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# Environmental Assessment of Channel Catfish *Ictalurus punctatus* Farming in Alabama

CLAUDE E. BOYD, JULIO QUEIROZ, JEONGYEOL LEE, MARTHA ROWAN,
GREGORY N. WHITIS, AND AMIT GROSS

*Department of Fisheries and Allied Aquacultures, Auburn University, Alabama 36849 USA*

## Abstract

**An environmental assessment was made of Alabama channel catfish *Ictalurus punctatus* farming which is concentrated in the west-central region of the state. There are about 10,000 ha of production ponds with 10.7% of the area for fry and fingerlings and 89.3% for food fish. Food fish production was about 40,800 tons in 1997. Watershed ponds filled by rainfall and runoff make up 76% of total pond area. Water levels in many of these ponds are maintained in dry weather with well water. The other ponds are embankment ponds supplied by well water. Harvest is primarily by seine-through procedures and ponds are not drained frequently. The main points related to Alabama catfish farming and environment issues are as follows: 1) catfish farming in Alabama is conservative of water, and excluding storm overflow, about two pond volumes are intentionally discharged from each pond in 15 yr; 2) overflow from ponds following rains occurs mostly in winter and early spring when pond water quality is good and stream discharge volume is high; 3) total suspended solids concentrations in pond effluents were high, and the main sources of total suspended solids were erosion of embankments, pond bottoms, and discharge ditches; 4) concentrations of nitrogen and phosphorus in effluents were not high, but annual effluent loads of these two nutrients were greater than for typical row crops in Alabama; 5) ground water use by the industry is about 86,000 $m^3/d$, but seepage from ponds returns water to aquifers; 6) there is little use of medicated feeds; 7) copper sulfate is used to control blue-green algae and off-flavor in ponds, but copper is rapidly lost from pond water; 8) although sodium chloride is applied to ponds to control nitrite toxicity, stream or ground water salinization has not resulted from this practice; 9) fertilizers are applied two or three times annually to fry and fingerling ponds and occasionally to grow-out ponds; 10) hydrated lime is applied occasionally at 50 to 100 kg/ha but this does not cause high pH in pond waters or effluents; 11) accumulated sediment removed from pond bottoms is used to repair embankments and not discarded outside ponds; 12) sampling above and below catfish pond outfalls on eight streams revealed few differences in stream water quality; 13) electricity used for pumping water and mechanical aeration is only 0.90 kW·h/kg of production; 14) each metric ton of fish meal used in feeds yields about 10 tons of dressed catfish.**

**Reduction in effluent volume through water reuse and effluent treatment in settling basins or wetlands does not appear feasible on most farms. However, some management practices are recommended for reducing the volume and improving the quality of channel catfish pond effluents.**

World aquaculture grew rapidly during the past 50 yr, and it is continuing to expand. This growth is possible because of an increasing demand for fisheries products and failure of capture fisheries to keep pace with demand. It is doubtful that aquacultural production can continue to increase fast enough to meet the rising demand for fisheries products (Boyd 1999). Channel catfish *Ictalurus punctatus* farming in the United States has followed the global trend with expansion from about 1,000 ha in the early 1960s to more than 77,000 ha in 1998 (Anonymous 2000). In Alabama, catfish farming has increased from a few farms in the early 1960s to about 10,000 ha at present (Anonymous 2000).

Recent environmental concerns could greatly diminish the future of aquaculture. Although these concerns have been directed primarily at marine shrimp farming and cage culture of salmon in marine environ-

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TABLE 1. *Monthly precipitation, pan evaporation, pond evaporation, average air temperatures, and runoff for west-central Alabama.*

| Month | Precipitation[a] (cm) | Pan evaporation[b] (cm) | Pond evaporation[b] (cm) | Runoff[c] (cm) | Mean air temperature[a] (C) |
|---|---|---|---|---|---|
| January | 12.73 | 6.07 | 4.93 | 10.87 | 7.34 |
| February | 12.17 | 7.67 | 6.22 | 10.80 | 9.17 |
| March | 17.32 | 11.53 | 9.35 | 14.73 | 13.18 |
| April | 13.77 | 14.17 | 11.48 | 8.71 | 17.96 |
| May | 9.98 | 16.51 | 13.36 | 0.15 | 21.85 |
| June | 10.44 | 17.93 | 14.53 | 0.00 | 25.52 |
| July | 11.91 | 17.81 | 14.43 | 0.00 | 27.02 |
| August | 8.96 | 16.94 | 13.72 | 0.00 | 26.74 |
| September | 9.02 | 13.11 | 10.62 | 0.00 | 24.07 |
| October | 6.98 | 10.41 | 8.43 | 1.19 | 17.74 |
| November | 8.28 | 6.93 | 5.61 | 6.05 | 12.12 |
| December | 13.79 | 5.61 | 4.55 | 12.55 | 8.56 |
| Annual | 135.35 | 144.69 | 117.23 | 65.05 | 17.61 |

[a] Data from Marion Junction (Southeast Agricultural Weather Service Center 1993).

[b] Pan evaporation data was taken from Demopolis, Alabama (Farnsworth and Thompson 1982), and pond evaporation was estimated as 0.81 × pan evaporation (Boyd 1985a).

[c] Estimated by the water accounting method (Yoo and Boyd 1994).

ments, there has been at least one report critical of channel catfish farming (Goldberg and Triplett 1997). Concerns about aquaculture include wetland destruction, conversion of agricultural land to ponds, water pollution, loss of biodiversity, competition for water use, use of toxic or bioaccumulative chemicals, and negative social impacts (Boyd 1997; Boyd and Clay 1998). The main environmental concern about channel catfish farming is water pollution by pond effluents; other environmental issues raised about aquaculture appear less problematic.

According to federal regulations, effluents from aquaculture farms in the United States are subject to permitting under the National Pollution Discharge Elimination System (NPDES) of the Clean Water Act (Boyd 2000), but in some states, aquaculture effluents have not been subject to permitting. The United States Environmental Protection Agency has recently initiated rule-making related to aquaculture effluents (Federal Register 2000), and the channel catfish industry will have to comply with resulting effluent regulations. The Alabama Catfish Producers Association requested that Auburn University make an environmental assessment of catfish farming in the state. This report provides results of the assessment and recommendations for management practices to prevent adverse environmental impacts.

## Land, Water, and Climate

Most catfish farming in Alabama is conducted in Bibb, Dallas, Greene, Hale, Marengo, Perry, and Tuscaloosa Counties in the west-central part of the state and centered in an 80-km radius of Greensboro. Climate consists of mild winters and hot summers. January is the coldest month with mean minimum and maximum air temperatures of 1.3 and 13.3 C, respectively (average = 7.3 C), and July is the warmest month with minimum and maximum air temperatures of 20.7 and 33.2 C, respectively (average 27.0 C) (Southeast Agricultural Weather Service Center 1993). Average annual rainfall is 135 cm; March is the wettest month and October is the driest month (Table 1). Annual pan evaporation averages 145 cm, and pond evaporation estimated as pan evaporation × 0.81 (Boyd 1985a) is 117 cm/yr. Evaporation is lowest in January and highest in June (Table 1). Runoff from watersheds, as estimated by the water accounting method (Yoo and Boyd 1994) averages 65 cm/yr, but runoff is negligible between May and October (Table 1).

The majority of the ponds in west-central Alabama is located in former pasture land of the Black Belt Prairie (Hajek et al. 1975). Soils often contain limestone and plastic clay (Hunt 1967) and are well suited for pond construction. The topography of the Black Belt Prairie ranges from gently to moderately rolling (Hunt 1967). The majority of ponds are constructed by damming watersheds to capture runoff. Some ponds are embankment ponds filled by well water. Well water also is used to maintain water levels in watershed ponds during dry weather.

The main aquifers used in catfish farming are the Eutaw, Gordo, and Coker formations and alluvial and terrace deposits of the Quaternary age (Causey et al. 1978; Davis et al. 1975; Reed et al. 1972; Scott et al. 1981; Wahl 1966). The Coker formation tends to be deep and has water of high salinity. However, in some places the Coker formation and underlying lower Cretaceous formation are close to the surface and provide artesian flow. Water from these sources is highly prized by catfish farmers because of the therapeutic qualities to fish of the high salt content (often 5,000 to 6,000 mg/L). The principle source of aquifer recharge is percolation of rainwater (Kidd and Lamberth 1995).

Surface waters in the Blackbelt Prairie usually have between 25 and 100 mg/L total alkalinity and total hardness (Arce and Boyd 1980). Ground waters usually are similar in hardness and alkalinity, but some ground waters contain up to 300 mg/L hardness and alkalinity (Boyd and Brown 1990). Also, some ground waters have very low hardness (10 to 30 mg/L) because of natural softening of ground water in which divalent cations in ground water are exchanged for monovalent cations in the geological matrix of aquifers (Hem 1970). Total dissolved solids usually exceed 60 mg/L in surface water (Arce and Boyd 1980) and 200 mg/L in ground water (Boyd and Brown 1990).

## Production Methods

An overview of the production methods used in Alabama catfish farming will be provided. More specific information on production methods will be provided in the discussion of the farmer survey made during this study.

### *Ponds*

Ponds usually are 4 to 5 ha in area with maximum depths of 2 to 3 m and minimum depths of 0.5 to 1 m. The freeboard is about 1 m for watershed ponds and about 0.5 m for embankment ponds. Drainpipes are extended through embankments or dams at the deepest ends of the ponds. Drains are mostly smooth, steel pipes with risers and valves on the insides of the ponds to facilitate water level control and draining. Ponds usually are designed according to specifications of the Natural Resources Conservation Service, United States Department of Agriculture. These standards result in a sound design, good construction practices, and a safe structure. Many ponds serve the dual purpose of fish production and flood control. The large area of ponds retains runoff and retards watershed discharge.

Wells for supplying ponds are up to 400 m deep, but most are 100 to 200 m deep. Well casings usually are 10 to 15 cm in diameter and capacity is about 1.5 to 2.5 $m^3$/min. Because wells are deep and have low yields, surface water is the preferred water source.

### *Fry and Fingerling Production*

Most of the fingerlings for stocking production ponds are produced in Mississippi, because there is seldom sufficient well water to quickly flood fry ponds that were drained and dried after the previous season, and because well water is too cool (20 to 22 C) for hatchery use.

Fry ponds are prepared by filling with ground water or surface water filtered through a fine mesh screen 2 to 3 wk before the hatching season. Water is fertilized with organic and inorganic fertilizers. Old fish feed and chicken manure (200 to 500 kg/ha) and inorganic fertilizers (5 to 10 kg N and $P_2O_5$/ha) are applied to encourage a plankton bloom to serve as natural food for fry. Fry are stocked at 200,000 to 600,000/ha and fed twice a day with 38% to 49% crude protein feed. Daily feeding rates commonly are 25 to 40 kg/ha.

Small (5-cm) fingerlings are fed a sinking crumble (crushed pellet) that contains 35 to 38% crude protein. As the fish grow to about 7.5 cm, they are fed small floating pellets containing 35 to 36% crude protein. Towards the end of the growing season ponds often have dense plankton blooms, and mechanical aeration is applied to maintain adequate dissolved oxygen. Near harvest time, feeding rates are about 100 kg/ha per day. Ponds have traditionally been drained for harvest, and yields of 4,000 to 5,000 kg/ha are considered optimal. Survival is usually >50%.

A new method of raising fingerlings is becoming increasingly popular. Food fish producers use one or two of their smaller production ponds for fingerling grow-out. Small fingerlings (5 to 7.5 cm) are stocked to meet the fingerling needs for the entire farm. They are raised to 12 to 15 cm in length before being stocked into food fish ponds. Large fingerlings can be seine harvested without draining ponds.

### *Food Fish Production*

The majority of commercial catfish ponds in Alabama are managed as seine-through, multiple-batch systems in order to conserve water and allow year around harvest. Ponds are initially stocked with fingerlings, and marketable-sized fish are harvested with a grading seine. Fingerlings are stocked for replacement of harvested fish, and ponds are not drained. However, some large fish escape the seine, and after a few years, there may be three or four distinct size classes of fish in the same pond. Ponds may contain in excess of 25,000 fish/ha and feeding rates often exceed 100 kg/ha per day. Crude protein concentrations in feed range from 28 to 32%. Most producers feed once a day from truck-mounted hoppers with blowers. They distribute feed over peripheral water surfaces. Average production in Alabama is near 4,500 kg/ha annually (Anonymous 2000).

The high feeding rates and resulting eutrophic conditions require that food fish ponds be aerated with electrical, paddle wheel aerators. Ponds usually are routinely aerated at rates of 2 to 4 kW/ha for 6 to 8 h/d (usually at night). In the event that electrical aerators cannot provide sufficient oxygen, producers will temporarily operate large, tractor-powered aerators (Boyd 1998).

## Water Quality Investigations

Researchers at Auburn University have been conducting studies on environmental aspects of channel catfish farming in Alabama since the early 1970s. Thus, a review of this work is provided.

### *Sources of Nutrients and Organic Matter*

The primary source of nutrients in ponds is feed, but fertilizers are used sparingly in some ponds. Feed also is a source of organic matter, but much of the organic matter in ponds originates from phytoplankton photosynthesis. In channel catfish farming, a typical feed conversion ratio (weight feed ÷ net fish production) is 2.0. The calculated inputs in feed and outputs in fish for dry matter, carbon, nitrogen, and phosphorus in pond culture of channel catfish are given in Table 2 for production of 1,000 kg live fish. Waste loads to the pond (inputs in feed − outputs in fish) represent 87.5% of dry matter, 84.9% of carbon, 81.7% of nitrogen, and 79.6% of phosphorus contained in the feed. In this example, no attempt was made

TABLE 2. *Calculated inputs, outputs, and loadings of carbon, nitrogen, and phosphorus for the production of 1,000 kg live channel catfish using 2,000 kg feed (feed conversion ratio = 2.0).*

| Variable[a] | Feed (input) (%) | Feed (input) (kg) | Fish (output) (%) | Fish (output) (kg) | Loading (kg) |
|---|---|---|---|---|---|
| Dry matter | 91.7 | 1,834 | 23.0 | 230 | 1,604 |
| Carbon | 45.8 | 840 | 55.0 | 126.5 | 713.5 |
| Nitrogen | 5.58 | 102.3 | 8.15 | 18.7 | 83.6 |
| Phosphorus | 0.87 | 15.96 | 1.42 | 3.26 | 12.7 |

[a] Oven dry basis.

to estimate carbon input from photosynthesis, and the carbon load would actually be much greater than indicated. Boyd (1985b) showed that nutrients released in the production of one unit weight of live channel catfish resulted in twice as much dry matter production by phytoplankton.

In ponds without aeration, feeding rates should not be greater than 30 kg/ha per d because of the increased probability of dissolved oxygen depletion at greater feeding rates (Tucker et al. 1979). In order to conserve land and water and to reduce investment costs, mechanical aeration has become standard practice. Water quality tends to deteriorate when feeding rates are high (Boyd et al. 1978; Cole and Boyd 1986). As farmers periodically harvest and restock fish, feeding rates increase until fish are harvested. Feeding rates decrease immediately after harvest and then increase as newly-stocked fish grow. Feed application is based on feeding response. Feeding rates often exceed 100 kg/ha per day, and feeding rates above 100 to 120 kg/ha per day can result in highly eutrophic conditions (Cole and Boyd 1986; Boyd and Tucker 1995). During winter, water is cooler, feed is not applied, phytoplankton abundance diminishes, and water quality improves.

### *Fate of Nutrients and Organic Matter*

Waste resulting from fertilization and feeding can be assimilated by processes within a pond. Much of the organic carbon produced and oxygen released by phytoplankton cells in gross photosynthesis will be used in respiration by the same phytoplankton cells that produced it (Boyd 1973, 1985b). Most phytoplankton in catfish ponds will become particulate organic matter or dissolved organic matter, settle to the pond bottom, or be lost from the pond in outflowing water. Dead phytoplankton and aquatic animals, uneaten feed, and feces will be decomposed by microorganisms and converted to mineral components such as carbon dioxide, water, ammonia, and phosphate.

Phosphate usually is adsorbed by pond sediment and bound in largely unavailable form (Boyd 1995). Masuda and Boyd (1994) found that about 67% of the phosphate added in feeds to channel catfish ponds at Auburn, Alabama was bound in bottom soils. Carbon dioxide released by respiration can be used in photosynthesis, bound in bicarbonate, lost to the atmosphere by diffusion, or converted to methane by microorganisms. Methane will diffuse into the atmosphere. Ammonia may be adsorbed by plants and incorporated into plant protein. Small amounts of ammonium can be adsorbed on cation exchange sites in sediment. Ammonia volatilizes from pond water into the atmosphere (Gross et al. 1999b). Ammonia can be nitrified to nitrate and nitrate may be converted to gaseous nitrogen by denitrifying bacteria in anaerobic sediment and lost to the atmosphere (Gross 2000). Dissolved and particulate substances also are contained in outflowing water.

Gross et al. (1998) measured concentrations of phosphorus in waters of channel catfish ponds receiving equal amounts of feed with phosphorus concentrations of

0.60, 0.68, 0.75, 0.81, and 1.03%. There were about the same amounts of phosphorus in waters of all ponds regardless of diet. However, more phosphorus was adsorbed by bottom soils in ponds with high phosphorus diets than in those with low phosphorus diets. Bottom soil adsorption was the major control on phosphorus concentrations in the water. Lowering phosphorus concentrations in diets will reduce the input of phosphorus to bottom soils and conserve their capacity to adsorb phosphorus. It is often assumed that reductions in nitrogen concentrations in water also can be achieved through use of lower nitrogen content feeds, but this assumption was not verified in pond studies (Gross et al. 1999a).

A pond ecosystem has a large capacity to assimilate nutrients and organic matter. For example, Schwartz and Boyd (1994a) found that only 3.1%, 28.5%, and 7.0% of carbon, nitrogen, and phosphorus, respectively, added to channel catfish ponds in feed were contained in pond effluents. The ponds had small amounts of overflow after heavy rains, and most effluent was released during pond draining for harvest.

### *Suspended Solids*

The two major sources of suspended solids in pond waters are suspended soil particles and particulate organic matter resulting from live plankton and detritus (Masuda and Boyd 1994). Solids enter ponds from erosion of watersheds, but these solids tend to settle onto pond bottoms. Internal processes that contribute to sediment load include erosion of edges by wind action, erosion of levees and bottoms by water currents generated by aerators, bioturbation caused by bottom disturbance by fish, seining, and water currents caused by pond draining. Soil particles that are resuspended by these processes will settle again within ponds unless they are lost in outflowing water. Erosion of channels carrying effluents away from the pond can contribute to the load of suspended solids reaching receiving waters.

A flocculent layer extends a few centimeters above the soil-water interface and the highly-fluid surface layer of bottom soil contains about 50% organic matter (Munsiri et al. 1995). When ponds are drained, the flocculent layer and sediment resuspended by fish activity, seining operations, and water currents will be included in effluent. The average concentration of settleable solids discharged during complete drain-harvest of catfish ponds at Auburn, Alabama, ranged from 2,867 to 16,300 kg/ha (average = 9,362 kg/ha) (Schwartz and Boyd 1994a).

### *Water Quality Management*

Pond management techniques that improve water quality can lessen stress on aquatic animals, and this presumably lowers their susceptibility to disease, improves survival, and enhances growth. There are many water quality management techniques, but the most significant are as follows: protection of watersheds and other water sources from external sources of pollution; neutralization of soil acidity and enhancement of total alkalinity in acidic ponds by liming; drying pond bottoms between crops when ponds are drained for harvest to increase organic matter decomposition rates; mechanical aeration to enhance the dissolved oxygen supply (Boyd and Tucker 1998).

Mechanical aeration prevents dissolved oxygen concentrations from falling low enough to stress fish and other aquatic animals. It also prevents thermal stratification and protects against anaerobic conditions in deeper water and at the soil-water interface. By enhancing dissolved oxygen concentrations, aeration increases the capacity of ponds to assimilate organic matter by aerobic processes. Higher dissolved oxygen concentrations also increase the ability of nitrifying organisms to oxidize ammonia to nitrate (Boyd 2000). Aeration can be applied in excessive amounts. Erosion of pond

TABLE 3. *Mean concentrations (± SD) of water quality variables of samples collected from the surface of 25 commercial channel catfish ponds in central and west-central Alabama during winter (February), spring (May), summer (August), and fall (November) of 1991* (n = *100) (Schwartz and Boyd 1994b).*

| Variable | Range | Mean ± SD |
|---|---|---|
| 5-d biochemical oxygen demand (mg/L) | 1.28–35.54 | 9.42 ± 4.75 |
| Settleable solids (mL/L) | 0.00–1.80 | 0.08 ± 0.13 |
| Total suspended solids (mg/L) | 0.7–329 | 69.4 ± 49.0 |
| Total volatile solids (mg/L) | 0.2–208 | 27.8 ± 30.5 |
| Total phosphorus (mg/L) | 0.05–1.48 | 0.25 ± 0.18 |
| Soluble reactive phosphorus (mg/L) | 0.001–0.017 | 0.010 ± 0.012 |
| Total nitrogen (mg/L) | 0.58–14.04 | 5.19 ± 1.68 |
| Total ammonia-nitrogen (mg/L) | 0.01–7.71 | 1.13 ± 1.19 |
| Nitrite-nitrogen (mg/L) | 0.001–1.37 | 0.065 ± 0.05 |
| Nitrate-nitrogen (mg/L) | 0.18–16.8 | 0.70 ± 0.80 |
| Dissolved oxygen (mg/L) | 1.9–16.8 | 8.7 ± 4.0 |
| pH (standard units) | 6.0–9.3 | 8.2 ± 0.5 |

bottoms and levees can suspend large amounts of particles and increase the suspended solid concentration in pond effluents (Boyd 1995). Improved pond management is a highly effective way of abating pollution, because the costs of these procedures normally are defrayed by increased efficiency of production resulting from water quality improvement and less stress on culture organisms (Boyd and Tucker 1995).

Some chemicals are used in channel catfish ponds in attempts to improve water quality or for reducing phytoplankton abundance. Other than fertilizers and liming materials, the most common ones are copper sulfate for controlling algae, potassium permanganate as an oxidant, and calcium hypochlorite as a general disease treatment and water quality enhancer. Tucker and Boyd (1977) showed that potassium permanganate did not improve water quality in ponds, and it is no longer used except occasionally for bacterial disease treatment. Potts and Boyd (1998) demonstrated that chlorination was not effective for any purpose in grow-out ponds, and it also is seldom used today. Copper sulfate is still widely used, but the small applications quickly precipitate from the water and become bound in the sediment (Tucker and Boyd 1978; Masuda and Boyd 1993). A thorough discussion of the use of chemicals in aquaculture ponds and the associated environmental, worker safety, and food safety risks was provided by Boyd and Massaut (1999).

### *Effluent Composition*

Schwartz and Boyd (1994b) measured concentrations of several water quality variables in waters of 25 channel catfish ponds over a 12-mo period. Although the highest concentrations of most of the variables tended to occur in summer and fall, averages for most of the variables did not differ greatly with season. Thus, only averages and ranges are provided in Table 3. It appears that concentrations of total phosphorus and total suspended solids are potentially the most problematic in terms of water pollution potential. The 5-d biochemical oxygen demand averaged only 9.4 mg/L, and another study by Boyd and Gross (1999) also revealed that 5-d biochemical oxygen demand seldom exceeded 8 to 10 mg/L in catfish ponds. Boyd and Gross (1999) also found that the biochemical oxygen demand in catfish pond effluent resulted mostly from plankton respiration. Boyd (1978) showed that the most concentrated effluents are those that are discharged during the time that fish or crustaceans are being captured by seining (Table 4).

Schwartz and Boyd (1994a) recorded

TABLE 4. *Average concentrations of different water quality variables during initial drawdown phase and seine-harvest phase in eight channel catfish ponds (Boyd 1978).*

| Variable | Water released during initial drawdown of pond | Final water released while fish were harvested with seine |
|---|---|---|
| Settleable solids (mL/L) | 0.08 | 28.5 |
| 5-d biochemical oxygen demand (mg/L) | 4.31 | 28.9 |
| Soluble reactive phosphorus (mg/L) | 0.02 | 0.06 |
| Total phosphorus (mg/L) | 0.11 | 0.49 |
| Total ammonia-nitrogen (mg/L) | 0.98 | 2.34 |
| Nitrate-nitrogen (mg/L) | 0.16 | 0.14 |

changes in effluent composition during pond draining. Concentrations of water quality variables were measured in samples dipped from the water surface of ponds opposite to drains and from effluent discharge pipes during draining. Concentrations of water quality variables were almost identical between surface water and effluent until about 75 to 80% of the pond water had been discharged. Concentrations of most variables then increased markedly in the final effluent as illustrated in Fig. 1 for total settleable solids and biochemical oxygen demand. This resulted from stirring of sediment by fish, disturbance of the bottom by seining, and sediment resuspension by outflowing water. More than 50% of the total load of most water quality variables was released in the final 20% of pond water as illustrated in Fig. 2. Sediment resuspension can be avoided if the drain is closed after about 75 to 80% of the pond water has been released, and no water released during seining.

### *Volume of Effluents*

The volume of effluents discharged from aquaculture ponds depends upon rainfall, type of pond, and management procedures employed. Watershed ponds have discharge roughly equal to the volume of runoff entering from watersheds. In annually-drained ponds this occurs because runoff retained for filling the ponds each year will be released at draining for harvest. In watershed ponds that are not drained for harvest, there will not be enough storage volume available to retain the runoff, and it will simply flow through the ponds (Shelton and Boyd 1993). The approximate volume of discharge can be estimated by the following equation:

$$Q = (P - PET)(A) \qquad (1)$$

where Q = discharge ($m^3$), P = rainfall (m/yr), PET = potential evapotranspiration (m/yr), and A = watershed area ($m^2$).

Shelton and Boyd (1993) measured discharge from embankment ponds with weirs and estimated discharge with Equation 1. Agreement in measured and estimated values was very close when the Baier and Robertson (1965) method was used to estimate PET. However, this method requires daily values for maximum and minimum air temperatures, solar radiation, and wind velocity. Satisfactory estimates of PET can be made with the Thornthwaite equation that only requires data on average monthly air temperatures or the Turc equation in which only data on mean annual air temperature and annual rainfall are needed (Yoo and Boyd 1994). The four watershed ponds studied by Shelton and Boyd (1993) had an average depth of 1.83 m and a watershed: pond area ratio of 11.4. These ponds had a discharge equal to 2.5 times pond volume in a year with 173 cm of rainfall (normal rainfall was 142 cm). The next year had 144 cm of rainfall, and discharge averaged 1.4 times pond volume. Thus, effluent volume is highly dependent upon rainfall patterns. Also, effluent volume will vary with the ratio of watershed area to pond storage volume.

Embankment ponds do not have enough

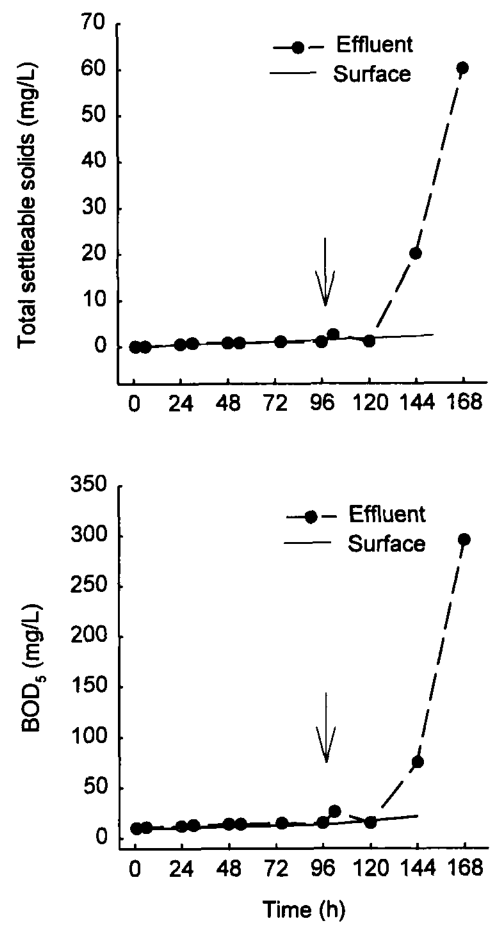


FIGURE 1. *Concentrations of settleable solids and 5-d biochemical oxygen demand ($BOD_5$) in pond surface water and effluent during draining of channel catfish ponds at Auburn, Alabama for harvest. Vertical arrows indicate time that harvest of fish began. Source: Schwartz and Boyd (1994a).*

watershed area to contribute significant amounts of runoff. If ponds are operated so that water levels are normally 7.5 to 10 cm below the intakes to overflow structures, little outflow will occur except during periods of high rainfall (Boyd 1982, 1986, 1987; Boyd and Gross 2000). For example, at Auburn, Alabama, overflow from embankment ponds operated with water levels 7.5 cm below intakes of overflow structures would be about 11 cm on a year with average rainfall. Two or three times as much overflow might occur in west-central Alabama where ponds were built on less pervious soils and have less seepage loss than ponds at Auburn, Alabama, but the overflow still would be small compared to watershed ponds.

### *Effluent Treatment*

Many schemes for treating pond effluents or using them for a beneficial purpose have been advanced over the years. These include the following: hydroponics; irrigation; culture medium for other aquatic organisms; treatment by wetlands and settling basins; biological filtration. The most promising procedure appears to be treatment in settling basins or wetlands. Effluents from ponds are not concentrated enough in nutrients for use in hydroponics without nu-

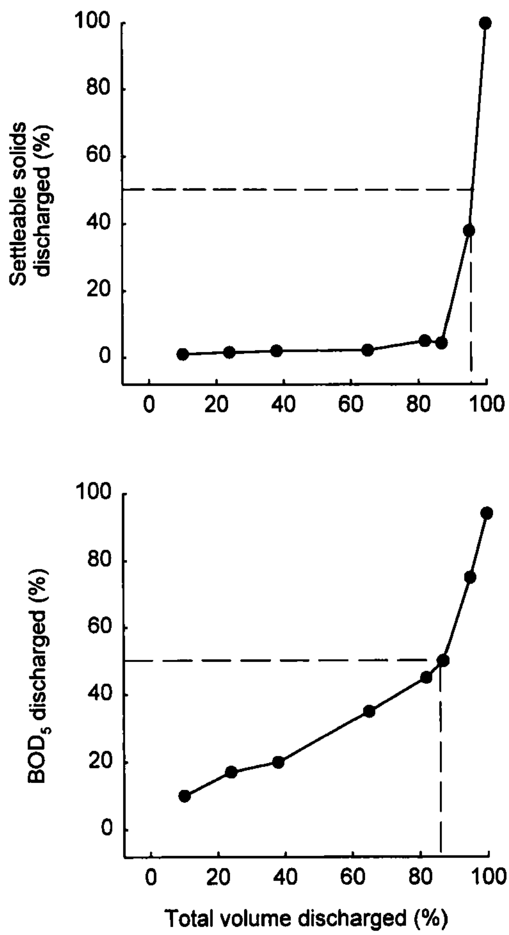


FIGURE 2. *Percentages of settleable solids and 5-d biochemical oxygen demand ($BOD_5$) discharged in relation to percentage of pond effluent discharged during draining of channel catfish ponds at Auburn, Alabama for harvest. Dashed lines indicate percentage of total pond volume discharged before 50% of $BOD_5$ and settleable solids loads were attained. Source: Schwartz and Boyd (1994a).*

trient supplementation, which defeats the purpose of this procedure. Filter-feeding fish, mollusks, and certain plants have been successfully cultured in effluents, but this practice has seldom been economical or greatly improved effluent quality. Complicated water treatment procedures such as biological filtration are likely too expensive to use with pond effluents. Also, nutrient and organic matter concentrations are not great enough to make these treatment procedures effective. The problems with using catfish pond waters for irrigation in Alabama are that there is little overflow during dry periods when irrigation is needed, and farmers prefer not to drain ponds during the growing season. The fish crop is more valuable than traditional plant crops. Thus, there is no incentive to cause a potential hazard to the fish crop by using water from ponds for irrigation and causing water levels to decline.

Water from a production pond for channel catfish in Hale County, Alabama, was passed through a constructed wetland consisting of two cells, one planted with California bulrush *Scirpus californicus* and giant cutgrass *Zizaniopsis miliacea* and one planted with Halifax maidencane *Panicum hemitomon* (Schwartz and Boyd 1995). The removal of potential pollutants from water flowing through the wetland was determined for 1-, 2-, 3-, and 4-d hydraulic residence times (HRTs). Concentrations of potential pollutants were much lower in effluent from the wetland than in influent from the channel catfish pond. The following reductions in concentrations were recorded at different times during the study: total ammonia nitrogen, 1 to 81%; nitrite-nitrogen, 43 to 98%; nitrate-nitrogen, 51 to 75%; total nitrogen, 45 to 61%; total phosphorus, 59 to 84%; biochemical oxygen demand, 37 to 67%; suspended solids, 75 to 87%; volatile suspended solids, 68 to 91%; and settleable solids, 57 to 100%. Overall performance of the wetland was best when operated with a 4-d HRT in the vegetative season, but good removal of potential pollutants was achieved for shorter HRTs. The wetland was relatively efficient in improving water quality even in the late fall and winter when vegetation was dormant. The disadvantage of constructed wetlands for treating wastes from channel catfish ponds is the large amount of space necessary to provide adequate hydraulic residence time. Schwartz and Boyd (1995) estimated that a minimum wetland area of 0.7 times pond area would be needed during

TABLE 5. *Average concentrations of selected water quality variables in the final water (approximately 20% of pond volume) discharged from ponds after channel catfish were harvested by seining (Seok et al. 1995).*

| Discharge schedule | Total suspended solids (mg/L) | Total nitrogen (mg/L) | Total phosphorus (mg/L) | 5-d biochemical oxygen demand (mg/L) |
|---|---|---|---|---|
| Immediately after seining | 370 | 11.9 | 0.97 | 30.1 |
| 1 d after seining | 408 | 12.2 | 0.52 | 19.2 |
| 2 d after seining | 16 | 3.1 | 0.30 | 12.4 |

pond draining. However, if natural wetlands are available below catfish pond outfalls, they could be used as water purification systems.

Settling basins are easier to construct and operate than wetlands because they do not have to be seeded with plants, and ponds can substitute as settling basins. Seok et al. (1995) showed that when the last 20 to 25% of water was held in ponds for 2 d after harvest, drastic improvement in quality resulted from sedimentation (Table 5). If remaining water must be discharged, it should be allowed to slowly exit ponds to prevent resuspension of sediment. Findings summarized in Table 6 suggest that settling basins can be just as effective as wetlands in improving the quality of catfish pond effluents. Results of a laboratory-scale study of sedimentation (Boyd et al. 1998) also revealed that large reductions in concentrations of key water quality variables could be effected. Removal of total phosphorus, total suspended solids, turbidity, and biochemical oxygen demand was usually greater than 50% after 8 h. This results because much of the phosphorus and organic matter in pond effluents is associated with suspended matter, and the suspended matter will quickly settle if water is held in settling basins. The disadvantage of settling basins is that land must be available for their construction. However, as discussed above, an empty production pond could possibly be used as an alternative, but pumping costs would be incurred for transferring water.

TABLE 6. *Comparison between effectiveness of a settling basin and a constructed wetland for treating catfish pond effluent. Values represent percentage removal of the variables (Schwartz and Boyd (1995).*

| Variable | Settling basin, 2-d retention | Constructed wetland, 2-d retention |
|---|---|---|
| Total suspended solids | 95.6 | 88.8 |
| Total nitrogen | 73.9 | 64.6 |
| Total phosphorus | 69.0 | 64.3 |
| 5-d biochemical oxygen demand | 58.8 | 59.5 |

## Farm Survey

A survey was conducted between July 1997 and August 1998 by personal interviews with owners or managers of 25 channel catfish farms in Hale, Greene, Tuscaloosa, Perry, and Dallas Counties of west-central Alabama. Farms were selected to represent differences in size, topography and soils, water sources, production intensity, and management approach. The farms also were selected to cover the entire geographic area. Greg Whitis of the Alabama Fish Farming Center, Greensboro, Alabama made final selections, and his knowledge of individual farmer's willingness to cooperate with researchers also influenced selection. A questionnaire was prepared (Appendix I) and the owner or manager of each farm was asked to respond to each question and the answers were recorded. Where later evaluation revealed inconsistencies in answers, further discussion for clarification was done by telephone. Investigators also toured the farms to observe infrastructure, watershed topography, water management, discharge points, and other items of interest. Investigators also flew over the farms in a small plane to observe watershed activities in addition to catfish farming.

*Production*

Farms in the survey represented about 24% of the total area devoted to channel catfish farming in Alabama. Of the 2,378 ha in the survey, 26 ha (1.1%) were in fry production, 227 ha (9.5%) were in fingerling production, and 2,125 ha (89.4%) were in food fish production. All farmers produced food fish, but only 14 of the 25 farmers produced fry or fingerlings. Although channel catfish was the primary culture species on all farms, grass carp *Ctenopharyngodon idella* or threadfin shad *Dorosoma petenense* were stocked in production ponds for controlling aquatic macrophytes and phytoplankton, respectively, on 16 of 25 farms.

All farmers applied feed to ponds on a daily basis. Crude protein content of feed was 48 to 50% for fry, 36 to 38% for fingerlings, and 28 to 32% for food fish. The 28 to 32% protein feed contained about 1% phosphorus, but fry and fingerling feed contained 1.2% phosphorus, or more.

Fertilizers were used in fry and fingerling ponds. Fertilizers included triple superphosphate, diammonium phosphate, 10-34-0 liquid fertilizer, and urea. Normal application rates were 5 to 10 kg N and $P_2O_5$/ha, and fertilizers are applied 2 to 3 times during the first part of the culture. Three farmers reported using one or two applications of 5 to 10 kg $P_2O_5$/ha from triple superphosphate in food fish ponds to encourage phytoplankton blooms when water was too clear.

Mechanical aeration was used in all types of catfish culture at an average of 2.5 kW/ha. These aerators were paddle wheel aerators with 3.75 or 7.5 kW electric motors, and they normally were operated at night and in the morning. Evidence of bottom soil and bank erosion caused by aerator-induced water currents was common.

Chemical use other than fertilizers on farms included copper sulfate (92%), burnt or hydrated lime (72%), sodium chloride (64%), herbicides (8%), rotenone (4%), and formalin (4%). Only three farms claimed to have used medicated feed within the past year. Usual treatment frequencies (per yr) and rates were as follows: copper sulfate, 3 to 4 applications of 0.75 to 1.0 mg/L; lime, 3 to 4 applications of 50 to 100 kg/ha; sodium chloride, periodic applications to maintain 50 to 80 mg/L chloride; the herbicide Rodeo® (Monsanto, St. Louis, Missouri, USA) or glyphosate was sprayed around pond edges to control weeds; formalin, single applications of 15 mg/L; rotenone, single applications to puddles of water in bottoms of empty ponds.

The production of fry and fingerlings was highly variable depending upon the objectives of individual farmers. Fry production was reported to range from 250,000 to 1,500,000/ha and estimates of fingerling production were from 100,000 to 250,000/ha with standing stock at harvest being between 1,000 and 3,000 kg/ha. The average was about 2,240 kg/ha per yr for farmers in the survey. Feed conversion ratio (weight feed ÷ net fish production) was about 2.0.

Food fish production for farms in the survey averaged 6,300 kg/ha per yr (SD = 1,460 kg/ha) with a range of 2,240 to 8,400 kg/ha per yr. Feed consisted of 28% to 32% crude protein floating pellets that were applied daily between March and October. The average feed conversion ratio was 1.88 (SD = 0.28) with a range of 1.25 to 2.50. Based on survey data and an estimated food fish pond area of 8,858 ha, about 105,000,000 kg of feed are used to produce about 56,000,000 kg catfish. However, industry records for 1997 suggest that food fish production in Alabama was only 40,800,000 kg (Anonymous 1998). Thus, farmers in the survey appeared to have higher production than average.

*Ponds and Water Management*

Ponds on six farms were embankment type with small watersheds (inside slopes and tops of embankments) and runoff was a negligible source of water. On five of these farms, wells were the water source; the other farm obtained water from a stream. The remaining farms (19) had watershed ponds or both watershed ponds and embankment ponds. It is a common practice to construct ponds so that one overflows into another, and where a combination of watershed and embankment ponds were used, the watershed ponds overflowed into the embankment ponds. In the survey, 24% of ponds were classified as embankment ponds and the remainder were watershed ponds. The ratio of watershed area to pond water surface area varied from 0.52 to 50. The ratio watershed area:pond surface area averaged 6.32 (SD = 11.7). Because about 10 ha of watershed is required to maintain the water level in a 1-ha pond in west-central Alabama (Yoo and Boyd 1994), only six farms were operated with runoff as the sole source of water. On 13 farms with a combination of watershed and embankment ponds, wells had been developed to supplement the water supply. Average pond size was 5.5 ha (SD = 1.9 ha) with a range from 0.1 to 15.4 ha. The average water depth in ponds was 1.67 m (SD = 0.43 m) with a range from 0.61 to 2.74 m.

Topography of watersheds was rolling prairie for 19 farms, four farms were located on flood plains, and the other two farms were in hilly areas. Watersheds on 15 farms were in pastureland for cattle, the other four farms where ponds were supplied by runoff had watersheds of woodland or abandoned fields.

Twenty-four of the farms reported overflow only during winter and spring, while one farm had overflow all year. Of course, some overflow may occasionally occur after heavy rains even in summer or fall. Only one farmer in the survey reported using water exchange for attempting to improve pond water quality, and he indicated that this was rarely done. Overflow from 23 farms exited ponds from the surface, but deep water intakes (trickle tubes) had been installed at two farms.

All fry ponds and nearly all fingerling ponds were drained annually, but food fish ponds seldom were drained. Harvest was normally done by seining and without drawdown of water levels. However, some fish learn to escape the seine, and after a few years, ponds must be partially drained to allow for more complete fish removal. Minor repairs of embankments also can be made following partial drawdown. Partial drawdown involves reducing pond volume by about 50% and then closing the drain. Farmers want to retain as much water as possible, because it may take a long time to refill ponds with rainfall and runoff. Also, wells in the area seldom have great enough discharge for rapidly refilling ponds. The intervals for partial draining were as follows: annually (2 farms); 2 to 5 yr (3 farms); 5 to 10 yr (12 farms); more than 10 yr (8 farms). The average was once every 6 yr. Of course, ponds must be drained completely to make repairs of embankments and to remove sediment from bottoms at about 15-yr intervals.

Fry and fingerling ponds were drained whenever fish were needed for restocking. Partial drawndowns of food fish ponds may be done anytime of the year. Complete draining of ponds is done in summer so that bottoms will dry and allow repairs and sediment removal in the fall during dry weather.

The average number of discharge points for overflow and draining on a farm was 6.5 (SD = 6.5) with a range of 1 to 14. Water usually is released from ponds into a ditch that empties into a creek. At six farms, water was discharged directly into creeks via a pipe. Four farms discharged water into natural wetlands. None of the farms had constructed wetlands or settling basins for receiving pond effluents.

The farmers were asked about the possibility of reusing effluent by pumping it back into other ponds. All but six individuals felt that water reuse by pumping would be too expensive. Most of the farms were built to include most available land and extended to creeks or natural wetlands. Only 7 of 25 farms had land available for constructing settling basins or wetlands. Only two farmers felt that water from ponds could be used for irrigation, but their farms did not have land for crops.

### *Earthwork and Sediment*

Sediment removal and levee repairs had been necessary at 14 of the farms. All of the farmers reported using the sediment for reworking levees, and no one had disposed of sediment outside of ponds or planned to do so.

Observations indicated that there is appreciable erosion. In some cases, watersheds had areas of denuded soil or poorly vegetated areas that were obvious sources of suspended soil particles when runoff entered ponds. There was evidence of erosion of pond earthwork and edges by wind and aerator-generated water currents. Many ponds had poorly vegetated embankments, and embankment erosion served as a source of suspended soil particles to ponds or nearby streams. At most farms, there was evidence of extensive erosion of the back sides of embankments and ditches receiving pond discharge. In addition, the outfalls into streams often caused local areas of severe bank erosion. This erosion on the downstream side of ponds was caused by the energy of the flowing water discharged from the ponds. We also observed ponds that had been drained and left fallow with discharge structures open. Rain falling into ponds suspended soil particles that were swept out of the ponds in outflow.

On a number of farms, we saw accumulation of uneaten feed in corners of ponds and in the discharge ditches. This suggested that farmers were sometimes feeding more feed than the fish were eating. Accumulation of wasted feed causes local deterioration in sediment quality and may adversely influence water quality in ponds.

## Effluent Quantity

It was not possible in this study to install water-measuring devices for determining effluent volumes directly. However, effluent volumes can be estimated with a good degree of accuracy with equations from Boyd (1982, 1986, 1987) and Shelton and Boyd (1993) and information about water management on catfish farms from the survey.

### *Overflow*

Monthly overflow from ponds full of water on 1 January and operated without water level drawdown until 31 December was estimated for a 1-ha unit of water surface. These volumes will be called the unit overflow (UOF). The following equations were used to obtain UOF:

Watershed ponds:

$$WD_f = WD_i + P + RO - (E + S) \quad (2)$$

$$OF = WD_f - PD \quad (3)$$

Embankment ponds:

$$WD_f = WD_i + P - (E + S) \quad (4)$$

$$OF = WD_f - PD \quad (5)$$

where $WD_i$ = water depth at beginning of month, $WD_f$ = water depth at end of month if overflow was prevented, P = direct precipitation, RO = runoff, E = evaporation, S = net seepage, PD = average pond depth (based on elevation of overflow intake structure), and OF = overflow. The following assumptions were applied in solving the equations: 1) the unit pond area is 1 ha; 2) the unit watershed area is 6.32 ha for watershed ponds (survey data); 3) embankment ponds do not receive significant runoff (Boyd 1982); 4) average pond depth was 167 cm (survey data); 5) water was added to ponds from wells or streams to maintain the water level 10 cm below the overflow intakes during dry weather (survey data); 6) net seepage from ponds was 0.15 cm/d (Yoo and Boyd 1994); 7) precipitation, pond surface evaporation, and runoff were as reported in Table 1. The resulting monthly estimates of UOF are provided in Table 7.

Negligible runoff entered embankment ponds, and rain falling into ponds seldom exceeded evaporation plus seepage out of

TABLE 7. *Monthly and annual estimates of overflow from 1-ha catfish ponds in west-central Alabama or unit overflow (UOF).*

| Month | Embankment pond (cm) | Watershed pond (cm) |
|---|---|---|
| January | 3.07 | 71.78 |
| February | 1.67 | 69.90 |
| March | 3.25 | 96.37 |
| April | 0.00 | 52.78 |
| May | 0.00 | 0.00 |
| June | 0.00 | 0.00 |
| July | 0.00 | 0.00 |
| August | 0.00 | 0.00 |
| September | 0.00 | 0.00 |
| October | 0.00 | 0.00 |
| November | 0.00 | 27.51 |
| December | 0.00 | 83.82 |
| Annual | 7.99 | 402.16 |

ponds. Thus, embankment ponds have very little overflow (annual UOF = 8 cm). Because of runoff, watershed ponds have large amounts of overflow (annual UOF = 402 cm) from late fall to mid spring.

Partial or complete water level drawdown in watershed ponds will reduce overflow below UOF, because part of the water entering in rainfall and runoff will be retained to replace that intentionally discharged. Thus, UOF values (Table 7) were adjusted for the average drawdown schedule for fry and fingerling ponds and for food fish ponds. For fry and fingerling ponds that are normally drained annually, the adjusted annual unit overflow (annual $UOF_{adj}$) is:

$$\text{Annual } UOF_{adj} = \text{Annual } UOF - PD \quad (6)$$

In food fish ponds, partial drawdown occurs on an average of every 6 yr and complete drawdown occurs about every 15 yr. In 15 yr, there will be two drawdowns of 50% pond volume and one drawdown of 100% pond volume. Thus, the annual $UOF_{adj}$ is:

$$\text{Annual } UOF_{adj} = \frac{(\text{Annual } UOF \times 15) - 2PD}{15} \quad (7)$$

For embankment ponds, there is no runoff

TABLE 8. *Annual estimates of overflow and drawdown volume (m³/ha per yr) for partial harvest or complete draining per hectare of channel catfish ponds in Alabama.*

| Type of pond | Overflow | Partial or complete draining | Total |
|---|---|---|---|
| | | Fry and fingerlings | |
| Embankment | 799 | 16,700 | 17,499 |
| Watershed | 23,500 | 16,700 | 40,200 |
| | | Food fish | |
| Embankment | 700 | 2,226 | 3,025 |
| Watershed | 37,974 | 2,226 | 40,200 |

input, so water levels must be restored after drawdown by water from wells or streams. Therefore, no adjustment of annual UOF is necessary. Volumes of unit overflow expected annually are provided in Table 8.

## *Drawdown and Draining*

Drawdown volume was estimated assuming that ponds are completely full when drawdown was initiated. As mentioned above, fry and fingerling ponds will yield drawdown effluent equal to pond volume each year, and food fish pond water levels will be drawn down an amount equal to two pond volumes every 15 yr on average. Volumes of drawdown effluent also are given in Table 8.

These effluent volumes represent the average condition for a large farm or an area with several farms. An individual food fish pond would obviously yield more effluent on a year when it was drawn down for partial harvest or drained than in other years. Also, in these calculations, it was assumed that fry and fingerling ponds were drained each year. There is a trend towards seine-harvesting of fingerling ponds with draining. Fingerling ponds drained this way would have effluent volumes similar to food fish ponds.

The unit values from Table 8 were expanded to give an estimate of the total amount of effluent released by catfish farming in Alabama on an average year (Table 9). Overflow represents 82% of total efflu-

TABLE 9. *Annual effluent discharge ($\times 10^6$ $m^3$) from Alabama channel catfish farms.*

| Pond and production type | Overflow | Drawdown | Total |
|---|---|---|---|
| | | Fry and fingerlings | |
| Embankment ponds | 0.20 | 4.23 | 4.43 |
| Watershed ponds | 18.88 | 13.42 | 32.30 |
| Total | 19.08 | 17.65 | 36.73 |
| | | Food fish | |
| Embankment ponds | 1.70 | 4.73 | 6.43 |
| Watershed ponds | 255.6 | 15.0 | 270.6 |
| Total | 257.30 | 19.73 | 277.03 |
| Grand total | 276.38 | 37.38 | 313.76 |

TABLE 10. *Average composition of final effluent released during draining of channel catfish ponds.*

| Variables | Final drawdown |
|---|---|
| pH (standard units) | 7.1 |
| Dissolved oxygen (mg/L) | 5.0 |
| Total suspended solids (mg/L) | 1,027 |
| 5-d biochemical oxygen demand (mg/L) | 31.8 |
| Soluble reactive phosphorus (mg/L) | 0.06 |
| Total phosphorus (mg/L) | 1.59 |
| Nitrate-nitrogen (mg/L) | 0.14 |
| Total ammonia-nitrogen (mg/L) | 1.37 |
| Total nitrogen (mg/L) | 9.58 |

ent. Fry and fingerling ponds generate 47% of drawdown and draining effluent even though they represent only about 11% of pond area.

## Effluent Quality

Effluents are of three types: overflow; water discharged in lowering water levels to 50 to 80% of pond volume; final 20% of discharge to empty ponds. Overflow occurs mostly in the cool, wet months (late fall to mid spring) in response to rainfall. The water released to lower water levels to facilitate harvest is similar to pond water in composition and may be released any time of the year. The final water discharged from ponds is more concentrated in most water quality variables than is pond water. It usually is released in the summer or early fall so that bottoms of empty ponds will dry and repairs can be made to earthwork.

Samples of pond overflow from 55 different outfalls in winter and early spring 1998 were analyzed for several water quality variables by standard protocol (Eaton et al. 1995). The data are summarized in Figs. 3, 4, and 5. Turbidity, total suspended solids, and total phosphorus were the only variables consistently higher in concentration than concentrations reported by Schwartz and Boyd (1994b) as normally allowed in NPDES permits. Dissolved oxygen concentrations were > 7 mg/L in all samples. The mean concentrations of variables in overflow did not differ greatly from those for surface waters of channel catfish ponds (Table 3).

Partial drawdown allows for complete harvest of fish. The first 80% of the water released when ponds are completely drained will be considered as partial drawdown effluent. Partial drawdown effluent is similar to pond water in composition (Schwartz and Boyd 1994b), and data in Table 3 also are representative of partial drawdown effluent.

Grab samples were collected for 23 catfish ponds during the final 20% of discharge and analyzed for several water quality variables by standard protocol (Eaton et al. 1995). This water (Table 10) was much more concentrated in total suspended solids, 5-d biochemical oxygen demand, total phosphorus, and total nitrogen than overflow or partial drawdown effluent.

Wood et al. (1999) reported average concentrations of 4.93 mg/L nitrate-nitrogen, 0.92 mg/L total ammonia-nitrogen, 6.66 mg/L total nitrogen, 0.05 mg/L soluble reactive phosphorus, 0.42 mg/L total phosphorus, and 620 mg/L total suspended solids in runoff from corn produced by conventional tillage with winter cover crops in Alabama. Catfish pond overflow was lower in concentrations of nitrogen components and total suspended solids and higher in phosphorus components (Figs. 3, 4, and 5) than runoff from cornfields. Drawdown effluent from catfish ponds has lower concentrations of all nitrogen and

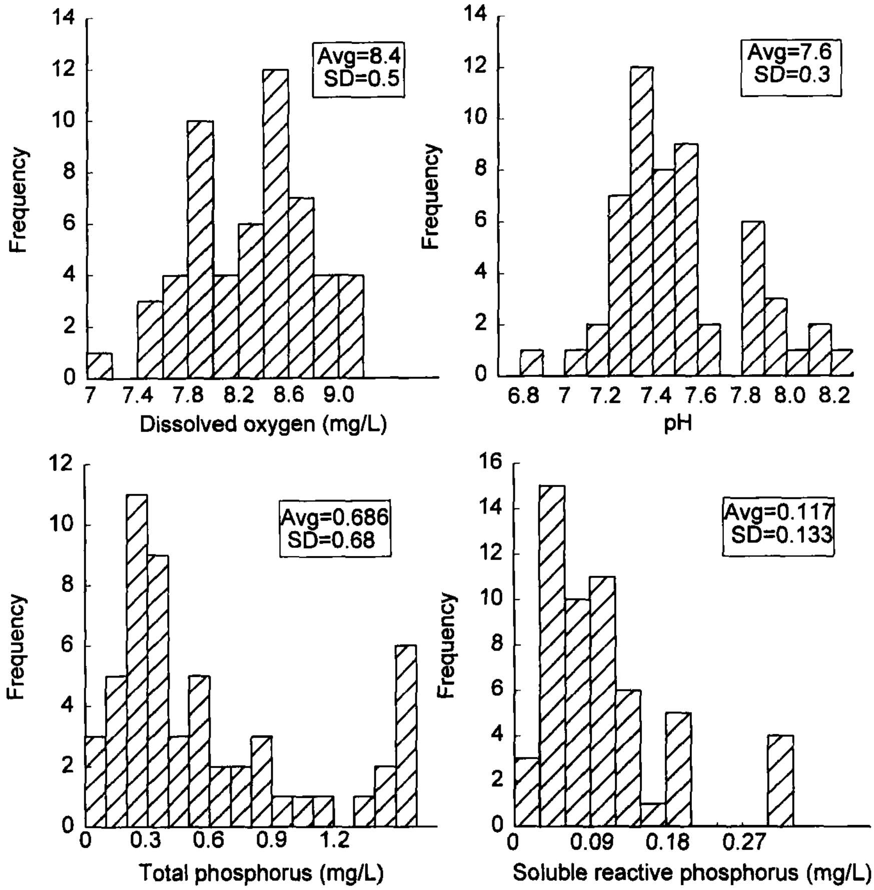


FIGURE 3. *Concentrations of dissolved oxygen, pH, total phosphorus, and soluble reactive phosphorus in storm overflow from commercial channel catfish ponds in west-central Alabama.*

phosphorus components and total dissolved solids (Table 3) than cornfield runoff. However, final draining effluent from catfish ponds averaged higher in phosphorus components and total suspended solids concentration (Table 10) than cornfield runoff.

## Effluent Loads

The composition of overflow, partial drawdown, and final drawdown effluent can be used with estimates of annual unit discharge from Alabama catfish farms to compute loads of substances in effluents. Overflow occurred mostly in winter and early spring when little or no feed was applied, phytoplankton was not abundant, and 5-d biochemical oxygen demand and nutrient concentrations were low in ponds. The overflow from watershed ponds was caused by rain falling directly into ponds and by runoff. Thus, the water flowing from ponds was a mixture of pond water, rainfall, and runoff, and substances in the water came from the ponds and the other sources. Thus, for watershed ponds, the load should be attributed to the pond plus its watershed. The watershed:pond ratio was 6.32, so a 1-ha pond represented 7.32 ha of water and land surface. The equation for estimating the loads from watershed ponds was:

$$\text{Load} = \frac{(\text{Overflow volume})(\text{concentration})}{7.32} \quad (8)$$

The drawdown effluent was considered to

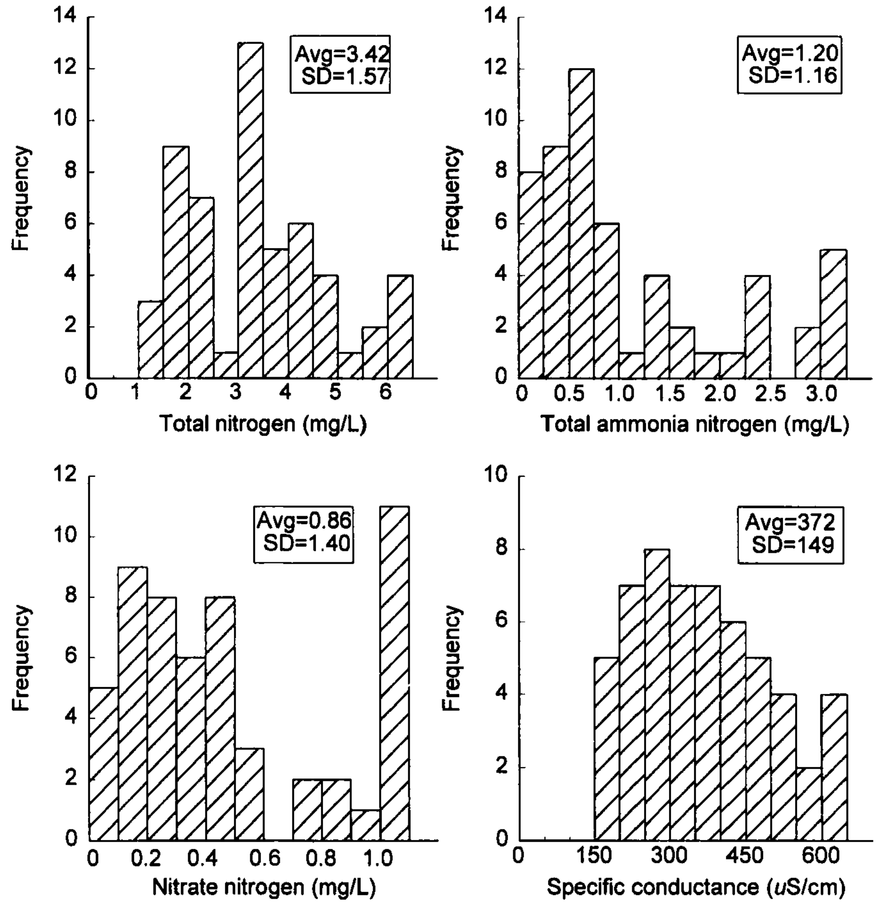


FIGURE 4. *Concentrations of total nitrogen, total ammonia-nitrogen, nitrate-nitrogen, and specific conductance in storm overflow from commercial channel catfish ponds in west-central Alabama.*

be any effluent released while pond volumes exceeded 20% of total pond volume. Fry and fingerling ponds are drained completely in one event. Food fish pond water levels are reduced by about 50% at about 6-yr intervals for complete harvests, and ponds are completely emptied about every 15 yr. Thus, partial drawdown effluent in food fish ponds is 1.8 pond volumes in 15 yr, and final drawdown effluent is 0.2 pond volumes in 15 yr. Thus, only 10% of the effluent is final drawdown effluent and 90% partial drawdown effluent. The following equations were used to estimate loads of substances in partial drawdown effluent:

Fry and fingerling ponds:

$$\text{Load} = (0.8)(\text{Drawdown volume}) \times (\text{concentration}) \qquad (9)$$

Food fish ponds:

$$\text{Load} = (0.9)(\text{Drawdown volume}) \times (\text{concentration}) \qquad (10)$$

where drawdown volumes are provided in Tables 8 and 9 and concentrations in Table 3.

In fry and fingerling ponds, 20% of the drawdown volume is represented by final drawdown. In food fish ponds, 0.2 PD/2.0 PD or 10% of the drawdown volume can be considered final drawdown. The equations for estimating loads of potential pollutants are:

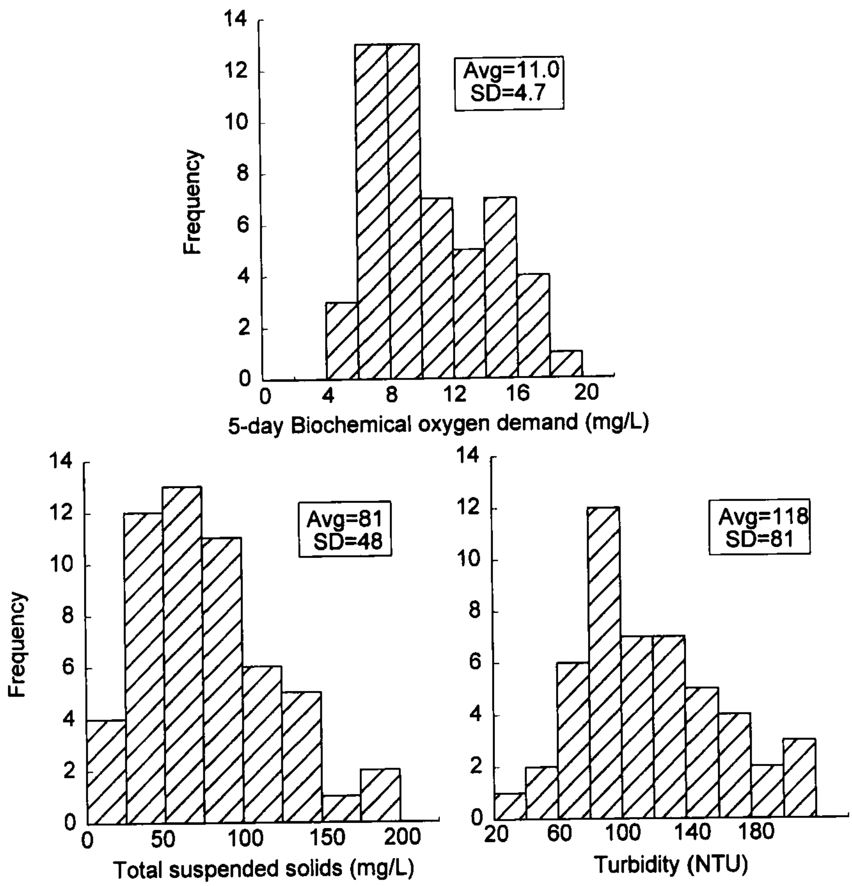


FIGURE 5. *Concentrations of 5-d biochemical oxygen demand, total suspended solids, and turbidity in storm overflow from commercial channel catfish ponds in west-central Alabama.*

Fry and fingerling ponds:

$$\text{Load} = (0.2)(\text{Drawdown volume}) \times (\text{concentration}) \quad (11)$$

Food fish ponds:

$$\text{Load} = (0.1)(\text{Drawdown volume}) \times (\text{concentration}) \quad (12)$$

The loads in Table 11 represent averages for a large farm or an area with several farms. An individual food fish pond would obviously have greater effluent loads on a year when it was drawn down for partial harvest or drained than in other years. Also, fingerling ponds harvested without draining should have effluent loads similar to food fish ponds. Embankment ponds have smaller effluent loads than watershed ponds, because they have smaller effluent volumes than watershed ponds. Also, fry and fingerling production generates much greater effluent loads than does food fish production because of annual draining.

Wood et al. (1999) reported that the annual loads of total nitrogen, total phosphorus, and total suspended solids were 8.53, 0.58, and 839 kg/ha for corn produced by conventional tillage and winter cover crop in Alabama. Fingerling and fry production ponds produce much greater loads of these substances than cornfields. Total suspended solids load did not differ greatly between catfish and corn production, but nitrogen and phosphorus loads were greater for catfish production. Based on average produc-

TABLE 11. *Average annual effluent loads (kg/ha per yr) for total suspended solids (TSS), 5-d biochemical oxygen demand ($BOD_5$), total nitrogen (TN), and total phosphorus (TP) from channel catfish ponds in Alabama.*

| Pond type and kind of effluent | TSS | $BOD_5$ | TN | TP |
|---|---|---|---|---|
| | | Fry fingerlings | | |
| Embankment | | | | |
| Overflow | 65 | 8.8 | 5.0 | 0.54 |
| Drawdown | 922 | 125.8 | 84.3 | 3.34 |
| Final draining | 3,430 | 106.2 | 2.0 | 5.31 |
| Total | 4,417 | 240.8 | 121.3 | 9.19 |
| Watershed | | | | |
| Overflow | 260 | 35.3 | 11.0 | 2.18 |
| Drawdown | 921 | 125.8 | 84.3 | 3.34 |
| Final draining | 3,430 | 106.2 | 32.0 | 5.31 |
| Total | 4,611 | 267.3 | 127.3 | 10.83 |
| | | Food fish | | |
| Embankment | | | | |
| Overflow | 65 | 8.8 | 5.0 | 0.54 |
| Drawdown | 138 | 18.9 | 6.8 | 0.50 |
| Final draining | 229 | 7.1 | 21.3 | 0.35 |
| Total | 432 | 34.8 | 33.1 | 1.39 |
| Watershed | | | | |
| Overflow | 827 | 57.1 | 17.7 | 3.53 |
| Drawdown | 138 | 18.9 | 6.8 | 0.50 |
| Final draining | 229 | 7.1 | 21.3 | 0.35 |
| Total | 1,194 | 83.1 | 45.8 | 4.38 |

TABLE 12. *Estimated annual amounts (metric ton/yr) of total suspended solids (TSS), 5-d biochemical oxygen demand ($BOD_5$), total nitrogen (TN), and total phosphorus (TP) released in effluents from channel catfish ponds in Alabama.*

| Pond type | TSS | $BOD_5$ | TN | TP |
|---|---|---|---|---|
| | | Fry and fingerlings | | |
| Embankment | 1,121 | 61 | 31 | 2.3 |
| Watershed | 3,715 | 215 | 103 | 8.8 |
| Subtotal | 4,836 | 276 | 134 | 11.1 |
| | | Food fish | | |
| Embankment | 927 | 75 | 71 | 3.0 |
| Watershed | 8,112 | 564 | 311 | 29.8 |
| Subtotal | 9,039 | 639 | 382 | 32.8 |
| Total | 13,875 | 915 | 516 | 43.9 |

tion, feed conversion rate, and fish and feed composition (Table 2), 401.7 kg/ha more nitrogen and 73.6 kg/ha more phosphorus were applied to ponds in feed than removed in fish. Fertilization rates for corn (Wood et al. 1999) were only 157 kg/ha nitrogen and 21.8 kg/ha phosphorus. Thus, it is not surprising that catfish ponds produce greater nitrogen and phosphorus loads than cornfields.

The total phosphorus loads were high, but the majority of phosphorus was in particulate form (83% in overflow, 96% in drawdown effluent and final draining effluent). Overflow occurs mostly in the winter and spring during heavy rains and ponds are turbid with suspended soil particles at this time. Thus, most of the phosphorus is apparently associated with soil particles. During drawdown and final draining, most of the phosphorus is thought to be associated with plankton and dead organic matter. Most of the organic nitrogen and 5-d biochemical oxygen demand is probably associated with plankton and dead organic matter.

The estimates for total annual effluent loads from Alabama catfish farming (Table 12) show that fry and fingerling production release about 35% of the total suspended solids, 30% of $BOD_5$, 35% of total nitrogen, and 18% of total phosphorus, but they represent only10.6% of total pond area.

### Other Sources of Suspended Solids

If pond drains are left open in empty ponds, rain falling on pond bottoms and runoff entering ponds from watersheds will cause water to flow across the empty bottom and carry large amounts of suspended solids out the open drains. This process is undesirable because it causes severe erosion of the inside slopes of embankments and shallow areas of the bottom in addition to transporting suspended solids into natural waters. Also, coarse solids tend to settle in deeper areas of ponds and make these areas shallower.

Effluent outfalls also can cause erosion outside of ponds to contribute to suspended solid loads to natural water. The main reasons for erosion at outfalls are the impact of outflowing water against the earthen bottoms and sides of ditches that convey water away from ponds, improperly designed

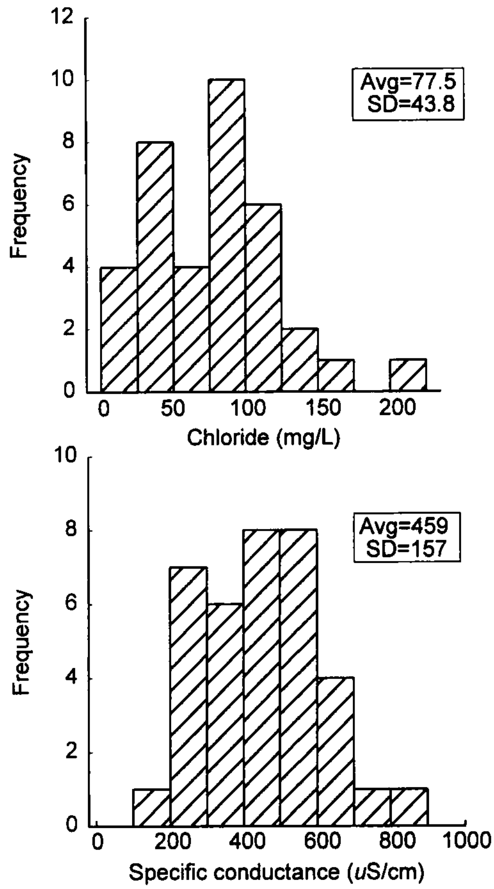


FIGURE 6. *Chloride concentrations and specific conductance in pond waters from 36 ponds on 11 channel catfish farms in an area of west-central Alabama. None of the ponds were filled from wells with salty water.*

ditches subject to scouring by water currents, and erosion of stream banks at points where effluents enter streams. There was no way in this assessment to estimate the amount of suspended solids contributed by the two sources mentioned above. However, erosion of ditches and at outfall points in streams was commonly observed and is thought to be a significant source of suspended solids.

## Specific Conductance and Chloride

Some ponds were supplied with well water of high salinity. Boyd and Brown (1990) found that these wells yielded water with 1,000 to 3,000 mg/L chloride and specific conductance of 2,000 to 6,000 μS/cm. Water samples were collected from 11 channel catfish ponds on three farms using high salinity water from wells. Samples were analyzed for chloride concentration by mercuric nitrate titration to the *s*-diphenylcarbazone endpoint (Boyd and Tucker 1992) and specific conductance was measured with a conductivity meter. Chloride concentrations ranged from 120 to 2,565 mg/L with an average of 637 mg/L (SD = 867 mg/L). The specific conductance ranged from 391 to 6,910 μS/cm with an average of 3,217 μS/cm (SD = 2,732 μS/cm).

Ponds may have nitrite-nitrogen concentrations of 1 to 5 mg/L or more for brief periods. High nitrite concentration can result in severe methemoglobinemia and even mortality in channel catfish (Boyd and Tucker 1998). If chloride concentrations in water are 6 to 10 times greater than nitrite concentrations, nitrite absorption by fish is minimized (Boyd and Tucker 1998). Salt (sodium chloride) is added routinely as a precaution against nitrite toxicity. Samples were collected from 36 ponds on 11 farms without access to high salinity water from wells. The chloride concentrations (Fig. 6) ranged from 2 to 210 mg/L with an average of 78 mg/L (SD = 44 mg/L). Specific conductance values averaged 459 μS/cm (SD = 157 μS/cm) with a range of 183 to 856 μS/cm. Arce and Boyd (1980) found that chloride concentrations averaged 6.8 mg/L (SD = 4.1 mg/L) in watershed ponds filled by runoff in the prairie region of Alabama, and the highest value that they reported was 24 mg/L. Chloride concentrations and specific conductance values (Fig. 6) tend to be higher than natural, ambient levels, but most freshwater organisms can readily tolerate specific conductance values up to 1,500 μS/cm (Boyd 2000). Effluents from salt-treated ponds will not be ecologically hazardous.

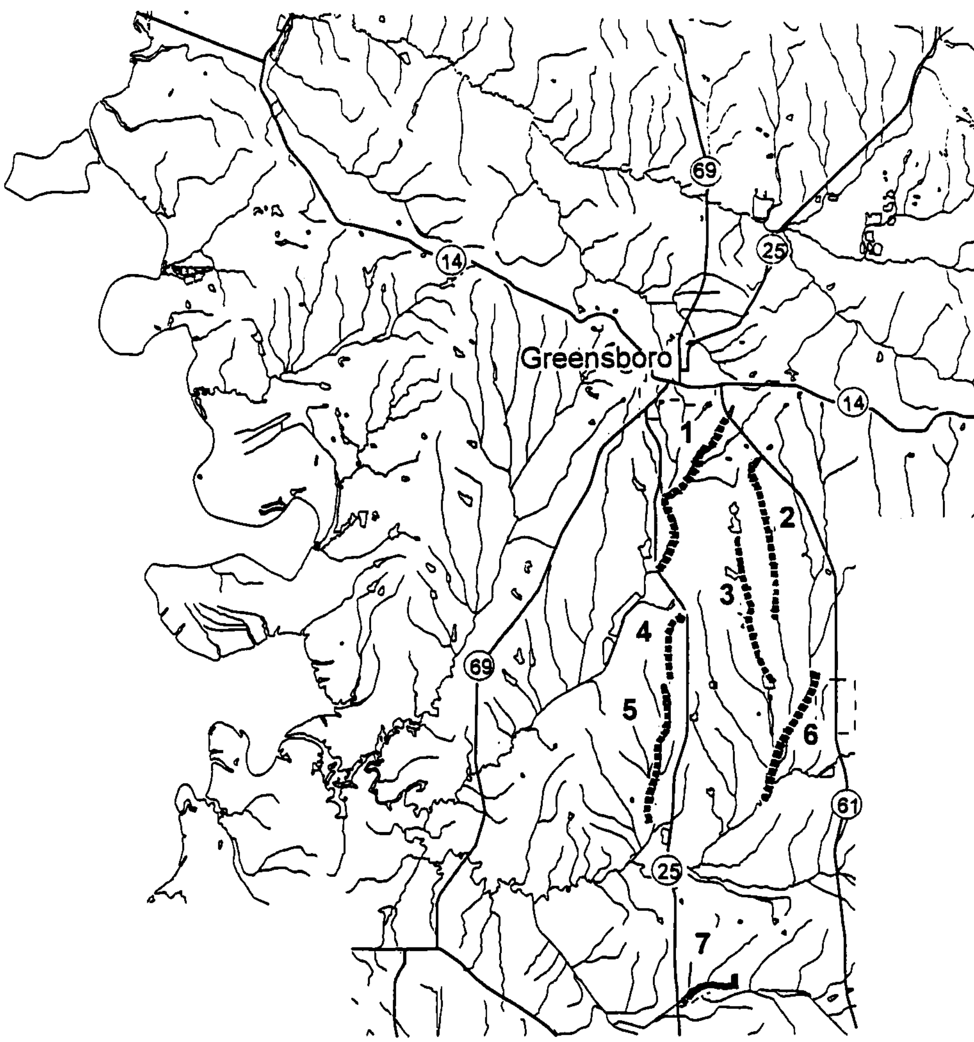


FIGURE 7. *Map showing location of streams in Hale County, Alabama, where water samples were taken above and below channel catfish farming areas. Circled numbers indicate state highway numbers. Uncircled numbers and heavy lines represent streams: 1 = Pick's Creek; 2 = Kaiser Creek; 3 = Rosemary Creek; 4 = Upper Lake Creek; 5 = Lower Lake Creek; 6 = Whitsitt Creek; 7 = Greer Creek.*

## Catfish Farms and Stream Water Quality

Seven streams were selected in Hale County as follows: Kyser Creek, Whitsitt Creek, Rosemary Creek (also called Upper Whitsitt Creek because it finally joins Whitsitt Creek), Pick's Creek, Upper Lake Creek, Lower Lake Creek, and Greer Creek (Fig. 7). For all streams except Lower Lake Creek, there were no catfish farms above the upstream sampling site. There were catfish farms above the upstream sampling site for Lower Lake Creek. One stream, Mud Creek, was sampled in Dallas County near Browns, Alabama. There were no catfish farms above the upstream sampling point.

Water samples were collected from the streams at monthly intervals between July 1997 and August 1998. In a few streams, flow ceased for 1 or 2 mo during the fall,

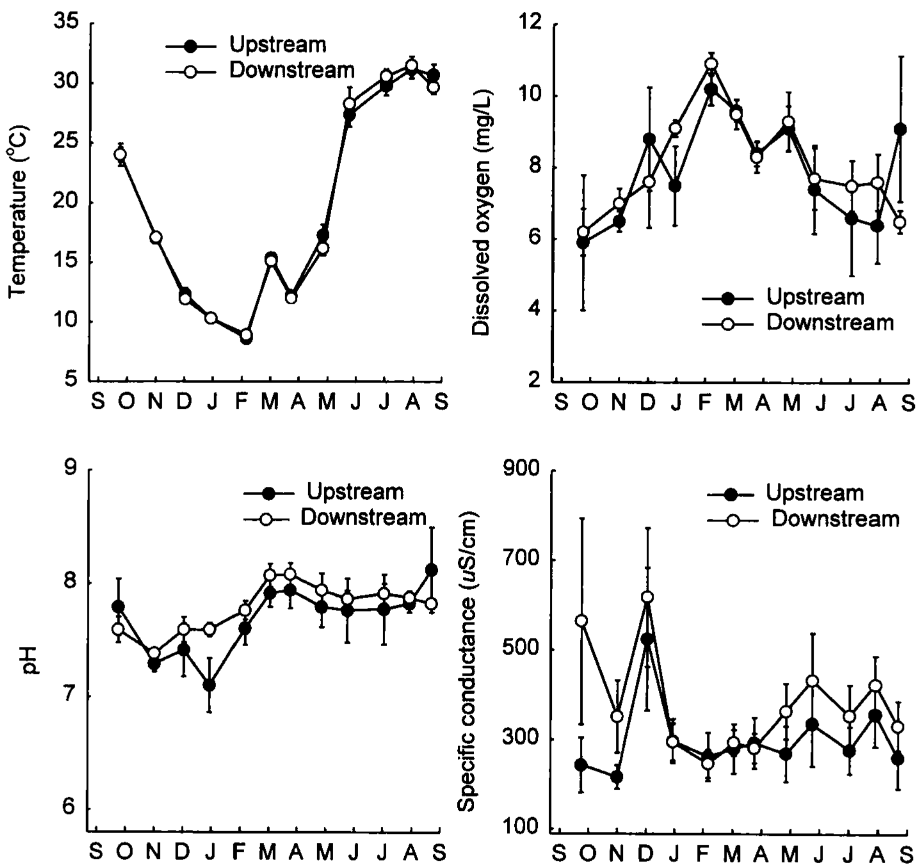


FIGURE 8. *Averages (± SE) for water temperatures and concentrations of dissolved oxygen, pH, and specific conductance in eight streams at points upstream and downstream from catfish farming areas in west-central Alabama.*

and samples could not be collected. Samples were analyzed for turbidity, total suspended solids, soluble reactive phosphorus, total phosphorus, total ammonia-nitrogen, nitrate-nitrogen, total nitrogen, 5-d biochemical oxygen demand, dissolved oxygen, pH, specific conductance, and temperature (Eaton et al. 1995).

The averages for upstream and downstream results are provided in Figs. 8, 9, and 10. Average water temperature was essentially identical between sites upstream and downstream from catfish farms (Fig. 8). The pH was slightly greater downstream of catfish farms than above (Fig. 8), but the average pH was between 7.1 and 8.2 at all sites. Dissolved oxygen concentrations were essentially the same downstream and upstream of catfish farms (Fig. 8), and all average concentrations exceeded 5 mg/L. Specific conductance values tended to be elevated downstream of catfish farms during the drier months (Fig. 8). However, the highest average value was less than 600 μS/cm. The average 5-d biochemical oxygen demand was generally similar between upstream and downstream sites (Fig. 9). However, in June and July 1998, biochemical oxygen demand was greater above catfish farms than below them. In fall 1997, total ammonia nitrogen tended to be higher below farms than above, but the opposite was true in June 1998 (Fig. 10). Except for a single sampling date in September 1997, there was little difference in average nitrate-nitrogen and total nitrogen concentrations

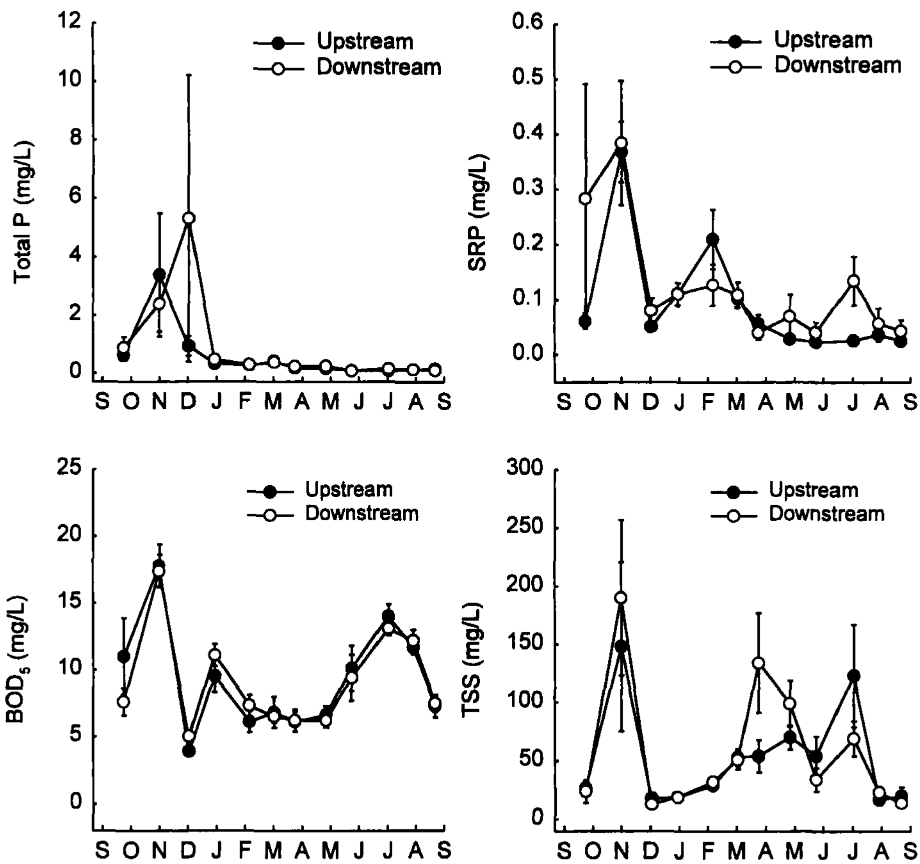


FIGURE 9. *Averages (± SE) for concentrations of total phosphorus (TP), soluble reactive phosphorus (SRP), 5-d biochemical oxygen demand ($BOD_5$), and total suspended solids (TSS) in eight streams at points upstream and downstream from channel catfish farming areas in west-central Alabama.*

between upstream and downstream sites (Fig. 10). There were no clear trends of difference in either soluble reactive phosphorus (Fig. 9) or total phosphorus (Fig. 9) between sites upstream and downstream of catfish farms. Total suspended solids tended to be greater downstream of catfish farms in March and April 1998, but concentrations were higher above catfish farms than below them in June and July 1998 (Fig. 9), and similar trends were observed in turbidity values (Fig. 10).

The small streams into which Alabama catfish farms discharge drain mostly cropland, pastures, and woods, and they do not have especially good quality water. Upstream of catfish farms, 5-d biochemical oxygen demand values usually are above 5 mg/L and concentrations of total suspended solids are often above 50 mg/L after rains.

There were almost an equal number of cases in which water quality variables were higher above catfish farms than below. Furthermore, there were no cases in which extremely high concentrations of variables (or very low dissolved oxygen concentrations) were noted downstream of farms. The findings suggest that catfish farm effluents are not having adverse impacts on stream water quality.

## Water Use

In making the unit overflow estimates (Table 8), it was necessary to compute water additions used to maintain water levels. Thus, it was possible to estimate consump-

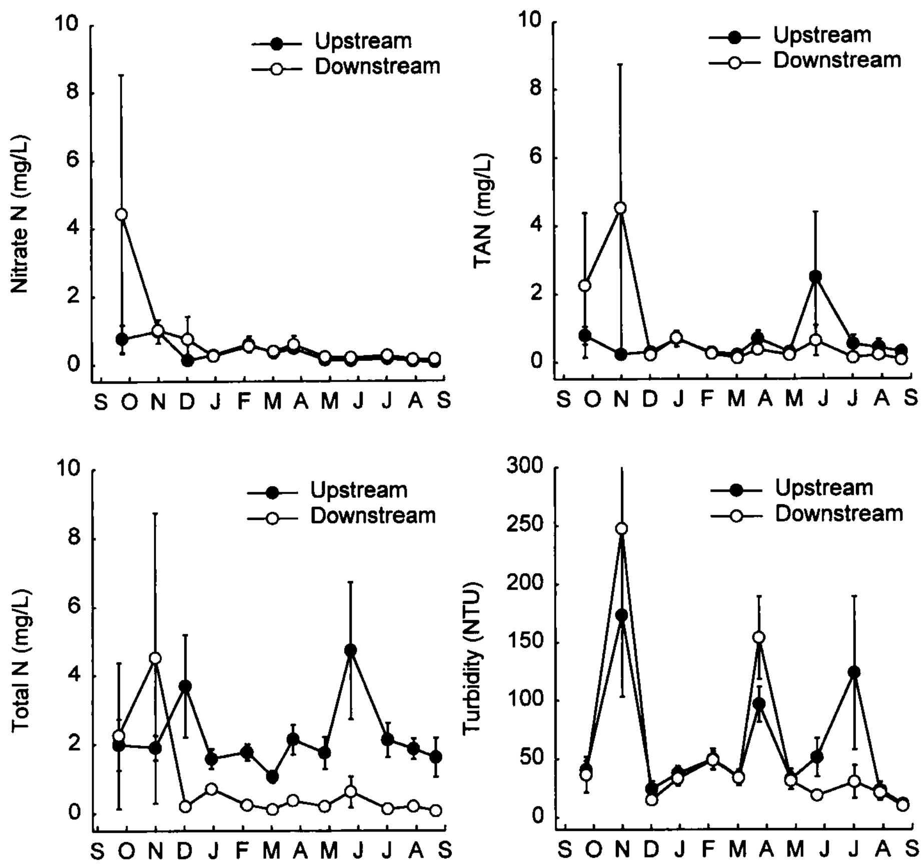


FIGURE 10. *Averages (± SE) for concentrations of nitrate-nitrogen (nitrate N), total ammonia-nitrogen (TAN), total nitrogen (total N), and turbidity in eight streams at points upstream and downstream from channel catfish farming areas in west-central Alabama.*

tion of ground water from wells and surface water from streams (Table 13). Embankment ponds use much more well or stream water per unit area than watershed ponds. Also, in embankment ponds, fry and fingerling production uses about three times as much water as food fish production. On a state-wide basis, catfish farming consumes well and stream water at about 42,000,000 $m^3$/yr, or an average of about 115,000 $m^3$/d. In a 1990–1991 survey of water use in Alabama catfish farming made by the United States Geological Survey, Kidd and Lamberth (1995) placed well and stream water use at 82,500 $m^3$/d. The larger estimate for the 1997–1998 survey is thought to reflect increased water use because of the growth of the industry.

TABLE 13. *Average annual use of water from well and streams ($m^3$/ha) of channel catfish in Alabama.*

| | Filling | Maintaining water-level | Total |
|---|---|---|---|
| | Fry and fingerling | | |
| Embankment | 16,700 | 3,933 | 20,693 |
| Watershed | 0 | 2,866 | 2,866 |
| | Food fish | | |
| Embankment | 2,775 | 3,933 | 6,768 |
| Watershed | 0 | 2,866 | 2,866 |

We could not separate ground water and stream water use in our computations. However, as most farmers in the survey used wells to supply ponds, we assume that mostly well water is used. According to Kidd and Lamberth (1995), about 75% of the water use was from wells and the rest from streams.

## Possible Impacts on Water Quality

The possible impacts of channel catfish farming can be identified from this study, and their probable magnitudes assigned.

### *Nutrients and Oxygen Demand*

All catfish farms ultimately discharge into Alabama streams. However, because water for filling and maintaining levels in ponds is scarce during summer and fall, farmers have adopted techniques that minimize the discharge of water. Other than fry and fingerling ponds that comprise about 11% of the production area, ponds are seldom drained. Thus, most of the nutrients and organic wastes from feeding of fish are assimilated in ponds rather than being discharged to the environment.

Overflow from watershed ponds cannot be prevented, but overflow has relatively low concentrations of potential pollutants, and it is discharged at a time when streams have high flow. Thus, potential pollutants in pond effluents are quickly diluted and transported to larger streams. The stream water quality survey based on samples from above and below outfalls from catfish farms did not reveal deterioration of water quality immediately downstream from farms.

### *Suspended Solids*

Effluents from ponds are relatively high in suspended solids, and additional suspended solids may enter water as a result of erosion of effluent ditches and inflow points into streams. Although we did not observe sedimentation problems or high concentrations of suspended solids or turbidity in steams resulting from catfish pond effluents, the relatively large input of suspended solids appears undesirable and largely preventable.

Removing fry and fingerling production from consideration, loads of total suspended solids did not differ greatly between catfish ponds and corn production, and we assume that soybeans and cotton, the other crops sometimes cultivated in west-central Alabama, would be similar to corn with respect to suspended solids load. Thus, we suspect that the conversion to catfish farming has not increased the suspended solids load to streams.

### *Salinization*

No impact of adding salt to ponds on stream water chloride concentrations could be detected. The amounts added to ponds do not raise chloride concentrations or specific conductance above levels tolerated by freshwater species endemic to the region. The possibility of large, accidental spills of sodium chloride onto the land or into water bodies exists.

Rather high concentrations of chloride and specific conductance were found in ponds supplied by ground waters high in dissolved ions and specific conductance. Nevertheless, this practice is conducted primarily in embankment ponds with little overflow. Food fish production in embankment ponds generates little drawdown effluent. More drawdown effluent is released from watershed ponds for fingerling production. Because few farms have wells with salty water and only a small area of embankment ponds is devoted to fry and fingerling production, significant stream salinization should not result from the use of high-salinity ground water in catfish farming.

### *Dissolved Oxygen*

Overflow from catfish ponds occurs at times of year when pond waters have high concentrations of dissolved oxygen. Ponds are mechanically aerated to prevent low dissolved oxygen concentrations at night, and daytime dissolved oxygen concentrations are high because of high rates of phytoplankton photosynthesis (Boyd and Tucker 1998). Therefore, pond effluents should not cause dilution of stream dissolved oxygen concentrations in the outfall area. Results of the stream survey support this conclusion, and in several cases, dissolved oxygen concentrations were higher downstream from catfish farms than above them.

### *pH*

Because of rapid photosynthesis by phytoplankton, pond water can have pH values of 8.5 to 9.5 in the afternoon. Ponds overflow in the cooler part of the year when phytoplankton is less abundant, and during overflow periods, cloudy weather reduces sunlight and photosynthesis is less than at other times. Thus, the pH of overflow should seldom exceed 8.5 as was true for overflow samples obtained in this study (Fig. 3).

The use of lime in ponds can cause elevated pH. However, farmers are careful not to use too much lime for it can harm the culture species by increasing pH. Water is not released soon after lime application, so liming will not influence stream water.

Occasionally, the pH of drawdown effluent may exceed 8.5, because it may be released during the afternoon when photosynthesis is proceeding rapidly. However, there is no evidence from the stream survey that high pH will be problematic in streams receiving catfish pond effluent.

### *Toxic Chemicals*

There is little use of chemicals in channel catfish farming. The most commonly used chemicals, lime and fertilizers, are not toxic at the concentrations used in catfish farming. The most common chemical used other than lime and fertilizers is copper sulfate for algal control. Copper sulfate can be toxic to fish at high concentration, and to prevent fish toxicity, it is applied at a dose equal to the total alkalinity (in mg/L) × 0.01 (Boyd and Tucker 1998). Copper from copper sulfate has a short residence time in pond water, because it quickly precipitates as copper oxide (Masuda and Boyd 1993). Thus, effluents from ponds will not have high concentration of copper, and there should be no impact of copper on stream biota. Of course, copper will accumulate in pond sediments (Masuda and Boyd 1993).

Rotenone and formalin occasionally are used in ponds, but these compounds degrade quickly and should not be present in pond effluent.

### *Fuels and Oils*

Mechanical aerators and pumps are operated by electricity so fuel and oils are not used and stored around ponds. There is always the possibility of accidental spills when fueling or lubricating tractors and other equipment. However, fish farming presents no greater danger of fuel and oil spill than does any other type of mechanized agriculture.

### *Erosion and Sediment*

Considerable erosion was observed in ditches for conveying effluents and at outfalls from pipes emptying into ditches or directly into streams. Rainfall erosion can be considerable in the bottoms of empty ponds, and if drains are left open, solids will be suspended and exported from ponds. Earthwork without vegetation is also a major source of suspended solids after rains.

Ponds are renovated after 15 to 20 yr by moving sediment from the bottoms of ponds and using it to repair erosion damage to embankments or dams. It is not necessary to dispose of sediment outside of ponds, because it is needed for the repairs. The work must be done in the dry season, so if drains are closed during the work, little turbid runoff will result even if a rainstorm occurs.

### *Effects on Biodiversity*

Catfish farmers use broodstock and fry and fingerling that are produced on catfish farms. Therefore, they do not deplete native fish stocks for use in aquaculture. Channel catfish is a native species, and its escape into streams in the area is of no ecological consequence. Effluents do not cause severe water pollution and associated water pollution in streams, so they should not negatively impact biodiversity. Of course, some local impact on the biodiversity of stream benthos may occur in the areas of effluent outfalls as a result of sedimentation, erosion, or both.

## Resource Use

Channel catfish farming requires resources that include land, water, fertilizers, feed, energy, and labor. One of the general criticisms of aquaculture is that it does not make efficient use of resources in relation to animal protein production (Goldberg and Triplett 1997; Naylor et al. 2000).

### *Land*

Traditional agriculture such as cotton, soybeans, corn, and cattle has not been very profitable in west-central Alabama in recent years. The agricultural and general economy of the region is depressed, and much traditional agricultural land is not in production. Therefore, conversion of pasture and crop land to ponds for catfish is not causing competition for land use. The area is sparsely populated and installation of ponds in the landscape has not resulted in conflicts among different resource users. The presence of ponds is not causing ecological degradation. Ponds are located mainly on former pasture land, and wooded areas are not being cleared to make ponds.

### *Water*

Most of the water used in ponds comes from storm runoff. The runoff is captured in ponds. Once ponds are full, runoff simply flows through ponds to streams. Ponds do not significantly reduce the annual runoff from watersheds, but they do tend to dampen runoff peaks. Water will be released to streams more gradually from watersheds with ponds than from those without ponds (Yoo and Boyd 1994). Thus, catfish ponds reduce peak flows in streams and reduce the incidence of stream overflow onto flood plains in rainy weather.

Some ground water from wells is applied to ponds. However, it is doubtful that catfish farming in Alabama causes a net withdrawal of ground water with reduction in average water table depth. Water seeps under pond dams and embankments and through pond bottoms. Using an average estimated net seepage rate of 0.15 cm/d and assuming that 70% of the seepage is downward through the pond bottom, the return of pond water to ground water aquifers would be 38,325,000 $m^3$/yr. The use of ground water from wells is about 31,500,000 $m^3$/yr. Thus, ponds probably more than replace the water withdrawn by wells. Likewise, water seeping under dams or embankments enters streams to replace water removed from streams for use in ponds.

Phosphorus in water seeping through pond bottoms is mostly adsorbed by the soil, nitrate is lost by denitrification, and some ammonium is adsorbed by cation exchange sites in soil (Boyd and Tucker 1998). Particulate organic matter will be filtered from the water by the soil. Toxic chemicals with long residual lives are not used in catfish ponds. Thus, seepage from catfish ponds does not pose a ground water pollution threat.

### *Fertilizers and Feeds*

Based on the survey, fry and fingerling producers used up to three applications per year of 5 to 10 kg N and $P_2O_5$/ha in fertilizer, and about 12% of food fish producers used up to two applications of fertilizer at similar N and $P_2O_5$ rates. Expanded statewide, about 35 metric tons/yr of N and $P_2O_5$ are used for fry and fingerling production, and 24 metric tons/yr of N and $P_2O_5$ are used in food fish production. This is about 5.9 kg N and $P_2O_5$/ha per yr for the entire production area. Thus, the catfish industry is not a large consumer of fertilizers. Food fish production was reported as about 41,000 metric tons in 1997 (Anonymous 1998), so only 1.4 kg of N and of $P_2O_5$ are applied in fertilizer per metric ton of fish production.

Because the food fish producers in the survey exceeded the industry average for production, we assumed that the fry and fingerling producers surveyed did likewise. Fry and fingerling production in Alabama probably averages about 1,800 kg/ha per yr and average food fish production is roughly 4,600 kg/ha per yr (Anonymous 1998). Assuming FCR values of 2.0 for fry and fingerling and 1.88 for food fish, feed use should be around 3,820 metric tons/yr for fry and fingerlings and 77,300 metric tons/yr for food fish or a total of about 81,120 metric tons/yr. However, most of the protein in catfish feeds comes from plant meals, and only 3% of the weight of feed used is fish meal (Boyd and Tucker 1995). Therefore, about 2,400 metric tons of fish meal are used in feeds for food fish in Alabama. The dress-out percentage for catfish is 62% of live weight, thus for each metric ton of fish meal in feed, about 10 metric tons of dressed catfish are placed in the market for human consumption. The allegation that aquaculture uses more fish meal for feed than it produces animal protein for human consumption (Goldberg and Triplett 1997) is not true for channel catfish farming.

*Energy*

Electricity is the primary source of energy for pumping water and operating mechanical aerators. Aggregate water use from wells was estimated at 86,000 $m^3$/d or about 60 $m^3$/sec. The equation for pump horsepower is:

$$P = \frac{\gamma Q H}{E} \qquad (13)$$

where P = power by pump, $\gamma$ = specific weight of water (9.81 kW/$m^3$), Q = discharge ($m^3$/sec), H = pumping head (m), and E = pump and drive efficiency (decimal fraction).

Assuming that the average well discharges 1 $m^3$/min (0.017 $m^3$/sec), has a pumping head of 100 m, and a combined pump and drive efficiency of 65%, solution of Equation 13 gives a value of 25.66 kW. The entire industry uses 86,000 $m^3$/d, so the power requirement is 1,502 kW/d or about 36,000 kW·h of electricity per day (13,140,000 kW·h/yr).

The survey suggested that aeration is applied at about 2.5 kW/ha, and Boyd and Tucker (1995) estimated that aerators were operated up to 8 h/d for 4 mo/yr (960 h/yr). The energy use would be about 2,400 kW·h/ha per yr or 24,000,000 kW·h/yr for the entire industry.

The combined use of electrical energy for pumping and aeration is around 37,140,000 kW·h, or 0.90 kW·h/kg production. This is a very low input of electrical energy in terms of production. Of course, there are additional energy inputs for use of other machinery on catfish farms, but it does not appear that catfish farming is wasteful of energy inputs when compared to the production of food by the industry.

*Labor*

Catfish farming in Alabama is highly mechanized and well organized. Most farms are family-operated, and relatively few employees are necessary. However, if feed manufacturing, production, harvesting, processing, and other support services are included, about 2,500 jobs result (Anonymous 1998).

## Better Management Practices

Evaluation of the production practices and environmental status of channel catfish farming in Alabama revealed that the industry generally uses good production practices and does not cause widespread, negative environmental impacts. It is not possible to operate channel catfish ponds with current technology and not have effluent. Farmers must discharge water occasionally to repair ponds, and overflow occurs after rain storms. Water reuse could reduce the amount of discharge when ponds must be drawn down, but this practice represents an additional expense because farmers would need to purchase and operate pumps to transfer water. On a few farms there is space to construct settling basins, or a natural wetland is available for treating effluents. However, on most farms, an existing pond would have to be used as a settling basin. Renovation of the farm infrastructure to permit the use of existing ponds as settling basins also would be expensive and pumping costs would be incurred.

The industry releases little water other than storm overflow, and the major water quality concern is high concentrations of total suspended solids. Because the source of these solids is primarily erosion, it should be possible to greatly reduce total suspended solids concentrations through erosion control techniques.

The use of standard NPDES permits with the requirement of water quality monitoring to verify compliance would be very difficult and expensive because of the large number of outfalls associated with catfish farming. The installation of management practices to prevent environmental effects could be an alternative to NPDES permits and an effective means of improving environmental management for the Alabama catfish industry.

A list of better management practices that could make farm operations more efficient and provide environmental protection will be provided. Some farmers are currently using many of these practices, but widespread adoption of good management procedures is desirable.

(1) Establish grass cover on denuded areas of pond watersheds to minimize erosion.
(2) Provide grass cover on the interior and exterior of pond embankments to minimize erosion.
(3) Divert excess runoff from large watersheds away from ponds to minimize total suspended solids input to ponds.
(4) Use stocking and feeding rates that do not lead to excessive phytoplankton blooms and serious water quality deterioration within ponds.
(5) Avoid feeding more than the fish will eat in order to prevent accumulation of uneaten feed in ponds.
(6) Use fertilizers only if necessary to promote plankton blooms.
(7) Maintain storage capacity in ponds to capture rainfall and runoff and minimize the necessity to add water from wells.
(8) Avoid deep-water discharge structures in ponds because surface waters usually are of higher quality than deeper waters.
(9) Position mechanical aerators to minimize erosion of pond bottoms and embankments, but use adequate aeration to prevent low dissolved oxygen concentrations.
(10) Avoid discharging water during final seining, and when ponds are completely drained, release the final volume of water as slowly as possible to minimize discharge of potential pollutants.
(11) Where possible, construct check dams in farm ditches to retain discharge and allow solids to settle.
(12) Do not leave ponds empty in winter, and shut valves when ponds are empty to prevent discharge of suspended solids after rains.
(13) Close pond valves when renovating inside earthwork to prevent discharge of suspended solids after rains and to conserve water.
(14) Use sediment removed from pond bottoms to repair earthwork rather than disposing of it outside of ponds to reduce potential erosion from the farm.
(15) Extend drain pipes beyond toes of embankments to prevent erosion of the embankment by discharge.
(16) Construct ditches with adequate hydraulic cross sections and side slopes to minimize erosion, and establish grass cover in ditches.
(17) Install concrete structures or rip-rap to protect areas subject to erosion by rapidly flowing discharge.

(18) Extend pipes that discharge directly into streams to prevent bank erosion.
(19) Where possible, release pond effluents into natural wetlands to take advantage of natural water treatment.
(20) Store materials such as fertilizers, lime, salt, and other pond amendments so that they are not washed into streams by rainfall.

## Conclusions

The catfish farming system developed over the past three decades in Alabama is water efficient. Most ponds are supplied by storm runoff, and ground water removed by wells to maintain water levels in dry weather is replaced by seepage from ponds. Other than overflow after heavy rains, little water is intentionally discharged from ponds. Water conservation is necessary to prevent loss of production time because ponds drained during warm months will not refill until the following winter.

Pond effluents do not have extremely high concentrations of pollutants, and the variable that appears most problematic is total suspended solids. Some farms fill ponds with water from an aquifer of high salinity. This is a localized practice, and little overflow occurs. The normal use of sodium chloride in ponds does not result in sufficiently high concentrations to pose the threat of stream salinization by pond effluents. None of the other chemicals, i.e., fertilizers, lime, copper sulfate, rotenone, formalin, and herbicides, represent a significant ecological hazard provided that they are stored, handled, and applied properly. There is no evidence of large impacts of channel catfish pond effluents on the water quality immediately below outfalls in eight streams monitored during this assessment.

Catfish farming in Alabama appears to be highly beneficial to local economics and environmentally responsible. The ratio of resource use to food production is quite favorable. In summary, channel catfish farming does not appear to be harmful to the environment and is conservative of land, water, feed protein, energy, and other resources. However, management practices should be implemented to reduce the amount of suspended solids lost from farms in effluents and erosion, and to assure that each individual farm operates in as environmental-responsible manner as the industry in general.

## Acknowledgments

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## Appendix—Catfish Farm Survey

### *Information Requests and Observations*

*General*

Date/Owner/Location

Farm area/water surface area/watershed area

Watershed: activities/topography/soils/cover/erosion

Wells: number/size/access to salty ground water

*Fry and fingerling production*

Type and area of ponds

Production practices: stocking rates/feeding rates/use of fertilizers, lime, and other chemicals/amount and type of aeration

Harvest method

Production: harvest weight/feed conversion ratio

*Food fish production*

Type and area of ponds

Production practices: stocking rates/feeding rates/use of fertilizers, lime, and other chemicals/amount and types of aeration

Harvest method

Production: harvest weight/feed conversion ratio

*Condition of earthwork*

Embankments: presence of cover/evidence of erosion by rainfall
Evidence of erosion by aerators
Evidence of sedimentation within ponds

*Effluents*

Normal time for draining (month)
Draining time to empty ponds (days)
Frequency of partial drawdown/complete draining
Months with overflow
Number of discharge points on farm
Type of discharge structure (trickle tube or pipe)
Type of receiving water body
Description of discharge (into ditch, onto land, into wetland, directly into stream, etc.)
Observation on erosion at effluent outfalls
Evidence of erosion prevention devices
Evidence of sedimentation around outfalls

*Specific Questions*

Is water exchange used?
Could water be conserved by transfer to other ponds?
Could water be discharged through a settling basin?
Could water be applied to pasture or crops?
Is it necessary to completely drain ponds for reworking levees?
Is it necessary to remove sediment at intervals of several years?
Is sediment disposed of in repairing levees or put outside ponds?
What chemicals do you use in pond management?
Do you anticipate building more ponds in the future? How many hectares?
Do you use medicated feed?
Do you use other species with catfish?