Southern Regional
Aquaculture Center

SRAC Publication No. 6004
February 2012

Management of Aquacultural Effluents from Ponds

Final Project Report on the
SRAC Regional Research Project

Management of Aquacultural Effluents from Ponds

SRAC No. 6004

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Cover photos (clockwise from top left):

Fratesi catfish ponds (Mississippi). Photo provided by Jimmy Avery, Mississippi State University

Baitfish farm (Arkansas). Photo by Eric Goodwin, Arkansas

Effluent from catfish pond. Photo provided by Jimmy Avery, Mississippi State University

Preface

The project summarized in this report was developed and funded through the Southern Regional Aquaculture Center, which is one of five regional aquaculture research and Extension centers established by Congress in 1985 and administered by the United States Department of Agriculture (USDA). The five centers are located in the northeastern, north central, southern, western, and tropical Pacific regions of the country. The Southern Regional Aquaculture Center began organizational activities in 1987, and the first research and Extension projects were initiated in 1988. The thirteen states and two territories included in the southern region are Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, Oklahoma, Puerto Rico, South Carolina, Tennessee, Texas, U.S. Virgin Islands, and Virginia.

The regional aquaculture centers encourage cooperative and collaborative research and Extension educational programs in aquaculture having regional or national applications. Center programs complement and strengthen existing research and Extension educational programs provided by the Department of Agriculture and other public institutions.

The mission of the centers is to support aquaculture research, development, demonstration, and Extension education to enhance viable and profitable domestic aquaculture production for the benefit of consumers, producers, service industries, and the American economy. Projects developed and funded by the centers are based on regional industry needs and are designed to aid commercial aquaculture development in all states and territories. The centers are organized to take advantage of the best aquaculture science, education skills, and facilities in the United States. Center programs ensure effective coordination and a region-wide, team approach to projects jointly conducted by research, Extension, government, and industry personnel. Interagency collaboration and shared funding are strongly encouraged.

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Executive Summary

This document summarizes the findings of the Southern Regional Aquaculture Center Project *Management of Aquacultural Effluents from Ponds*. Aquaculture operations nationwide are under scrutiny because of the potential environmental degradation caused by the discharge of water from production facilities. The regulation of pond aquaculture effluents in the southeastern United States, by either federal or state statutes, is possible. The aquaculture industry can be involved in the process of formulating potential regulations by conducting research that can provide information for permit writers to use in developing regulatory mechanisms.

Effluent research was conducted in six states (Alabama, Arkansas, Louisiana, Mississippi, North Carolina, and South Carolina) with channel catfish, hybrid striped bass, baitfish, crawfish, and marine shrimp. The project had the following objectives: 1) characterize the components of aquaculture effluents that are most likely to harm the environment; 2) evaluate the effect of aquaculture pond effluent discharge on water quality in receiving streams; 3) evaluate pond water management techniques for reducing the quantity and improving the quality of discharged water; 4) evaluate models for predicting risks to the environment and the costs and benefits of implementing best management practices (BMPs); 5) develop BMPs for reducing the environmental impacts of pond aquaculture; and 6) share information generated from this project with producers and regulators through workshops and Extension publications.

Objective 1. Characterize the components of aquaculture effluents that are most likely to harm the environment (e.g., suspended solids, total phosphorus).

Suspended solids can leave a pond when it overflows after heavy rain or when the pond is intentionally drained. Most particles are small and organic and do not settle easily. A settling time of 2 to 4 hours can reduce total suspended solids in effluents by 75 to 90 percent, and retaining water in settling basins for 8 hours will improve effluent quality. Chemical coagulants applied at practical rates did not improve the settling of suspended solids. Concentrations of solids, nutrients, and biochemical oxygen demand were generally lower in baitfish pond effluents than in catfish pond effluents. Development of water budgets for crawfish ponds showed that about 23 inches of water is released annually as intentional and unintentional effluent. Of that amount, 37 percent is intentional summer drawdown, 29 percent is unintentional release, 22 percent is levee seepage, and 12 percent is intentional flushing for oxygen management. During summer drawdown, 89 percent of total suspended solids and 70 percent of the total phosphorus, total nitrogen, and biochemical oxygen demand released from crawfish ponds occurs in the first 5 percent and final 20 percent of the water released.

Objective 2. Evaluate the effect of aquaculture pond effluent discharge on water quality in receiving streams.

When effluent from a channel catfish pond was released into a drainage ditch, the concentration of suspended solids increased over a distance of 300 feet from the outfall, but then the solids decreased to concentrations that were less than or equal to the initial ditch concentrations. The poor water quality of catfish pond effluent lasts only briefly, and suspended solids settle rapidly within receiving ditches. At 17 locations sampled, no changes in stream water quality could be attributed to effluent releases from ponds. The concentrations of solids and nutrients in crawfish pond effluents released during summer drawdown were significantly reduced over a distance of 800 feet in vegetated drainage ditches. Likewise, suspended solids concentrations in marine shrimp pond effluent discharged during harvest were reduced significantly in a drainage ditch over distance. However, baitfish pond effluents showed no significant reduction in solids concentration in drainage ditches 300 feet from the point of discharge. It appears that baitfish drainage ditches might require modification to be effective settling basins.

Objective 3. Evaluate management techniques for reducing the quantity and improving the quality of discharged water.

The final 20 percent of effluent released from catfish ponds during intentional discharge can be retained in sedimentation basins for 8 hours. Drainage ditches can be used to settle the heaviest solids when internal drains are first opened and when the final 10 to 20 percent of effluent is released. Effluent released from catfish ponds can be reduced significantly by increasing pond depth by 1 foot to increase water storage capacity or by physically linking the deeper production pond to one or three adjacent conventional ponds to capture excess water volume. Effluent volume from baitfish ponds can be reduced if water can be reused, but it must first be filtered to remove zooplankton predators of newly stocked baitfish fry. Effluent from crawfish ponds can be reduced by increasing pond depth by 6 inches and allowing the final 10 to 20 percent of water during summer drawdown to evaporate. The annual drainage of hybrid striped bass production ponds can be eliminated by changing to a continuous production management strategy, which requires no annual drainage to harvest fish. Applying an anionic polyacrylamide was more effective in reducing turbidity than treatments with alum (aluminum sulfate) or gypsum (calcium sulfate) in hybrid striped bass ponds. Synthetic filter materials tested were not consistently effective in reducing concentrations of suspended solids and nutrients in hybrid striped bass pond water.

Objective 4. Develop and evaluate models for predicting risks to the environment and the costs and benefits of implementing best management practices (BMPs).

Partial enterprise budgets were developed for the various effluent management strategies evaluated in this project. Budget analyses were completed for sedimentation basin management options and for the integrated production/water storage pond strategies for commercial catfish ponds. The construction of settling basins or deeper production/storage ponds required a large financial investment and would reduce farm revenue. Using existing fish production ponds as sedimentation basins should be more economically feasible than building new sedimentation basins. A mixed-integer programming (MIP) model was developed to evaluate the farm-level effect of using effluent treatment options on hybrid striped bass farms. Not draining ponds annually and not flushing pond water are the best operational treatments. When discharge standards are imposed, the financial model selected the no-draining option because it minimizes treatment cost by reducing effluent volume.

Objective 5. Develop BMPs for reducing the environmental impacts of pond aquaculture in general. Develop supplemental BMPs particular to the various species cultured in the region, including best culture practices, waste handling and management, and water quality management and reuse.

Best management practices for reducing the volume and improving the quality of finfish farm effluents were developed. These include guidelines for:

- reducing storm runoff into ponds;
- managing ponds to reduce effluent volume;
- controlling erosion on watersheds and embankments;
- managing ponds to minimize erosion;
- controlling erosion caused by effluents;
- constructing settling basins and wetlands;
- managing feed;
- fertilizing catfish ponds;
- protecting water quality to improve effluents;
- using water quality enhancers;
- using therapeutic agents;
- handling fish carcasses;
- general operations and worker safety; and
- responding to and managing emergencies.

A set of BMPs for aquaculture production in Louisiana was written, and it includes individual reviews of BMPs for crawfish pond production and recirculating systems used to cultivate alligators, finfish, or shedding crustaceans.

Objective 6. Share information generated from this project with producers and regulators through workshops and Extension publications.

An aquaculture waste management symposium was held in Virginia to: 1) develop a prioritized list of practices that will minimize the environmental impacts of aquaculture and be economically acceptable to producers; and 2) familiarize state regulators and consultants with these issues and give them the information necessary for developing effective and reasonable regulations. Project scientists conducted field days, gave presentations, and distributed newsletters to commercial aquaculture producers and state regulatory agencies on BMPs for managing aquaculture effluents. Project scientists participated in the Federal Joint Subcommittee on Aquaculture—Effluents Task Force and provided the task force and Environmental Protection Agency (EPA) personnel with information on aquaculture in the southern region, the characteristics of pond effluents, and the effectiveness of various effluent management options and best management practices.

Project Background

Aquaculture operations nationwide have come under scrutiny because of potential environmental degradation caused by the discharge of water from production facilities. Since 1974, the discharge of water from many such facilities has been regulated and permitted by the National Pollutant Discharge Elimination System (NPDES), which is administered by the EPA. The regulation of discharges from fish hatcheries and farms has been under consideration by the EPA since 1977. The National Resources Defense Council brought a lawsuit against the EPA, alleging that the EPA failed to enforce provisions of the Clean Water Act, and in 1997, the Environmental Defense Fund (EDF) issued a report called "Murky Waters," in which the EDF suggested that the EPA impose effluent limitations on the aquaculture industry. As a result of these pressures, the EPA is considering regulations for the aquaculture industry.

The aquaculture industry has an opportunity to become involved in the process of formulating regulations. Through this regional research project, the research community was able to provide information required by permit writers for the development of rational regulatory mechanisms. Without involvement in the process by researchers and the aquaculture industry, regulatory agencies could impose unnecessarily strict water quality criteria through discharge permits and other regulations. For example, standard NPDES permits could be amended to include strict water quality criteria that would require advanced, best-available effluent treatment technology, with monitoring to demonstrate compliance. Should producers be required to eliminate pond discharge, traditional ways of managing pond facilities would change drastically and there would be additional financial burdens on existing operations. The further development of the regional aquaculture industry might also be restricted.

A research project funded by the Southern Regional Aquaculture Center from 1991 to 1994, *Characterization and Management of Effluents from Aquaculture Ponds in the Southeastern United States* (Tucker, 1998), characterized the effluents from channel catfish, hybrid striped bass, shrimp, and crawfish ponds in the southeastern U.S. and examined several options for managing effluents. The goal of this second project was to fill important gaps remaining in the characterization of effluents from aquaculture ponds, explore management methods for reducing the volume and improving the quality of pond effluents, develop a set of best-available pond water management practices, conduct modeling exercises to evaluate environmental risks and the economic performance of treatment technologies and BMPs, and share the results of this and the previous SRAC effluent project with producers and regulators. Findings from this project provide information for producers to use in seeking reasonable effluent regulations. These findings also recommend simple ways of reducing the volume and improving the quality of effluents, possibilities for water reuse, and inexpensive treatment methods based on sedimentation. This project benefits producers of channel catfish, hybrid striped bass, baitfish, crawfish, and marine shrimp.

Project Objectives

Objective 1: Characterize the components of aquaculture effluents that are most likely to harm the environment (e.g., suspended solids, total phosphorus).

Objective 2: Evaluate the effect of aquaculture pond effluent discharge on water quality in receiving streams.

Objective 3: Evaluate management techniques for reducing the quantity and improving the quality of discharged water.

Objective 4: Develop and evaluate models for predicting risks to the environment and the costs and benefits of implementing best management practices (BMPs).

Objective 5: Develop BMPs for reducing the environmental impacts of pond aquaculture in general. Develop supplemental BMPs particular to the various species cultured in the region, including best culture practices, waste handling and management, and water quality management and reuse.

Objective 6: Share information generated from this project with producers and regulators through workshops and Extension publications.

Objective 1: Characterize the components of aquaculture effluents that are most likely to harm the environment (e.g., suspended solids, total phosphorus).

The substances in pond effluents that have the highest concentrations relative to water quality criteria in NPDES permits are total suspended solids (TSS), total phosphorus (TP), and biochemical oxygen demand (BOD). Most of the suspended solids in aquaculture ponds are associated with phytoplankton. However, an in-depth study of the size distribution and settling characteristics of these particles has not been done. It is important to study the components of aquacultural effluent that pose the greatest risk to the environment so that sedimentation designs can be developed to improve the quality of effluent entering receiving waters.

Although effluents from other types of pond aquaculture have not been studied as thoroughly as channel catfish pond effluents, it is reasonable to assume that they are similar because methods of production are generally similar. The concentrations of nutrients and solids in hybrid striped bass effluents do not differ greatly from those in channel catfish ponds with similar feeding rates. But while channel catfish ponds use the multiple-batch cropping system and are not drained between crops, hybrid striped bass ponds must be drained because of potential cannibalism between fish cohorts. Baitfish ponds use a less intensive production system with less feed input than in channel catfish or hybrid striped bass culture. Baitfish ponds are usually drained in the winter or spring, but some ponds are drained only after several years of production. Crawfish aquaculture employs an extensive production strategy using cultivated vegetative forages rather than formulated feeds. Water exchange (flushing) is done routinely to increase dissolved oxygen, particularly in fall and spring, and ponds are drained annually in late spring or summer to accommodate the crawfish's reproductive cycle. Differences in water management among the different species cultivated may influence the characteristics and quantity of substances discharged from ponds.

Channel Catfish

Alabama

About 53 percent of total suspended solids, total phosphorus, total nitrogen, and biochemical oxygen demand was associated with particles less than 5 micrometers (µm) in diameter. A settling time of 2 to 4 hours is sufficient to reduce total suspended solids in effluents to 75 to 90 percent of original concentrations (Table 1), and retaining water in settling basins for 8 hours will improve effluent quality significantly. Solids removal is associated with declines in the mineral fraction, with little change in organic solids concentrations in effluents. Applying aluminum sulfate (alum) at 25 to 50 mg/L does not improve the efficiency of solids sedimentation. Estimates of runoff from watersheds suggest that settling basins for treating storm runoff from watershed ponds must hold 30 to 40 percent of pond volume to retain water for 8 hours. Because of the large storage capacity required, settling basins do not appear to be feasible for treating storm runoff. Settling basins for treating intentional discharge from partial drawdown or complete draining would need to be only 10 to 20 percent of the volume of the largest pond on the farm because the quality of catfish pond effluents is relatively high except for the final 20 to 25 percent of water released when ponds are drained completely.

Table 1. Time (hours) necessary for mineral and organic particles of different sizes to settle 1 meter (39 inches) at 25 °C (77 °F).

Filter pore size (µm)	Mineral particles	Organic particles
	Hours required to settle particles	
41	0.18	5.1
30	0.34	9.5
20	0.75	21
10	3.02	86
8	48	1,337
5	121	3,423

Most existing catfish farms in Alabama extend to property boundaries or streams, and there seldom is space for installing settling basins. However, settling basins could be considered an essential component in the design of new farms. On farms without settling basins, the pond being harvested can be used as its own settling basin by lowering the water level to 20 to 25 percent of full volume, closing drains, and harvesting fish by seining. Once fish have been removed, the water remaining should be allowed to stand until most of the suspended solids have settled (usually within 2 to 3 days). The water can then be released slowly to prevent re-suspension of solids.

Alabama channel catfish farmers try to maintain chloride concentrations of 50 to 100 mg/L by applying salt annually. The average and standard deviation for chloride concentration in salt-treated ponds was 87.2 ± 37.5 mg/L. The maximum chloride concentration measured was 189 mg/L. The maximum chloride concentration in Alabama streams allowed by the Alabama Department of Environmental Management is 230 mg/L. It is unlikely that effluents from salt-treated catfish ponds would violate this limit or harm aquatic life in streams. Chloride concentrations in ponds should be measured before salt is applied to ensure that water meets the in-stream chloride standard.

Mississippi

In commercial channel catfish ponds dominated by a dense bloom of the blue-green alga *Oscillatoria agardhii,* about 51 percent of total suspended solids have a diameter of less than 5 micrometers. Similar results are seen in ponds dominated by inorganic turbidity (55 percent of the total suspended solids are less than 5 micrometers). Treating water from a pond dominated by a dense bloom of *O. agardhii* with up to 50 mg/L aluminum sulfate (alum) reduced solids by 1.11 grams per gram of alum. Size fractionation of pond water after alum treatment indicated that the proportional removal of solids less than 5 micrometers in diameter was greatest, although the greatest absolute solids reduction rate occurs in whole (not fractionated) pond water. The proportion of solids in the smallest size fractions increases with alum dose, indicating that larger solids are selectively settled by alum treatment.

Hybrid Striped Bass

North Carolina

A water budget for a commercial hybrid striped bass farm was determined from data collected over 2 years. The farm has 78 water acres and consists of 18 ponds of about 4.5 acres each. The farm uses groundwater to fill ponds after draining, to replace evaporation and seepage losses, and to flush ponds to maintain adequate water quality for fish. Ponds are usually drained and dried after all fish are harvested. Discharge volume was calculated with a basic water budget equation. During the study, 24 major discharge events (excluding rainfall) were measured. There were no significant discharges of water during winter (December to March), and most effluent was released between April and August. Annual average effluent release was 48 inches of water per surface acre.

Effluents from the initial and final stages of pond draining showed that total suspended solids were 40 percent higher in the final 10 percent of water drained than in the first 10 percent, and that the increase was primarily from small mineral particles associated with pond sediment. Most of the suspended solids in the first 10 percent of water drained were volatile (organic), and 60 percent of the suspended solids in the final 10 percent of effluent released consisted of an organic fraction. Concentrations of total phosphorus and total nitrogen in the effluent did not increase significantly from the beginning of pond draining to the end. Total suspended solids accounted for only about 10 percent of total solids in waters used to cultivate hybrid striped bass.

Fractionation analysis of solids present in effluent released from unintentional (precipitation) or intentional (flushing) discharges showed that 95 percent of total solids and 65 percent of total suspended solids were less than 5 micrometers. Eighty percent or more of the biochemical oxygen demand, total phosphorus, and total nitrogen was associated with particles less than 5 micrometers. Of the total solids present in overflow water, 90 percent consisted of dissolved solids; 25 percent of total solids were volatile (organic). Total suspended solids, which comprised about 10 percent of total solids in effluent overflow, consisted of 63 percent organic matter. More organic matter was present in the smaller particle fractions than the larger particle fractions. The amount of settleable solids in overflow effluent was negligible, suggesting that sedimentation alone, without the use of chemical coagulants, would not be effective in reducing solids concentration in the overflow fraction of hybrid striped bass pond water effluent.

Baitfish

Arkansas

A field study characterized suspended solids and 5-day biochemical oxygen demand in baitfish pond effluents by serial fractionation. Total suspended solids in effluents at the point of discharge from ten ponds on five farms averaged 36 mg/L during the release of the first 10 percent of pond volume. Suspended solids concentration increased about 70 percent in the last 10 percent of the effluent released. On average, total suspended solids consisted of about 50 percent particulate organic matter (volatile suspended solids). The biochemical oxygen demand averaged 9 mg/L, and no significant increase was observed in the final 10 percent of effluent volume at pond drainage. Filtering baitfish pond effluents through a 10-micrometer screen removed more of the mineral fraction of suspended solids than the organic fraction, and it slightly reduced the concentration of total suspended solids. Volatile suspended solids and biochemical oxygen demand generally did not change with a reduction in the total suspended solids present in the first 10 percent of effluent that filtered through a 41-micrometer mesh screen. On average, 75 to 82 percent of suspended solids in baitfish pond effluents are less than 5 micrometers in size, and much of this fraction is organic matter. Smaller solid particles are present in higher concentrations in the final 10 percent of effluent released than in the first 10 percent of effluent released. The concentration of volatile suspended solids was more strongly correlated with biochemical oxygen demand in the last 10 percent of effluent released than in the first 10 percent released. In contrast, biochemical oxygen demand in both the first and last 10 percent of effluent was weakly correlated with total suspended solids. In general, concentrations of solids, nutrients, and BOD in commercial baitfish pond effluents were lower than or similar to those reported for commercial catfish ponds during the same seasons.

Crawfish

Louisiana

Water budgets in crawfish ponds calculated over three production seasons indicate that the average annual input is 91 inches per surface acre during the October through June production season, with precipitation contributing about 37 inches and groundwater about 55 inches. Nearly 68 inches (71 percent) of the water was consumed in evaporation, evapotranspiration by rice, and seepage through pond levees and pond bottoms, with the remaining 23 inches (29 percent) released as intentional and unintentional effluent (Fig. 1). Precipitation contributed nearly 40 percent of the total water inflow in these shallow-water ecosystems. Intentional water discharge during summer drawdown (an established management practice) averaged 11 inches per surface acre. Unintentional discharge, averaging 7 inches, was positively correlated with an increase in precipitation. Precipitation from October to June in year one (25.1 inches) and year three (27.2 inches) of the project resulted in low unintentional water release (3.6 and 2.5 inches, respectively). In year 2, rainfall was more

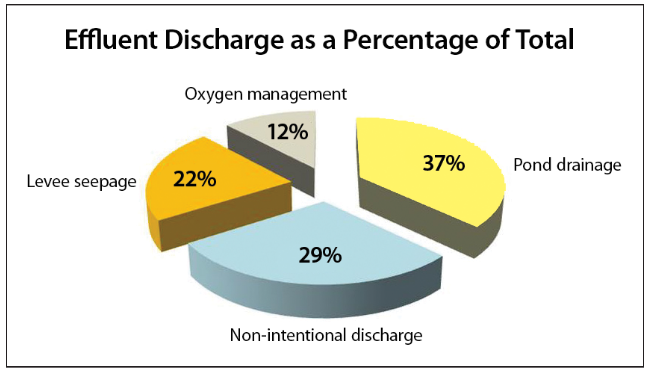

Figure 1. Effluent discharged, by source, from experimental rice/crawfish aquaculture ponds in southwestern Louisiana. Average total amount of effluent discharged was 23.4 inches of water per surface acre per year.

normal for southern Louisiana (53.6 inches), and the amount of water unintentionally released was 17.7 inches (24 percent of annual water budget). An average of 3 inches of effluent per year was released from flushing ponds for oxygen management (12 percent of effluent released), and lateral seepage through perimeter levees averaged 5 inches per year (22 percent of effluent release).

A water budget model was developed to determine seasonal effluent quantity and mass loading for solids and nutrients representative of single-crop crawfish production systems in south central Louisiana and rice/crawfish double crop or rice/crawfish rotational systems in southwest Louisiana. Precipitation, evaporation, evapotranspiration, and infiltration data for southern Louisiana was obtained from the National Climatic Data Center and published research. Model output closely agreed with annual water budgets calculated from the experimental crawfish ponds over three production seasons. Unintentional and intentional effluent discharge and seasonal mass loading for total suspended solids, total phosphorus, total nitrogen, and 5-day carbonaceous biochemical oxygen demand were determined under various simulation scenarios, which include type of crawfish production system (single crop, rice/crawfish double-cropping, and rice/crawfish rotational system), annual precipitation (average, wet, and dry years), additional pond water volume storage capacity (0, 2, 4 and 6 inches), and intentional flushing to improve water quality (one, two and three complete water volume exchanges per production cycle). Most water added by pumping replaces water lost to evaporation, evapotranspiration and seepage (usually 60 percent or higher). Unintentional effluent discharge, largely from precipitation, usually ranged from 13 percent of total effluent released in an average year to as much as 30 percent of total release in a high rainfall year; most of this discharge occurred in winter.

Estimates of seasonal mass loading (pounds/acre) of suspended solids, nutrients, and biochemical oxygen demand determined from samples collected from six single-crop crawfish production ponds were as follows: total suspended solids, 848 pounds per acre; total phosphorus, 1.99 pounds per acre; total nitrogen, 10.6 pounds per acre; and biochemical oxygen demand, 18.5 pounds per acre. Eighty-nine percent of total suspended solids and 70 percent of total phosphorus, total nitrogen, and biochemical oxygen demand released from crawfish ponds during summer drawdown is in the first 5 percent and last 20 percent of water released.

Marine Shrimp

South Carolina

Shrimp harvest involves the complete, rapid drainage of the pond to reduce injury and mortality to shrimp. The current need for rapid drainage during harvest makes it difficult to minimize the mass loading of solids and nutrients. In this study, solids were characterized in effluents from the last 25 percent of water released during harvest. Effluent from four plastic-lined, 0.25-ha research ponds was sampled. Ponds were stocked with 100 post-larvae (PL) per m^2, fed, and harvested after 160 days. Effluent was also sampled from commercial marine shrimp ponds (one 1-acre pond, one 2.5-acre pond, and two 6-acre ponds) with clay bottoms in which shrimp were stocked at densities of 11 to 50 PL per m^2. Grab and composite samples of pond effluent were collected from the drainpipe during pond drawdown, with more samples taken during the remaining 25 to 30 percent of water volume released.

In the first 70 percent of pond drainage, total suspended solids concentration ranged from 300 to 700 mg/L. In the remaining 30 percent, total suspended solids concentration ranged from 1,000 to 2,500 mg/L. In one pond, total suspended solids was 12,000 mg/L in a sample collected during the release of the last 5 percent of water in the pond. A fourfold increase in total suspended solids concentration occurred during the last 30 percent of pond volume drained. Excessively high suspended solids levels were occasionally recorded in the last 3 to 5 percent of pond volume released. The increase in total suspended solids concentration during drawdown of shrimp ponds was caused largely by re-suspension of sediment and organic sludge that accumulated during growout. The location of organic sludge accumulation was determined by aerator placement, pond slope, pond drainage rate during shrimp harvest, and aerator replacement during harvest. In some ponds the highest concentrations of sludge were near the centers of ponds. In other ponds the highest accumulations were near the drains. It was common to observe a shifting in sludge location during shrimp harvest, which resulted in extreme variability in the total suspended solids discharged among the different ponds.

The highest concentration of suspended solids is discharged in the first 10 percent and final 20 percent of effluent released during intentional drawdown in warmwater aquaculture ponds.

Settleable solids in pond effluent increased with the shifting and subsequent re-suspension of sludge and sediment during the final stages of shrimp harvest and effluent discharge.

Conclusions

Suspended solids in pond overflow, whether from precipitation or intentional discharge, are difficult to settle because most particles are less than 5 micrometers in size. Additionally, solids removal is associated with declines in the mineral fraction with little change in organic solids concentrations. A settling time of 2 to 4 hours can substantially reduce total suspended solids in effluents, and a water retention time in settling basins of 8 hours will improve effluent quality. Common chemical coagulants such as alum and gypsum do not appear to increase the sedimentation of suspended solids when applied at practical rates. The highest concentrations of suspended solids, nutrients, and biochemical oxygen demand in effluents from catfish, baitfish, hybrid striped bass, crawfish, and marine shrimp ponds are discharged in the final 10 to 20 percent of water released.

Objective 2. Evaluate the effect of aquaculture pond effluent discharge on water quality in receiving streams.

The previous Southern Regional Aquaculture Center project on effluents (Tucker, 1998) focused on water quality within ponds, particularly during discharge. However, the impact of the discharge on receiving water bodies has not been well established. The potential impact of channel catfish, baitfish, crawfish, and marine shrimp effluents on receiving waters is addressed in this objective.

Channel Catfish

Mississippi

Seventeen stream sample locations were selected and geo-referenced within four sub-watersheds with aquaculture ponds. Streams were sampled during base flow conditions and during the only significant rainfall runoff event that occurred during the study. Despite increased stream flow during this event, few ponds discharged water. No changes in stream water quality could be attributed to aquaculture ponds. In some stream reaches there was great in-stream variation in water quality over short distances.

The duration and settling characteristics of initial pond effluent from levee ponds was studied. Settling characteristics of effluent samples collected at the discharge point were determined. In addition, spatial and temporal variation of water quality in channels receiving the effluent was measured. When draining was initiated, shear forces generated by water moving into the drain pipe caused scouring in a zone around the entrance to the drain pipe. The initial flush of discharged water consisted of pond water and a slurry of sediment that had accumulated over the screen inside the pond. The initial discharge was very high in total suspended solids (43,860 mg/L), volatile suspended solids (3,770 mg/L), biochemical oxygen demand (118 mg/L), and nutrients. Within 2.5 minutes of the initial discharge, total suspended solids decreased to 1,790 mg/L, volatile suspended solids to 205 mg/L, and biochemical oxygen demand to 29 mg/L. Within 30 minutes the poorly consolidated sediment from around the drain structure inside the pond had been discharged, and the effluent quality was identical to the bulk pond water for the remainder of the draining period (about 5 days). For the effluent, 15.2 percent of the total solids was discharged with the first 1.7 percent of the total volume of water discharged. The initial solids concentration was 900 times higher than the solids concentration in the bulk pond water. In contrast, the biochemical oxygen demand of the initial flush of water discharged was only about nine times higher than the biochemical oxygen demand of the bulk pond water, and biochemical oxygen demand decreased more rapidly than total suspended solids. Therefore, cumulative discharge of biochemical oxygen demand as a function of water volume discharged did not have an initial spike of similar magnitude as for total suspended solids; rather, cumulative discharge of biochemical oxygen demand was roughly proportional to the volume of water discharged. These results suggest that the ratio of mineral solids to organic matter of the initial flush of water was relatively higher than that of subsequently discharged water.

The median settling velocity decreased from 0.3 cm/second in the initial effluent to 0.06 cm/second after 30 minutes. Total suspended solids in a ditch 300 feet from a catfish pond outfall increased to a maximum 30 minutes following the initiation of pond discharge, but then decreased to concentrations that were equal to or less than initial ditch concentrations. The poor water quality of initial effluent from catfish ponds with internal drains lasts less than 30 minutes, and discharged solids settle rapidly within receiving ditches.

Baitfish

Arkansas

Drainage ditches exiting from commercial baitfish ponds were evaluated for solids settling. Ditches ranged from 1,050 to 2,300 feet long and from 12 to 39 feet wide. Some ditches were vegetated and some were not. Volatile suspended solids (VSS) decreased by 14.1 percent over the first 300 feet of ditch. Total suspended solids (TSS) remained unchanged because of increases in fixed (inorganic) suspended solids (FSS). The velocity of water in the ditch was responsible for up to 65 percent of the change in solids concentration. Total suspended solids increased when average current velocity in the drainage ditches exceeded 2 feet per second. Fractionation may have affected the character of organic particles by breaking large particles into fine particles.

Additional work was done to characterize nutrient concentrations in baitfish pond effluents and receiving streams. Ten baitfish ponds were sampled and characterized from December through June in the central Arkansas Delta ecoregion. Effluent samples taken during the first and last 10 percent of pond drainage volume were analyzed for total nitrogen, total phosphorus, BOD, and TSS concentrations. Pond drainage ditches were sampled along the ditch length to determine overall reduction of TSS, and ditch water quality was sampled and analyzed prior to stream discharge. Upstream samples were collected concurrently with pond and ditch samples and were analyzed for similar nutrient concentration and physical characteristics. There were no significant differences in effluent quality between the first 10 percent and the last 10 percent of effluent volume, except that the last 10 percent had significantly higher TSS concentrations than the first 10 percent. There was no significant difference in nutrient concentrations in effluents sampled at the standpipes and effluents sampled at the ends of drainage ditches. Filtering pond effluents through a 5-micron mesh screen did not significantly reduce nutrient concentrations. Nutrient concentrations at the standpipes did not differ from those upstream of the discharge points.

Crawfish

Louisiana

Non-vegetated, moderately vegetated, and heavily vegetated drainage ditches of low gradient were evaluated for sedimentation of solids, nutrients, and organic matter discharged during final summer drawdown (maximum mass loading) from experimental crawfish ponds in south central Louisiana (six ponds, 3.5 to 5 surface acres each) and southwest Louisiana (three ponds, 0.25 surface acres each). Effluent velocity in the drainage ditches averaged about 1.5 feet per second. Total suspended solids concentrations varied in shallow, non-vegetated ditches: They increased as much as 15 percent over a distance of 800 feet at one location (narrow ditch) and decreased 28 percent at a second location (wide ditch). In contrast, when crawfish pond effluents were discharged into a heavily vegetated drainage ditch, the total suspended solids concentrations were reduced 79 percent over a distance of 800 feet and 93 percent over 2,400 feet. Concomitant reductions in TP, TN, and biochemical oxygen demand ranged from 26 percent to 77 percent in the heavily vegetated ditch over a distance of 800 feet. Heavily vegetated ditches with low slope gradients functioned as effective sedimentation filter strips in reducing suspended solids entering receiving streams.

Suspended solids in effluent discharged from warmwater aquaculture ponds generally settled rapidly in drainage ditches, improving the quality of effluent before it entered receiving streams.

Marine Shrimp

South Carolina

Total suspended solids, turbidity, and biochemical oxygen demand concentrations in shrimp pond effluent discharged during harvest were significantly reduced after passing through a discharge canal. At the discharge canal site, tidal water substantially diluted effluent within the drainage canal. Concentrations of solids and BOD over distance in the canal were comparable to concentrations in effluent following 20 hours of sedimentation. Sedimentation significantly reduced BOD and turbidity in one of the two canal outfall composite samples, but did not significantly reduce the concentration of other measured nutrients. These findings show that solids and nutrients are reduced considerably in drainage canals before effluents reach receiving waters.

Conclusions

Suspended solids discharged from catfish, hybrid striped bass, crawfish, and marine shrimp ponds generally settled rapidly in drainage ditches before effluent entered receiving streams. Ditch morphology and morphometry, water flow velocity, and the quantity of macrophytes present in the receiving ditches were important variables in effluent solids sedimentation. Baitfish drainage ditches might require modification to be effective settling basins. No changes in receiving stream water quality were attributed to effluent releases from catfish or baitfish ponds.

Objective 3. Evaluate management techniques for reducing the quantity and improving the quality of discharged water.

The cost of pumping water from wells, the need to conserve water, and the pressure to limit discharge from aquaculture facilities are factors that affect the way farmers now manage water. Water is discharged unintentionally with rainwater overflow, primarily during the winter, and intentionally during pond draining. One of the significant findings of the 1991–1994 SRAC effluents research project (Tucker, 1998) was that seasonal changes in overflow volume are more important than pond nutrient concentrations in determining the overall effect of discharge from aquaculture ponds. Water is discharged intentionally from catfish ponds only when ponds require renovation, usually after about 6.5 years of production. Pond water levels in catfish ponds are usually managed so that an additional 3 to 6 inches can be stored. This practice conserves groundwater and minimizes the discharge of water from ponds. Water is managed similarly in baitfish ponds, in that they are usually drained only to renovate ponds. In contrast, hybrid striped bass, marine shrimp, and crawfish ponds are drained annually either for harvest (hybrid striped bass and marine shrimp) or to accommodate the reproductive cycle of the animal (crawfish). In the crawfish industry it is common to flush ponds to increase dissolved oxygen levels, with an associated release of effluents, because mechanical aerators are not used. All these types of aquaculture need additional water conservation and management strategies to minimize the quantity and improve the quality of pond effluents.

Effluents from aquaculture ponds are most often out of compliance with standards with respect to suspended solids. In this project objective, two additional approaches to managing solids were explored. One is the use of settling basins. The second is increasing water storage and reuse. Water reuse has special concerns associated with potential disease transmission. And, in the case of baitfish culture, the presence of predaceous zooplankton in reused culture water can lower survival and production.

Channel Catfish

Mississippi

A 3-year study evaluated the accuracy of a mathematical model used to predict performance of a management strategy to reduce groundwater use and pond effluent volume. The strategy consisted of increasing the water storage capacity (depth) of one pond by 1 foot in an interconnected two-pond or four-pond module. The following configurations were tested:

- three conventional production ponds linked to one production-storage pond
- one conventional production pond linked to one production/storage pond
- one conventional (control) pond

During the study, effluent release, groundwater use, precipitation, evaporation, and infiltration were monitored to validate the model. Ponds were stocked at commercial rates and water quality (dissolved oxygen, temperature, total ammonia, nitrate, chlorophyll *a*, conductivity, alkalinity, and hardness) and occurrences of disease (proliferative gill disease, enteric septicemia of catfish) were monitored to determine whether the management strategy had unintended consequences.

The study period encompassed years that were both drier and wetter than normal. There was good agreement between the model and actual pond performance, indicating that the model is useful for a broad range of precipitation/evaporation regimes. Significant reductions in effluent release and groundwater use can be achieved using this approach. Harvest size, water quality, and occurrence of disease indicate no negative consequences of linking ponds.

During 2000, groundwater use in the 1:1 system was about 26 percent less than in the control pond. In the 3:1 system, groundwater use was about 29 percent less than in the control pond. This represented a water savings of approximately 9.7 inches and 10.9 inches, respectively. During 2001, groundwater use in the 1:1 system was about 58 percent less than in the control pond. In the 3:1 system, groundwater use was about 45 percent less than in the control pond. This represented a water savings of approximately 13.8 inches and 10.9 inches, respectively.

During 2000, groundwater use was roughly equivalent in the six treatment ponds. The decreased groundwater requirement of the treatment ponds was probably due to the storage capacity of the production/storage ponds. Once stored water was exhausted (as it was during the dry summer of 2000), groundwater requirements of the six ponds were similar. During the wetter summer of 2001, the production-storage ponds required no groundwater. In the four treatment production ponds, stored rainwater substantially decreased groundwater requirements relative to the control pond. In the production/storage ponds, residual stored water, perhaps coupled with other as yet unexplained effects, eliminated groundwater requirements entirely for the year.

Hybrid Striped Bass

North Carolina

Soil and water amendments. Fish production and water quality in hybrid striped bass ponds drained annually was compared to that in ponds managed with no discharge. Twelve 0.25-acre ponds were managed according to common commercial practices for hybrid striped bass production. After 3 years, fish production was not significantly different between the drained and undrained ponds. Although total suspended solids concentration was greater in undrained ponds, there were no other differences in water quality between the two water management regimes.

Turbidity and total suspended solids concentration in pond water were greater and feed consumption and mean weight of fish were lower in ponds that were not drained annually between fish crops as compared to ponds that were drained and dried and received soil or water amendments. Anionic polyacrylamide was more effective in reducing turbidity and improving water quality than alum (aluminum sulfate) or gypsum (calcium sulfate) when applied to pond water in soil/water ecosystems.

Fixed-film filter media. Two synthetic filter materials were evaluated for their ability to remove suspended solids and nutrients from hybrid striped bass pond effluents. BioStrata is made of black corrugated PVC sheets layered and glued into a honeycomb block form. It has a surface area to volume ratio of 110 ft^2 per ft^3. A total of 7 ft^3 was used in a tank. Koi brushes are cylindrical brushes 24 inches long by 4 inches wide. Twelve rows of six brushes each were suspended vertically in the center compartment of a tank. A tank with no baffles and no filter media served as a control. Tanks were rectangular fiberglass (96 inches by 24 inches by 24 inches) and fitted with baffles to contain the filter material and prevent laminar flow. Pond water was pumped into the tanks at one end, flowed over/through the filter media, and drained from the other end. Standpipes at the drain end of each tank maintained water depth at 24 inches. Three tanks were used in each trial: one containing BioStrata media, one with Koi brushes, and one control tank.

Water was pumped from a 0.25-acre hybrid striped bass growout pond stocked at 6,000 fish per acre. Total suspended solids concentration in the pond water during these trials ranged from 63 to 170 mg/L. Most of this turbidity was from suspended clay particles; the pond had little phytoplankton and

Unintentional effluent releases from warmwater aquaculture ponds can be reduced by increasing pond storage capacity 4 to 8 inches to capture excess precipitation.

chlorophyll *a* concentrations were low. Water quality was measured at the inflow and outflow of each tank about every 3 days during each trial, which lasted from 15 to 22 days. Four hydraulic loading rates ranging from 1.4 to 16.6 gallons per minute were tested, resulting in hydraulic retention times in the filter units of 2.5 hours to 12 minutes.

Neither filter media was consistently effective in removing solids and nutrients from pond water. The honeycomb BioStrata media reduced concentrations of chlorophyll *a* by 20 to 40 percent but usually resulted in increased concentrations of nitrogen, phosphorus, and suspended solids. The brushes removed 10 to 30 percent of nitrogen and less than 5 percent of solids, but was ineffective in removing phosphorus and chlorophyll *a*. Because of the small amount of phytoplankton in the pond water, changes in chlorophyll *a* concentrations as a result of filtration were small. The removal of nutrients and solids among sampling dates and within and among trials varied widely. Differences in quality between water entering and leaving the filters were not consistent.

Solids that accumulated in the tanks during filter media trials were collected and analyzed. The solids were primarily inorganic and about 15 percent volatile solids. In two trials, brush media removed three to four times more solids (by weight) than the control tank, and the honeycomb BioStrata media removed 9 to 15 times more than the control tank. In another trial, the effectiveness of the two media was reversed; the BioStrata media removed four times more solids than the control, and the brush media removed fifteen times the amount removed by the control. The most efficient removal of solids required the filtration of 30.7 gallons of pond water to remove 0.035 ounces (1 gram) of dried solids (this was using the BioStrata media at flow rates of 1.4 gallons per minute); the least efficient required twenty times that volume (brush media at 8.4 gallons per minute).

Baitfish

Arkansas

As a water conservation technique in response to declining aquifer levels, the reuse of pond water is growing popular in the Arkansas baitfish industry. Predation of fry by cyclopoid copepods present in reused water is the greatest challenge to widespread adoption of this practice. A study was conducted to evaluate treatments affecting zooplankton populations so that water can be reused and the volume of effluent reduced. The objective of this study was to evaluate methods of restarting the zooplankton bloom in pond water held from previous production operations. The abundance and evolution of rotifer and copepod populations in ponds containing aged pond water, aged water treated with 0.25 mg/L Dylox (trichlofon), and mechanically filtered aged water were compared to ponds filled with groundwater (new water). Zooplankton were sampled and water quality was monitored daily for 6 weeks. Rotifer abundance increased in ponds in all treatments during the first 8 days. Average rotifer density over 8 days did not differ between treatments. However, average copepod abundance was affected by treatments. New water had significantly fewer copepods than Dylox-treated or aged water, but did not have fewer copepods than mechanically filtered water. Mechanical filtration compared more favorably to ponds filled with groundwater than to ponds treated with Dylox or not treated. Filtration minimized adult copepods while maintaining sufficient rotifer density for baitfish culture. Mechanically filtered aged water has the potential to provide sufficient food (rotifers and copepod nauplii) for newly stocked baitfish fry while minimizing the risk of copepod predation on fry.

Crawfish

Louisiana

Several water management techniques for reducing solids and nutrients in crawfish ponds were evaluated alone and in combination. Three field trials took place during the production season and final summer drawdown. The techniques tested included

- cessation of crawfish harvesting activities 2 weeks before draining,
- rapid draining versus slow draining,
- draining from the surface as opposed to the bottom,
- retaining the last 20 percent of pond water followed by slow draining, and
- allowing the last 20 percent of pond volume to evaporate.

The most effective way of reducing the quantity and improving the quality of discharged water was to add 6 inches of water storage capacity and, when possible, eliminate the discharge of the last 10 to 20 percent of the pond volume by allowing it to evaporate within the pond.

Conclusions

The final 20 percent of effluent released from catfish ponds during intentional discharge can be treated in sedimentation basins with a hydraulic retention time of 8 hours. Drainage ditches can be used to settle the heaviest solids when internal drains are first opened and during discharge of the final 10 to 20 percent of effluent volume. Effluent released from catfish ponds and crawfish ponds can be reduced significantly by increasing water storage capacity or by physically linking ponds to each other to capture excess water volume during periods of significant effluent discharge. Effluent from baitfish ponds can be reduced if water can be reused. Filtering the effluent to remove zooplankton predators makes the water suitable for newly stocked baitfish fry. A continuous system of hybrid striped bass production (with no annual drainage of ponds) has the potential to reduce effluent volume without affecting yield. Synthetic filter materials were not consistently effective in reducing suspended solids and nutrients from hybrid striped bass pond water.

Objective 4: Develop and evaluate models for predicting risks to the environment and the costs and benefits of implementing best management practices (BMPs).

Although farmers, scientists and policy makers are concerned about the effect of pond effluent on the environment, few studies have focused on the economic feasibility of effluent management practices that might be adopted as best management practices or as components of regulatory requirements. Information on the economics of different practices would be useful to policy-makers, in terms of the effects of various regulations on farm profitability, and to farmers, who may need to make informed decisions about which practices to adopt. The development of BMPs must account for their effect on farm income to ensure that these are optimal management practices for achieving the stated goals. Models also can be used to estimate the environmental risk associated with effluent discharge from aquaculture ponds. The nature, magnitude and extent of this risk is not known, particularly as compared with the environmental risk of other point and non-point sources of pollution.

Traditionally, the acceptable uses of receiving waters are domestic (potable) use, fishing, and swimming. Waste treatment has not been considered an acceptable use of receiving waters. However, in tacit recognition of the inherent assimilative capacity of receiving waters, the EPA has established the TMDL (total maximum daily load) concept, which ascribes a certain allowable waste loading for a given watershed or basin. Clearly, aquaculture pond effluents, as point sources of potential pollutants, must be a component of the models that will be used to establish TMDLs in watersheds with significant aquaculture pond development. Ultimately, aquaculture producers will be allocated a certain portion of the TMDL by regulatory authorities.

This project objective was addressed by co-principal investigator C. Engle, University of Arkansas at Pine Bluff, with data input provided in part by other project participants.

Arkansas

Partial enterprise budgets were developed for the various effluent management strategies evaluated in this project. Budget analyses were completed for sedimentation basin management options for commercial catfish ponds (Table 2). In all, 108 different scenarios were analyzed for sedimentation basins on catfish farms. Budgeting work on the integrated production/storage pond strategies for catfish culture was also completed. Seventy-two different scenarios were analyzed for production/storage ponds. Preliminary cost data were collected on the fixed-film filter options reported in project objective 3.

Sedimentation basins. The costs associated with settling basins depend on the size and number of basins and whether sufficient land is available for basin construction or existing ponds must be retrofitted and taken out of fish production.

The sizing of settling basins is controlled by factors such as the type of effluent to be treated (drainage effluent or storm overflow), the layout of ponds, the size of the largest foodfish pond, the number of drainage canals, and the scope of regulations governing the release of aquacultural effluents. The number of settling basins is affected by the hydraulic residence time (HRT). The HRT is affected by the size distribution of suspended particles.

The number of settling basins is also affected by the number of drainage outlets on a farm. Some farms may drain in four or five different directions. Farms with ponds that are not contiguous would need more basins. Three farm size scenarios were considered in an analysis of settling basin costs: a 160-acre farm with 140 acres of water, a 320-acre farm with 280 acres of water, and a 640-acre farm with 560 acres of water. Average sizes of foodfish ponds in this analysis were assumed to be 10 and 15 acres, while fingerling ponds were 5 acres each.

Investment costs included the excavation of settling basins and the installation of stationary re-lift pumps to drain effluents from basins. Annual operating costs included copper sulfate applications (to promote sedimentation of phytoplankton cells), pumping, and levee mowing and maintenance. Annual fixed costs include depreciation of basins and pumps, interest on investment, and the opportunity costs associated with land taken out of production for settling basins. Estimates of lost production revenue from retrofitting production ponds were $300, $346 and $480 per acre for the 160-, 320- and 640- acre farms, respectively. On larger farms costs are higher and more variable.

Table 2. Areas for 5-foot-deep settling basins (in acres) necessary to provide 8-hour hydraulic retention time for pond draining effluents and storm overflow. Storm overflow was calculated for the 25-year, 50-year, and 100-year rain. The largest pond on each farm is assumed to be 13.5 acres.

Pond and settling basin type	Return period (yr)	Production area (acres)						
		25	62	125	185	250	370	500
Embankment ponds		**Acres of settling basins required**						
Basin for draining effluent		3.4	3.4	3.4	3.4	3.4	3.4	3.4
Basin for draining runoff and storm overflow	25	3.4	4.3	8.6	12.9	17.2	25.84	34.4
	50	3.4	9.7	9.7	14.4	19.5	29.2	38.9
	100	3.4	5.6	11.1	16.7	33.4	45.7	44.5
Watershed ponds		**Acres of settling basins required**						
Basin for draining effluent		3.7	3.7	3.7	3.7	3.7	3.7	3.7
Basin for draining runoff and storm overflow	25	10.8	27.1	53.7	80.6	107.5	154.4	215.0
	50	12.3	30.8	61.7	92.5	123.3	185.0	246.6
	100	14.1	35.3	70.6	105.8	141.1	211.6	282.2

Large investments are needed to construct settling basins. This investment cost depends heavily on the drainage layout of the farm and the scope of regulations governing the release of effluents. Regulations that require settling basins on catfish farms would increase total investment cost by $311 to $7,388 per acre and total annual costs by $47 to $907 per acre.

Using existing foodfish ponds for settling basins is a more economical approach than constructing new ones. This is particularly true where all effluent volume must be treated. The difference was a consequence of the extremely high cost of excavating a sedimentation basin deep enough to collect all farm effluents by gravity flow. Finally, compliance costs for the treatment of overflow effluents were moderate to high and strongly influenced by farm size.

For farms on which existing fish ponds would have to be converted to settling basins, more than half of the cost was from lost fish production and annual fixed costs of the pond. Requiring catfish farmers to construct settling basins would impose a disproportionately greater financial burden on smaller farms. The increased costs associated with settling basins was too high relative to market prices of catfish for this technology to be economically feasible.

Production/storage ponds. Two configurations (1:1 and 1:3), based on the number of production ponds served by each production/storage pond, were evaluated. The increased depth of the combined production/storage pond increases the storage capacity of the system but incurs higher earthmoving costs. Three additional depths were considered: 4.7, 9.5 and 14.2 inches (12, 24 and 36 cm). Seepage values of 0.0 and 1.0 mm per day were assumed. Cost estimates were developed for farms with average foodfish pond sizes of 10 and 15 acres. Fingerling ponds were not linked.

In total, 24 scenarios were defined for each of three farm sizes (total of 72 scenarios). Depth of storage pond and pond configuration were the two most important factors affecting the implementation costs of this technology. For instance, the estimated total investment costs for a 160-acre farm with 10-acre foodfish ponds, 1:1 configuration, and 0 mm/d infiltration rate ranged from $76,123 to $215,088 as the additional depth of storage ponds was increased from 4.7 to 14.2 inches. However, if the configuration is 3:1, investment costs decreased (ranging from $44,782 to $115,947).

Fixed-film filtering systems. Investment and operating costs were estimated for the fixed-film honeycomb and brush filtering systems. Based on the assumptions used, and on the experimental data available, the costs of filtering ranged from $0.066 to $0.154 per pound of fish produced.

Farm-level economic effects of imposing effluent treatments on hybrid striped bass farms. A mixed-integer programming (MIP) model was developed to evaluate the farm-level effect of requiring effluent treatment on hybrid striped bass farms. Settling basins and constructed wetlands entail high costs for farmers but reduce effluents significantly. Filtering treatments incur high cost but without much reduction in the nutrient concentration in effluents.

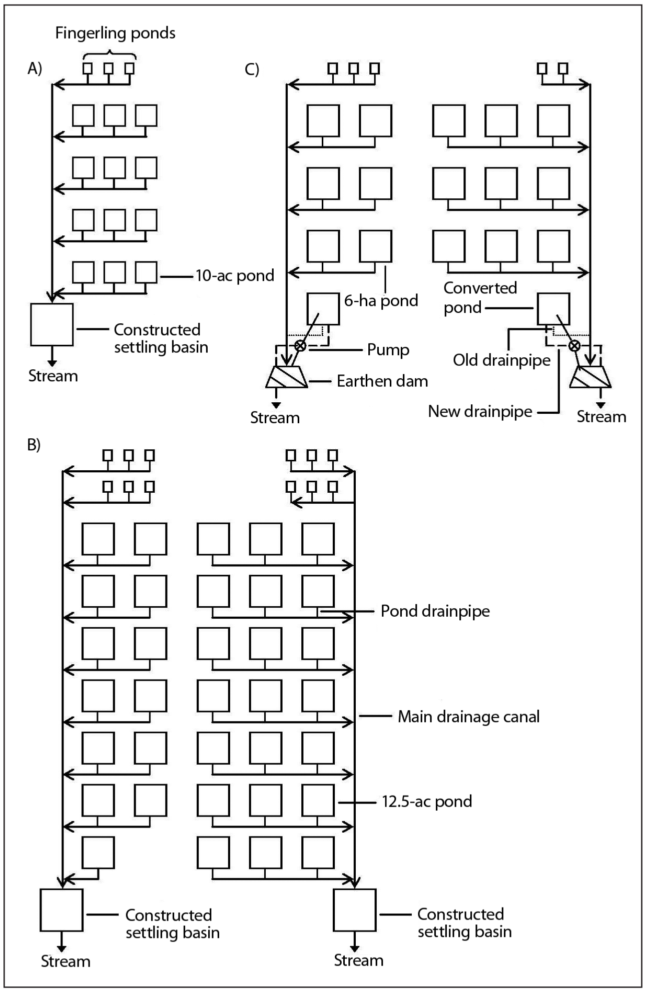

Figure 2. Pond layout of catfish farms designed to use settling basins to treat effluent discharges. Drainage pipes and canals and the location of constructed or retrofitted settling basins are shown for each layout. A) a 158-acre farm with 12 10-acre foodfish ponds, a single drainage system, and a constructed settling basin; B) a 632-acre farm with 34 12.5-acre ponds, a double drainage system, and two excavated sedimentation basins; C) a 316-acre farm with 17 12.5-acre ponds and a double drainage system. Two foodfish ponds have been retrofitted. Arrows denote the direction of water flow.

Eliminating the flushing of the pond to improve water quality, or not draining the pond annually, reduces effluent volume. Reducing the amount of water flushed or drained from the pond also decreases operating costs without any additional investment cost. It is estimated that various effluent treatment options would increase production costs by an average of $0.0005 to $3.09 per pound of fish. Based on the MIP model, not draining annually and not flushing pond water are the best operational treatments. When discharge standards are imposed, the model selected the no-draining treatment as best. By not draining ponds, farms would minimize treatment cost by reducing effluent volume. Additional research is needed to assess the long-term risks associated with not flushing or not draining hybrid striped bass production ponds.

Conclusions

Constructing settling basins or deeper production/storage ponds requires a large financial investment and would reduce farm revenue. Using existing fish production ponds as sedimentation basins is more likely to be economically feasible than constructing new sedimentation basins. A mixed-integer programming (MIP) model was developed to evaluate the farm-level effect of imposing effluent treatment options on hybrid striped bass farms. Budget analysis using an econometric model showed that eliminating the draining and flushing of ponds is the best way to minimize effluent discharge from hybrid striped bass ponds.

Objective 5. Develop BMPs for reducing the environmental impacts of pond aquaculture in general. Develop supplemental BMPs particular to the various species cultured in the region, including best culture practices, waste handling and management, and water quality management and reuse.

Best management practices (BMPs) have been widely adopted in agriculture and forestry, but have only recently been considered for fisheries and aquaculture. This project should help the regional pond-based aquaculture industries (e.g., channel catfish, crawfish, baitfish, hybrid striped bass) to be pro-active in developing BMPs. Although Extension personnel have provided the best available information from the research community and from practical experience, best practices have not been codified into a coherent set of guidelines and recommendations. This objective sought to assemble the best available information regarding culture practices, with particular attention to water management and effluent treatment options for freshwater commercial finfish species in the southern region. This information was compiled into a generic set of pond-based BMPs, which are presented in the Recommendations section on page 23. This activity was coordinated at Auburn University (by C. Boyd) with input from all project participants.

Catfish

Alabama

Funding from this SRAC effort supplemented funds from the Alabama Catfish Producers in developing BMPs for Alabama catfish farming. An environmental audit form for assessing the status of environmental management on catfish farms was developed. This instrument was used to identify potential problems that might be solved with BMPs. Project participants used the form to conduct environmental audits of aquaculture production facilities. A document containing BMPs to reduce the volume and improve the quality of channel catfish farm effluents was prepared through the cooperation of Auburn University, Alabama Catfish Producers Association, United States Department of Agriculture–Natural Resources Conservation Service (USDA–NRCS), and the Alabama Department of Environmental Management. These BMPs were reviewed by all agencies involved and were presented to the farmers for comment. Farmer meetings were held to ensure that farmers were aware of the BMPs and had opportunity for input. The BMPs are maintained by NRCS in the form of guide sheets, and they also have been published by Auburn University. Guide sheets were developed for the following topics:

- Reducing Storm Runoff into Ponds
- Managing Ponds to Reduce Effluent Volume
- Erosion Control on Watersheds and Embankments
- Pond Management to Minimize Erosion
- Control of Erosion by Effluents
- Settling Basins and Wetlands
- Feed Management
- Fertilization of Catfish Ponds
- Water Quality Protection to Improve Effluents
- Water Quality Enhancers
- Therapeutic Agents
- Fish Carcasses
- General Operations and Worker Safety
- Emergency Response and Management

These BMPs will be referred to in the Alabama Department of Environmental Management regulations that will be made for aquaculture effluents.

Crawfish

Louisiana

Current USDA–NRCS Conservation Practices were reviewed to assess their applicability to the development of BMPs for effluent and watershed management for the crawfish industry. The specific attributes of each conservation practice that were evaluated included applicability, need for clarification or modification, economic feasibility, environmental effectiveness, need for additional research, and need for educational programs for users. A set of BMPs for aquaculture production in Louisiana was drafted and reviewed by various commodity groups and state and federal agencies. The revised document, "Louisiana Aquaculture Best Management Practices," was published. It includes individual reviews of BMPs for crawfish pond production, catfish pond production, and recirculating system production (for alligators, finfish, or shedding crustaceans).

Objective 6. Share information generated from this project with producers and regulators through workshops and Extension publications.

Although the 1991–1994 SRAC effluents project resulted in four Extension publications, there was no explicit Extension component to the project. The project reported here included a formal objective related to education and outreach. Extension efforts were directed primarily to two target groups. First, producers were informed about the best practices related to culture and water management, as developed in Objective 3, through a series of workshops and Extension activities. Second, the results of the project were presented to the federal and state regulatory communities (via conferences, workshops, reports, and facts sheets) so they will have the information needed to make policy decisions regarding the regulation of effluents from aquaculture ponds.

Workshops and Outreach

The workshop "Aquaculture Waste Management Symposium" was held on November 6–7, 2000 in Roanoke, Virginia. The objectives of the workshop were to: 1) develop a prioritized list of practices that will minimize the environmental impacts of aquaculture and be economically acceptable to producers; and 2) familiarize state regulators and consultants with these issues and give them the information necessary for developing effective and reasonable regulations.

In Alabama, a document containing BMPs for reducing the volume and improving the quality of channel catfish farm effluents was prepared through the cooperation of Auburn University, Alabama Catfish Producers Association, USDA–NRCS, and the Alabama Department of Environmental Management. These BMPs were reviewed by all agencies involved and were presented to the farmers for comment. Farmer meetings were held to ensure that farmers were aware of the BMPs and had opportunity for input. The BMPs are maintained by NRCS in the form of guide sheets.

In Arkansas, information on effluents and BMPs for pond aquaculture was shared with producers. Two Extension newsletter articles were published. Results of the water reuse zooplankton study were presented to baitfish producers at the UAPB Aquaculture Field Day (attended by about 300 people). A poster presentation on effluents and BMPs was exhibited at the Aquaculture Field Day, and a presentation was made on the same topic at the annual convention of catfish and baitfish producers (150 people). Extension faculty assisted the Arkansas Bait and Ornamental Fish Growers Association in adapting BMPs proposed for catfish production to baitfish, and in developing the association's BMP document.

In Louisiana, presentations on water budgets and BMPs were made to commercial crawfish farmers at several meetings and at the Rice Field Day in Crowley, Louisiana (attended by several hundred). Two fact sheets were developed: "Water Exchanges in Crawfish Production: Avoiding Too Much of a Good Thing" and "Best Management Practices in Crawfish Production—Good for Producers and Their Watersheds." These fact sheets were mailed to everyone on the LSU AgCenter's list of crawfish producers.

Most scientists in this SRAC project were active participants in activities coordinated by the Joint Subcommittee on Aquaculture's Aquaculture Effluent Task Force, including the various subgroups representing the species and areas of specialization of project scientists.

Recommendations for Managing Effluents through the Implementation of Best Management Practices

Pond-based aquacultural production systems in the South cannot be operated without discharge. The findings of this SRAC project and a previous SRAC project on effluents reveal that current pond production methods practiced for warmwater species in the southern region do not have widespread, negative effects on the environment, nor do they waste natural resources. Nevertheless, warmwater aquaculture in the South should use environmentally responsible and sustainable production practices. The most practical way to minimize the possibility of harming the environment is to use BMPs that reduce the volume and improve the quality of pond effluents.

Suggested BMPs for managing effluents from aquacultural production systems in the southern region are listed below. The BMPs address effluent volume, suspended sediments, effluent quality, use of therapeutants and chemicals, and construction of new ponds and farms. Many of the BMPs apply to all aquacultural industries; others are more specific to finfish production systems that receive large quantities of feeds and in which therapeutants and other chemical agents are occasionally used. From research and industry experience, some of the BMPs listed below are effective and not difficult to implement; others could be effective in improving effluent management, but more research or experience with them is needed.

BMPs to Reduce Effluent Volume

- New watershed ponds should have a watershed area to pond area ratio of 10:1 or less.
- Use terraces to divert excess runoff around ponds. Build an additional pond to increase storage on the watershed.
- Maintain good vegetative cover on all parts of a watershed and, where feasible, replace short grass with evergreen trees.
- Harvest fish by seining and without partially or completely draining ponds unless it is necessary to renovate fish stocks or repair pond earthwork.
- Maintain at least 8 inches of storage capacity in finfish ponds during summer and fall and at least 4 inches of storage capacity in crawfish ponds in winter and spring. The upper 8 inches (finfish) or 4 inches (crawfish) of overflow pipe should be painted a bright color as a guide when adding well water to ponds.
- Do not flush well or stream water through finfish ponds. This practice does not improve water quality in ponds.
- When flushing crawfish ponds, avoid pumping and draining at the same time.

BMPs to Minimize Suspended Solids through Erosion Control

- Control erosion on watersheds with vegetative cover and construct terraces to route runoff away from areas with high erosion potential.
- Restrict livestock from the watersheds of ponds.
- Eliminate steep slopes on farm roads and cover these roads with gravel.
- Plant grass cover on sides of pond dams or embankments and cover the tops of dams or embankments with grass or gravel.
- Do not leave ponds partially or completely empty in winter and spring; immediately close drains in empty ponds.
- Install efficient mechanical aerators so that the water currents caused by these devices do not erode pond earthwork.
- Install drain outlets to draw precipitation overflow from the pond surface (crawfish).
- In crawfish ponds, suspend harvesting with mechanical combine boats for 1 to 2 weeks before summer drawdown.
- Do not dispose of sediment outside of ponds.

- Install structures to prevent drainpipe discharge from eroding earthwork.
- Construct ditches with adequate hydraulic cross section, and plant grass cover on sides of ditches.
- Place check dams in ditches to reduce water velocity and allow sedimentation.
- Use sediment from within the pond, or sediment removed from vegetated drainage ditches into which pond effluent is discharged, to rebuild or repair levees (crawfish)
- Where space is available, construct settling basins to improve the quality of the final volume of effluent from catfish ponds.
- Trees or shrubs could be used in critical areas to shelter ponds from excessive wind and reduce wave erosion of embankments.
- Where possible, discharge effluent from aquaculture ponds into natural wetlands.

BMPs to Improve Pond Water and Effluent Quality

- Select high quality feeds that contain adequate, but not excessive, nitrogen and phosphorous.
- Store feed in well-ventilated, dry bins, or if bagged, in a well-ventilated, dry room. Feed should be used by the expiration date on the label.
- Apply feed uniformly with a mechanical feeder.
- Do not apply more feed than the cultivated fish or crustaceans will eat.
- Feeding rates should not exceed 30 pounds per acre per day in unaerated ponds. In ponds with 1 horsepower (HP) of aeration per acre, feeding rates usually can be increased to 100 to 120 pounds per acre per day.
- When uneaten feed accumulates in corners of ponds, remove it manually.
- Apply fertilizers only when necessary to promote phytoplankton blooms.
- Use chemical fertilizers and avoid animal manures.
- Avoid excessive fertilization by using moderate doses and relying on Secchi disk visibility to determine whether fertilization is needed.
- Apply agricultural limestone to ponds with total alkalinity below 20 mg/L.
- Store fertilizers under a roof in a dry place to prevent rain from washing them into surface waters.

Sediments trapped in vegetated drainage ditches into which pond effluents are discharged can be used to rebuild or repair levees.

- Use adequate mechanical aeration to maintain dissolved oxygen concentrations above 4 mg/L.
- Do not have deep water intake structures in ponds.
- Install devices to prevent sediment re-suspension by water currents entering drains.
- Restrict livestock from watersheds of ponds.
- Avoid discharge when harvesting fish, but if ponds must be drained completely, hold the final 20 to 25 percent of pond volume for 2 or 3 days and then discharge it slowly.
- If possible, allow the final 10 to 20 percent of water volume in crawfish ponds to evaporate during summer drawdown.
- Reuse pond water discharged from crawfish ponds during summer drawdown to irrigate and replenish water in adjacent or downstream rice fields.

BMPs for Use of Therapeutic Agents and Other Chemicals

- Store therapeutants so that they cannot be accidentally spilled and enter the environment.
- Use good water quality management procedures to prevent unnecessary stress to fish.
- Obtain a definite diagnosis for diseases and a recommendation for disease treatment before applying therapeutic agents.
- Follow instructions on labels of therapeutic agents for dose, application method, safety precautions, etc.
- Store water quality enhancers under a roof where rainfall will not wash them into surface waters.
- Copper sulfate applications in milligrams per liter should not exceed 1 percent of total alkalinity, also measured in milligrams per liter, or a maximum dose of 1.0 mg/L. Pond water should not be released for 72 hours after the application of copper sulfate.
- Sodium chloride applications should not exceed 100 mg/L.
- Lime (calcium oxide or hydroxide) applications should not exceed 100 mg/L.
- Agricultural limestone and gypsum (calcium sulfate) applications should not exceed 5,000 pounds per acre and 2,000 pounds per acre, respectively.
- Calcium hypochlorite or other chlorine compounds should not be applied to catfish ponds.

BMPs for New Ponds or Farms

- New ponds should be constructed according to the USDA–NRCS standards. Riparian vegetation such as trees or shrubs should be preserved or established to provide a vegetative buffer zone along streams.
- New ponds should not be located on watersheds that are already affected by subdivisions, industrial activities, or row-crops.
- The design of new ponds should conform to NCRS standards and be compatible with the implementation of the BMPs outlined above.

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United States Department of Agriculture

National Institute of Food and Agriculture

The work reported in this publication was supported in part by the Southern Regional Aquaculture Center through Grant No. 2010-38500-21142 from the United States Department of Agriculture, National Institute of Food and Agriculture.