standards.

3) Settling basin inlet and outlet design should minimize turbulence and short-circuiting.

Flow surges, scour, wind shear, short-circuiting and excessive turbulence decrease settling basin efficiency and can contribute to increased solids in the effluent. Designs that evenly introduce the flow into the settling basin and decrease the influent water velocity maintain settling basin efficiency. Discharging settling basin effluent across a weir minimizes scour and upwelling. Other design considerations include constructing rectangular settling basins and providing protection from wind.

4) Solids should be removed from settling basins in a timely fashion.

Solids should be removed from quiescent zones with a frequency sufficient to prevent cohesion and limit release of solids-bound nutrients. The frequency will be determined by the level of feed application, settling basin efficiency, and relative storage capacities of the basins. Typically, quiescent zones are cleaned about every two weeks, however, as long as compliance limits are met, the frequency of solids removal is variable within and between facilities.

Sludge left too long in settling basins becomes sticky and viscous making removal difficult. Sludge accumulation may degrade water quality as nutrients are released through bacterial or physical degradation. Off-line and full-flow settling basins should be harvested when storage capacity is reached or as effluent concentrations near compliance limits.

The most common method of solids removal from quiescent zones is by suction through a vacuum head. Usually, a standpipe in each quiescent zone connects to a common pipe that carries the slurry to an off-line settling basin. Suction is provided by head pressure from raceway water depth and gravity, or where fall is not available, by pumps. A flexible hose and swivel joint connects the vacuum head to the standpipe so the vacuum can be manipulated to clean the quiescent zone. There are other methods used to clean quiescent zones. For example, the standpipe to the off-line destination may be removed and the solids can be pushed with a broom or squeegee device to the suction port.

To clean full-flow and off-line settling basins the inflow is usually diverted to another settling basin and the supernatant from the settling basin decanted. The slurry is allowed to dry sufficiently for removal by backhoe, front-end loader, or other equipment. Or the slurry may be pumped directly onto a tank truck or manure spreader. Other options include pumping the slurry out of the settling basin without diverting the flow, similar to cleaning a quiescent zone.

5) Circular rearing units should be designed to be self-cleaning.

Circular tanks with properly designed inlets and drains can remove the majority of solids with minimum labor for further treatment. 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 resuspending 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.

2.4 Solids Disposal

Aquaculture solids contain plant nutrients and can be used as a soil amendment. The composition of the solids will vary according to feed formulation fed and age of the solids. Aquaculture solids should be defined as an agricultural waste. However, state or local governments may consider the fish manure captured in an aquaculture waste management system an industrial or municipal waste (i.e., not an agricultural waste). This designation by local or state authorities can limit waste disposal options.

Guidance

1) Disposal of solids should comply with all applicable local and state regulations and done 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 at agronomic rates, storage lagoons, composting, and contract hauling.

a) Land Application

Land application of aquacultural solids is the most common disposal method. Proper application of aquacultural solids provides a safe method for solids utilization while fertilizing crops and amending the soil. Fish manure in liquid form may be sprinkler irrigated directly onto agricultural land. In slurry form, fish manure may be pumped into a tank truck or manure spreader and then applied to agricultural land. Finished compost generated from aquacultural solids may also be applied onto agricultural land at agronomic rates.

b) Evaporation Ponds/Lagoons

Manure slurries from aquaculture operations may be treated in evaporation ponds/lagoons that can thicken and stabilize the manure. Evaporation ponds/lagoons are effective in arid climates only.

c) Composting

Thickened and dewatered manure may be composted. Composting stabilizes the 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 require additional treatment. State and local regulations regarding composting should be considered.

d) Contract hauling

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

2) Solids from earthen flow-through systems can be used to repair embankments.

Earthen flow-through systems accumulate solids in the rearing units during production. It is not practical or necessary to remove solids during production from earthen rearing units. When it is necessary to remove solids from earthen rearing units, the source water is diverted around or away from the rearing units and they are allowed to dry. The solids removed can be used to repair the embankments and other areas of the rearing unit.

2.5 Management of Escapees

The escape of cultured species may pose a variety of potential risks to conspecific species, aquatic ecosystems, or unrelated economic activities. Potential risks include pathogen transmission, interbreeding with conspecific species and introgression of genetic traits, competition for limited resources, predation, rapid colonization and spread, or disruption and damage to commercial and recreational industries including aquaculture. For almost all of the aquatic species cultured in the United States, these outcomes have not occurred nor are anticipated to occur because: 1) diseases and pathogens are addressed by the farmer and regulatory agencies; 2) most of the species in culture are native; 3) successful introduction and spread of a non-native species meets strong biological resistance; and 4) federal and state agencies have implemented a variety of effective invasive species regulations to prevent, control, manage, or mitigate potential impacts.

In addition to potential ecological and economic damages off the farm, aquatic animals that escape negatively impact farm revenue in two ways: increased production costs and lost revenue. Farmers should make every effort to reduce the potential for species escape.

Guidance

1) Follow all local, state, and federal regulations that govern the species that may be imported, exported, cultured, or sold live locally or nationally.

Contact appropriate state agencies for regulations governing species, facility design and operation, holding and transport, or live sales. Seek the advice from aquaculture Extension Specialists and appropriate agencies when considering the culture of an unfamiliar species. Contact the United States Fish and Wildlife Service for an import/export license and information about injurious species identified under the Lacey Act. For regulations concerning species and production systems that can be used in marine waters, contact the National Marine Fisheries Service. For health certification of imports and exports, contact the USDA Animal Plant Health Inspection Service.

2) All holding, transportation, and culture systems should be designed, operated and maintained to prevent escape.

Screens of appropriate size and strength should be installed at the intake from the source and outlet to receiving waters to prevent loss and escape of cultured species. Periodically survey farm perimeters and use appropriate physical methods to prevent escapees.

3) If possible, avoid siting facilities in areas prone to frequent flooding.

Floods that overflow flow-through systems result in loss of cultured animals and are usually catastrophic for the farmer. Facilities adjacent to surface waters should be constructed to minimize the possibility of flood waters entering the facility.

2.6 Mortality Removal and Disposal

Mortality of cultured species in aquaculture is unpredictable and highly variable among rearing units, epizootics, and facilities. A facility may experience chronic mortality of a few fish per day or a catastrophic loss caused by infectious disease or acute environmental stress. Depending on water temperature and species, dead fish either float or sink after dying, with warm water fish typically floating and cold water fish sinking. In flow-through systems, whether floating or sinking, dead fish tend to accumulate on the screens at the end of the rearing units.

Guidance

1) Mortalities should be removed from rearing units on a regular basis.

Mortalities accumulating on screens prevent the efficient flow of water from unit to unit and represent a hazard for possible damage to the screen resulting in escape of fish from the unit or diversion of flow away from downstream units.

2) Follow recommended aquatic animal health management practices.

Prevention and minimization of mortalities through proper fish health surveillance and management are the best method for managing mortalities. Most states offer diagnostic services and treatment recommendations for disease problems. General guidance on aquatic animal health management can be found in Section 6.

3) Mortalities should not be discharged into receiving waters.

Appropriate screens on the outlet to receiving waters will prevent mortalities discharging into receiving waters. There are, however, restoration and stock-enhancement activities where spawned carcasses are returned to waters for nutrient replacement.

4) Only approved methods of mortality disposal should be used.

Disposal methods are site-specific and usually governed by state or local regulations. Disposal options include composting, rendering, use as fertilizer, incineration, burial, or landfill.

2.7 Facility Operation and Maintenance

Flow-through aquaculture systems are expensive to construct and operate. It is in the best interest of the owner/manager to operate the facility in a sustainable fashion. Facilities that are well-maintained, managed efficiently, and operated in compliance with all applicable regulations will improve long-term economic performance and reduce environmental impact.

Guidance

1) Chemicals should be used and stored in a manner to prevent contamination of the environment.

The most common chemicals used in flow-through systems are water treatments, herbicides, and disinfectants. When used according to label directions, these materials have no adverse effect on the environment. Chemicals should be used only when needed and only for the specific use indicated on the label. Chemical use is regulated by federal and state agencies, and individuals are responsible for using these products according to label directions and disposing of containers and unused chemicals according to applicable federal and state regulations. Chemicals should be stored away from rearing areas, feeds, and water sources, in locations that are dry, void of drains, well-ventilated, and not subject to extreme temperatures. Chemicals should be secured so as to avoid tampering or their use to poison aquatic species.

2) Spill prevention and containment plans for chemicals, petroleum products and other hazardous materials should be developed.

State and federal laws require reporting of significant spills of chemical and petroleum products. A plan should be developed specifying response procedures, key staff, and phone numbers of regulatory authorities. All facility employees should be aware of the plan.

3) Maintain structures and equipment to ensure staff safety and protection of the environment.

   Standard operating equipment and structures should be routinely inspected and repairs or replacement done as necessary.

4) Develop a record-keeping system.

   Good record-keeping is the hallmark of a well-operated aquaculture facility. Records, such as feeding, chemical use, water quality, serious weather conditions, fish culture operations, and fish inventory 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.

2.8 Resources

Ackefors, H. 2002. Best Environment Practice (BEP), health, monitoring and regulations, codes of conduct. ASEM Workshop. Aquaculture Challenges in Asia, After the Bangkok Declaration on Sustainable Aquaculture, The next step. Beijing, China, April 27-30, 2002.

Fornshell, G. 2001. Settling Basin Design. Western Regional Aquaculture Center Publication No. 106. University of Washington, Seattle, WA.

Hinshaw, J.M. and G. Fornshell. 2002. Effluents from raceways. Pages 77-104 in J. R. Tomasso, editor. Aquaculture and the Environment in the United States. United States Aquaculture Association/World Aquaculture Society, Baton Rouge, LA.

Idaho Department of Environmental Quality. Undated. Idaho Waste Management Guidelines for Aquaculture Operations. Idaho Department of Environmental Quality, Twin Falls Regional Office, Twin Falls, ID. <http://www.deq.state.id.us/water/gw/Aquaculture_Guidelines.htm>

Myrick, C. A. 2002. Ecological impacts of escaped organisms. Pages 225-245 in J. R. Tomasso, editor. Aquaculture and the Environment in the United States. United States Aquaculture Association/World Aquaculture Society, Baton Rouge, LA.

Tomasso, J. R., editor. 2002. Aquaculture and the Environment in the United States. United States Aquaculture Association/World Aquaculture Society, Baton Rouge, LA.

United States Trout Farmers Association. 1994. Trout Producer Quality Assurance Program. U.S. Trout Farmers Association, Charles Town,WV. <http://usfta.org/industry/quality.html>

SECTION 3

BEST MANAGEMENT PRACTICES FOR NET-PEN FACILITIES

Net pens and cages are submerged, suspended, or floating holding systems in which a number of different species are grown. Although cages may be used to enclose shellfish as well as finfish this section pertains only to finfish operations. Net pens or cages may be located along a shore or pier or anchored and floating offshore, either in fresh or salt water. Over the last ten years, significant technological improvements in cage design and materials have allowed systems to be located in increasingly high-energy, exposed sites. As technologies have improved there has been a general trend to larger cages in deeper water. Current cage technology allows for cage survival in extreme conditions.

Net pens and cages rely on tides, currents, and other natural water movement to provide a continual supply of high-quality water to the farmed animals. The health, welfare and quality of the animals and products produced by cage farms are directly impacted by water quality. Unlike riverine systems where nutrients discharged by a farm are swept away, effluents from net pens in marine systems often cycle back through farm sites due to tidal circulation. Animals cultured in net pens are directly dependant on the quality of the environment around them. Farmers using net pen enclosures have little ability to protect their animals from compromised water quality and other environmental influences. Thus any effect that fish farm practices may have on water quality or the local environment also directly impacts animal performance and farm economic returns. This linkage between environmental quality, animal performance and farm economic returns provides incentives for farmers to manage operations in synergy with the local environment. A farmer’s understanding of local site characteristics is critical to managing farm operations so that the sites ability to assimilate and process nutrients is not exceeded.

Net pens and cages often constitute new underwater structures in local environments. These structures and their associated mooring systems provide three-dimensional habitat much the same as engineered, artificial reefs do. Cage farms can increase both the total amount of habitat available and habitat complexity. Structures such as cages and their associated anchoring systems preclude access by trawlers to benthic ecosystems under and around the farms. These ecosystems are therefore protected from the physical damage associated with destructive fishing practices. Greater habitat diversity, protection from physical damage and increased nutrients can result in local ecosystems with increased species diversity and heterogeneity. These local ecosystems often have a large capacity to assimilate, process and convert nutrients. The complexity, diversity and health of these local ecosystems are intimately tied to the management practices of the cage farm they are associated with. It is the interrelationship between the management practices of the farm, and the oceanographic and geophysical characteristics of the farm site that determine the potential for environmental impacts of a cage farm. Different sites have different abilities to assimilate, process and convert nutrient loads from cage farms. If this “carrying capacity” is exceeded, areas under the cages may ultimately become overloaded and species diversity may significantly decrease. Taken to the extreme, benthic sediments may become anoxic and the site's ability to assimilate, process, and convert nutrients can be reduced. Net pen and cage farms often operate in public waters. Strict siting requirements typically restrict the number of units at a given site to ensure sufficient flushing to distribute wastes and prevent degradation of the bottom below and near the net pens. Baseline environmental studies are often used to characterize a site before net pen operations are established. Ongoing monitoring programs are then used to examine and document how site ecosystems evolve in response to farm operations. These monitoring programs should include methods to distinguish farm impacts from natural background ecological events and other anthropogenic impacts. Monitoring programs typically include quantitative and qualitative thresholds. These thresholds clearly identify emerging environmental impacts that are of concern and give farmers guidance on what constitutes an unacceptable impact. Monitoring programs should provide a regular mechanism for consultation between farmers and regulators to facilitate communication, identify potential environmental problems and provide incentives for the adjustment of farm practices as necessary. Leasing or licensing programs that grant use of or access to public waters typically contain provisions that allow revocation in the event of unacceptable ecological impact.

This section provides a list of options that can be used to improve the environmental performance of net pen aquaculture facilities. Recommended practices are provided for site selection, feed management, solids management and disposal, management of escapees, mortality removal and disposal, and facility operation and maintenance. Net pen systems are used to culture several species of coldwater and warmwater fish in salt, fresh, and brackish water. The diversity of species and culture methods used in net pen systems make the development of generic environmental management practices challenging. A reasonable practice for one species or facility may be totally inappropriate for another. Furthermore, practices may be combined in unique ways to achieve the goal of pollutant reduction. As such, BMPs should never be developed without consultation with technical experts and all stakeholders.

3.1 Site Selection

Site selection is always a balancing of multiple factors. Appropriate site selection for net pens and cages is critical for the minimization of potential environmental impacts, optimal fish health and performance, worker safety and the minimization of production costs. With the exception of site selection, net pen and cage farm operators have little ability to control the environmental conditions their fish are exposed to. Fish physiology, metabolic performance and health are all highly influenced by the environmental conditions in which they are cultured. Small changes in environmental conditions can cause sublethal stress, suppressed growth rates and elevated food conversion ratios. All of these effects result in elevated production costs to the farmer.

Site selection has significant potential to determine the risk of environmental impacts associated with net pens and cages. Site selection to minimize environmental impacts may have to balance conflicting goals. For example high-energy exposed sites tend to reduce the risk of benthic deposition of wastes. However, due to their exposure, these same sites may increase the risk of storm damage and fish escapes, or compromise worker safety. Appropriate sites combined with careful farm management can result in minimal environmental impact.

Guidance

1) Evaluate each potential farm site to insure that environmental conditions on the farm site are appropriate for the species being considered for culture and the equipment proposed for use.

2) Whenever practical, select sites with good water exchange that are not depositional environments.

3) Baseline site surveys should be conducted in order to characterize the marine habitat, ecosystem and hydrographic conditions that prevail on the site.

   At a minimum, water depth, circulation patterns, current speeds, and wave fetch should be documented. Predominant seasonal weather patterns should be documented. Baseline studies should also include a characterization of the seasonal variation in the above characteristics and the potential maximum sea state of the site. These surveys should be used to confirm that site conditions are appropriate for the species being cultured and equipment to be deployed.

4) Impacts on worker safety, product quality, and animal welfare should also be considered during the prospective site review.

   Sites with frequent, extreme weather or sea-state conditions that would limit the grower's access to the farm site and cultured animals should be reconsidered.

5) Care should be taken during site selection to minimize the risk of negative impacts on farm animals from off-farm human activities such as residential or industrial development, oil, chemical and sewage spills, fertilizer, herbicide and pesticide runoff or overspray.

6) The distribution and prevalence of potential pests and predators should be examined when selecting sites. Where practical, farmers should select farm sites away from high pest and predator concentrations.

7) Sites for polyculture of shellfish and finfish should be assessed for primary productivity levels to ensure adequate food sources are available for the shellfish. Polyculture operations should also be examined to ensure they do not compromise either the biosecurity or product safety of finfish and shellfish production. Assure the water quality of the proposed site meets water quality standards of the Interstate Shellfish Sanitation Conference (ISSC; Columbia, South Carolina) where the intent is to produce shellfish for human consumption. This is not a crucial criteria where shellfish are being cultured solely for the ecological benefits they provide.

3.2 Feed Management

Waste feed and fish feces constitute a major portion of the wastes generated by a cage farm. However, because net pens and cages operate high-energy environments, the concentration and collection of wastes is difficult. Therefore, the most effective way to reduce the potential environmental impact of net pens and cages is aggressive feed management. Effective feed management is based on two components: waste reduction and optimal feed conversion ratio. Waste reduction focuses on ensuring that feed used by the farm is not lost or discharged prior to intake by the fish. Optimal conversion focuses on ensuring that all feed intake offered to the fish is actually consumed and optimally digested and utilized by the fish.

Fish nutrition and feeding practices are active areas of research, and technology is constantly evolving. An important research goal is to improve the efficiency of nutrient utilization by fish, thereby enhancing economic returns and reducing waste production. Because technology is rapidly changing, BMPs for feed management should be flexible so that newer and better practices can be implemented as they become available.

Guidance

1) Feed storage, handling, and delivery methods should minimize waste and fine particles of feed.

   Feed storage areas should be secure from contamination, vermin, moisture, and excessive heat. Long-term storage of feed can affect feed quality. As such, feed should be rotated (use the oldest feed first) and not stored beyond the manufacturer's recommended use date. Care should be taken during feed handling to minimize pellet damage or crushing and reduce the creation of fine feed particles that cannot be utilized by the fish.

2) Farms should calculate feed conversion ratios by using feed and fish biomass inventory tracking systems that should also allow farmers to quickly identify significant changes in feed consumption and waste production rates on an individual cage or net pen basis.

3) In cooperation with feed manufacturers, farmers should seek to minimize nutrient and solids discharges through optimization of feed formulations.

   Feeds should be formulated for optimum feed conversion ratios and retention of protein (nitrogen) and phosphorus. Feed formulations should consider numerous factors including, pellet stability, digestibility, palatability, sinking rates, energy levels, moisture content, ingredient quality and the nutritional requirements of the species being grown. Feeds should be formulated and manufactured using high-quality ingredients. Feed ingredients should have high dry matter and protein apparent digestibility coefficients. Formulations should be designed to enhance nitrogen and phosphorus retention efficiency, and reduce metabolic waste output. Feeds should contain sufficient dietary energy to spare dietary protein (amino acids) for tissue synthesis. Feeds should be water stable for sufficient periods such that pellets remain intact until eaten by fish. Questions regarding feed formulations should be referred to a qualified fish nutritionist or feed manufacturer.

4) Farmers should experiment with feed formulations designed to reduce the total environmental impact of the feed.
Care should be taken to consider all environmental impacts throughout the full production process for the feed. Consideration should be given to the environmental impacts associated with each feed ingredient and any specialized processing and handling necessary for the ingredient. If experimental formulations that use alternative protein and lipid sources are tried, care should be taken to ensure that digestibility is not decreased and the nutritional needs of the species being cultured are met. Farmers should be careful that alternate formulations do not increase feed conversion ratios, decrease fish growth, and result in increased fecal waste associated with protein sources of plant origin.

5) Farmers should use efficient feeding practices.

Feed can be delivered by hand, demand feeders, automatic feeders, or by mechanical feeders. Regardless of the delivery method or system, the amount of feed offered should optimize the balance between maximum growth and maximum feed conversion efficiency. The appropriate quantity and type of feed for a given species is influenced by fish size, water temperature, dissolved oxygen levels, health status, reproductive status, and management goals. Feed particle size should be appropriate for the size of fish being fed. Feeding behavior should be observed to monitor feed utilization and evaluate health status.

6) Feeding equipment should be regularly checked to ensure efficient operation.

Improperly adjusted or malfunctioning feeding equipment can over or under feed a cage of fish and lower feed and production efficiency.

7) Whenever practical, farmers should grow fish strains that have demonstrated efficient feed conversion ratios.

8) Farmers should make every effort to reduce fish stress and optimize culture conditions to reduce feed conversion ratios.

9) Farms should conduct employee training in fish husbandry and feeding methods to ensure that workers have adequate training to optimize feed conversion ratios.

10) Wherever practical, monitoring technologies such as video, “lift-ups,” Doppler, or sonar sensors should be used to monitor feed consumption and reduce feed waste.

If automated feeding systems are used, fish monitoring systems should, if possible, be actively linked to feeding control systems to provide direct control feedback to reduce feed wastage. Even if monitoring systems are employed, active monitoring by farm operators should also occur to ensure that all systems are functioning properly and fish are behaving and feeding normally.

11) If water depths and currents allow, farmers should regularly examine the bottom under their cages and net pens.

    Close attention should be paid to the presence of any waste feed and how the benthic environment appears to be assimilating the nutrient load. When bottom surveys are conducted by third parties or regulators, survey results should be directly communicated to farm operators in a timely fashion to allow farm operators to adjust management practices if necessary.

3.3 Solids Management and Disposal

Waste feed and fish feces constitute a major portion of the solid wastes generate by a cage farm. In many cases, waste feed will be consumed by fauna attracted to the net pen. However, concentration and collection of unconsumed solid wastes is difficult because net pens and cages operate in high-energy, open-waters environments exposed to currents, waves, and storms.

While it is theoretically possible to install secondary net or deflector systems to collect solid wastes, to date experimental trials have demonstrated significant operational and economic problems with this approach. For example, the industry trend is towards sites with higher current speeds, and in areas with even moderate currents, pellets that are not consumed by the fish may be swept out of the cage before they are deposited on a collector located on the bottom of the net. Waste pellet collection systems are also expensive and typically require a power source such as a generator with an associated electrical or air distribution system. Cage systems are moored structures that are moving constantly, and distribution systems that link cages are subject to constant wear and require high maintenance. On cages systems that may be intermittently submerged during rough weather electrical distribution systems can represent a significant worker safety risk.

The most effective and practical way to manage solid wastes associated with feeding fish is aggressive feed management and proper site selection, as described above. Other possible sources of solid waste include biofouling organisms that colonize nets, mortalities, feedbags, packaging materials and scrap rope and netting.

Guidance

1) In order to effectively manage, use, and dispose of wastes generated during production activities farmers should conduct a systematic review of their operations and develop a waste management plan. This plan should identify all wastes generated on a site or from a facility.

Waste management plans should clearly identify all wastes generated on a site and classify them with respect to any risks associated with their collection and appropriate disposal. The waste management plan should be designed to minimize the generation of waste while recognizing the practical challenges associated with marine operations. Whenever possible, waste management plans should encourage recycling of waste except in cases where human or animal health may be compromised. In these cases, a clear containment and disposal method should be outlined. These methods and actions should be designed to minimize any human or fish health risks associated with the waste. At a minimum waste management plans should address, human waste, feedbags, scrap rope and netting, fish mortalities, packaging materials, and chemical or fuel spills.

2) Proactive efforts should be taken to minimize the generation of all solid waste types.

Farmers should review their operations and consider whether there are alternative practices that help reduce the use of materials that generate solid waste. The use of packaging and materials handling methods that reduce total packaging needs should be strongly considered.

3) Farmers should avoid the discharge of substances associated with in-place pressure washing of nets into the waters of the United States.

Every effort should be made to use gear and production strategies that minimize or eliminate the need for on-site wash down and rinsing to reduce biofouling. The use of air-drying, mechanical, biological, and other non-chemical procedures to control net fouling are strongly encouraged. In some areas with high flushing rates or great depth, in-place net washing may be acceptable. In areas with high fouling rates, treatment of nets with anti-fouling compounds permitted by EPA may represent a lower environmental risk than frequent net washing.

4) Any processing or harvesting waste should be collected and disposed of properly.

5) All feed bags, packaging materials, waste rope and netting should be collected, returned to shore and disposed of properly using methods and facilities approved by appropriate regulatory authorities. Recycling is strongly encouraged.

3.4 Management of Escapees

The escape of cultured species may pose a variety of potential risks to conspecific species, aquatic ecosystems or unrelated economic activities. Potential risks include pathogen transmission, interbreeding with conspecific species and introgression of genetic traits, competition for limited resources, predation, rapid colonization and spread, or disruption and damage to commercial and recreational industries including aquaculture. For almost all of the aquatic species cultured in the United States, these outcomes have not occurred nor are anticipated to occur because: 1) diseases and pathogens are addressed by the farmer and regulatory agencies; 2) most of the species in culture are native; 3) successful introduction and spread of a non-native species meets strong biological resistance; and 4) federal and state agencies have implemented a variety of effective invasive species regulations to prevent, control, manage or mitigate potential impacts.

There are three principle causes of escapees from net pen or cage farms: equipment failure, operational errors, and predator attacks. Fish that escape from farms impact farm revenue by increasing production costs and by direct loss of potential revenue. Thus farmers have strong incentives to reduce escapes.

All net pen and cage farms should continuously strive to reduce the risk of fish escapes. While it is theoretically possible to prevent fish escape by the installation of secondary containment nets, these systems have environmental costs. Double netting systems significantly reduce water flow rates through cages and net pens. This flow reduction may negatively impact dissolved oxygen in and around cages, increase sedimentation rates, and alter water circulation patterns on farm sites. The additional stress on fish may predispose fish to diseases and increase feed conversion ratios, resulting in increased waste production per unit of fish biomass. The use of double netting increases the net surface area subject to biofouling, thereby increasing the need for net cleaning and disposal of fouling waste. The heavier physical loads associated with double netting structural, flotation, and mooring requirements will all increase. These increased equipment requirements, in combination with the additional netting required, would significantly increase the consumption of energy and petroleum products used in the manufacture of cage farming equipment.

The two most effective ways to reduce potential environmental impacts of escapees are prevention and genetic isolation. Prevention involves proactively reducing the potential causes of escape. Genetic isolation is accomplished by using highly domesticated strains that are unlikely to survive in the wild or unable to interbreed with wild fish. Escape response actions such as recovery plans, may also help mitigate the impact of escapes if they occur.

Guidance

1) Follow all local, state, and federal regulations that govern the species that may be imported, exported, cultured, or sold live locally or nationally.

   Contact appropriate state agencies for regulations governing species, facility design and operation, holding and transport, or live sales. Seek the advice from aquaculture Extension Specialists and appropriate agencies when considering the culture of an unfamiliar species. Contact the United States Fish and Wildlife Service for an import/export license and information about injurious species identified under the Lacey Act. For regulations concerning species and production systems that can be used in marine waters, contact the National Marine Fisheries Service. For health certification of imports and exports contact the USDA Animal Plant Health Inspection Service.

2) Before installing net pen or cages on a site, operators should consider how site characteristics might impact the risk of escapes.

Site characteristics that may be relevant include frequency of extreme weather, degree of site exposure, type of bottom, and distribution and prevalence of predators, and navigational considerations. When practical, sites should be selected that minimize the impacts of these aspects.

3) Net pen and cage farms should develop and employ systematic loss-control plans.

Plans should include a site-specific analysis of the potential risks of escapes, their causes, and the specific procedures employed by the farm to reduce the risk. Loss-control plans should be designed to address the three principle causes of escapes (equipment failure, operational errors, and predator attacks) and may include minimum equipment and operating standards. Plans should allow for continuous improvement and revisions based on innovations in farming methods and technology.

4) Fish transfers such as stocking, grading, transfer, or harvest should be conducted in appropriate weather conditions and under constant visual supervision of at least one person. Equipment appropriate to the weather and cage designs should be used. Where necessary appropriate shields or additional net should be used to prevent stray fish escape during transfer.

5) All holding, transportation, and culture systems should be designed, operated and maintained to prevent escape.

6) Nets should only be obtained from a manufacturer or supplier whose equipment design specifications and manufacturing standards meet generally accepted standards prevalent in the aquaculture industry.

Net design and specification should be commensurate with the prevailing conditions of the site. Stress tests should be preformed on all nets with more than three years of use in the marine environment when the net is pulled out and cleaned. All nets in use should be UV-protected.

7) Cages should only be obtained from a manufacturer or supplier whose equipment design specifications and manufacturing standards meet generally accepted standards prevalent in the aquaculture industry.

Cage design, specification, and installation should be commensurate with the prevailing conditions and capable of withstanding the normal maximum weather and sea conditions.

8) Net pens and cages should have jump nets installed to prevent fish from jumping out of the primary containment net.

Jump nets should be an integral part of the primary containment net or joined to it in a fashion that prevents fish escape between the primary net and the jump net. Jump nets should be of a height appropriate to the jumping ability and size of fish they are containing. In areas with extreme winters, cages may sink slightly due to ice loads from freezing spray. This is a temporary condition that abates as the ice melts during submergence. In areas where winter icing occurs regularly, bird nets should be exchanged for winter cover nets. These nets should be constructed of netting designed to withstand the rigors of icing and with mesh sizes appropriate to contain the fish size being reared.

9) Nets should be secured to the cage collar such that the collar bears the strain and not the handrail of the cage.

Net weights, when used, should be installed in such a manner as to prevent chafing. A second layer of net should be added one foot above and below wear points. The use of weight rings should be encouraged at appropriate sites.

10) A preventative maintenance program for nets should be developed.

The program should have the ability to track individual nets, and schedule and document regular maintenance and testing. Nets that fail testing standards should be retired and disposed of properly.

11) Mooring system designs should be compatible with the cage systems they secure.

Mooring systems should be installed in consultation with the cage manufacturer or supplier. Mooring system design, specification and installation should be commensurate with the prevailing conditions of the site and be capable of withstanding the normal maximum conditions likely to occur at a site.

12) Site operators should regularly inspect and adjust mooring systems as needed.

Rigging tension should be maintained to installation standards. New components should undergo their first inspection no later than 2 years after deployment. A diver or remote camera should regularly visually inspect subsurface mooring components. Special attention should be given to connectors and rope/chain interfaces. Chafe points should be identified and subject to more frequent inspection and removal of marine growth. With the exception of rock pins, mooring systems should be hauled out of the water for a visual inspection of all components at least every 6 years. When considering what inspection method to employ net pen operators should consider the relative risks and benefits associated with the inspection method. On sites frequently exposed to severe weather or where it is difficult to set anchors, breaking out anchors for visual, above-water inspection may represent a greater risk than regular underwater inspections.

13) Shackles used in mooring systems should be either safety shackles, wire-tied, or welded to prevent pin drop-out.

14) A preventative maintenance program for cages and mooring systems should be developed.

The program should monitor maintenance of individual cages, and schedule and document regular maintenance, the nature of the maintenance, date conducted, any supporting documentation for new materials used, and who conducted the maintenance.

15) Where appropriate, bird nets should be used to cover net cages in order to reduce the risk of escape due to bird predation. Bird nets should be constructed using appropriate materials and mesh sizes designed to reduce the risk of bird entanglement.

16) All net pen or cage sites should be clearly marked in accordance with the farm's permit for fixed private aids to navigation from the U.S. Coast Guard and appropriate state authorities.

17) Site operators should develop a Standard Operating Procedure (SOP) for all routine vessel operations.

Vessel operations around a net pen or cage site can cause escapes. All vessel operators should receive appropriate training in the operation of the vessel. The SOP should minimize the risk of damaging nets and/or mooring system components with the propeller of the vessel. When mooring barges on a permanent or semi-permanent basis, local current and wind patterns should be considered. The mooring location should be selected so that in the event of a vessel breaking free of its moorings the chance of the vessel impacting a cage is minimized.

18) Where practicable, in the event of a significant escape, farmers should make attempts to recapture escaped fish.

Recapture procedures should be based on a escape-response plan the farmer has developed in consultation with the appropriate resource management agencies responsible for the protection of wild fish and wildlife populations. Care should be taken to use methods that do not violate fish and wildlife regulations. Farmers should consult with the appropriate resource management agencies before undertaking recovery actions.

3.5 Mortality Removal and Disposal

Proper fish health management is the best method of managing mortalities in net pens and cages. Optimizing fish health will reduce the need to deal with dead fish. Even under optimal conditions some mortalities will occur naturally. Net pens and cages by their very design contain and collect any mortalities that may occur. This facilitates the close monitoring of mortality rates and their timely removal. Severe weather may temporarily prevent mortality removal; however, these time periods tend to be intermittent and infrequent. Exposed sites may be more subject to these conditions.

Guidance

1) Farmers should proactively manage their fish stocks to optimize animal health.

   Refer to Section 6 for guidance on aquatic animal health management.

2) Weather permitting, mortalities should be collected regularly and frequently.

   When collecting and removing mortalities, care should be taken to use methods that do not stress remaining animals, compromise biosecurity, or jeopardize worker safety. Mortalities should only be stored and transported in closed containers with tight fitting lids. Mortalities should be returned to shore and disposed of properly using methods and facilities approved by appropriate regulatory authorities. The use of composting is strongly encouraged.

3.6 Facility Operations and Maintenance

Net pen and cage farms are expensive to install and operate. Net pen and cage operators are subject to elevated public scrutiny because they generally operate in public waters. Net pens and cage farms operate in these public waters under licenses or permits that can be summarily revoked by local, state or federal authorities. Net pen and cage operators who do not operate their facilities in a responsible and sustainable fashion risk the revocation of these licenses and permits and directly jeopardize their own investments.

Guidance

1) Farms should conduct a systematic review of their current operations and identify any documented environmental impacts. When considering modifications to existing farming methods, growers should include a review of the type and extent of probable environmental impacts that may occur as a result of the new methods.

2) When conducting activities such as stocking/seeding, harvesting, feeding, grading, thinning, transfer, cleaning, or gear maintenance, all standard operating procedures should include diligent efforts to minimize probable environmental impacts. Impacts on worker safety, product quality, and animal welfare should also be considered during the planning and implementation of any prevention and/or mitigation efforts.

3) Comprehensive stocking and production strategies that optimize production while minimizing environmental impacts should be used. Production planning should include a systematic review of any probable environmental impacts that would be associated with a particular production plan or method.

4) All net pen and cage sites should be clearly marked and in full compliance with U.S. Coast Guard marking regulations.

5) When installing net pens and cages and their associated mooring systems, careful consideration should be given to their potential impacts on water circulation patterns. Gear deployment should seek to optimize circulation patterns and maximize water exchange.

6) Harvest procedures and equipment should be designed and operated in a fashion that reduces any associated discharges. Harvest and post-harvest vessel and equipment clean up procedures should minimize any wastes discharged overboard.

7) Net pen and cage operators should strongly consider the practicality of polyculture using shellfish and/or marine plants to reduce potential discharge of nutrients and particulate matter.

   Where practical, shellfish, marine plant and finfish farms should be co-located in order to maximize production synergies and reduce potential water quality impacts. When considering polyculture, growers should also consider possible impacts on biosecurity, worker health and safety, public health, and water circulation patterns.

8) Farm support vessels should only be fueled at approved fueling stations.

   All fuel or oil spills should be immediately reported to the fueling station operator. All on-board spills and leaks should be immediately reported to the captain of the vessel. Appropriate clean up and repair actions should be initiated as soon as practicably possible. All fuel or oil spills should be reported as required to the appropriate state and federal authorities.

9) Farm support vessels of the appropriate size should have approved Marine Sanitation Devices (MSD) on board. All human wastes should be disposed of according to applicable state and federal regulations.

10) If antifouling paints are used on farm support vessels, nets or structures, only boat-bottom paints approved for use by state or federal regulations should be used.

11) Develop a record-keeping system.

    Good record-keeping is the hallmark of a well-operated aquaculture facility. Records, such as feeding, chemical use, water quality, serious weather conditions, fish culture operations, and inventory 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.

3.7 Resources

Brooks, K. M., C. Mahnken, and C. Nash. 2002. Environmental effects associated with marine netpen waste with emphasis on salmon farming in the Pacific Northwest. Pages 159-203 in R. R. Stickney and J.P. McVey, editors. Responsible Marine Aquaculture. CAB International, Oxon, UK.

Gowen, R. J. and N. B. Bradbury. 1987. The ecological impact of salmonid farming in coastal waters: a review. Oceanography and Marine Biology Annual Review 25:563-575.

Levings, C.D., A. Ervik, P. Johannessen, and J. Aure. 1994. Ecological criteria used to help site fish farms in fjords. Estuaries 18(1A):81-90.

Myrick, C. A. 2002. Ecological impacts of escaped organisms. Pages 225-245 in J. R. Tomasso, editor. Aquaculture and the Environment in the United States. United States Aquaculture Association/World Aquaculture Society, Baton Rouge, LA.

Silvert, W. 1992. Assessing environmental impacts of finfish aquaculture in marine waters. Aquaculture 107:76-79.

Silvert, W. and J. W. Sowles. 1996. Modeling environmental impacts of marine finfish aquaculture. Journal of Applied Ichthyology 12:75-81.

Stickney, R. R. 2002. Impacts of cage and net-pen culture on water quality and benthic communities. Pages 105-118 in J. R. Tomasso, editor. Aquaculture and the Environment in the United States. United States Aquaculture Association/World Aquaculture Society, Baton Rouge, LA.

SECTION 4

BEST MANAGEMENT PRACTICES FOR RECIRCULATING AQUACULTURE SYSTEMS

Recirculating aquaculture systems consist of an organized set of complementary processes that allow at least a portion of the water leaving a fish culture tank to be reconditioned and then reused in the same fish culture tank or other fish culture tanks. Recirculating aquaculture systems generally require at least several of the following treatment processes, depending upon their water-use intensity and species-specific water quality requirements:

- sedimentation units, granular filters, or mechanical filters to remove particulate solids;
- suspended growth or fixed-film biological filters to remove dissolved wastes (soluble BOD, ammonia and nitrite);
- strippers/aerators to add dissolved oxygen and decrease dissolved carbon dioxide or nitrogen gas to levels closer to atmospheric saturation;
- oxygenation units to increase dissolved oxygen concentrations above atmospheric saturation levels;
- advanced oxidation units (i.e., ultraviolet filters or units to add ozone) to disinfect, oxidize organic wastes and nitrite, or supplement the effectiveness of other water treatment units;
- pH controllers to add alkaline chemicals for maintaining water buffering or reducing dissolved carbon dioxide levels; and
- heaters or chillers to bring the water temperature to a desired level.

Recirculating aquaculture systems 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, allowing fish production in regions where water is scarce. However, minimizing water use also puts the wastes into a concentrated and relatively small volume effluent. The concentrated effluent reduces the volume of wastewater to be treated and, thus, the size and 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 significantly reduces the 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 a higher level of management. Recirculating aquaculture systems also allow fish farms to locate in better market areas or where niche markets provide a better price for local or fresh fish.

The costs associated with construction and operating the additional water treatment equipment, however, 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 growout 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, 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. 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 17,600,000 pounds 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 POTWs 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 among 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 country. 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. Others may 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 retention 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.

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

This section provides a list of options that can be used to improve the environmental performance of recirculating aquaculture systems. Recommended practices are provided for site selection, feed management, solids management, solids storage, solids treatment and disposal, management of escapees, mortality removal and disposal, and facility operation and maintenance. Recirculating systems are used to culture many different fish species and system design varies considerably. The diversity of systems make the development of generic environmental management practices challenging. A reasonable practice for one facility may be totally inappropriate for another. Furthermore, practices may be combined in unique ways to achieve the goal of pollutant reduction. As such, BMPs should never be developed without consultation with technical experts and all stakeholders.

4.1 Site Selection

Location on substandard sites is a frequent cause of failure of aquaculture projects. Most of the siting criteria important in reducing environmental impacts of recirculating aquaculture systems are also critical in assuring profitability of the venture. For example, site selection should avoid areas prone to flooding in order to avoid contaminating the recirculating system with surface water or even catastrophic loss of fish and equipment. Site selection also requires identification of a reliable make-up water supply for the recirculating aquaculture system that is clean and uncontaminated and of sufficient volume to meet the requirements of the system. As such, a careful site evaluation should be made prior to construction regardless of the legal requirements. Identification of potential problems before construction and either addressing those problems or locating an alternative site is much less expensive and environmentally benign that solving problems by implementing mitigation measures after construction or, in the extreme, having to close the farm and abandon the site. Because of the relatively small facility footprints and water requirements, siting of recirculating aquaculture systems is commonly less of a problem compared to other production systems.

Guidance

1) Before purchasing land or building a recirculating aquaculture facility, be aware of all restrictions and regulations that may apply to the use of the land and water for aquaculture.

   Several state or federal agencies may have jurisdiction 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 Pollutant 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, which administers and enforces provisions of Section 404 of the Clean Water Act. Section 404 regulates, among other activities, conversion of wetlands to farming, including aquaculture facilities.

   City and county zoning and building restrictions can seriously impact construction costs and can vary widely between different locations. Local and state coastal zone agencies can restrict development in the coastal zone and may require extensive design review of architectural design and layout features.

2) Recirculating aquaculture systems should not be sited where the discharge may impair protected water resources, at-risk water bodies, and special habitats.

   These areas are generally excluded from coverage under an NPDES permit and typically are sensitive habitats for threatened and endangered species. At-risk water bodies may include downstream drinking water intakes for municipalities.

3) Recirculating aquaculture systems should not be built in areas prone to flooding or displace salt marshes, freshwater wetlands or other ecologically sensitive areas.

   Floods that back-up into the lowest point of a recirculating system (typically the pump sump) or, even worse, overtop mechanical equipment and culture tanks will result in contamination of the culture water with potential fish pathogens and potentially poor quality flood waters. The local USDA Natural Resources Conservation Service can provide information on historic flood levels and guidance on selecting sites to avoid flood-prone areas.

   Most flood-prone areas, wetlands and coastal areas within the normal tidal range are poor sites for aquaculture development because construction costs, soil properties, susceptibility to storms or flooding, and other characteristics often result in increased costs of production and long-term management problems.

4) Site topography and hydrology should be suitable for aquaculture development.

Site topography should 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 in saturated conditions. Because of the relatively low water requirement, the make-up water supply does not have to flow to the recirculating aquaculture system by gravity as the relatively low volume of make-up water can be pumped. However, site topography should allow for discharge into receiving waters at an elevation above flood level. Construction of facilities and access roads should not alter natural water flows needed to maintain surrounding habitats.

5) Water supplies should be free from contamination.

Recirculating aquaculture systems depend on a reliable water supply with clean and uncontaminated water of sufficient volume to meet the make-up water requirements of the system. Although most recirculating systems can be operated without make-up water for some period, within days to weeks depending upon the system, resumption of the make-up water flow will be required to replace water lost to evaporation or from flushing concentrated biosolids. Historical records of the water supply should be assessed, when available, to check the reliability of the water supply.

Water supplies for recirculating aquaculture systems should be free of contaminants that may harm fish or cause poor water quality in the culture system and its effluents. Water supplies should also be free of chemicals that can accumulate in fish tissues and affect product quality or food safety. Ground water is considered a better source than surface water 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. However, the drilling of new water wells for agriculture in the Western United States or other regions may be difficult due to strict laws governing water rights. 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 systems, but the chlorine must first be removed from the water and the cost of this water may be cost prohibitive.

6) Wastewater treatment 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.

4.2 Feed Management

Feed is the major input of nitrogen, phosphorus, biochemical oxygen demand (BOD), and solids in recirculating aquaculture systems. The water treatment processes in a recirculating system remove or transform a portion of the feed derived wastes in the recirculating water. 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 flow of recirculating and make-up water. However, operating recirculating systems at a feed loading within the assimilative capacity of the water treatment processes is important to maintain water quality inside the culture tank and provide a better environment for fish growth. 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. Feed management is only one factor among many in the control of potential pollution from recirculating aquaculture systems. Feed management does, however, 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.

Fish nutrition and feeding practices are active areas of research, and technology is constantly evolving. An important research goal is to improve the efficiency of nutrient utilization by fish, thereby enhancing economic returns and reducing waste production. Because technology is rapidly changing, BMPs for feed management should be flexible so that newer and better practices can be implemented as they become available.

Guidance

1) Use high quality feeds.

   Feeds should be formulated to meet the nutritional requirements of the fish under culture, and to optimize digestibility, improve efficiency, and reduce waste output. In the case of feeds used in recirculating systems, minimizing metabolic excretion of nitrogen from amino acids catabolized to provide metabolic energy, and minimizing nitrogen excretion in feces from indigestible protein is the top priority in feed formulation. Therefore high quality feeds for recirculating systems are those with balanced amino acid profiles, e.g., profiles that meet but do not substantially exceed dietary requirements for individual essential amino acids, and those containing sufficient dietary energy from carbohydrates and lipids to "spare" dietary protein for tissue synthesis. Further, available phosphorus levels in feeds should slightly exceed the dietary requirements of the fish, taking into consideration the species and life history stage. Efforts should be made in feed formulation to keep total phosphorus levels as low as possible while maintaining available phosphorus levels at appropriate levels. Finally, feeds should be formulated using highly digestible feed ingredients, especially those having high apparent digestibility coefficients for dry matter and protein. Pellets should be manufactured to be water stable, and feeds should be shipped and handled at the farm to minimize pellet breakage and production of fine particles.

2) Use efficient feeding practices.

The feed ration for a given species is influenced by feed formulation, water temperature, fish size, dissolved oxygen and carbon dioxide concentrations, fish health status, and management goals. Feed size should be appropriate for the size of fish in each rearing unit. Feed ration offered should optimize the balance between maximum growth and maximum feed efficiency. 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. Multiple feeding periods distributed over a 24-hour period will provide more uniform water quality within a recirculating system than a feeding schedule only offering feed once or twice daily.

3) Manage feed not to exceed the carrying capacity of the recirculating 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. Dissolved oxygen is usually the first water quality parameter to limit culture tank carrying capacity, which, in simplistic terms, is the maximum fish biomass that can be supported at a selected feeding rate. Note that the culture vessel volume does not determine carrying capacity unless water flow is in excess of all other water quality based carrying capacity requirements. Because recirculating systems will by definition treat and reuse large portions of the system make-up water flow, the water flow requirements through the culture vessels within a recirculating system can be much greater than the make-up water flow requirements that flush the system. 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. 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. However, when a unit treatment process (e.g., biofilter or aeration column) is designed, the designer should also predict the expected water quality exiting a culture tank within a recirculating system to help ensure that the design will provide safe water quality for the fish when reared at maximum carrying capacity, i.e., feed loading.

4) Feed should be properly stored.

Feed storage should be secure from contamination, vermin, moisture and excessive heat. Long term storage of feed can affect feed quality. Feed should be rotated (use oldest feed first) and not stored beyond the manufacturer's recommended length of time.

5) Feeding equipment should be checked to ensure efficient operation.

Feeding equipment improperly adjusted or malfunctioning can over or under feed a population of cultured species diminishing feed and production efficiency.

4.3 Solids Management

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 make-up water flow rates.

The particulate wastes discharged from the recirculating system are contained in either a small but concentrated flow (such as the intermittent backwash from a solids capture unit) and/or in a more continuous flow of displaced water (such as an overtopping flow from a pump sump that is water that has been displaced by make-up water addition) that has a concentration of solids similar to that found in the fish culture tanks. Not all recirculating systems will have an overtopping flow, depending upon their make-up water requirements. When the solids are discharged, as with backwashing water, the concentration of solids is typically relatively high. However, if an overtopping flow is discharged from the system, it will be relatively small in volume compared to the discharge from a flow-through system.

Solids can impact the aquatic environment and should be intercepted and removed as thoroughly as possible prior to discharge. Therefore, nearly all recirculating aquaculture systems ultimately must use an on-site treatment or disposal option to remove 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 waste flows could be discharged to a POTW.

Much of the phosphorus exiting a recirculating system is bound in waste solids. However, beyond the adoption of good solids capture and disposal technologies, there are no economically viable phosphorus removal options.

Guidance

A. Solids capture within a recirculating system.

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

a) Linear rearing units designed to promote plug flow and sufficient water velocity to prevent the settling of solids within the rearing unit allows the capture of solids either in quiescent zones or other settling basins. Solids allowed to settle in rearing units degrade water quality and may irritate fish gills leading to disease. Proper design and construction can be an economical means of managing solids through settling of solids in designated areas which allows for efficient removal.

b) 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. 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 solids removal process in comparison to those removed from an un-concentrated flow.

2) Remove solids rapidly, but gently.

Rapid, effective, and gentle removal of waste solids within a solids treatment unit is the best approach to use when targeting optimum water quality within a recirculating system. The longer the waste feed and fish manure – which can be fragile and labile organic particles – are held within the recirculating water flow the more opportunity that dissolution forces such as hydraulic shear and micro-organisms will have to disintegrate larger particles into much finer and more soluble particles. Finer particles can more rapidly leach nutrients and biochemical oxygen demand (BOD) and these components are harder to remove from the water column than the original intact fecal pellet or waste feed pellet. Thus, 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. Products of solid decomposition are more difficult to remove from aquacultural effluents.

Waste solids exiting the rearing tank can be removed from the bulk flow leaving the culture tank using a treatment unit such as 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 dissolved organic matter, so they complement solids removal via settling or filtration. Conventional sedimentation and microscreen filtration processes are often used to remove solids larger than 40-100 μm. However, few processes used in aquaculture can remove dissolved solids or fine solids smaller than 20-30 μm, although granular media filtration has been used to remove these fine solids. 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. Significant degradation or re-suspension/flotation of the solids matter should be avoided, but can occur in treatment units that have relatively infrequent backwash cycles. Therefore, the best solids removal processes remove solids from the system as soon as possible and expose 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.

Backwash of the solids capture unit will create an intermittent solids-laden flow that will require treatment before discharge (see 4.3.B. below for more information), unless discharged to a POTW.

It is important to note that not all recirculating aquaculture systems maintain low levels of suspended solids, as is typically the goal in 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. 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.

B. Remove solids from the concentrated backwash flows before discharge.

Solids backwashed from solids removal processes tend to be dilute at less than 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.

1) Design settling basin size on overflow rate.

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. Compression settling develops when a compressed layer of particles forms at the basin bottom. 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. If laminar flow conditions are perfectly maintained, then any particle with a settling velocity greater than or equal to the overflow rate will settle within the settling basin.

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.

2) Settling basin inlet and outlet design should minimize turbulence and short-circuiting.

Flow surges, scour, wind shear, short-circuiting and excessive turbulence decrease settling basin efficiency and can contribute to increased solids in the effluent. Designs that evenly introduce the flow into the settling basin and decrease the influent water velocity maintain settling basin efficiency. Discharging settling basin effluent across a weir minimizes scour and upwelling.

3) Solids should be frequently removed from settling basins.

Settling basins should be cleaned as frequently as practical. Sludge left too long in settling basins becomes sticky and viscous making removal difficult. Sludge accumulation may degrade water quality and can provide a substrate for bacterial growth.

A procedure or mechanism to remove the dewatered manure from the thickening device must be incorporated.

4) Overflows from solids thickening tanks may require additional treatment.

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.

C. Removal of solids in the overtopping flow.

1) When necessary, remove solids from the recirculating system's overtopping flow (if present) before it is discharged.

Depending upon their make-up 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 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.

4.4 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.

Guidance

1) Store sludge in an appropriate facility or container.

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 anoxic. 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 should be considered.

4.5 Solids Treatment and Disposal

Fish feces contain nitrogen and phosphorus and can be used as a soil amendment. The composition of solids 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 solids 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. Fish manure should be defined as an agricultural waste. However, state or local government authorities may consider the fish manure captured in an aquaculture system’s 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.

Guidance

1) Disposal of solids should comply with all applicable local regulations and done 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.

   a) 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.

b) Lagoons

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

c) 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.

d) 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 2-4 inches 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.

e) Contract hauling

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

4.6 Management of Escapees

The escape of cultured species may pose a variety of potential risks to conspecific species, aquatic ecosystems or unrelated economic activities. Potential risks include pathogen transmission, interbreeding with conspecific species and introgression of genetic traits, competition for limited resources, predation, rapid colonization and spread, or disruption and damage to commercial and recreational industries including aquaculture. For almost all of the aquatic species cultured in the United States, these outcomes have not occurred nor are anticipated to occur because: 1) diseases and pathogens are addressed by the farmer and regulatory agencies; 2) most of the species in culture are native; 3) successful introduction and spread of a non-native species meets strong biological resistance; and 4) federal and state agencies have implemented a variety of effective invasive species regulations to prevent, control, manage or mitigate potential impacts.

Barriers should be used to ensure that the cultured species remains contained within a recirculating system, preventing its inadvertent escape to avoid economic loss and potentially adversely affecting local wild populations. In some cases, inadvertent losses should pose no threat to wild fish in receiving waters because many recirculating aquaculture systems in the United States are based on growing native North American fish. However, important exceptions do exist. Therefore, before introducing any new species into a recirculating system, contact appropriate state and federal agencies for regulations governing aquaculture, importation, holding, and transport.

Guidance

1) Follow all local, state, and federal regulations that govern the species that may be imported, exported, cultured, or sold live locally or nationally.

   Contact appropriate state agencies for regulations governing species, facility design and operation, holding and transport, or live sales. Seek the advice from aquaculture Extension Specialists and appropriate agencies when considering the culture of an unfamiliar species. Contact the United States Fish and Wildlife Service for an import/export license and information about injurious species identified under the Lacey Act. For health certification of imports and exports contact the USDA Animal Plant Health Inspection Service.

2) 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 make-up water entry into the facility. A procedure or mechanisms should also be identified to prevent debris from plugging the barriers, thus preventing water from overflowing or by-passing the screens.

3) Avoid areas prone to flooding when siting facilities.

Floods that overflow a recirculating system could result in loss of cultured animals and would likely be catastrophic for the farmer. Avoid areas prone to flooding when siting facilities.

4.7 Mortality Removal and Disposal

Mortality of cultured species in aquaculture is unpredictable and highly variable among rearing units, epizootics, and facilities. A facility may experience chronic losses of a few fish dying per day for long periods or a catastrophic loss caused by infectious disease or acute environmental stress. Depending on water temperature and species, dead fish either float or sink after dying, with warm water fish typically floating and cold water fish sinking. 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.

Guidance

1) Mortalities should be removed from rearing units on a regular basis.

   Dead or moribund fish can be transported by flowing water to a tank drain, where they can accumulate against screens and restrict the water flow out of the culture unit. 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.

2) Follow recommended aquatic animal health management practices

   Prevention and minimization of mortalities through proper fish health management is the best method for managing mortalities. Most states offer diagnostic services and treatment recommendations for disease problems. General guidance on health management can be found in Section 6.

3) Mortalities should not be discharged into receiving waters.

   Appropriate screens on the outlet to receiving waters will prevent discharge of fish mortalities into receiving waters.

4) Only approved methods of mortality disposal should be used.

Disposal methods will be site-specific and usually governed by state or local regulations. Disposal options include composting, rendering, use as a soil amendment, incineration, or landfill.

4.8 Facility Operation and Maintenance

Recirculating aquaculture systems are expensive to build and operate. Protection of the investment by operating facilities in a sustainable fashion is in the best interest of facility owners and environmental protection. Facilities that are well-maintained, managed efficiently, and operated in compliance with all applicable laws and regulations will improve long-term economic performance and reduce environmental impacts. As such, all of these management practices are simply part of good management.

Guidance

1) Use and store petroleum products to prevent contamination of the environment.

Petroleum leaking from storage tanks or farm equipment wastes a valuable resource and can contaminate surface or underground water supplies. Petroleum products are highly odorous and small amounts in water can produce an off-flavor in aquatic animals. Petroleum storage in above-ground and underground tanks is regulated by federal and state agencies. Information on petroleum storage regulations can be obtained from State Departments of Commerce, State Departments of Environmental Quality or Protection, or from EPA regional offices. Aquaculturists should also implement a regular maintenance schedule for tractors, trucks, and other equipment to prevent oil and fuel leaks. Used oil should be disposed of through recycling centers.

2) Use and store chemicals to prevent contamination of the environment.

The most common chemicals used in recirculating aquaculture are water treatments and disinfectants. When used according to label directions, these materials will have no adverse effects on the environment. Chemicals should be used only when needed and only for the specific use indicated on the label. 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. All chemicals should be stored in secure, well-ventilated, water tight buildings.

3) Develop a response plan for spills of petroleum products, pesticides, and other hazardous materials.

Reporting significant spills of petroleum and pesticides is required by state and federal law. A plan should be developed specifying response procedures, key staff, and regulatory authority phone numbers and all facility employees should be aware of the plan.

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

   Solid waste containers should be installed in convenient locations on the farm. Containers should be emptied regularly and the waste disposed of in a permitted landfill or county-operated dumpster.

5) Maintain structures and equipment to ensure staff safety and protection of the environment.

   Standard operating equipment and structures should be routinely inspected and repairs or replacement done as necessary.

6) Develop a record-keeping system.

   Good record-keeping is the hallmark of a well-operated aquaculture facility. Records, such as feeding, chemical use, water quality, serious weather conditions, fish culture operations, and fish inventory 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 operations.

4.9 Resources

Bergheim, A., S. J. Cripps, and H. Liltved. 1998. A system for the treatment of sludge from land-based fish-farms. Aquatic Living Resources 11:279-287.

Beveridge, M. C. M., M. J. Phillips, and R. M. Clark. 1991. A quantitative and qualitative assessment of waste from aquatic animal production. Pages 506-533 in D. E. Brune and J. R. Tomasso, editors. Aquaculture and Water Quality. World Aquaculture Society, Baton Rouge, LA.

Chen, S., D. E. Coffin, and R. F. Malone. 1997. Sludge production and management for recirculating aquacultural systems. Journal of World Aquaculture Society 28:303-315.

Chen, S., S. T. Summerfelt, T. Losordo, and R. Malone. 2002. Recirculating systems, effluents, and treatments. Pages 119-140 in J. R. Tomasso, editor. Aquaculture and the Environment in the United States. U. S. Aquaculture Association/World Aquaculture Society, Baton Rouge, LA.

Chen, S., M. B. Timmons, D. J. Aneshansley, and J. H. Bisogni. 1993. Suspended solids characteristics from recirculating aquacultural systems and design implications. Aquaculture 112:143-155.

Colt, J. E., K. Orwicz, and G. Bouck. 1991. Water quality considerations and criteria for high-density fish culture with supplemental oxygen. Pages 372–385 in J. Colt and R. J. White, editors. Fisheries Bioengineering Symposium 10. American Fisheries Society, Bethesda, MD.

Cripps, S. J. and A. Bergheim. 2000. Solids management and removal for intensive land-based aquaculture production systems. Aquacultural Engineering 22:33-56.

Environmental Protection Agency. 1987. Dewatering municipal wastewater sludges. EPA Center for Environmental Research Information, Cincinnati, OH.

Heinen, J.M., J.A. Hankins, and P.R. Adler. 1996. Water quality and waste production in a recirculating trout culture system with feeding of a higher-energy or a lower-energy diet. Aquaculture Research 27:699-710.

Henderson, J. P. and N. R. Bromage. 1988. Optimizing the removal of suspended solids from aquaculture effluents in settlement lakes. Aquacultural Engineering 7:167-188.

Liao, P. B. and R. D. Mayo. 1974. Intensified fish culture combining water reconditioning with pollution abatement. Aquaculture 3:61-85.

Losordo, T. M., P. W. Westerman, and S. K. Liehr. 1994. Water treatment and wastewater generation in intensive recirculating fish production systems. Bull. Natl. Res. Inst. Aquaculture, Suppl. 1:27-36.

Mudrak, V. A. 1981. Guidelines for economical commercial fish hatchery wastewater treatment systems. Pages 174-182 in L. J. Allen and E. C. Kinney, editors. Proceedings of the Bio-engineering Symposium for Fish Culture. American Fisheries Society, Fish Culture Section, Bethesda, MD.

Myrick, C. A. 2002. Ecological impacts of escaped organisms. Pages 225-245 in J. R. Tomasso, editor. Aquaculture and the Environment in the United States. United States Aquaculture Association/World Aquaculture Society, Baton Rouge, LA.

Outwater, A. B. 1994. Reuse of Sludge and Minor Wastewater Residuals. Lewis Publishers, Inc., Boca Raton, FL.

Overcash, M.R., F.J. Humenik, and J.R. Miner. 1983. Livestock Waste Management, Volume II. CRC Press, Inc., Boca Raton, FL.

Rakocy, J.E. 1997. Integrating tilapia culture with vegetable hydroponics in recirculating systems. Pages 163-184 in B.A. Costa-Pierce and J.E. Rakocy, editors. Tilapia Aquaculture in the Americas, Volume 1. The World Aquaculture Society, Baton Rouge, LA.

Reed, S. C., R. W. Crites, and E. J. Middlebrooks. 1995. Natural Systems for Waste Management and Treatment, 2nd Edition. McGraw-Hill, Inc., New York, NY.

Serfling, S. A. 2000. Closed-cycle, controlled environment systems: The Solar Aquafarms story. Global Aquaculture Advocate 3(3):48-51.

Summerfelt, S.T. 1999. Waste handling systems. Pages 309-350 in E.H. Bartali and F. Wheaton, editors, CIGR Handbook of Agricultural Engineering, Volume II: Animal Production and Aquacultural Engineering, American Society of Agricultural Engineers, St. Joseph, MI.

Summerfelt, S. T., J. Bebak-Williams, and S. Tsukuda. 2001. Controlled Systems: Water Reuse and Recirculation. Pages 285-395 in Gary Wedemeyer, editor. Fish Hatchery Management, 2nd Edition. American Fisheries Society, Bethesda, MD.

Timmons, M. B. and T. M. Losordo. 1994. Aquaculture Water Reuse Systems: Engineering Design and Management. Elsevier Science B.V., New York, NY.

Timmons, M. B., J. M. Ebeling, F. W.Wheaton, S. T. Summerfelt, and B. J. Vinci. 2002. Recirculating Aquaculture Systems, 2nd Edition. Cayuga Aquaculture Ventures, LLC., Ithaca, NY.

Twarowska, J.G., P.W. Westerman and, T.M. Losordo. 1997. Water treatment and waste characterization evaluation of an intensive recirculating fish production system. Aquacultural Engineering 16:133-147.

United States Department of Agriculture, Natural Resources Conservation Service (USDA-NRCS). 1996. Agricultural Waste Management Field Handbook. USDA-NRCS, Washington, DC.

Wright, P., W. Grajko, D. Lake, S. Perschke, J. Schenne, D. Sullivan, B. Tillapaugh, B. Timothy, and D. Weaver. 1999. Earthen Manure Storage Design Considerations. Natural Resource, Agriculture, and Engineering Service, Ithaca, NY.

SECTION 5

BEST MANAGEMENT PRACTICES FOR POND AQUACULTURE

Ponds are by far the most common production system used in United States aquaculture. From the standpoint of aquatic animal production, ponds can be operationally defined as confined bodies of standing water that are managed to produce a crop of the target aquatic organism. Ponds are usually envisioned as being constructed entirely of soil, but that is not a necessary part of the definition. Some ponds, for example, may be lined with plastic to reduce seepage.

With respect to possible environmental effects of pond aquaculture, ponds can be functionally defined as aquatic systems where, by virtue of long hydraulic residence times, suitable water quality for animal production is primarily controlled by natural physical, chemical, and biological processes. In contrast, suitable water quality is maintained by water exchange in flow-through and net-pen systems and by discrete unit processes for water treatment in recirculating systems. This is an important distinction because it suggests that effluent volume from most ponds is relatively low and that much of the waste loading to the system is removed before water is discharged.

Aquaculture ponds can be classified hydrologically as either embankment (or levee) ponds, excavated ponds, watershed ponds, or hybrid embankment-watershed ponds. The classification is important because effluent volume and, to a lesser degree, effluent quality are affected by pond hydrology. Approaches to effluent management are also affected by pond hydrology.

Embankment ponds are the most common type of pond used in aquaculture and are constructed in flat areas by scraping soil from the pond bottom and using that soil to form embankments around the pond perimeter. Catchment areas are small, consisting only of the pond surface and the inside embankment slopes, so there must be a source of pumped water to fill ponds and maintain water levels during droughts.

Excavated ponds are similar to embankment ponds with respect to general construction and primary water source, but are usually smaller and the pond bottom is further below the original ground level than embankment ponds. In some areas with high water tables, excavated ponds may extend below the water table and be partially filled with groundwater inflow. Water may have to be pumped from excavated ponds to empty them.

Watershed ponds are built in hilly areas by damming a temporary or permanent stream. The major source of water is runoff from the drainage basin above the dam, although a source of pumped water is often available to help maintain water levels during droughts. The third pond type is a hybrid between embankment and watershed ponds. These ponds may have two or three sides consisting of embankments (actually low dams) across a relatively small, shallow drainage basin. A significant amount of water may be obtained from runoff, but a source of pumped water also must be available because the catchment area above the pond is relatively small. Hybrid watershed-embankment ponds are built in regions with gently rolling topography that is not ideally suited for embankment ponds or watershed ponds.

Embankment and excavated ponds have much less overflow than watershed ponds, with the overflow volume from hybrid ponds being intermediate. Also, the quality of effluents from watershed ponds may be affected (either positively or negatively) by upstream water quality, which is, in turn, affected by land-use practices in the catchment area.

Most pond culture systems discharge water intermittently (only after heavy rains or when ponds are drained) and effluent quality varies widely over time and among individual ponds. The intermittent and unpredictable discharge from ponds impacts the cost and potential effectiveness of nearly all "end-of-pipe" treatment options. Such treatment systems for pond effluents would be idle for far more time than they are used and the average annual hydraulic loading to the system will be low. However, when discharge occurs, the volume may be relatively 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 effluent discharge also makes it extremely difficult to assess the performance of waste treatment technology by simply monitoring waste concentration.

Overall, adoption of management practices that minimize environmental impacts will 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 by reducing effluent volume or by improving nutrient utilization within ponds.

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.

This document provides a list of options that can be used to improve the environmental performance of pond aquaculture. Recommended practices are provided for site selection, feed management, solids management, solids disposal, management of escapees, mortality removal and disposal, and facility operation and maintenance. Ponds are used to culture a wide range of species, including channel catfish, baitfish, ornamental fish, hybrid striped bass, bluegill, largemouth bass, walleye, trout, crawfish, penaeid shrimp, freshwater prawns, and many other species of freshwater and saltwater aquatic animals.

Production practices vary widely among species and for different life stages of the same species. Appropriate culture methods also vary with geographical location, intended market, and other factors. The diversity of species and culture methods employed in pond aquaculture make the development of generic environmental management practices particularly challenging. A reasonable practice for one species may be totally inappropriate for another, and some practices are more appropriate for a particular facility than other practices. Furthermore, practices may be combined in unique ways to achieve the goal of pollutant reduction. As such, BMPs should never be developed without consultation with technical experts and all stakeholders.

5.1 Site Selection

Location on substandard sites is a frequent cause of failure of aquaculture projects. Most of the siting criteria important in reducing environmental impacts of pond aquaculture are also critical in assuring profitability of the venture. For example, selection of sites with proper soils and protection against floods will reduce long-term expenses associated with water use and replacement of escaped stock, while also protecting the environment by reducing water use, reducing infiltration of pond water into groundwater supplies, and preventing escaped fish from entering nearby water bodies. As such, careful site evaluation should be made prior to construction regardless of the legal requirements. Identification of potential problems before construction and either addressing those problems or locating an alternative site is much less expensive and environmentally benign that solving problems by implementing mitigation measures after construction or, in the extreme, having to close the farm and abandon the site.

Guidance

1) Before purchasing land or building ponds, be aware of all restrictions and regulations that may apply to the use of the land for pond aquaculture.

   Several state or federal agencies may have jurisdiction over land use and pond construction. Contact the local office of the USDA Natural Resources Conservation Service for guidance. Additional site review may be required by the United States Army Corps of Engineers, which administers and enforces provisions of Section 404 of the Clean Water Act. Section 404 regulates, among other activities, conversion of wetlands to farming, including aquaculture ponds.

2) Ponds should not be sited in mangroves, salt marshes, or other ecologically sensitive wetlands.

   Most coastal areas within the normal tidal range are poor sites for aquaculture development because construction costs, soil properties, susceptibility to storms or flooding, and other characteristics often result in increased costs of production and long-term management problems. Furthermore, the long-term intrinsic ecological value of natural wetlands may exceed that derived from conversion to aquaculture ponds.

3) Ponds should not be sited in areas prone to flooding.

Floods that overtop pond levees result in loss of cultured animals, contamination of ponds with feral aquatic animals, and mixing of potentially poor quality flood waters and pond waters. Aside from the possible escape of non-native fish, the major impact of floods will usually be catastrophic for the farmer but benign to the environment since pond waters will be greatly diluted by flood waters. The local USDA Natural Resources Conservation Service can provide information on historic flood levels and guidance on selecting sites to avoid flood-prone areas.

4) Site topography and hydrology should be suitable for aquaculture development.

Site topography should allow construction of ponds and any required treatment facilities. Typically, ponds are constructed in low gradient landscapes with average slopes <5%. Construction of facilities and access roads should not alter natural water flows needed to maintain surrounding habitats.

5) Soils should be suitable for pond construction.

The soil must have the proper mix of sand, silt, and clay to permit compaction, provide stable levees, resist erosion, and provide low hydraulic conductivity. Ponds should be constructed with soils having a sufficient range of particle sizes to prevent seepage and construct stable embankments. Ponds constructed on sites with proper soils will reduce environmental impacts by isolating pond water from underground water supplies and reducing erosion of levee slopes. Pond areas with sand lenses or former stream channels can be sealed by replacement with clay, although such measures can be expensive.

6) Water supplies should be free from contamination.

Water supplies for pond aquaculture should be free of substances that may cause poor water quality in ponds and pond effluents, disease in cultured animals, or accumulate in fish tissues and affect product quality or food safety. Local aerial pesticide applicators should be notified of the location of aquaculture ponds and measures to prevent contamination of ponds with pesticide drift should be discussed.

7) Ponds should not be constructed in sites with contaminated soils.

Soils previously exposed to certain agricultural, industrial, or urban activities may be contaminated with chemicals that may affect the health of the cultured species or accumulate in tissues affecting product quality or safety. Effluents from ponds constructed on sites with contaminated soils may contain harmful chemicals.

8) Watershed ponds should not be located where embankment failure could result in loss of life or damage to residences, industrial buildings, highways, or public utilities.

   Design and construction of embankments should be supervised by a qualified engineer or reputable pond construction companies. Embankments should be constructed in compliance with local or state dam safety regulations.

9) Watershed pond sites should be constructed with the proper ratio of watershed to pond area.

   Watershed ponds should not have watershed areas larger than necessary to keep ponds full because excessively large watersheds increase runoff into ponds and result in high discharge. Pond design will vary with climate, relief, soil type, and plant cover in the watershed. Consult the local USDA Natural Resources Conservation Service office for guidance on proper pond design and construction practices.

5.2 Feed Management

The major source of nitrogen, phosphorus, and other plant nutrients in all commercial aquaculture ponds is formulated feed. For ponds, however, output (loading of potential pollutants to a receiving body of water) is not directly related to feed input. Natural biological and chemical processes transform and remove much of the nutrients and organic matter soon after wastes are excreted by fish. Concentrations of nitrogen, phosphorus, and organic matter in ponds with long hydraulic residence times are therefore much lower than expected based on waste loading. Also, most aquaculture ponds discharge intermittently, which further disconnects output from input. Feed management therefore offers limited opportunities for control of potential pollution from ponds, unless ponds are managed with relatively short hydraulic residence times, where water quality is maintained by water exchange rather than naturally occurring waste removal processes. 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.

Fish nutrition and feeding practices are active areas of research, and technology is constantly evolving. An important research goal is to improve the efficiency of nutrient utilization by fish, thereby enhancing economic returns and reducing waste production. Because technology is rapidly changing, BMPs for feed management should be flexible so that newer and better practices can be implemented as they become available.

Guidance

1) Use high quality feeds.

Feeds should be formulated to meet the nutritional requirements of the cultured species. Feeds should be formulated using feed ingredients that have high dry matter and protein apparent digestibility coefficients. Formulations should be designed to enhance nitrogen and phosphorus retention efficiency, and reduce metabolic waste output. Feeds should contain sufficient dietary energy to spare dietary protein (amino acids) for tissue synthesis. Available phosphorus levels should be slightly in excess of the dietary requirements of the species of fish for each life-history stage, and formulation should be designed to minimize the difference between total feed phosphorus levels and available feed phosphorus levels. Consult a qualified fish nutritionist or feed manufacturer for information regarding feed formulation. Feeds should be water stable for sufficient periods such that pellets remain intact until eaten by fish. Feeds should be manufactured, stored, shipped, and handled at the farm such that they contain a minimum amount of fine particles.

2) Use efficient feeding practices.

Research indicates that growth and feed conversion ratios of most pond-raised fish are optimized when fish are fed to just short of satiation. Examples of efficient feeding practices include feeding from the upwind side of ponds, broadcasting feed across as large an area as possible, feeding what fish will consume within a specified time period (e.g., 15 minutes), and taking time to observe fish feeding behavior. Feeding rates should be adjusted with season, with lower feeding rates used in winter.

3) Feeding regimes for ponds should be based on the assimilative capacity of the pond for waste nutrients.

Water quality deteriorates when the nutrient load from feeding exceeds the capacity of the pond to assimilate those nutrients. Impaired water quality stresses fish and reduces the efficiency of feed conversion and fish production. High stocking and feeding rates also lead to effluents with a greater pollution potential, although the impact of feeding rates on effluent quality depends on when effluent is discharged relative to the time of highest feeding rates. Nevertheless, stocking and feeding at profit-maximizing rather than yield-maximizing rates is more efficient and the likelihood of water pollution by effluents is less. There is no set value for pond assimilative capacity, which can vary greatly depending on water temperature, pond size and depth, amount of supplemental aeration, and other factors. Assimilation capacity can be loosely determined empirically by monitoring fish feeding response. A reduced feeding response that can not be attributed to infectious disease may indicate that pond assimilative capacity has been exceeded.

4) Maintain adequate dissolved oxygen levels.

Farmers should be aware of current research on this subject and strive to maintain adequate dissolved oxygen concentrations for the cultured species. Adequate aeration will also enhance degradation of organic matter in pond soils and will accelerate the loss of nitrogen and phosphorus from the water column.

5.3 Solids Management

Ponds are unlike other aquaculture systems in that fish fecal matter is not the major constituent of total suspended solids. Fish fecal matter is quickly decomposed in ponds and the nutrients released in the mineralization process support the growth of aquatic plants—usually phytoplankton—which constitute the majority of total suspended solids in most ponds. Organic and inorganic solids derived from erosion of pond banks and resuspension of pond sediments also contribute to total suspended solids in pond water.

With respect to solids discharge, ponds have two distinct types of effluents. First, water overflows from ponds when rainfall exceeds pond storage capacity or when water is pumped into the pond for water exchange or "flushing." Solids in overflow effluent are principally phytoplankton, phytoplankton-derived detritus, and finely divided clay derived from pond bank and watershed erosion. Since ponds act as their own settling basins and solids that settle rapidly are constantly removed from pond water, the solids that remain in overflow effluent have poor settling characteristics and are difficult to remove in post-discharge treatment. Reducing mass discharge is best accomplished by reducing effluent volume and reducing erosion. Second, water is discharged intentionally when ponds are drained. Depending on pond hydrological type and management practices used to harvest fish and drain ponds, sediments resuspended from the pond bottom may contribute a significant amount of solids to draining effluent. Typically, these solids settle readily and can be managed by practices that rely on settling either before or after the water is discharged.

Guidance

A. Management of overflow effluents

1) Manage ponds to capture rainfall.

Most aquaculture ponds cannot be operated economically without some water being discharged during unusual precipitation events, but the overall volume of water discharged can be greatly reduced by keeping the pond water level below the level of the drain to maintain storage volume. Capturing rainfall in this manner also reduces the need for pumped groundwater to maintain pond water levels in levee ponds. Storage can be maintained by not adding water to the pond until the water level falls to a certain level below the top of the standpipe. Then, the pond is not refilled completely, but water is added to allow the maintenance of some rainfall storage capacity. The potential reduction in effluent volume increases as water storage capacity increases. The desired storage level can be indicated by painting the upper section of water level control structures.

2) Minimize water exchange.

Water exchange can be used to reduce high concentrations of ammonia or other toxic substances if large volumes of pond water are exchanged quickly, which is difficult to accomplish in practice. Because incoming water is greatly diluted when added to large ponds, it is unlikely that sufficient water can be exchanged in a sufficiently short period of time to have a beneficial effect during acute water quality crises. The effectiveness of water exchange as a water quality management procedure in large commercial aquaculture ponds is questionable. Research has shown that routine water exchange at rates possible on most farms (less than 5% daily) has little or no effect on pond water quality and should not be used. Furthermore, the displaced pond water represents a pollution load in receiving waters, and high rates of water exchange should not be used unless absolutely necessary. If water exchange is practiced, consideration should be given to circulating water between a treatment or reservoir pond and production ponds.

3) Position mechanical aerators to minimize erosion of pond bottoms and embankments.

Aerators produce strong water currents that can erode pond bottoms and embankments. Aerators should not be positioned to cause strong currents to impinge on embankments. Areas immediately in front of aerators can be hardened by compaction during pond construction and renovation, or rip-rap installed to reduce the tendency for erosion. Erosion reduces the interval between pond renovations, causes deposition of sediment on the pond bottom, reduces pond depth, and can result in high concentrations of inorganic suspended solids in effluents.

4) Inspect pond drains frequently and repair when needed.

Drains that leak can significantly increase water use and long-term effluent volume. Drains can leak through faulty valves and improperly compacted soil around drain pipes that extend through pond embankments. Most drains can be inspected for leakage during routine farm activities. Leaking drains can also be tentatively identified by excessive water use in a pond relative to adjacent ponds.

5) Optimize the ratio of watershed to pond area.

Watershed ponds should not have watershed areas larger than necessary to keep ponds full because excessively large watersheds increase runoff into ponds and result in high discharge. Runoff from watersheds may be partially diverted from ponds by terracing, supply stream diversion, or other means. Optimal pond design will vary with climate, soil type, and watershed use. Consult representatives of the local office of the USDA Natural Resources Conservation Service for assistance with pond design.

6) Control erosion on pond watersheds and pond levees.

Vegetative cover will reduce erosion of watershed soils and the loading of suspended solids to ponds in runoff. In watersheds used for grazing, maintenance of appropriate livestock stocking rates will allow maintenance of sufficient plant cover. In degraded watersheds or those subject to erosion, streamside management zones (SMZs) or buffer strips adjacent to water supply streams should be maintained. Seed pond levees with a cover crop, such as Bermuda or centipede grass, shortly after pond construction. Planting a cover crop will limit sedimentation of the pond, thereby extending the interval before renovation is required.

7) Divert excess runoff from large watersheds away from ponds.

Runoff can be diverted by constructing temporary low-elevation embankments or ditches running across slope on watershed areas adjacent to ponds. This practice can divert turbid runoff where it is not possible to provide erosion control on watersheds. Diversion can extend the production interval between draining and renovation in watershed ponds by minimizing reduction in pond depth caused by deposition of sediment derived from turbid runoff. Less water passing through ponds will reduce erosion of embankments and farm ditches, and the output of suspended solids will be less.

B. Management of draining effluent

1) Allow solids to settle before discharging water.

Some watershed ponds must be partially drained to facilitate fish harvest. In those instances, water should not be discharged during seining to avoid the discharge of sediment suspended by harvest activities. After seining, hold the water in the pond for 2-3 days to allow solids to settle before draining completely. Alternatively, this last portion of water can be held without discharge. Holding water for 2 days after seining can greatly reduce the discharge of solids, organic matter, and nutrients.

2) Reuse water that is drained from ponds.

Rather than draining ponds for fish harvest, it may be possible to pump water to adjacent ponds where it can be reused in the same or other ponds. Production ponds can be built with higher levees or water levels maintained with more freeboard to provide greater storage volume. Water from one pond can be transferred to another with a low-head lift pump and then, where topography permits, returned to the empty pond by siphon. If topography of the landscape allows, ponds can be constructed in such a way to allow draining of one pond into adjacent, lower elevation ponds.

3) Treat pond effluents in settling basins or constructed wetlands prior to discharge.

Where space is available, settling basins or constructed wetlands can be used to remove nutrients and solids from the effluent before discharge. However, settling basins and constructed wetlands are very expensive to install, increase both operating and investment costs, increase the need for borrowed capital, and are not feasible in a number of locations. Settling basins are designed primarily to remove easily settled solids and should be constructed to provide a minimum hydraulic retention time of 8 hours. Constructed wetlands can be effective in removing dissolved nutrients and solids, provided that the wetlands are constructed and managed with at least a 2-day hydraulic retention time for nutrient removal. Constructed wetlands are the most expensive treatment option considered and are not economically feasible under most conditions. Because of the large land requirement for settling basins and constructed wetlands, treating only the most concentrated effluents in the final stages of draining would minimize the amount of land needed for treatment.

4) Where possible, release pond effluents into low-gradient drainage ditches.

Low-gradient ditches, particularly those with natural or planted vegetation to impede flows, can function as effective settling basins for rapidly settling solids released during pond draining.

5) Where practical, use effluents to irrigate terrestrial crops.

Under certain conditions, the water discharged from ponds may have value as irrigation water for agronomic crops. However, routine overflow from ponds cannot be relied upon for irrigation water because crop water requirements seldom correspond to the availability of pond effluents. Also, pumping water through a pond solely to provide irrigation water should not be practiced because water is lost to evaporation while the water is in the pond and the nutrient content of water from aquaculture ponds is too low to significantly reduce the crop's fertilizer requirements. In addition, dilution of pond water can reduce the capacity of natural processes to maintain water quality.

C. Other solids-reduction practices

1) Construct drainage ditches to minimize erosion and establish plant cover on embankments.

Ditches should be sufficiently large and of proper cross section and slope to convey farm discharges without the occurrence of excessive current that can cause bottom scouring and erosion of the sides. Plant cover can protect against bank erosion from both in-stream flows and rainfall. This practice can reduce the input of suspended solids to streams and minimize ditch maintenance.

2) Protect embankments in drainage ditches from erosion.

Extending drain pipes beyond the toes of the embankments at the point of discharge protects streams from inputs of suspended solids derived from embankment erosion. In addition, rip-rap can be placed on the embankment opposite the point of discharge. Modulating the flow rate of effluent from ponds can minimize ditch erosion. Maintaining plant cover on the exterior of pond embankments will prevent erosion and reduce the amount of solids entering drainage ditches. Less maintenance will be needed for embankments and to remove accumulated sediment in ditches.

3) Avoid leaving ponds drained in winter, and close valves once ponds are drained.

Rain falling on drained ponds can cause serious erosion of internal embankments and pond bottoms, sedimentation in deeper areas of ponds, and loss of suspended solids through the open drain. Refilling ponds promptly and keeping valves closed in empty drained ponds are practices that can protect the pond infrastructure and reduce suspended solids loads to farm ditches and finally to receiving streams.

4) Close drain valves when renovating ponds.

When empty ponds are renovated, heavy rains may sometimes occur. If valves are open, large amounts of suspended solids may be discharged from ponds into drainage ditches and streams. If rains occur during renovation, accumulated rainwater can be held for 1-2 days prior to discharge to allow any suspended solids to settle.

5) During pond renovation, excavate to increase operational depth.

Increasing depth during renovation can increase water storage and permit greater fluctuation in water level without compromising fish production. Ponds can be constructed with shallow harvesting benches at one end of the pond to facilitate activities of farm personnel associated with fish harvest. Increased water storage will reduce the volume of effluent. However, increasing the depth of ponds will substantially increase the cost of constructing ponds.

5.4 Solids Disposal

Ponds act as their own settling basins and most of the solids generated during pond aquaculture are retained within the pond and accumulate as pond sediment. The organic fraction of the sediment is derived mainly from phytoplankton and rapidly decomposes, especially in warmwater aquaculture ponds. Nearly all of the sediment that accumulates in aquaculture ponds consists of inorganic solids derived from erosion of pond embankments or erosion on the watershed.

If settling basins, constructed wetlands, or vegetated ditches are used to capture solids during pond draining, the accumulated solids will eventually reduce the volume of the basin or ditch, which will affect hydraulic retention time and the efficiency of solids removal. These solids should be removed or compacted periodically to maintain treatment efficiency.

Guidance

1) Use sediment from within the pond to repair embankments rather than disposing of it outside of ponds.

   Depending on pond hydrological type, most or nearly all the sediment that accumulates in ponds is derived from erosion of the pond bank. This sediment is a valuable resource that is needed to restore proper pond morphology when the pond is repaired.

2) Solids removed from settling basins should be disposed of properly.

   This will be a site-specific practice. Accumulated solids are unlikely to contain toxic concentrations of metals or other chemicals and therefore can be used without concern as fill material.

5.5 Management of Escapees

The escape of cultured species may pose a variety of potential risks to conspecific species, aquatic ecosystems or unrelated economic activities. Potential risks include pathogen transmission, interbreeding with conspecific species and introgression of genetic traits, competition for limited resources, predation, rapid colonization and spread, or disruption and damage to commercial and recreational industries including aquaculture. For almost all of the aquatic species cultured in the United States, these outcomes have not occurred nor are anticipated to occur because: 1) diseases and pathogens are addressed by the farmer and regulatory agencies; 2) most of the species in culture are native; 3) successful introduction and spread of a non-native species meets strong biological resistance; and 4) federal and state agencies have implemented a variety of effective invasive species regulations to prevent, control, manage or mitigate potential impacts.

In addition to potential ecological and economic damages off the farm, escape of the cultured stock from ponds represents an economic loss to the producer and all efforts should be made to manage ponds to prevent escape. In most cases, inadvertent losses should pose no threat to wild fish in receiving waters because most pond aquaculture in the United States is based on growing native North American fish. Important exceptions include non-native fish used for some aspect of pond management (such as grass carp *Ctenopharyngodon idella* used for weed control) or culture of certain ornamental fish.

Guidance

1) Follow all local, state, and federal regulations that govern the species that may be imported, exported, cultured, or sold live locally or nationally.

   Contact appropriate state agencies for regulations governing species, facility design and operation, holding and transport, or live sales. Seek the advice from aquaculture Extension Specialists and appropriate agencies when considering the culture of an unfamiliar species. Contact the United States Fish and Wildlife Service for an import/export license and information about injurious species identified under the Lacey Act. For regulations concerning species and production systems that can be used in marine waters, contact the National Marine Fisheries Service. For health certification of imports and exports contact the USDA Animal Plant Health Inspection Service.

2) All holding, transport, and culture systems should be designed, operated, and maintained to prevent escape. Methods of containment will be site-specific.

3) Ponds should not be constructed in flood-prone areas.

5.6 Mortality Removal and Disposal

Fish mortality in ponds is unpredictable and highly variable among ponds and among farms. Numbers of fish dying range from chronic losses of a few fish per day over long periods to catastrophic losses caused by acute environmental stress or infectious diseases. Dead fish may float or sink, depending mainly on water temperature. In warm water, nearly all fish that die will float for several days before decomposing and sinking. In cold water, many fish may sink after dying. Although there are benefits to timely removal of dead fish from culture ponds, routine removal from large-scale farms is difficult and costly, and may not even be physically possible. Fortunately, most aquaculture ponds can be operated as self-contained hydrological units during fish kills, which will prevent the discharge of carcasses, infectious agents, or products of decomposition into receiving water bodies. Natural pond processes have considerable ability to assimilate the products of fish decomposition so mortalities do not have a lasting effect on water quality within the pond or on effluents released after the die-off. Nonetheless, depending on the number of fish that die, removal of mortalities may improve water quality by minimizing dissolved oxygen depletion associated with carcass decomposition and may limit the transmission or release of fish pathogens.

Guidance

1) Follow recommended aquatic animal health management practices.

   Proper fish health management is the best method of managing mortalities in ponds. Reducing the incidence of fish loss will reduce the need to deal with dead fish. Most states offer aquatic animal health services to aid in diagnosis and treatment of disease problems. General guidance on health management can be found in Section 6.

2) Measures should be taken to insure that dead fish are not discharged with overflow.

   Screens or trash racks installed on overflow structures will prevent carcasses from being discharged with overflow.

3) Whenever possible, prevent water discharge from ponds during fish kills.

   If the fish kill was caused by deleterious water quality, preventing water discharge during fish kills will limit the release of potentially poor quality water. Furthermore, preventing water discharge from ponds during fish kills will limit the release of potential fish pathogens. Drainage structures can be temporarily plugged or blocked to prevent overflow.

4) If practical, dead fish should be removed from ponds for sanitary disposal.

   Dead fish may be deposited in a permitted landfill, incinerated, composted, rendered, or ground up and applied to fields as fertilizer. The best disposal method will be site specific and may depend on local or state regulations.

5.7 Facility Operation and Maintenance

Pond aquaculture facilities are expensive to build and operate. Protection of the investment by operating farms in a sustainable and economically efficient fashion is in the best interest of both farm owners and environmental protection. Facilities that are well-maintained, managed efficiently, and operated in compliance with all applicable laws and regulations will simultaneously improve long-term economic performance and reduce environmental impacts. As such, all of these management practices are simply part of good farm management.

Guidance

1) Use and store petroleum products to prevent contamination of the environment.

Petroleum leaking from storage tanks or farm equipment wastes a valuable resource and can contaminate surface or underground water supplies. Pond aquaculturists should also be aware that petroleum products are highly odorous and small amounts in water can cause a disagreeable off-flavor to aquatic animals. For example, as little as 1 gallon of diesel fuel in a 10-acre pond can cause a detectable taint in fish. That amount of fuel can be released in just one day from a fuel line leaking one drop every second. Petroleum storage in above-ground and underground tanks is regulated by federal and state laws, and information can be obtained from State Departments of Commerce, State Departments of Environmental Quality or Protection, or from regional EPA offices. A protective containment berm that retains leakage or tank contents in the event of failure can be constructed around storage tanks. Aquaculturists should also implement a regular maintenance schedule for tractors, trucks, and other equipment to prevent oil and fuel leaks. Used oil should be disposed of through recycling centers.

2) Use and store chemicals to prevent contamination of the environment.

The most common chemicals used in pond aquaculture are fertilizers, liming materials, and herbicides. These materials will have no adverse effects on the environment when used properly. They should be used only when needed and only for the specific purpose for which they are intended. Herbicide use is regulated by federal and state laws and farmers are responsible for using products according to label instructions and disposing of out-of-date chemicals and empty containers according to applicable state and federal regulations. All chemicals should be stored in secure, well-ventilated, water tight buildings.

3) Develop a response plan for spills of petroleum products, pesticides, and other hazardous materials.

Reporting significant spills of petroleum and pesticides is required by state and federal law, and farmers should be aware of all applicable regulations. Farmers should develop an emergency response plan for all hazardous materials on the farm and all farm employees should be aware of the plan.

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

Solid waste containers should be installed in convenient locations on the farm. Containers should be emptied regularly and the waste disposed of in a permitted landfill or county-operated dumpster.

5) Prevent soil erosion on the farm property.

Leave the maximum amount of vegetation intact between ponds and natural water bodies. Encourage vegetative cover on pond levees and farm grounds. Build and maintain roads, storage areas, and staging areas to minimize erosion. Install rip-rap, water diversion berms, or other erosion control features in steeply sloping areas adjacent to ponds.

6) Develop a record-keeping system.

Good record-keeping is the hallmark of a well-operated aquaculture facility. Records, such as feeding, chemical use, water quality, serious weather conditions, fish culture operations, and fish inventory 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.

5.8 Resources

Arkansas Bait and Ornamental Fish Growers Association. Undated. Best Management Practices (BMPs) for Bait and Ornamental Fish Farms. Available from the Aquaculture/Fisheries Center, University of Arkansas at Pine Bluff, Pine Bluff, AR.

Boyd, C. E. 1999. Codes of practice for responsible shrimp farming. Global Aquaculture Alliance, St. Louis, MO.

Boyd, C. E. and M. C. Haws. 1999. Good management practices (GMPs) to reduce environmental impacts and improve efficiency of shrimp aquaculture in Latin America. Pages 9-33 in B. W. Green, H. C. Clifford, M. McNamara, and G. M. Moctezuma, editors. Asociacion Nacional de Aquicultores de Honduras (ANDAH). Quinto Simposio Centroamericano de Acuacultura, San Pedro Sula, Honduras.

Boyd, C. E. and J. F. Queiroz. 2001. Feasibility of retention structures, settling basins, and best management practices for Alabama channel catfish farming. Reviews in Fisheries Science 9(2):43-67.

Boyd, C. E. and C. S. Tucker. 1998. Aquaculture Pond Water Quality Management. Kluwer Academic Publishers, Boston, MA.

Boyd, C.E., J. Queiroz, J. -Y. Lee, M. Rowan, G. Whitis, and A. Gross. 2000. Environmental assessment of channel catfish *Ictalurus punctatus* farming in Alabama. Journal of the World Aquaculture Society 31:511-544.

Boyd, C.E., J. Queiroz, G. Whitis, R. Hulcher, P. Oakes, J. Carlisle, D. Odum, M. M. Nelson, and W. Hemstreet. 2003. Best management practices for channel catfish farming in Alabama. Alabama Agricultural Experiment Station, Alabama Catfish Producers, Alabama Department of Environmental Management, and USDA Natural Resources

Conservation Service. Special Report Number 1 for Alabama Catfish Producers, Alabama Agricultural Experiment Station, Auburn, University, AL.

Brunson, M. W. 1997. Catfish quality assurance. Mississippi Cooperative Extension Service, Publication 1873, Mississippi State University, MS.

Engle, C. R. and D. Valdarrama. 2003. Farm-level costs of settling basins for treatment of effluents from levee-style catfish ponds. Aquacultural Engineering 28:171-199.

Florida Department of Agriculture and Consumer Services. 2000. Aquaculture Best Management Practices Manual. Florida Department of Agriculture and Consumer Services, Division of Aquaculture, Tallahassee, FL.

Food and Agricultural Organization (FAO). 1997. Technical Guidelines for Responsible Aquaculture 5: Aquaculture Development. Food and Agricultural Organization of the United Nations, Rome, Italy.

Kouka, P.-J. and C. R. Engle. 1996. Economic implications of treating effluents from catfish production. Aquacultural Engineering 15:273-290.

Louisiana State University Ag Center. 2003. Aquaculture Production Best Management Practices (BMPs). Publication 2894. Louisiana State University Ag Center, Baton Rouge, LA.

Myrick, C. A. 2002. Ecological impacts of escaped organisms. Pages 225-245 in J. R. Tomasso, editor. Aquaculture and the Environment in the United States. United States Aquaculture Association/World Aquaculture Society, Baton Rouge, LA.

Schwartz, M. F. and C. E. Boyd. 1996. Suggested management to improve quality and reduce quantity of channel catfish pond effluents. Leaflet 108, Alabama Agricultural Experiment Station, Auburn University, AL.

Tomasso, J. R. (Editor). 2002. Aquaculture and the Environment in the United States. United States Aquaculture Association/World Aquaculture Society, Baton Rouge, LA.

Tucker, C. S. and J. A. Hargreaves. 2003. Management of effluents from channel catfish (*Ictalurus punctatus*) embankment ponds in the southeastern United States. Aquaculture 266:5-21.

Tucker, C. S., C. E. Boyd, and J. A. Hargreaves. 2002. Characterization and management of effluents from warmwater aquaculture ponds. Pages 35-76 in J. R. Tomasso, editor. Aquaculture and the Environment in the United States. United States Aquaculture Association/World Aquaculture Society, Baton Rouge, LA.

United States Department of Agriculture, Natural Resources Conservation Service USDA-NRCS). Undated. Ponds—Planning, Design, and Construction. Agricultural Handbook 590, USDA-NRCS, Washington, DC.

SECTION 6

BEST MANAGEMENT PRACTICES FOR MINIMIZING THE USE OF DRUGS AND CHEMICALS

Maintaining the health of cultured fish requires good management and continuous attention to detail. In its most basic sense, disease can be defined as a deviation of the body from its normal or healthy state, and disease in fish can be caused by infectious agents or by noninfectious conditions, such as environmental or nutritional factors. As such, optimal fish health is best achieved by rearing fish in a good environment, with good nutrition, with a minimum of stress, and isolated from sources of infectious agents. Whenever possible, prevention of infectious disease by avoidance of contact between the host fish and a pathogen should be a critical goal. This is best achieved with a pathogen-free water supply, the use of certified pathogen-free stocks, and strict attention to sanitation.

The best management practices summarized in this section focus on development and implementation of appropriate integrated fish health management strategies that will reduce the incidence of aquatic animal disease and subsequent need for drug treatments. Vaccination and judicious use of antibiotics are emphasized. Prevention of disease is particularly important in US aquaculture operations for obvious economic reasons but also because there are so few therapeutic agents or other drugs approved by the US Food and Drug Administration (FDA) for use. There is also a need to minimize drug use because of concerns about potential drug residues in aquatic animals and in the environment.

Chemicals that are registered by EPA should be used according to label instructions and discharges must comply with State water quality standards. The "Guide to Drug, Vaccine, and Pesticide Use in Aquaculture" should be referred to for further information about chemical uses. Contact the nearest Extension Service office or aquaculture Extension specialist for more information about chemical use and how they can be incorporated into a BMP plan.

The use of drugs and chemicals in aquaculture is minimized for many reasons:

1) Drugs and chemicals are expensive. When they are used it is because they are necessary. The use of approved drugs and chemicals is the responsibility of the grower in conjunction with their aquatic animal health specialist.

2) Quality Assurance Programs: Producers already have quality assurance programs in place that spell out the best way to maintain their stocks of aquatic animals. Included in every quality assurance program is the proper and legal use of drugs and chemicals.

3) All processors of fish and fishery products must develop and implement a FDA required Hazard Analysis Critical Control Point (HACCP) plan. Included in all plans are requirements to ensure that there is no hazard from use of aquaculture drugs at aquaculture facilities. HACCP covers use of approved drugs, drugs under investigation (INADs), extra-label use, and Low Regulatory Priority drugs by producers. The processor may get a receipt of evidence that the producer operates under a third party audited Quality Assurance Program for aquaculture drug use (United States Food and Drug Administration 1998). This type of scrutiny ensures that the producer is not using an unapproved drug or in a manner that will cause hazards, either for consumers or the environment. Producers and processors take the FDA's HACCP requirements very seriously and have gone to considerable effort to ensure they do not process and market any fish that have not complied with any withdrawal times. There are no publicly available reports of any domestic product violating FDA standards for drug residues.

State, federal, and tribal pathogen control programs exist and have existed for a long time. Their goal is to prevent the introduction of significant fish pathogens into the US, specific states, regions, or facilities. Pathogens are regulated that meet criteria such as (1) serious pathogens exotic to an area, (2) pathogens known to cause serious problems, (3) pathogens which are highly infectious and easily transmitted, and/or (4) pathogens which regional watershed compacts have agreed are of concern in that region. Additionally, pathogen inspections are required before fish are brought onto an aquaculture facility and routine disease inspections may be required of fish on the facility. State resource management agencies and/or state agriculture departments oversee these programs in public and private aquaculture operations. The United States Fish and Wildlife Service also has an importation inspection program (Title 50) to prevent the introduction of foreign animal pathogens and the National Marine Fisheries Service and the United States Department of Agriculture-Animal Plant Health Inspection Service (USDA-APHIS) may also be involved under certain circumstances. These regulatory control programs have been successful at limiting the introduction of important fish pathogens which has concomitantly minimized the use of drugs in the culture of aquatic animals.

6.1 Good Husbandry Practices

While BMPs must be tailored to an individual operation, certain general guidelines can be used. Factors to consider include production system water quality, production system (pond, flow-through, net-pen, or recirculation), type of aquatic animal raised, production requirements, feed fed, and availability of approved drugs. Basic good husbandry practices are fundamental to minimizing drug use. Selection of the appropriate aquatic animal for farming—given available water quality characteristics and production systems—is essential.

Water source quality should be evaluated prior to siting a farm for use in fish production operations to ensure it meets basic physiological requirements of the animal. For certain species, e.g. channel catfish, waters naturally containing elevated chloride concentrations are particularly advantageous since the higher the concentration, the less likely challenges with nitrite toxicity (toxic methemoglobinemia) are to occur. Waters with low concentrations of chloride can be safely used but extra water quality monitoring must be made to ensure sufficient chloride concentrations are present. Prevention of toxic methemoglobinemia is important since such a condition can predispose catfish to opportunistic bacterial diseases that subsequently may require antibiotic treatment.

Water quality must also be assessed for the potential aquatic animal pathogen transmission risk from feral aquatic animal populations. Increased potential for disease occurrence does not necessarily preclude use of a water source, but its use may require additional biosecurity measures than otherwise needed to protect animal populations. Biosecurity measures will help to prevent the introduction of additional pathogenic microorganisms that could cause diseases requiring drug treatments.

Each production system will have optimal aquatic animal stocking rates that maximize production yet minimize morbidity and mortality. General guidelines can be obtained from peer-reviewed scientific and Extension Service literature. Insuring high quality nutrition for both broodstock and rapidly growing production fish is of paramount importance for maintenance of aquatic animal health and will provide health benefits throughout the production cycle. When there is an increased disease incidence, efforts to identify and correct stress (immunosuppressive) factors should be implemented.

6.2 Disease Prevention: Vaccines

Disease prevention and reduced drug use can also be attained through effective vaccination. Prevention of infectious disease through vaccination can be an important adjunct to the maintenance of fish health. Vaccination is important because the availability of antibiotics that can legally be used in the United States is very limited and the effectiveness of the few available drugs is limited. Secondly, the prospects for increasing the availability of drugs in the domestic aquaculture industry is small due to the expensive federal approval process and increasing concerns that antibiotic resistance might be transmissible to microorganisms of public health importance. Finally, viral disease and many of the bacterial, fungal, or protozoan infections in fish can not be successfully treated using the antibiotics currently available or anticipated in the near future.

Immunization does not generate antibiotic resistant microorganisms. It can be applied to control viral, as well as bacterial diseases. Fish may be vaccinated economically and conveniently while still very small. Protection conferred by vaccination is often durable thus eliminating the need to treat diseased aquatic animals. Finally, with killed vaccines, at least, the requirements for licensing vaccines are considerably less problematic than those required for the licensing of drugs.

Vaccination of aquatic animals has improved in recent years making immunization of large numbers of animals more economical and practical. In addition, improvements in adjuvant formulations and the development of multivalent vaccines have led to the widespread use of vaccines for prevention of several of the most important bacterial diseases of fish. In Norway, the use of effective vaccines revolutionized and stabilized Norwegian salmon farming. The use of antibiotics per unit biomass of fish produced was reduced by more than 99.9%, production costs were reduced and financial predictability stabilized. Recent advances in the molecular biology of fish pathogens and the development of novel approaches in vaccination have opened the way for a new generation of fish vaccines that promise further improvements in the ability to protect populations of cultured fish against significant diseases. The availability of new vaccines for many important fin fish pathogens should improve dramatically over the next several years. Individuals may also contract with a veterinarian to develop autogenous vaccines (site-specific) to meet particular needs.

6.3 Disease Treatment: Antibiotics

While vaccines have an important role in disease prevention, at times drug treatments may be required. It is essential that these drugs are used judiciously and with thorough understanding of how they can be safely used. In the United States, there are two FDA-approved antimicrobials for use in aquaculture but their approvals are limited to specific food fish (catfish, salmonids and lobster) and specific diseases. These antimicrobials are oxytetracycline (Terramycin® for Fish, oxytetracycline monoalkyl trimethyl ammonium) and a potentiated sulfonamide (Romet-30®, ormetoprim: sulfadimethoxine). These drugs can only be administered through feed in a specific feed formulation. A third antimicrobial is approved, sulfamerazine, but is not currently manufactured. The limitations on these drugs exist because the safety of the antimicrobial in the approved aquatic animals, their effectiveness to cure the diseases they are approved for and their environmental safety have been satisfactorily demonstrated by the drug sponsor.

Terramycin® for Fish is the only approved oxytetracycline product and it is approved to treat certain diseases in catfish, salmonids and lobster. This oxytetracycline medicated feed can be used to treat bacterial hemorrhagic septicemia and pseudomonas disease in catfish at a dose of 2.5-3.75 grams/100 pounds of fish/day for 10 days when the water temperature is above 62EF. For salmonids, when the water temperature is above 48EF, Terramycin® for Fish can be used to control ulcer disease, furunculosis, bacterial hemorrhagic septicemia, and pseudomonas disease. The treatment duration is again 10 days. Terramycin® for Fish is not currently approved for use in salmonids at temperatures below 48EF. Lobster can be treated with Terramycin® for Fish to cure gaffkemia. The treatment duration is only 5 days at 1 gram/pound of medicated feed. This product has a withdrawal time of 21 days for catfish and salmonids and 30 days for lobster. The FDA withdrawal time is the period between the last administration of the drug to the aquatic animal and the time when the aquatic animal can be harvested and offered for food (human or animal). The withdrawal time ensures no harmful drug residues are present when the animal is harvested for human consumption.

Romet-30® can be used in medicated feed to treat enteric septicemia of catfish and furunculosis in salmonids. The dose is 50 mg/kg body weight/day for 5 days. In catfish there is a 3-day mandatory withdrawal time and for salmonids, a 42-day withdrawal time. The shorter withdrawal time for catfish occurs because any Romet-30 residues that might be present are removed with the skin of catfish during processing.

There is only one approved antibiotic for ornamental fish (Nifurpirinol: Furanace Caps). The drug is approved for treatment of columnaris disease in freshwater aquarium fish that are not reproducing. There are no drugs approved for other non-food aquatic animals.

6.4 Safe and Effective Use of Drugs and Chemicals

To maximize the benefit of antimicrobials for curing disease while minimizing the probability of any detrimental effects, it is important to institute various disease prevention techniques, and to understand and follow FDA and EPA regulations on the use of drugs and chemicals in aquaculture. These include:

1) Emphasize disease prevention strategies, such as appropriate husbandry and hygiene, biosecurity, routine health monitoring, and immunization.

   Each producer can best design their own aquatic animal husbandry practices to minimize the probability of disease. Various factors must be considered including water quality (temperature, dissolved oxygen, pH, hardness, alkalinity, total ammonia nitrogen, nitrite concentrations and other contaminants), type of aquatic animal, feed quality, production system and production goals. If complete harvest is not practiced, then grading practices should be designed to minimize stress and fish injury. Biosecurity practices should be implemented such as restricted access to sensitive life stages. For example, limiting people and animal traffic into areas where early life stage rearing occurs. Feed should be of suitable quality to ensure good health under normal environmental conditions. Vaccines are often available and should be used since they prevent disease and can significantly reduce the need to use antibiotics. Good hygiene should be practiced in all production systems. Movement of aquatic animals between farms should be carefully scrutinized to ensure new aquatic animal diseases are not introduced. Producers may want to consult with fish health professionals (e.g. fish health veterinarians, American Fisheries Society-Fish Health Section certified fish pathologists), university scientists, Extension agents, consultants or peers to determine best practices for disease prevention and management .

2) Obtain accurate disease diagnosis prior to initiating any disease treatment.

   Timely and accurate aquatic animal disease diagnosis is essential. Many diseases affecting aquatic animals are caused by viruses, protozoan or metazoan parasites, or fungi. Antibiotic treatments are ineffective against these diseases and are expensive. Accurate diagnosis can only be obtained if representative sick animals are examined and the animals are submitted for diagnosis in a fresh condition. Representative water samples should also be tested since water quality factors can be significant contributors to disease outbreaks. Producers are encouraged to work with fish health professionals to develop written standard operating procedures for initiating disease diagnostic activities and implementing treatment. The protocols should include specific instructions for procedures to follow when administering antimicrobials at fish production facilities.

3) Ensure bacteria causing the aquatic animal disease are sensitive to the antimicrobial considered for use.

   If bacteria are isolated from representative, clinically sick fish, the diagnostic laboratory should determine the sensitivity of the bacteria to available antibiotics before treatment is begun. Only use a labeled antibiotic to which the pathogenic bacteria are clearly sensitive. This determination is best done in consultation with fish health professionals. Use of prescription, veterinary feed directive, or extra-label drugs should only be done under the direction and supervision of a licensed veterinarian.

4) If medicated feed is used, ensure aquatic animals are feeding before treatment is applied.

   The primary means of delivering antibiotics to aquatic animals is through the feed. If this delivery mechanism is to succeed, the animals must be feeding. Bacterial diseases often cause diminished feeding so care must be exercised to feed amounts that can be consumed. Early disease diagnosis helps ensure that treatments can begin before extensive off-feeding occurs. Operators should visually monitor feeding activity. In some circumstances, the best treatment is to stop feeding rather than to administer a medicated feed.

5) Limit therapeutic exposure according to label instructions.

   It is important to provide the medicated feed for the full duration of time (5 days for lobster and 10 days for other aquatic animals) indicated on the label and to minimize development of antimicrobial resistance. Terramycin® is a broad spectrum, short acting (does not stay very long in the body) bacteriostatic antibiotic. Since this antibiotic does not directly kill disease-causing bacteria, the aquatic animals own host defenses must work if therapy is to be successful. Reduction of fish stress can enhance host defenses. Even though the potentiated sulfonamide Romet-30® is generally bactericidal and broad spectrum, it is still crucial to also reduce aquatic animal stress if therapeutic success is to be expected.

6) Observe all required withdrawal times.

It is essential that the withdrawal times on the FDA approved products be strictly followed. Withdrawal times are established to ensure human food safety is maintained and there are no harmful antimicrobial residues in edible tissues. Individual animals or animal groups subject to antibiotic exposure should be identified (flagged or otherwise identified by sign) and monitored to ensure they do not intermingle with non-treated animals destined for early harvest.

7) Maintain accurate records of treatment.

Complete records should be kept documenting animals treated with antimicrobial drugs. Food animal producers should maintain these records to ensure compliance with mandatory FDA seafood inspection regulations and any information required by processors.

8) Use good waste management practices.

Antibiotic delivered to aquatic animals in feed may enter the environment through uneaten feed and feces. Those aquaculture practices with manure or sediment capture capabilities should utilize this ability and reduce discharge of antibiotics. Medicated feed should only be provided while fish are actively consuming feed. Sunlight and other degradative processes may decrease the amount of active antibiotics. Some antibiotics can also combine with benthic sediments and become biologically unavailable. All waste and effluents containing antibiotics must be handled in accordance with federal, state, and local environmental laws and regulations

9) Ensure all chemicals and drugs are secured to prevent unauthorized use.

Chemical storage facilities should be locked to prevent vandalism (contamination of drugs) or unauthorized treatments. Certain chemicals used at aquaculture facilities may be toxic when directly applied to fish. Securing them from unauthorized use may limit such toxicity.

10) Properly dispose unused medicated feed and medicated articles.

Applicable federal and state statutes and regulations do not consider ready-to-feed or complete medicated feed as a hazardous substance requiring special disposal. In fact, feed, in general, does not require a material safety data sheet (MSDS), which is the best guide to identifying hazardous substances. On the other hand, feed supplements or concentrates (feed with higher levels of medications and nutrients) may require special handling and disposal. There should be an MSDS for these products indicating if the supplements or concentrates contain hazardous substances, thereby requiring special handling and disposal. Such disposal must meet local, state, and federal requirements. Contact a commercial waste disposal provider for compliance procedures. Some drug sponsors may also accept the return of product on a case by case basis. The last and most potent category of feed products are medicated articles, commonly referred to “drug premixes.” For those medicated articles approved for use in fish feed, which are antibiotics, you should contact the pharmaceutical manufacturing firm listed on the label for specific disposal instructions. Some firms will accept return of the products for disposal.

The Environmental Protection Agency’s “List of Lists” at

<http://www.epa.gov/swercepp/pubs/title3.pdf>

will list those ingredients deemed hazardous and the permitted threshold amounts.

There are some unique aspects of cage and net pen culture that warrant specific recommendations. For example, growers operating in the same local area that is linked hydrographically should develop cooperative fish health and biosecurity agreements. Additionally, site fallowing, site rotation and year class separation should be considered as potential methods for disease and pest control. Depending on the species being cultured and the production strategy employed these control methods may require between one and three sites per production cycle. The use of third-party biosecurity audits is also strongly encouraged.

6.5 Approved Uses of Therapeutants

Drugs in aquaculture are not used for growth promotion, nor are there drugs approved for that use. In fact, fish growth tends to decrease relative to that of fish fed a control diet when antibiotics are supplemented into the diet (Rawles et al 1997). Antibiotics are used for specific therapeutic purposes. Spawning hormones are used on selected adult broodstock (that are not processed for human consumption) in confined and controlled situations using FDA-approved drugs (e.g. reproduction). Some EPA-registered chemicals are used according to label to mitigate further outbreak of disease (disinfection).

There are some very limited circumstances, under supervision of a licensed veterinarian, where Terramycin® for Fish or Romet-30® medicated feed can be used for other aquatic animals not listed on the label. This is considered extra-label use, meaning use of a drug in any way that is not in accordance with approved product labeling. In 1994, Congress passed legislation, Animal Drug Use Clarification Act (AMDUCA), which allows veterinarians to prescribe FDA approved drugs in an extra-label manner under specific conditions. The regulations that implement AMDUCA can be found in Title 21 Code of Federal Regulations (CFR) Part 530. These extra-label uses have limited utility in most commercial aquaculture but might be feasible for valuable brood stock or ornamental fishes.

While the AMDUCA prohibits the use of an FDA approved drug in or on feed, FDA recognized that for certain animal populations there was a need. FDA has exercised its regulatory discretion to allow extra-label use of medicated feeds under specific conditions. If the conditions are met, FDA is unlikely to take regulatory action. These conditions are identified in the FDA Compliance Policy Guide (Extra-label use of medicated feeds for minor species, Sec. 615.115). The Guide describes how a veterinarian can prescribe medicated catfish or salmonid feeds to treat bacterial diseases in other aquatic animals or for different bacterial diseases than what the products are approved. A veterinarian can prescribe the extra-label use of medicated feed when the health of animals is threatened and suffering or death would result from failure to treat affected animals. To use a medicated feed in an extra-label manner, the following conditions must be met:

1) There is express written recommendation and oversight of an attending licensed veterinarian within the context of a valid veterinarian-client-patient relationship.

2) The medicated feed is already approved for use in aquatic species. This means you can only use medicated catfish, salmonid or lobster feed.

3) There cannot be any reformulation of the feed and they must be labeled for the approved species.

4) Extra-label use can only be for therapeutic purposes, i.e. to treat a disease.

5) The aquaculturist is required to:

    a) Keep complete and accurate records of feeds received, including labels, invoices, and date fed. Records must be kept for at least one year.

    b) Keep a current copy of the veterinarian's written recommendation.

    c) Institute procedures to assure that the identity of treated animals is carefully maintained.

    d) Take appropriate measures to assure that the withdrawal time provided by the veterinarian is met and no unsafe drug residues occur in any food-producing animal.

    e) Use the medicated feed in accordance with federal, state, and local environmental laws and regulations.

    f) Follow user safety provisions.

Additionally, as part of the FDA scientific data gathering requirements needed to approve a new antibiotic or other drug, an Investigational New Animal Drug (INAD) exemption may be issued by FDA. The exemption allows a scientist or aquatic animal producer involved in generating data to support a specific drug approval to test the safety and effectiveness of the drug. INAD exemptions must be approved from FDA Center for

Veterinary Medicine prior to drug use and entail considerable scrutiny to assure the testing will be valid and that human, animal and environmental safety are protected.

Other approved drugs containing formalin can be used to treat certain diseases (fungal infection of eggs and external parasitic diseases) of aquatic animals. Such uses must comply with label instructions and meet water quality standards if the drug is discharged. Refer to label instructions for specific information. FDA has also published a list of “low regulatory priority drugs” that can be used when specific conditions are met. Examples include salt (NaCl) and ice. Additional information can be obtained at

<http://www.fda.gov/cvm/index/aquaculture/LRPDrugs.pdf>

6.6 Resources

Federal Regulations of Drugs, Biologicals, and Chemicals Used in Aquaculture Production. 1992. Joint Subcommittee on Aquaculture, Working Group on Quality Assurance in Aquaculture Production. Beltsville, Maryland. September 1992.

United States Department of Agiculture-Animal and Plant Health Inspection Service (USDA-APHIS) Veterinary Services Center for Veterinary Biologics. <http://www.aphis.usda.gov/vs/cvb>

National Aquaculture Association. 2003. Judicious Antimicrobial Use in US Aquaculture: Principles and Practices. National Aquaculture Association, Charles Town ,WV.

American Veterinary Medical Association. 2002. Judicious and Prudent Antimicrobial Drug Use for Food Fish Veterinarians. American Veterinary Medical Association, Schaumburg, Illinois.
<http://www.avma.org/scienact/jtua/fish/jtuafish.asp>

SECTION 7

REFERENCES

Arkansas Bait and Ornamental Fish Growers Association. Undated. Best Management Practices (BMPs) for Bait and Ornamental Fish Farms. Available from the Aquaculture/Fisheries Center, University of Arkansas at Pine Bluff, Pine Bluff, AR.

Boyd, C. E. 1999. Codes of practice for responsible shrimp farming. Global Aquaculture Alliance, St. Louis, MO.

Boyd, C. E. 2003. The status of codes of practice in aquaculture. World Aquaculture 34(2):63-66.

Boyd, C. E. and J. Queiroz. 2001. Feasibility of retention structures, settling basins, and best management practices in effluent regulation of Alabama channel catfish farming. Reviews in Fisheries Science 9:43-67.

Boyd, C. E., J. Queiroz, J. Lee, M. Rowan, G. N. Whitis, and A. Gross. 2000. Environmental assessment of channel catfish, *Ictalurus punctatus*, farming in Alabama. Journal of the World Aquaculture Society 31:511-544.

Boyd, C.E., J. Queiroz, G. Whitis, R. Hulcher, P. Oakes, J. Carlisle, D. Odum, M. M. Nelson, and W. Hemstreet. 2003. Best management practices for channel catfish farming in Alabama. Alabama Agricultural Experiment Station, Alabama Catfish Producers, Alabama Department of Environmental Management, and USDA Natural Resources Conservation Service. Special Report Number 1 for Alabama Catfish Producers, Alabama Agricultural Experiment Station, Auburn, University, AL.

Engle, C. R. And D. Valderrama. 2003. Farm-level costs of settling basins for treatment of effluents from levee-style catfish ponds. Aquacultural Engineering 28:171-199.

Florida Department of Agriculture and Consumer Services. 2000. Aquaculture Best Management Practices Manual. Florida Department of Agriculture and Consumer Services, Division of Aquaculture, Tallahassee, FL.

Food and Agricultural Organization (FAO). 1997. Technical Guidelines for Responsible Aquaculture 5: Aquaculture Development. Food and Agriculture Organization of the United Nations, Rome, Italy.

Hammer, S.A. and H.L. Blankenship. 2001. Cost comparison of marks, tags, and mark-with-tag combinations used in salmonid research. North American Journal of Aquaculture 63:171-178.

Howerton, R. 2001. Best Management Practices for Hawaiian Aquaculture. Center for Tropicaql and Subtropical Aquaculture Publication 148. Center for Tropical and Subtropical Aquaculture, The Oceanic Institute, Waimanalo, HI.

Idaho Department of Environmental Quality. Undated. Idaho Waste Management Guidelines for Aquaculture Operations. Idaho Department of Environmental Quality, Twin Falls Regional Office, Twin Falls, ID.

Louisiana State University Ag Center. 2003. Aquaculture Production Best Management Practices (BMPs). Publication 2894. Louisiana State University Ag Center, Baton Rouge, LA.

Martin, J. and J. Edgley. 1998. Environmental Management Systems. Government Institutes, Rockville, MD.

Pietrak, M.D., D. Bean, J.D. Bailey, D. Guest, and C. Bartlett. 2003. Estimated Cost Analysis for Various Marking Strategies. A report prepared for National Fish and Wildlife Foundation Grant No. 01-0009-004 “The Development of a Comprehensive Aquaculture Containment Verification System.”

Rawles, S.D., A. Kocabas, and D.M. Gatlin. 1997. Dietary supplementation of terramycin and Romet-30 does not enhance growth of channel catfish but does influence tissue residues. Journal of the World Aquaculture Society 28:392-401.

United States Food and Drug Administration (USFDA). 1998. Fish and fisheries products hazards and controls guide: Second Edition. Center for Food Safety and Applied Nutrition, Office of Seafood. Rockville, MD.

APPENDIX A

ACRONYMS AND ABBREVIATIONS

ADEM	Alabama Department of Environmental Management
AMDUCA	Animal Drug Use Clarification Act (Allows veterinarians to prescribe FDA-approved drugs in an extra-label manner under specific conditions.)
BMP	Best Management Practice
BOD	Biochemical Oxygen Demand (An indirect measure of the amount of biodegradable organic matter in water. The test uses a standardized laboratory procedure to measure the amount of oxygen consumed over a 5-day test period by microorganisms as they decompose organic matter in a water sample)
CFR	Code of Federal Regulations
COD	Chemical Oxygen Demand (The amount of organic matter in water that is susceptible to oxidation by a strong chemical oxidizing agent.)
CWA	Clean Water Act
EMS	Environmental Management System
EPA	United States Environmental Protection Agency
FAO	Food and Agriculture Organization of the United Nations
FDACS	Florida Department of Agriculture and Consumer Services
GAA	Global Aquaculture Alliance (A private aquaculture organization representing producers and producer associations)
HACCP	Hazard Analysis Critical Control Point (FDA plan that is required by all processors of fish and fishery products.)
HRT	Hydraulic Retention Time (The average time a particle of water is retained within a system; equal to volume divided by flow.)
IDEQ	Idaho Department of Environmental Quality
INAD	Investigational New Animal Drug
MSD	Marine Sanitation Device
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Service
ODAS	Organic Detrital Algae Soup (a production system that depends on algae and bacteria to produce feed for fish or crustaceans.)
POTW	Publicly Owned Treatment Works
SMZ	Streamside Management Zone
SOP	Standard Operating Procedure
TSS	Total Suspended Solids (A measure of the particulate solids content of water made by filtering a water sample through a tared standard glass-fiber filter, drying the residue to a constant weight at 103-105EC, and reweighing the filter plus residue.)
USCG	United States Coast Guard

APPENDIX B

GLOSSARY

Aquaculture. The propagation and rearing of aquatic species in controlled or selected environments.

Best Management Practices. Schedules of activities, prohibitions of practices, maintenance procedures, and other management practices that prevent or reduce pollution (Title 40 CFR Part 122.2).

Code of Conduct. A system of principles or rules about how some activity should be conducted; general statements of policies and practices to assure a particular outcome. They do not provide details on how to implement programs of better management.

Code of Practice. Management activities needed to solve a resource management problem. Similar to Best Management Practice.

Drugs of low regulatory priority. Drugs that have not been approved but may be used under some conditions. These include such things as salt and ice.

Environmental Management System. A plan of activities designed to maintain and improve compliance with environmental requirements. The requirements may be mandated by governmental agencies or certifying bodies, but they often are developed by the EMS owner. The typical components of an EMS follow: impact identification; development of standards; adoption of practices to comply with standards; identification of indicators; monitoring; review and correction for non-compliance; confirmation of compliance; sanctions for non-compliance.

Exotic species. An organism introduced from a foreign country (i.e., one whose entire native range is outside that country where found).

Extra-label use. The use of a drug in any way that is not in accordance with approved labeling. Extra-label use may be allowed under specific conditions.

Flow-through systems. Culture systems that use flowing water to provide dissolved oxygen and remove waste products. Flow-through systems are found throughout the United States, wherever a consistent volume of water is available. Most flow-through systems use well, spring, or stream water as a source of production water.

Harmful Algal Blooms. A community of phytoplankton with species that contain toxins or that causes a negative impact to natural resources or humans.

Introduced species. A plant or animal moved from one place to another by human activities (i.e., an individual, group, or population of organisms that occur in a particular locale due to human activities).
Invasive species. A species that is 1) exotic or transplanted to the ecosystem under consideration and 2) whose introduction causes or is likely to cause economic or environmental harm or harm to human health. (Executive Order 13112).

Native species. Any species living within its historical range.

Net pens and cages systems. A culture system that uses suspended or floating systems to culture fish or shellfish. These systems may be located along a shore or pier or may be anchored and floating offshore. Net pens and cages rely on tides, currents, and other natural water movement to provide a continual supply of high-quality water to the cultured animals.

Non-native species. A species found outside of its historical range. Also may be defined as a species found outside of its historical range defined in terms of state or federal boundaries. For example, the historical range of rainbow trout in the United States was restricted to west of the Rocky Mountains, but the fish has been widely introduced throughout the country. Many states east of the Rocky Mountains consider this species a native species.

Ponds. Culture systems characterized by hydraulic retention times sufficiently long to allow natural processes to reduce metabolic waste concentrations. Commonly used to culture warmwater fish, such as channel catfish.

Recirculating systems. These are highly intensive culture systems that actively filter and reuse water many times before it is discharged. These systems typically use tanks or raceways to hold the growing animals and have specific filtration and support equipment to maintain adequate water quality.

Transgenic organism. Organisms where genetic constructs are inserted, directly or through inheritance, into the chromosomal DNA so that they are expressed and passed along to subsequent generations.

Transplanted species. An organism moved outside its native range but within a country where it occurs naturally (i.e., one whose native range includes at least a portion of the country where found).

Wild fish. Fish that grow and reproduce in the natural environment; some wild fish may be protected by the Endangered Species Act.