USE OF CONSTRUCTED WETLANDS TO IMPROVE WATER QUALITY IN FINFISH POND CULTURE

FINAL REPORT

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ABSTRACT

Use of constructed wetlands in finfish pond culture water recirculation was studied to evaluate their effectiveness in improving water quality, determine optimal design and operating criteria and assess the associated benefits and costs in finfish pond production. The initial experiment was conducted at the MSU-Coastal Aquaculture Unit using 12 six-year-old quarter-acre ponds and nine newly constructed wetlands. The experimental design used in this experiment was as follows: three control ponds (no wetlands), three ponds with standard wetlands (25% of pond size and 2-day retention time), one pond each with standard wetland size and variable retention time (0.5, 1 and 3 days) and one pond each with standard retention time (2 days) and variable wetland size (15, 35 and 50%). Channel catfish (*Ictalurus punctatus*) fingerlings were stocked at a rate of 5,000 fish per acre in December 1993 and raised for one year. Wetlands were planted in September 1993 with a combination of soft rush (*Juncus effusus*) and duck potato (*Sagittaria lancifolia*). Substantial improvements and lesser variations in many water quality variables were observed among ponds with standard wetlands as compared to control ponds. Significant differences in many water quality variables were also noted among ponds with variable wetlands sizes and retention times. Due to the relatively young age and incomplete vegetative coverage in constructed wetlands, there were no definitive trends in the effects of wetland sizes and retention times on water quality. At this stage of determining the effectiveness of using constructed wetlands in finfish pond production, the significant improvements in pond water quality did not lead to significantly observable benefits, namely: higher yields and lesser incidence of off-flavor. Marked differences, however, were observed in pond aeration time and wetland pumping time. The application of the initial experimental results to a 48-acre commercial catfish farming enterprise in the Mississippi Black Belt indicated that the observed additional costs more than offset any limited economic benefits derived. Total revenues from the catfish enterprise with or without constructed wetlands remained at $174,720 per year, $3,640 per production acre or $0.70 per pound harvested. Annual specified costs for the catfish enterprise without constructed wetlands amounted to $146,912 per year, averaging $3,060 per production acre or $0.59 per pound harvested. When constructed wetlands were added to the catfish enterprise, total costs rose by $18,930 annually, $394 per production acre or $0.075 per pound harvested. With the additional costs arising from the use of constructed wetlands, average yield needs to increase by eight percent or 417 pounds per production acre in order for the catfish enterprise to recover the added specified costs amounting to $292 per production acre. As the documentation of the effectiveness of marsh systems in reducing water quality problems progresses, future work could take several directions. First, changes in marsh system function with age need to be evaluated. Second, there is a need to evaluate the potential of improving yields of marketable fish through increased stocking densities. Third, there is a need to investigate the culture of more economically valuable and environmentally sensitive finfish species in order to convert marked improvements in water quality into higher yields and revenues. Fourth, cheaper methods of creating vegetative cover in constructed wetlands need to be evaluated. Finally, it would be desirable to conduct pilot tests of this new technology in commercial scale operations in cooperation with the fish farming industry.

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I. INTRODUCTION

Water quality is a primary concern for the pond culture of all finfish species. Parameters such as dissolved oxygen, ammonia, nitrite concentrations and turbidity limit stocking densities and production capabilities, contribute to off-flavor problems, and increase risks of mortality and disease. With over 472 million pounds of catfish harvested for processing (USDA, 1997a) from over 167,000 water surface acres in the U.S. (USDA, 1997b), the economic consequences of fish loss and off-flavor to the industry can be very significant. For off-flavor alone, the social welfare costs is estimated at about 12 percent of industry revenues (Kinnucan et al., 1988).

Three principal water quality problems occur in fish culture ponds: 1) excessive phytoplankton production, 2) low dissolved oxygen, and 3) toxic metabolite accumulation (Kleinholz, 1987). Poor water quality often leads to health problems in stocked fish including parasite incidence, bacterial incidence, fungal infections, nitrite toxicity and ammonia toxicity. Methods commonly used in the finfish pond culture industry to treat the causes and effects of poor water quality include water exchange, aeration, and application of chemicals. There are significant production costs associated with these treatment methods as well as environmental impacts. The estimated costs of annual chemical requirements for various size fish farms in the Mississippi Delta range from $15 to $61 thousand per farm, while fuel costs for aeration and pumping range from $16 to $66 thousand annually per farm (Keenum and Waldrop, 1988). Posadas and Dillard (1997) estimated that in the Mississippi Black Belt Area, the annual costs of chemicals and electricity for aeration for a 48-acre catfish farm were $3,000 and $6,000 per farm, respectively. In the case of water exchange, however, the efficacy of this practice has been questioned. A study of fish culture ponds in Israel showed that despite the high rate of water exchange (five to 10 times the pond volume a day), high concentrations of metabolites and low concentrations of oxygen were occasionally detected (Rijn and Shilo, 1989). This study demonstrated the necessity for a biological breakdown of accumulating organic matter, together with the biological transformation of metabolites.

From the standpoint of environmental impact, fish farm effluents are currently being closely scrutinized as non-point pollution sources and for possible inclusion in the National Pollutant Discharge Elimination System (NPDES) Wastewater Permit process. In Mississippi, a permit is not required unless the fish farm discharges wastes at least 30 days per year and has an annual production exceeding 100 thousand pounds of aquatic animals. Permits are also required for groundwater use, and in some cases, surface water diversion (McLaughlin et al., 1992). Mississippi law closely mirrors the regulatory framework of other states where fish culture activities exist. Use of groundwater and surface water for water exchange in fish ponds is constrained in many areas of the country due to limits on water supplies. More stringent regulations on pond effluents may improve water quality, but the added cost may raise the price of pond-raised fish relative to other products.

There is, therefore, a need for new cost-effective, environmentally-compatible techniques to reduce the effects of water quality degradation in pond culture systems as well as reducing the impact of nutrient release into the environment. Research activities to develop technology to improve water quality are typically beyond the capability of producers operating on small profit margins. Assuming that constructed marsh systems are effective in reducing water quality problems and associated risks to production, the added costs associated with their construction and operation must be compared with the benefits in avoiding crop loss, disease, or off-flavor. Under the current regulatory scheme concerning fish farm effluents, pond culturists faced with marginal profit margins most likely would not voluntarily adopt this technology solely for the purpose of environmental protection.

The general goal of this project was to evaluate the use of constructed wetlands in improving water quality and assess the associated benefits and costs in finfish pond production. Specifically, this project aimed to achieve the following objectives:

1) to evaluate the effectiveness of constructed marsh systems toward improving water quality in aquaculture ponds and the concomitant reductions in risk of crop loss, incidence of off-flavor and release of nutrient-laden effluent into the environment, and improvements in fish growth rate and food conversion;
2) to determine optimal design and operating criteria for constructed marsh systems used in pond culture;
3) to document the costs versus benefits of using this technology in pond culture; and
4) to provide information and technology transfer to the pond culture industry.

II. MATERIALS AND METHODS

The experiments were conducted in 12 of the 26 production ponds (approximately 0.25 water surface acres each) at the Mississippi State University-Coastal Aquaculture Unit (MSU-CAU) located at Mississippi Power Company's Plant Watson power generating station in Gulfport, Mississippi. Each pond is about 125 ft long, 85 ft wide and 6 ft deep. Six of the ponds were used in a replicated fashion to evaluate the effectiveness of constructed marshes toward improving water quality while the remaining six ponds were used in a range testing fashion to determine optimal wetland design criteria and operation parameters.

Experimental Design.

The 12 ponds used in the study were randomly assigned to four sets of three ponds in the following experimental design:

Wetland Effectiveness:

- Set A: Control Ponds (no marsh, simulated water flow).
- Set B: Treatment Ponds (with marshes of a "standard" size and flow rate).

Optimal Design/Operation:

- Set C: Wetland Size Variations [three variations of relative marsh to pond size (not including the "standard" size), using the "standard" flow rate].
- Set D: Wetland Flow Rate Variations [three variations of the flow rate through the marsh (not including the "standard" flow rate), using the "standard" marsh size].

Wetland Design and Construction

For the purposes of this study, and as a starting point for evaluating these marsh systems, the "standard" marsh size and flow rate were chosen based on reasonable ratios of pond to marsh size, rates of flow and retention times reported for similar systems, and factors relating to expected logistics and costs of installing and operating such a system. The standard marsh size was set as 25% of the surface area of the pond (Figure 1), with the length set equal to the pond margin along which it is located (85 ft). For the size variation portion of the study, the width was adjusted to achieve the following marsh/pond ratios:

Small:	15% or 12.75 ft,
Standard:	25% or 21.25 ft,
Large:	35% or 29.75 ft,
Extra large:	50% or 42.50 ft.

The choice of a standard flow rate and the experimental rates were based on a combination of reported values of water exchange in fish culture ponds and estimates of retention time of water through wetlands used to treat municipal and agricultural wastes (Hammer et al., 1989). Water exchange rates through fish ponds were reported to range from two to 40% per day, with an average rate of approximately eight to 10% per day (Boyd, 1990). Current studies of wetlands used for treatment of wastewater report retention times between three and 14 days. The standard flow rate (and associated retention time) chosen for use in the present study reflects the differences between pollutant loads in pond culture systems as compared to sewage and animal waste treatment (i.e., lower levels). For example, total ammonia nitrogen concentrations (TAN) in livestock lagoon effluent are typically on the order of 300 - 500 mg/L (Hammer et al., 1989) while TAN averages 1 mg/L in fish ponds during peak periods (Boyd, 1990). The proposed standard flow rate is 6.5 gal/min which, based on the volume of the standard marsh system, equates to an exchange rate of 3% of the pond volume per day and a retention time of two days. Flow rate, retention time or exchange rate levels for the rate variation portion of the study included the following:

Slow:	3.25 gal/min, 3 day retention or 1.5% exchange rate,
Regular:	6.5 gal/min, 2 day retention or 3% exchange rate,
Fast:	13 gal/min, 1 day retention or 6.25% exchange rate,
Very fast:	26 gal/min, 0.5 day retention or 12.5% exchange rate.

Marshes were constructed by raising a 3-4 ft high levee around the specified area to achieve the desired size. Water was gravity fed from the pond into the marsh and returned to the pond via a sump pump. To facilitate circulation, water was drawn from the pond via a 2 to 3-inch diameter PVC pipe placed approximately halfway across the width of the pond, approximately 5-10 ft from the pond edge, and positioned 1 ft off the pond bottom. Water was siphoned into the intake side of the marsh across the top of the pond levee and into a 2 to 3-inch diameter PVC pipe positioned across the width of the marsh. Water flowed from the center of this pipe in both directions through a series of holes drilled along its length in order to distribute the flow across the entire width of the marsh. Flow rate was set by altering the size of an orifice drilled into an end cap placed on the feeder pipe. A sump (55-gal) and sump pump (a to ½ HP) on the discharge side of the marsh distributed water back into the pond through a 2 to 3-inch diameter pipe that was laid out in a similar manner as that of the intake pipe. The pump was set to maintain water level in the marsh at the design depth of 1 ft, which allowed for adequate growth of the target plant species.

Each marsh system was planted with a combination (50/50) of two plant species: soft rush (*Juncus effusus*) and duck potato (*Sagittaria lancifolia*) in September 1993. Both species are readily available through commercial nurseries and are indigenous to the southeast. *Juncus effusus* is an evergreen and was chosen to reduce winter dormancy effects. Plants were planted on 1-ft centers. Each individual plant was at least 12 inches tall during planting.

Control ponds were fitted with influent and effluent pipes with water pumped through an interconnecting pipe run along the levee. This arrangement simulated the water flow conditions of those ponds with marshes, without the actual marsh. This should control for any variations due solely to water circulation by the pumping systems.

Fish Species, Stocking Density, Feeds and Feeding

Seven-inch channel catfish (*Ictalurus punctatus*) fingerlings were stocked in the ponds at a density of 5,000 fish per acre or 1,250 fish per pond in December 1993. Due to the shortage of 7-inch fingerlings from the initial source, 4-inch fingerlings were stocked in the other nine treatment ponds. The stocking size (in pounds per thousand fingerlings) in control and treatment ponds were as follows:

Control ponds without wetlands: 19.8.
Ponds with variable wetland sizes and constant retention time:
- 15% & 2 days: 48.2,
- 25% & 2 days: 18.6,
- 35% & 2 days: 21.3,
- 50% & 2 days: 40.7.

Ponds with variable wetland retention time and fixed wetland size:
- 3 days & 25%: 18.4,
- 2 days & 25%: 18.6,
- 1 day & 25%: 23.8,
- 0.5 day & 25%: 43.7.

The catfish fingerlings were raised to marketable size for about 12 months according to accepted industry practices. Both floating (32% protein) and sinking catfish feeds (25% protein) were used during the experiment. Sinking feeds were used when large populations of sea gulls were observed near the vicinity of the ponds. The fish were fed on a daily basis except during winter months and bad weather. Limited feeding was undertaken during the winter months. Daily feed rations were adjusted weekly depending on the temperature and estimated fish biomass in each pond. The same feeding rate as recommended by Robinson (1991) was applied to all experimental ponds.

Monitoring

Water quality parameters were monitored on both daily and weekly schedules and included factors assessed as part of standard pond management practice (e.g., dissolved oxygen, temperature, pH, total ammonia nitrogen, nitrite) as well as additional factors (e.g., nitrate and phosphorous) and parameters (e.g., total suspended solids, chlorophyll *a* concentration) that were needed for a more detailed assessment of nutrient removal. Dissolved oxygen and temperature were measured twice per day (early morning, mid-afternoon). Salinity, pH, total ammonia, nitrate, nitrite, phosphorus, total suspended solids, and photosynthetic pigments (chlorophyll *a* and phaeophytin) were measured on a weekly basis.

All measurements and water samples were taken from three locations in each pond/marsh system. A "pond" sample, that should reflect the general water quality condition of each pond, was taken near the pond edge at a point midway between the effluent and influent pipes for the marsh and on the opposite bank from the marsh. Samples were also be taken at the points where water enters (distribution pipe) and leaves (sump) the marsh in order to assess the level of water quality improvement by the marsh itself. The pond sample served as a measure of the effect of the marsh on overall pond water quality. Only the pond water sample was taken in control ponds. Water quality parameters were measured using a combination of meters and standard analytical testing procedures (APHA, 1989).

The monthly growth of fish was monitored during the months of June, July and August 1993. Samples of 30 fish per pond were collected every other 28 days by using cast nets and other methods including seines, traps, and hook and line. The standard length and wet width of each fish was individually measured. The monthly sampling was stopped after August 1993 primarily due to the problems encountered in the collection of fish samples. The final samples were taken during harvest time.

The testing for off-flavor was conducted by Delta Pride, Inc., a large catfish processing firm located in Indianola, Mississippi. Samples of three fish from each pond were collected during the first week of December 1994. The fish samples were delivered to Delta Pride in whole and fresh form the following day the fish were harvested. The flavor scale used by the processing plant was from 0 to 4, where 0 is on flavor and 4 is worst off-flavor.

Each pond/marsh system was metered for electric power consumption. Individual weekly readings of electric consumption of each pond were recorded. Water flow rates were monitored weekly both at the influent and effluent ends of the marsh cells to account for variances in seepage and evapotranspiration throughout the production cycle. Checking and cleaning of the inlet and outlet pipes were conducted on a weekly basis.

III. EFFECTS OF CONSTRUCTED WETLANDS ON POND WATER QUALITY

The effects of using constructed wetlands on pond water quality were evaluated by comparing the weekly values of selected variables in control ponds versus ponds with standard wetland size and retention time. Improvements in water quality were also examined among ponds with variable wetland sizes and variable retention times. It was assumed that the effects of water temperature, rainfall, bird predation, and other extraneous environmental factors on pond water quality were similar among control and treatment ponds.

Dissolved Oxygen

The optimal range of dissolved oxygen (DO) for catfish pond culture is between 5 to 15 ppm (Tucker and Boyd, 1985; Boyd and Frobish, 1990). At concentrations below 4 ppm, fish may survive but slow growth occurs when exposed for prolonged periods, while the lethal level is about 1 ppm (Boyd and Frobish, 1990; Wellborn, 1987). In order to maintain the optimal range, daily DO concentrations in each pond were monitored three times during summer months (dawn, morning, afternoon) and twice (morning, afternoon) during cooler months. When the DO level in a pond was expected to fall below the optimal range, the 1-hp electric aerator was turned on until such time when the DO level reached the desired range.

The DO levels in the control and standard ponds varied significantly during most of the entire duration of the experiment (Table 1). During spring months, morning DO readings in ponds with standard wetlands were significantly lower than those in control ponds. Although the afternoon readings varied significantly between control and standard ponds, DO levels were within the optimal range. Eventually, more aeration time was used by control ponds than standard ponds.

During summer months, the morning DO levels reached critical levels in both control and standard ponds. The afternoon DO concentrations were within the optimal range during this period despite the significant variations observed between control and standard ponds. Similar use of aeration equipment was recorded in both control ponds and standard ponds.

In fall, the morning DO levels were also within critical levels in both control ponds and ponds with standard wetlands. Optimal DO values were recorded in the afternoon during these period despite the significant variations observed between control and standard ponds. Significantly higher daily use of aeration equipment was recorded in control ponds than in standard ponds.

Among ponds with variable wetland sizes, significant variations were observed in both morning and afternoon dissolved oxygen readings between late March to December (Table 9). Similar results were observed in ponds with variable retention times (Table 17). The average morning and afternoon DO readings (in parts per million), respectively, in the ponds for the entire duration of the experiment were as follows:

Control ponds without wetlands: 6.2, 9.4,
Ponds with variable wetland sizes and constant retention time:
- 15% & 2 days: 5.8, 8.2,
- 25% & 2 days: 6.1, 8.5,
- 35% & 2 days: 5.9, 8.1,
- 50% & 2 days: 6.2, 7.9.

Ponds with variable wetland retention times and fixed wetland size:

3 days & 25%: 6.5, 8.8,
2 days & 25%: 6.1, 8.5,
1 day & 25%: 5.9, 8.6,
0.5 day & 25%: 5.8, 7.5.

Salinity

Channel catfish are freshwater fish (Wellborn, 1987) and achieve optimal growth rates at salinity levels ranging from 0.5 to 3 ppt (Tucker and Boyd, 1985). This fish species also thrives in brackish water (Wellborn, 1987) and tolerates salinity ranging from 0.1 to 8 ppt.

The use of constructed wetlands did not affect the salinity levels in ponds with standard wetland sizes during the entire experiment (Table 2-6). The ponds with smaller wetland sizes were observed to have lower salinity readings between March and late June (Tables 10-14). Wetlands with variable retention time did not show a clear trend in their effectiveness to reduce pond salinity levels (Tables 18-22). The weekly pond water salinity (in parts per thousand) during the entire experiment in control and treatment ponds averaged as follows:

Control ponds without wetlands: 0.4,
Ponds with variable wetland sizes and constant retention time:

15% & 2 days: 0.8,
25% & 2 days: 0.4,
35% & 2 days: 0.4,
50% & 2 days: 0.2,

Ponds with variable wetland retention times and fixed wetland size:

3 days & 25%: 0.1,
2 days & 25%: 0.4,
1 day & 25%: 0.1,
0.5 day & 25%: 0.5.

pH

The optimal range of pH for fish culture is between 6.5 and 9 (Tucker and Boyd, 1985; Wellborn, 1987) although channel catfish can tolerate as low as 5 or as high as 10. When pH reaches 4 or 11, acid or alkaline death occurs (Boyd and Frobish, 1990). Slow grow occurs if fish are exposed to pH below 6.5, while no reproduction takes place when pH is between 4 to 5 (Boyd and Frobish, 1990).

Optimal and significantly lower pH readings were observed in ponds with standard wetlands as compared to control ponds (Tables 2-6). Ponds with larger wetlands tended to have more acidic waters than those with smaller wetlands (Tables 10-14). The ponds with constructed wetlands having shorter retention times were observed to have lower pH readings (Tables 17-22). The average weekly pond water pH readings during the entire experiment in control and treatment ponds were as follows:

Control ponds without wetlands: 7.6,
Ponds with variable wetland sizes and constant retention time:
- 15% & 2 days: 7.0,
- 25% & 2 days: 7.1,
- 35% & 2 days: 6.9,
- 50% & 2 days: 6.5,

Ponds with variable wetland retention times and fixed wetland size:
- 3 days & 25%: 7.3,
- 2 days & 25%: 7.1,
- 1 day & 25%: 7.1,
- 0.5 day & 25%: 6.9.

Total Ammonia

When proteins in the feed are digested by fish, ammonia is excreted through the gills and in feces (Tucker and Boyd, 1985; Durborow et al., 1992b). Ammonia also enters into the ponds from bacterial decomposition of organic matter, e.g., excess feed, dead algae and aquatic plants (Durborow et al., 1992b). Total ammonia nitrogen is composed of un-ionized ammonia and ionized ammonia (Durborow et al., 1992b). Un-ionized ammonia is considered toxic to aquatic animals (Boyd and Frobish 1990; Durborow et al., 1992b). Short-term exposure to toxic un-ionized ammonia of about 0.6 mg/l is capable of killing fish in a few days while chronic exposure to levels as low as 0.06 mg/l can cause gill and kidney damage, growth reduction, brain malfunction, and reduction in oxygen-carrying capacity (Durborow et al., 1992b).

There were no significant variations in total ammonia levels in control ponds and ponds with standard wetlands except during the summer months (Tables 2-6). During summer, total ammonia readings were higher in control ponds than standard ponds. Total ammonia concentrations in ponds with variable wetland sizes did not show any marked differences during all seasons monitored (Tables 10-14). The effectiveness of wetlands with variable retention times to reduce total ammonia in ponds was not clearly indicated in the experimental results (Table 18-22). For the entire duration of the experiment, the average weekly ammonia concentrations (in milligrams per liter) in the pond waters in control and treatment ponds were as follows:

Control ponds without wetlands: 0.1415,
Ponds with variable wetland sizes and constant retention time:
- 15% & 2 days: 0.0568,
- 25% & 2 days: 0.0412,
- 35% & 2 days: 0.0812
- 50% & 2 days: 0.0604.

Ponds with variable wetland retention times and fixed wetland size:
- 3 days & 25%: 0.0378,
- 2 days & 25%: 0.0412,
- 1 day & 25%: 0.0330,
- 0.5 day & 25%: 0.0545.

Nitrite

Total ammonia nitrogen is converted to nitrite which, under normal conditions, is quickly converted to non-toxic nitrate by naturally occurring bacteria (Durborow et al., 1992a). When nitrite concentrations exceed that which the pond's bacterial populations can rapidly transform to nitrate, brown blood disease may occur due to the rapid accumulation of nitrite in the pond (Durborow et al., 1992a). Fish tolerance to nitrites, however, depends on chloride concentrations in the ponds (Tucker and Boyd, 1985).

Nitrite concentrations in control ponds were relatively higher than in ponds with standard wetlands during summer and fall months (Tables 2-6). During summer months, lower nitrite concentrations were observed in ponds with larger wetlands (Tables 10-16). Lower nitrite readings were recorded among ponds with shorter retention times during summer months (Tables 18-22). The average weekly pond water nitrite levels (in milligrams per liter) during the entire experiment in control and treatment ponds were as follows:

Control ponds without wetlands: 0.0083,
Ponds with variable wetland sizes and constant retention time:
- 15% & 2 days: 0.0269,
- 25% & 2 days: 0.0047,
- 35% & 2 days: 0.0043,
- 50% & 2 days: 0.0092,

Ponds with variable wetland retention times and fixed wetland size:
- 3 days & 25%: 0.0081,
- 2 days & 25%: 0.0047,
- 1 day & 25%: 0.0054,
- 0.5 day & 25%: 0.0109.

Nitrate

With constructed wetlands, it is expected that the conversion of nitrites to nitrates by the bacterial populations in the ponds and wetlands is enhanced. The rate at which nitrites were converted to nitrates was faster in ponds with standard wetlands during early winter and spring months (Tables 2-6). Despite the significant variations in concentrations during early winter months, there were no clear indications on which wetland size or retention time had produced significant improvements in nitrate levels in pond waters (Tables 10-16 and 18-22). The average weekly pond water nitrate concentrations (in milligrams per liter) in control and treatment ponds were as follows:

Control ponds without wetlands: 0.2793,
Ponds with variable wetland sizes and constant retention time:
- 15% & 2 days: 0.1598,
- 25% & 2 days: 0.2061,
- 35% & 2 days: 0.1604,
- 50% & 2 days: 0.1483.

Ponds with variable wetland retention times and fixed wetland size:

3 days & 25%: 0.2410,
2 days & 25%: 0.2061,
1 day & 25%: 0.2649,
0.5 day & 25%: 0.1829.

Phosphorus

The supply of native and added phosphorous affects the productivity of natural waters (Boyd and Frobish, 1990). With intensive feeding between June and October, it is expected that phosphorous concentrations will rise steadily. The build up of phosphorous in ponds will enhance the growth of wetland plants as wells as phytoplanktons in ponds. The availability of natural food in ponds will also enhance fish growth. A healthy and mature population of plants will make the wetlands more effective in improving water quality. When planktonic blooms in ponds become over-abundant, however, additional culture problems are encountered (e.g., off-flavor, oxygen depletion).

The reduction in phosphorous concentrations in ponds with standard wetlands as compared to control ponds was observed between late June to November (Tables 2-6). Between late September and November, the ponds with larger wetland sizes recorded significantly lower phosphorous readings (Tables 12-16). Lower phosphorous concentrations were reported in ponds with shorter retention times in late September to November (Tables 18-22). The average weekly concentrations of phosphorus (in milligrams per liter) in pond water in control and treatment ponds were as follows:

Control ponds without wetlands: 0.5806,
Ponds with variable wetland sizes and constant retention time:

15% & 2 days: 0.1772,
25% & 2 days: 0.1364,
35% & 2 days: 0.1093,
50% & 2 days: 0.0767,

Ponds with variable wetland retention times and fixed wetland size:

3 days & 25%: 0.2169,
2 days & 25%: 0.1364,
1 day & 25%: 0.1174,
0.5 day & 25%: 0.1648.

Total Suspended Solids

The total suspended solids (TSS) measures the particular matter in suspension and indicate the pollution strength of pond effluents (Boyd and Tucker, 1992). The TSS concentrations in control ponds proved to be higher than in ponds with standard wetlands during summer and fall months (Tables 2-6). During the same months, ponds with larger wetland sizes recorded lower TSS concentrations (Tables 10-16). Higher TSS levels were observed in the pond with the longest retention time during summer and early fall months. The average weekly total suspended solids readings (in milligrams per liter) during the entire experiment in control and treatment ponds are as follows:

Control ponds without wetlands: 0.0148,
Ponds with variable wetland sizes and constant retention time:
15% & 2 days: 0.0149,
25% & 2 days: 0.0046,
35% & 2 days: 0.0034,
50% & 2 days: 0.0060,
Ponds with variable wetland retention times and fixed wetland size:
3 days & 25%: 0.0166,
2 days & 25%: 0.0046,
1 day & 25%: 0.0109,
0.5 day & 25%: 0.0027.

Chlorophyll a

In intensive pond culture, the metabolic activities of plankton influence concentrations of dissolved oxygen, carbon dioxide, ammonia, nitrite, and other substances that affect the growth and survival of fish (Boyd and Tucker 1992). Van der Ploeg and Boyd (1991) reported that a study of *Anabaena* blooms over a period of 4-8 weeks at Auburn University Fisheries Research Station showed that changes in geosmin were correlated significantly with changes in algal abundance and chlorophyll a. A close relationship usually exists between the concentrations of chlorophyll a in water and the total abundance of phytoplankton (Boyd and Tucker 1992).

Chlorophyll a concentrations were relatively lower in ponds with standard wetlands than in control ponds between late March to November (Table 2-6). The concentrations of chlorophyll a varied significantly among ponds with variable wetland sizes (Tables 10-16) and retention times (Tables 18-22) during spring and fall months. The average weekly chlorophyll a readings (in milligrams per cubic meter) during the entire experiment in control and treatment ponds were as follows:

Control ponds without wetlands: 0.0272,
Ponds with variable wetland sizes and constant retention time:
15% & 2 days: 0.0142,
25% & 2 days: 0.0087,
35% & 2 days: 0.0037,
50% & 2 days: 0.0109,

Ponds with variable wetland retention times and fixed wetland size:
3 days & 25%: 0.0237,
2 days & 25%: 0.0087,
1 day & 25%: 0.0154,
0.5 day & 25%: 0.0042.

Phaeophytin

The phaeophytin concentrations in ponds with standard wetlands showed to be lower than control ponds during summer and fall (Tables 2-6). During fall, lower phaeophytin concentrations were observed in ponds with the standard (25%) and large (35%) wetlands (Tables 10-16). Significant variations were also observed in ponds with variable retention times (Tables 18-22). The average weekly phaeophytin readings (in milligrams per cubic meter) during the entire experiment in control and treatment ponds were as follows:

Control ponds without wetlands: 0.0160,
Ponds with variable wetland sizes and constant retention time:
- 15% & 2 days: 0.0077,
- 25% & 2 days: 0.0051,
- 35% & 2 days: 0.0026,
- 50% & 2 days: 0.0055,

Ponds with variable wetland retention times and fixed wetland size:
- 3 days & 25%: 0.0165,
- 2 days & 25%: 0.0051,
- 1 day & 25%: 0.0101,
- 0.5 day & 25%: 0.0024.

IV. EFFECTS OF CONSTRUCTED WETLANDS ON POND EFFLUENTS

Water is discharged from ponds to reduce water depth during harvest and after heavy rains due to runoff entering ponds. Schwartz and Boyd (1994) suggested that the best way to minimize the pollution potential of pond effluents during harvest is to harvest the ponds as quickly as possible. During the seining phase of the harvest, the authors further suggested that the pond effluents should either not be discharged to the natural environment or be discharged to a settling basin or retention pond.

The water purification functions of constructed wetlands are dependent upon several components: vegetation, water column, substrates, microbial populations, and animals (Hammer, 1993; Hammer and Bastian, 1989; Reed et al., 1995). Wetland plants perform two major functions, namely: (1) stems and leaves within the water column increase surface area for attachment of microbial populations, and (2) wetlands plants transport atmospheric gases including oxygen down into the roots enabling them to survive in an anaerobic environment. Surface and subsurface water transports substances and gases to microbial populations, carries off by-products, and provides the environment and water for biochemical processes of plants and microbes. Substrates, including various soils, sand or gravel provide physical support for plants, reactive surface area for ions, anions, and some compounds, and attachment surfaces for microbial populations. The effectiveness of wetlands depends on the development and maintenance of optimal environments for desirable microbial populations. Invertebrate and vertebrate animals harvest nutrients and energy by feeding on microbes and macrophytic vegetation, recycling and in some cases transporting substances outside the wetland systems.

The improvements in the quality of catfish pond effluents were evaluated by measuring the changes in the weekly values of selected water quality parameters. The percentage change was computed from the weekly values of the water quality variables at the points of entry to and exit from the constructed wetlands. The efficacy of wetlands in improving water quality, however, was severely hampered by the limited populations of desired vegetation developed and maintained in two of the nine constructed wetlands. The vegetative coverage of the constructed wetlands after one catfish growing season averaged as follows:

Wetlands with variable sizes and constant retention time:
- 15% & 2 days: 90%,
- 25% & 2 days: 70%,
- 35% & 2 days: 50%,
- 50% & 2 days: 0%,

Wetlands with variable retention times and fixed size:
- 3 days & 25%: 70%,
- 2 days & 25%: 70%,
- 1 day & 25%: 80%,
- 0.5 day & 25%: 0%.

Salinity

The was no consistent seasonal reduction in weekly salinity values at the outlets as compared to those at the inlets in constructed wetlands with different sizes (Tables 29-33) and different retention times (Tables 34-38). The percentage change in the average salinity readings from the wetland inlets to the outlets during the entire experiment were as follows:

Wetlands with variable sizes and constant retention time:
- 15% & 2 days: 0%,
- 25% & 2 days: -15%,
- 35% & 2 days: 8%,
- 50% & 2 days: -20%,

Wetlands with variable retention times and fixed size:
- 3 days & 25%: 100%,
- 2 days & 25%: -15%,
- 1 day & 25%: -33%,
- 0.5 day & 25%: 0%.

pH

The optimum pH levels in the wetlands in order to enhance the growth of the chosen vegetation (5 to 6.5) was lower than the optimal range for the catfish ponds (6.5 to 9). In almost all seasons, the outlet pH levels were relatively lower than the inlet pH in wetlands with different sizes (Tables 29-33) and different retention times (Tables 34-38). The percentage change in the average pH readings from the points of entry to exit from the wetlands during all seasons were as follows:

Wetlands with wetland sizes and constant retention time:

15% & 2 days: -13%,
25% & 2 days: -1%,
35% & 2 days: -5%,
50% & 2 days: -21%,

Wetlands with variable retention times and fixed size:

3 days & 25%: -1%,
2 days & 25%: -1%,
1 day & 25%: -2%,
0.5 day & 25%: 1%.

Total ammonia

Total ammonia concentrations at the outlets were not consistently lower than those recorded at the inlets of the constructed wetlands with different sizes (Tables 29-33) and different retention times (Tables 34-38) during different seasons. The percentage change in the weekly total ammonia concentrations from the points of entry to exit from the constructed wetlands during the whole period were as follows:

Wetlands with variable sizes and constant retention time:

15% & 2 days: -21%,
25% & 2 days: 21%,
35% & 2 days: -14%,
50% & 2 days: 22%,

Wetlands with variable retention times and fixed size:

3 days & 25%: 0%,
2 days & 25%: 21%,
1 day & 25%: 13%,
0.5 day & 25%: -10%.

Nitrite

Nitrites were mostly reduced as the water reached the other end of the constructed wetlands with variable sizes especially during spring and fall months (Tables 29-33). The reduction in nitrite concentrations at the outlets of constructed wetlands with different retention times was not consistent over the experimental period (Tables 34-38). The percentage change in the weekly nitrite readings during the entire experiment in treatment ponds were as follows:

Wetlands with variable sizes and constant retention time:

15% & 2 days: -92%,
25% & 2 days: -7%,
35% & 2 days: -25%,
50% & 2 days: -74%,

Wetlands with variable retention times and fixed size:
3 days & 25%: 0%,
2 days & 25%: -7%,
1 day & 25%: 16%,
0.5 day & 25%: -38%.

Nitrate

Constructed wetlands with variable sizes (Tables 29-33) and variable retention times (Tables 34-38) showed mixed seasonal results in changing the nitrate concentrations of pond effluents entering and leaving the wetlands. The percentage change in the weekly nitrate levels during the entire experiment in treatment ponds were as follows:

Wetlands with variable sizes and constant retention time:
15% & 2 days: -23%,
25% & 2 days: 5%,
35% & 2 days: -5%,
50% & 2 days: 173%,
Wetlands with variable retention times and fixed size:
3 days & 25%: 15%,
2 days & 25%: 5%,
1 day & 25%: -14%,
0.5 day & 25%: -14%.

Phosphorus

Phosphorous concentrations entering and leaving the constructed wetlands did not change consistently among different wetland sizes (Table 29-33) during different seasons. During winter and spring, phosphorous levels systematically declined in all constructed wetlands with variable retention times (Tables 34-38). The percentage change in the weekly phosphorous readings during the entire experiment in wetlands with different sizes and retention times were as follows:

Wetlands with variable sizes and constant retention time:
15% & 2 days: -25%,
25% & 2 days: -20%,
35% & 2 days: -77%,
50% & 2 days: -65%,

Wetlands with variable retention times and fixed size:
3 days & 25%: -68%,
2 days & 25%: -20%,
1 day & 25%: -21%,
0.5 day & 25%: -80%.

Total Suspended Solids

Reductions in TSS concentrations were observed among different wetland sizes except during winter months (Tables 29-33). During fall, all the constructed wetlands with different retention times effectively lowered TSS levels at the outlets as compared to those at the inlets (Tables 34-38). The average change in the weekly TSS readings in various wetland sizes and retention times during the entire experiment were as follows:

Wetlands with variable sizes and constant retention time:
- 15% & 2 days: -84%,
- 25% & 2 days: -7%,
- 35% & 2 days: -27%,
- 50% & 2 days: -35%,

Wetlands with variable retention times and fixed size:
- 3 days & 25%: -20%,
- 2 days & 25%: -7%,
- 1 day & 25%: 8%,
- 0.5 day & 25%: -26%.

V. EFFECTS OF CONSTRUCTED WETLANDS ON CATFISH POND PRODUCTION

Analysis of variance (ANOVA) or general linear models (GLM) were used to evaluate catfish survival, growth and yield, feed conversion and off-flavor in ponds with or without constructed wetlands stocked with 5,000 catfish fingerlings per acre. Fish survival rates, growth and yield, feed conversion and incidence of off-flavor did not vary significantly between control ponds and treatment ponds with standard wetlands. Similar results were observed among treatment ponds with variable wetland sizes and fixed retention time and ponds with fixed wetland sizes and variable retention time.

Marked differences, however, were observed on water pump electric consumption and aeration time. Larger wetland sizes and lower retention time tend to require more pumping time than smaller wetland sizes and longer retention time. A significant reduction in the average daily aeration time was observed in ponds with standard wetlands as compared to control ponds. The pond with the largest wetland size required more aeration time than those with smaller wetlands sizes. Significantly more aeration time was required by the pond with the shortest retention time when compared to those ponds with longer retention times.

Catfish Survival

Fish survival rates observed in control ponds and ponds with standard wetlands were not statistically different (Table 8). Statistical comparison of treatment ponds by wetland size and retention time showed insignificant differences in fish survival rates (Tables 16 & 24). The survival rates (in percent) of catfish stocked in control and treatment ponds are shown below:

Control ponds without wetlands: 70.5,
Ponds with variable wetland sizes and constant retention time:
15% & 2 days: 98.0,
25% & 2 days: 69.3,
35% & 2 days: 71.0,
50% & 2 days: 89.0.
Ponds with variable wetland retention time and fixed wetland size:
3 days & 25%: 74.0,
2 days & 25%: 69.3,
1 day & 25%: 85.0,
0.5 day & 25%: 79.0.

Catfish Growth

The growth of the catfish stocked in control ponds was not significantly different from those stocked in ponds with standard wetlands (Table 8). Similar fish growth was observed in ponds with variable wetlands sizes (Table 16) and variable retention times (Table 24). The growth rates (in pounds per fish) of catfish stocked in control and treatment ponds were as follows:

Control ponds without wetlands: 0.89.
Ponds with variable wetland sizes and constant retention time:
15% & 2 days: 0.61,
25% & 2 days: 0.75,
35% & 2 days: 0.78,
50% & 2 days: 0.56.
Ponds with variable wetland retention time and fixed wetland size:
3 days & 25%: 0.75,
2 days & 25%: 0.75,
1 day & 25%: 0.66,
0.5 day & 25%: 0.61.

Both the individual (Tables 7, 15 &23) and pooled semi-logarithmic catfish growth equations were estimated using fish sampling data collected from June 2 to December 16, 1994. The pooled growth equations showed that the dummy variables representing wetland size and retention time did not have any significant effect on catfish growth. The individual catfish growth equations estimated by treatment type were as follows:

Control ponds without wetlands : log (gram) = 1.8732 + 0.0124 * sampling date.
Treatment ponds with variable wetland sizes and fixed retention time:
15% & 2 days: log (gram) = 2.7070 + 0.0094 * sampling date,
25% & 2 days: log (gram) = 1.9088 + 0.0118 * sampling date,
35% & 2 days: log (gram) = 2.0785 + 0.0111 * sampling date,
50% & 2 days: log (gram) = 1.8559 + 0.0123 * sampling date.

Treatment ponds with variable retention time and fixed wetland sizes:

3 days & 25% log (gram) = 1.7798 + 0.0123 * sampling date,
2 days & 25% log (gram) = 1.9088 + 0.0118 * sampling date,
1 day & 25% log (gram) = 2.4160 + 0.0096 * sampling date,
0.5 day & 25% log (gram) = 2.4884 + 0.0095 * sampling date.

where: log - natural logarithm, gram - weight of fish sample (gram/fish) and sampling date - date fish samples were taken.

Catfish Yield

Harvest size in control ponds was not statistically different from those in ponds with standard wetlands (Table 8). Similar fish sizes were harvested from ponds with different wetland sizes (Table 16) and different retention times (Table 24). The average size (in pounds per fish) of catfish harvested from control and treatment ponds were the following:

Control ponds without wetlands: 0.91.
Ponds with variable wetland sizes and constant retention time:

15% & 2 days: 0.66,
25% & 2 days: 0.76,
35% & 2 days: 0.80,
50% & 2 days: 0.60.

Ponds with variable wetland retention time and fixed wetland size:

3 days & 25%: 0.77,
2 days & 25%: 0.76,
1 day & 25%: 0.68,
0.5 day & 25%: 0.65.

Fish harvest from control ponds was not significantly higher than those with standard wetlands (Table 8). Ponds with variable wetlands sizes (Table 16) and variable retention times (Table 24) reported the same catfish yields. The average fish harvest (in pounds per pond) from control and treatment ponds are shown below:

Control ponds without wetlands: 765.5.
Ponds with variable wetland sizes and constant retention time:

15% & 2 days: 814.0
25% & 2 days: 657.3,
35% & 2 days: 718.0,
50% & 2 days: 666.0.

Ponds with variable wetland retention time and fixed wetland size:

3 days & 25%: 715.0,
2 days & 25%: 657.3,
1 day & 25%: 727.0,
0.5 day & 25%: 647.0.

Incidence of Off-flavor

Off-flavor occurs when catfish acquire certain flavors perceived as unacceptable by the consumer (Keenum and Waldrop, 1988; Van der Ploeg, 1989; Boyd and Frobish, 1990). Biological processes that take place in the pond environment produce odorous compounds that are absorbed by fish through the gills and accumulate in the flesh (Van der Ploeg, 1989). Mississippi Cooperative Extension Service (1993) reported that studies conducted at the Delta Research and Extension Center in Stoneville, Mississippi provide new information for efficient management of the off-flavor problem, as follows:

> "It is now known that, during the summer, 75% of all off-flavors are caused by a compound called MIB (*2-methylisoborneol*). Although at least 10 species of blue-green algae are found in the Delta, only one is responsible for MIB production. This species (*Oscillatoria chalybea*) first appears in ponds during the summer when water temperatures exceed 70 ^oF (20 ^oC). It usually disappears when water temperatures fall below this level in September or October, but is has been found at temperatures as low as 60 ^oF (15 ^oC).
>
> When present in a pond, this alga releases MIB into the water. MIB is then absorbed through the gills and stored in fish flesh causing fish to become off-flavor. While research has shown that fish can purge MIB once the alga disappears, the purging process depends on water temperature and is very slow at temperatures below 60 ^oF. Fish exposed to MIB during summer and early fall may not be able to get rid of off-flavor due to cooler water temperatures; the off-flavor that is acquired in the summer can thus last the entire winter. In addition, the alga responsible for MIB is likely to return to the same pond summer after summer. This means that if fish do not purge MIB before May or June, they may be exposed to MIB once more, off-flavors will intensify.
>
> Most ongoing research is focusing on learning more about the species that produces MIB. This knowledge is necessary to develop possible treatments or control methods. As for now, the only proven option available to producers is to "manage around the problem."

Catfish samples taken from control and standard ponds tested positive for off-flavor (Table 28). Similar results were also observed among ponds with variable wetland sizes and variable retention times. Boyd and Frobish (1990) suggested that water in ponds be exchanged to flush out substances responsible for off-flavor. The average off-flavor scale (0 being on flavor and 4 being the worst case of off-flavor) for the control and treatment ponds were as follows:

Control ponds without wetlands: 3.0.
Ponds with variable wetland sizes and constant retention time:
- 15% & 2 days: 4.0,
- 25% & 2 days: 3.3,
- 35% & 2 days: 4.0,
- 50% & 2 days: 3.3.

Ponds with variable wetland retention time and fixed wetland size:

- 3 days & 25%: 2.0,
- 2 days & 25%: 3.3,
- 1 day & 25%: 4.0,
- 0.5 day & 25%: 4.0.

Feed Conversion

Feed conversion was not statistically different in control ponds and ponds with standard wetlands (Table 8). There were no marked differences in the feed conversion computed among treatment ponds (Tables 16 & 24). The average feed conversion (in pounds of feed fed per pound of catfish weight gained) of control and treatment ponds by wetland size and retention time were as follows:

Control ponds without wetlands: 2.32.

Ponds with variable wetland sizes and constant retention time:

- 15% & 2 days: 2.30,
- 25% & 2 days: 2.70,
- 35% & 2 days: 2.46,
- 50% & 2 days: 2.84.

Ponds with variable wetland retention time and fixed wetland size:

- 3 days & 25%: 2.46,
- 2 days & 25%: 2.70,
- 1 day & 25%: 2.45,
- 0.5 day & 25%: 2.97.

Electricity Consumption

Electricity used by submersible water pumps to recirculate treated water from constructed wetlands to production ponds varied significantly with the size of constructed wetlands and retention time (Tables 25-27). The weekly electricity consumption (in kilowatt-hours per pond) of treatment ponds by wetland size and retention time were the following:

Ponds with variable wetland sizes and constant retention time:

- 15% & 2 days: 18.3,
- 25% & 2 days: 14.4,
- 35% & 2 days: 11.6,
- 50% & 2 days: 21.8.

Ponds with variable wetland retention time and fixed wetland size:

- 3 days & 25%: 17.3,
- 2 days & 25%: 14.4,
- 1 day & 25%: 44.1,
- 0.5 day & 25%: 51.9.

Pond Aeration

A significant reduction in the average daily aeration time was observed in ponds with standard wetlands as compared to control ponds (Table 1) during warmer months. The pond with the largest wetland size (50%) required more aeration time than those with smaller wetlands sizes (Table 9) during the later part of the growing season. Significantly more aeration time was required by the pond with the shortest retention time (0.5 day) when compared to those ponds with longer retention times (Table 17) during summer and fall months. The daily aeration time (in hours per pond) of control and treatment ponds by wetland size and retention time were the following:

Control ponds without wetlands: 1.61.
Ponds with variable wetland sizes and constant retention time:
- 15% & 2 days: 0.83,
- 25% & 2 days: 0.53,
- 35% & 2 days: 0.46,
- 50% & 2 days: 1.75.

Ponds with variable wetland retention time and fixed wetland size:
- 3 days & 25%: 0.06,
- 2 days & 25%: 0.53,
- 1 day & 25%: 0.11,
- 0.5 day & 25%: 1.58.

VI. BENEFITS AND COSTS OF CONSTRUCTED WETLANDS

The added benefits and costs associated with constructed wetlands were estimated by applying the initial experimental results to a diversified commercial operation in the Mississippi Black Belt area. Mississippi Black Belt was selected due to the following reasons: steady increase in catfish acreage and processing capacity, lack of a cheap water supply, and dependence on surface run-off as the major source of pond water. There are about 7,000 water surface acres devoted to catfish farming in the area and three catfish processing plants with a combined daily processing capacity of about 150,000 pounds. Deep water wells used by two commercial farms in the area were dug at a depth of 1,600 feet. In areas like the Mississippi Black Belt, therefore, constructed wetlands can be used to treat and conserve pond water and surface-run-off.

The multi-enterprise farm had 504 land acres used in crop production (corn, cotton and/or soybeans), 48-water surface acre catfish enterprise, and contract swine growing operation (Posadas and Dillard, 1997). This farm is owned and operated by the farmer with additional labor provided by other family members and occasional hired workers during peak months. The investment requirements and annual costs of the catfish enterprise were estimated with the assumption that some common farm assets (e.g., building, tractors and truck) were also used in other farm enterprises (Table 40).

Investment Requirements

The initial investment requirements for six 8-water surface acre catfish ponds on a multi-enterprise farm in the Mississippi Black Belt area added up to $169,312 or $3,527 per production acre (Table 39). With six 2-water surface acre constructed wetlands (25% of pond size and 2-day retention time) built adjacent to the catfish ponds, total initial investment requirements rose by $199,713 or $4,161 per production acre (Table 43). The breakdown of the investment requirements ($) for the 48-acre catfish enterprise (Posadas and Dillard, 1997) and the six 2-acre constructed wetlands (Posadas, 1997) were as follows:

Item	Catfish	Wetlands
Land	40,656	10,164
Pond/Wetland construction	67,611	169,531
Surveying	2,904	726
Earth moving	58,214	14,554
Drainage structure	3,888	NA
Gravel	2,064	516
Vegetative cover	541	135
Plants & planting	0	153,600
Electrical system	1,300	NA
Recycling system	0	20,018
Equipment	59,745	0
Total	169,312	199,713

The total initial investment required to build six 2-acre constructed wetlands (25% of pond size and 2-day retention time) amounted to 118% of the total initial investment required to construct six 8-acre catfish farm. Seventy seven percent of total initial investment ($3,200/acre) were spent on the purchase and planting of the desired wetland plants. The average purchase and planting cost of 12-inch duck potato and soft rush was $0.40 per seedling. This method of creating the desired growth of vegetative cover was necessary to allow the constructed wetlands to achieve the highest removal efficiencies during the experimental period.

Annual Costs and Returns

At a stocking density of 5,700 seven-inch fingerlings per production acre, the annual yield of the six 8-acre catfish ponds in the Mississippi Black Belt area totaled 249,600 pounds or 5,200 per production acre (Posadas and Dillard, 1997). Experimental results conducted at the Mississippi State University-Coastal Aquaculture Unit (MSU-CAU) showed that at a stocking density of 5,000 fingerlings per production acre, there were no significant differences in the yields of ponds with and without wetlands, ponds with variable wetland sizes or ponds with variable retention times (Tables 8, 16, & 24). At this stage of determining the effectiveness of using constructed wetlands in finfish pond production, the significant improvements in pond water quality did not lead to significantly observable benefits, namely: higher yields, faster growth, higher survival and lesser incidence of off-flavor. With these catfish production results, the total revenues from the 48-acre catfish enterprise with or without constructed wetlands amounted to

$174,720 per year or $3,640 per production acre, assuming a farm-gate price of $0.70 per pound harvested.

Total specified operating (variable) and ownership (fixed) costs of the 48-acre Mississippi Black Belt catfish enterprise without constructed wetlands amounted to $146,912 per year, averaging $3,060 per production acre or $0.59 per pound harvested (Table 41). When constructed wetlands were added to the catfish enterprise, total costs rose by $18,930 annually, $394 per production acre or $0.075 per pound harvested (Table 45). Most of the increase in total costs are attributable to the higher fixed costs associated with the construction of the wetlands. The reduction in electricity consumption due to lower aeration time was more than offset by the increase use of the water pumps to recirculate treated water back to the production ponds.

Kelly et al. (1991) reported that the ability to sell fish on time by most of the Mississippi Black Belt farmers had been adversely affected by off-flavor problems. Off-flavor lasted between 3 to 4 months and occurred in about 2 to 3 ponds of the 4 ponds stocked with catfish. When the cost of delayed sales due to off-flavor is incorporated in the costs analysis of the Mississippi Black Belt catfish enterprise, annual specified costs will rise between 0.29-2.65 cents per pound harvested depending on the number of ponds affected and the length of the off-flavor occurrence (Posadas, 1997). In the Mississippi Delta, Keenum and Waldrop (1988) calculated the added costs due to off-flavor occurring in one (second or fourth) and two (second and fourth) quarters as 1.86 or 1.75 and 3.61 cents per pound, respectively. Using a synthesized 323-acre catfish farm, Coats et al. (1989) estimated that off-flavor occurring 16 weeks in all 16 Mississippi Delta ponds would add 4.5 cents per pound to the cost of catfish production. With a multi-period mathematical programming model, Engle et al. (1995) suggested that in order to be feasible, systems designed to purge off-flavor from catfish would need to cost less than 2.27 cents per pound (if cash flow is not a consideration) or 1.81-11.36 cents per pound (with cash flow considerations). Since the incidence of catfish off-flavor during the initial experiment at MSU-CAU was not significantly different between control and standard ponds and among treatment ponds with variable wetland sizes and retention times, the cost of delayed sales due to off-flavor are considered the same for the Mississippi Black Belt catfish enterprise operated with and without constructed wetlands.

Annual Fixed Costs

The total ownership (fixed) costs of the 48-water surface acre catfish operation in the Mississippi Black Belt area amounted to $25,891 per year, $539 per production acre or $0.10 per pound of fish harvested (Table 41). The annual fixed costs associated with the construction of six 2-acre wetlands totaled $14,016, $292 per production acre or $0.056 per pound of catfish harvested (Table 45). The major categories of annualized fixed costs ($/yr) of the six 8-acre catfish ponds (Posadas and Dillard, 1997) and the six 2-acre constructed wetlands (Posadas, 1997) are shown below:

Item	Catfish	Wetlands
Depreciation	14,099	3,522
Interest on investment	10,498	10,494
Taxes and insurance	1,294	NA
Total	25,891	14,016

Annual Operating Costs

The total operating (variable) costs of the 48-water surface acre catfish enterprise in the Mississippi Black Belt area added up to $121,021 per year, $2,521 per production acre or $0.48 per pound of fish harvested (Tables 41-42). The total variable costs associated with the operation of six 2-acre wetlands amounted to $4,913 per year, $102 per production acre or $0.02 per pound of catfish harvested (Table 45). The primary components of total operating costs ($/yr) of the six 8-acre catfish ponds (Posadas and Dillard, 1997) and the six 2-acre constructed wetlands (Posadas, 1997) were as follows:

Item	Catfish	Wetlands
Repair and maintenance	4,308	760
Fuel	4,276	0
Electricity	5,952	2,277
Chemicals	2,976	0
Telephone	248	0
Water quality analysis	378	0
Fingerlings	20,520	0
Feed	51,892	0
Labor	7,101	1,534
Harvesting and hauling	12,480	0
Liability insurance	300	0
Miscellaneous	800	0
Operating interest	7,406	342
Inventory interest	2,383	0
Total	121,021	4,913

At a stocking density of 5,000 fingerlings per acre, significant improvements in water quality observed during the experiments conducted at MSU-CAU did not lead to higher yields of marketable catfish. The application of these preliminary results to the commercial catfish farming enterprise in the Mississippi Black Belt indicated that the additional costs more than offset any limited economic benefits derived from the use of constructed wetlands. With the additional costs ($14,016/yr) arising from the use of constructed wetlands, average fish yield needs to increase by 8% or 417 pounds per production acre in order for the catfish enterprise to recover the added specified costs amounting to $292 per production acre. When the farm-gate price of catfish falls from $0.70 to $0.60 per pound, the required increase in the yield of marketable catfish would be 9.3% or 487 pounds per production acre. The desired increase in average yield of marketable fish necessary to break-even can be achieved by higher fish survival, faster fish growth, bigger fish harvest size, higher stocking densities, and lower incidence of off-flavor. Further experimental trials were conducted at MSU-CAU in 1995-96 and 1996-97 growing seasons in order to verify the effects of the use of relatively mature constructed wetlands on water quality and associated costs and benefits of ponds stocked with 6,000 and 8,000 7-inch catfish fingerlings, respectively.

VII. **CONCLUSIONS**

The results of the initial experiment conducted at MSU-CAU showed that at a stocking density of 5,000 per acre, constructed wetlands were effective in improving water quality but did not necessarily enhance the yields of marketable fish. Substantial improvements and lesser variations in many of the water quality variables monitored were observed among ponds with standard wetlands as compared to control ponds. Significant differences in many water quality variables were also noted among ponds with variable wetlands sizes and retention times. Due to the relatively young age and incomplete vegetative coverage in constructed wetlands, there were no definitive trends in the effects of wetland sizes and retention times on water quality. Fish survival rates, growth, harvest and production, feed conversion and incidence of off-flavor did not vary significantly between control ponds and treatment ponds with standard wetlands. Similar results were observed among treatment ponds with variable wetland sizes and fixed retention time and ponds with fixed wetland sizes and variable retention time.

Marked differences, however, were observed on water pump electric consumption and aeration time. Electricity used by submersible water pumps to recirculate treated water from constructed wetlands to production ponds varied significantly with the size of constructed wetlands and retention time. Larger wetland sizes and lower retention time tend to require more pumping time than smaller wetland sizes and longer retention time. A significant reduction in the average daily aeration time was observed in ponds with standard wetlands as compared to control ponds. The pond with the largest wetland size required more aeration time than those with smaller wetlands sizes. Significantly more aeration time was required by the pond with the shortest retention time when compared to those ponds with longer retention times.

The total initial investment on constructed wetlands ($4,161/acre) amounted to 118 % of the investment required to construct the 48-acre catfish farm ($3,527/acre). Seventy seven percent of total cost of building the wetlands ($3,200/acre) were spent on the purchase and planting of the 12-inch duck potato and soft rush seedlings. The high cost of creating thick and healthy vegetative coverage in constructed wetlands was necessary to achieve the desired removal efficiencies during the experiment.

The application of the initial experimental results observed at MSU-CAU to the commercial catfish farming enterprise in the Mississippi Black Belt indicated that the observed additional costs more than offset any limited economic benefits derived. The significant improvements in pond water quality did not lead to significantly observable benefits, namely: higher yields and lesser incidence of off-flavor. Consequently, total revenues from the 48-acre catfish enterprise with or without constructed wetlands totaled $174,720 per year or $3,640 per production acre. Annual specified costs for the 48-acre Mississippi Black Belt catfish enterprise without constructed wetlands amounted to $146,912 per year, averaging $3,060 per production acre. When constructed wetlands were added to the catfish enterprise, total costs rose by

$14,016 annually or $292 per production acre. With constructed wetlands, average yield needs to increase by 8% or 417 pounds per production acre in order for the catfish enterprise to recover the added costs. This required increase in average yield in order to break-even can be achieved by an improvement in fish survival, by faster fish growth, by increasing stocking rates and/or bigger fish harvest size.

VIII. **RECOMMENDATIONS**

As the documentation of the effectiveness of marsh systems in reducing water quality problems progresses, future work could take several directions. First, changes in marsh system function with age need to be evaluated. The constructed wetlands are expected to mature after two growing seasons and show peak removal efficiencies. Second, there is a need to evaluate the potential of improving yields of marketable fish through increased stocking densities. Third, there is a need to investigate the culture of more economically valuable and environmentally sensitive finfish species (e.g., hybrid striped bass, freshwater prawns) in order to convert marked improvements in water quality into higher yields and revenues. Fourth, cheaper methods of creating vegetative cover in constructed wetlands need to be evaluated. Finally, it would be desirable to conduct pilot tests of this new technology in commercial scale operations in cooperation with the fish farming industry.

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Table 1. Means and standard deviations of daily readings of dissolved oxygen and aeration time in control ponds and ponds with standard wetlands by season, March 2-November 30, 1994

Variable	Unit	Control Ponds (No Wetland)	Standard (25%, 6.5 gpm)
All seasons (March 2-November 30, 1994)			
Morning dissolved oxygen [ns]	ppm	6.1470 [a] (1.8859)	6.0503 [a] (1.5452)
Afternoon dissolved oxygen [***]	ppm	9.3668 [a] (2.1610)	8.5299 [b] (1.7770)
Aeration time [***]	hr/day	1.6274 [a] (5.2853)	0.5337 [b] (3.0327)
Winter (March 2-March 19, 1994)			
Morning dissolved oxygen [ns]	ppm	8.6161 [a] (0.6492)	8.5971 [a] (0.6999)
Afternoon dissolved oxygen [ns]	ppm	9.0920 [a] (0.9101)	9.2000 [a] (0.7189)
Aeration time [ns]	hr/day	0.0000 [a] (0.0000)	0.0000 [a] (0.0000)
Spring (March 20-June 19, 1994)			
Morning dissolved oxygen [*]	ppm	7.1943 [a] (1.2797)	6.9187 [b] (1.2123)
Afternoon dissolved oxygen [***]	ppm	9.0976 [a] (1.7746)	8.2992 [b] (0.9981)
Aeration time [***]	hr/day	1.1403 [a] (4.9240)	0.0000 [b] (0.0000)
Summer (June 20-September 21, 1994)			
Morning dissolved oxygen [***]	ppm	4.5640 [b] (1.1663)	4.9652 [a] (0.9798)
Afternoon dissolved oxygen [***]	ppm	9.1609 [a] (2.2259)	8.2894 [b] (1.9425)
Aeration time [ns]	hr/day	1.3635 [a] (3.9233)	1.1251 [a] (4.3655)

Fall (September 22-November 30, 1994)			
Morning dissolved oxygen ***	ppm	6.9256 [a] (1.7216)	6.1690 [b] (1.4250)
Afternoon dissolved oxygen ***	ppm	10.0512 [a] (2.4748)	9.0756 [b] (2.2007)
Aeration time ***	hr/day	2.9873 [a] (7.3473)	0.5311 [b] (2.9770)

Legend: Means with the same letter are not significantly different at 5%; numbers in parentheses are standard deviations; ns - not significantly different at 5%; * - significantly different at 5%; *** - significantly different at 0.01%.

Table 2. Means and standard deviations of weekly readings of selected water quality variables in control ponds and ponds with standard wetlands during all seasons, March 2-November 30, 1994

Variable	Unit	Control (No Wetland)	Standard (25%, 6.5 gpm)
Salinity [ns]	ppt	0.4166 [a] (0.8359)	0.3500 [a] (0.7293)
pH [***]		7.5859 [a] (0.6462)	7.0613 [b] (0.4821)
Ammonia [ns]	mg/l	0.1415 [a] (0.8259)	0.0412 [a] (0.0467)
Nitrate [ns]	mg/l	0.2793 [a] (0.7536)	0.2061 [a] (0.7287)
Nitrite [**]	mg/l	0.0083 [a] (0.0108)	0.0047 [b] (0.0064)
Phosphorous [***]	mg/l	0.5806 [a] (0.9358)	0.1364 [b] (0.2374)
Total suspended solids [***]	mg/l	0.0148 [a] (0.0275)	0.0046 [b] (0.0053)
Chlorophyll A [***]	mg/m^3	0.0272 [a] (0.0454)	0.0087 [b] (0.0151)
Phaeophytin [**]	mg/m^3	0.0160 [a] (0.0323)	0.0051 [b] (0.0101)

Legend: Means with the same letter are not significantly different at 5%; numbers in parentheses are standard deviations; ns - not significant at 5%; ** - significant at 0.1%; *** - significant at 0.01%.

Table 3. Means and standard deviations of weekly readings of selected water quality variables in control ponds and ponds with standard wetlands during winter months, March 2-March 19, 1994

Variable	Unit	Control (No Wetland)	Standard (25%, 6.5 gpm)
Salinity [ns]	ppt	0.7778 [a] (0.9718)	0.5555 [a] (0.8819)
pH [***]		7.5233 [a] (0.5213)	7.1155 [b] (0.3298)
Ammonia [ns]	mg/l	1.0439 [a] (2.9957)	0.0450 [a] (0.0240)
Nitrate [***]	mg/l	0.0905 [b] (0.0545)	0.1417 [a] (0.1039)
Nitrite [ns]	mg/l	0.0101 [a] (0.0093)	0.0067 [a] (0.0047)
Phosphorous [ns]	mg/l	0.1087 [a] (0.2016)	0.0338 [a] (0.1793)
Total suspended solids [ns]	mg/l	0.0070 [a] (0.0113)	0.0029 [a] (0.0041)
Chlorophyll A [ns]	mg/m^3	0.0048 [a] (0.0054)	0.0024 [a] (0.0040)
Phaeophytin [ns]	mg/m^3	0.0006 [a] (0.0065)	-0.0011 [a] (0.0057)

Legend: Means with the same letter are not significantly different at 5%; numbers in parentheses are standard deviations; ns - not significantly different at 5%; *** - significantly different at 0.01%.

Table 4. Means and standard deviations of weekly readings of selected water quality variables in control ponds and ponds with standard wetlands during spring months, March 20-June 19, 1994

Variable	Unit	Control (No Wetland)	Standard (25%, 6.5 gpm)
Salinity [ns]	ppt	0.8462 [a] (1.1593)	0.7692 [a] (1.0120)
pH [***]		7.7176 [a] (0.6389)	7.1407 [b] (0.5280)
Ammonia [ns]	mg/l	0.0732 [a] (0.1252)	0.0580 [a] (0.0617)
Nitrate [*]	mg/l	0.2824 [a] (0.4492)	0.1116 [b] (0.1661)
Nitrite [ns]	mg/l	0.0036 [a] (0.0058)	0.0028 [a] (0.0049)
Phosphorous [ns]	mg/l	0.3296 [a] (0.7110)	0.1087 [a] (0.2514)
Total suspended solids [**]	mg/l	0.0029 [a] (0.0023)	0.0049 [b] (0.0048)
Chlorophyll A [*]	mg/m^3	0.0042 [a] (0.0045)	0.0023 [b] (0.0024)
Phaeophytin [ns]	mg/m^3	0.0012 [a] (0.0013)	0.0016 [a] (0.0018)

Legend: Means with the same letter are not significantly different at 5%; numbers in parentheses are standard deviations; ns - not significantly different at 5%; * - significantly different at 5%; ** - significantly different at 1%; *** - significantly different at 0.01%.

Table 5. Means and standard deviations of weekly readings of selected water quality variables in control ponds and ponds with standard wetlands during summer months, June 20-September 21, 1994

Variable	Unit	Control (No Wetland)	Standard (25%, 6.5 gpm)
Salinity [ns]	ppt	0.2381 [a] (0.4843)	0.1666 [a] (0.3771)
pH [**]		7.3519 [a] (0.4628)	6.9981 [b] (0.6016)
Ammonia [*]	mg/l	0.0674 [a] (0.1045)	0.0303 [b] (0.0346)
Nitrate [ns]	mg/l	0.4622 [a] (1.1730)	0.4191 [a] (1.1990)
Nitrite [**]	mg/l	0.0067 [a] (0.0067)	0.0026 [b] (0.0042)
Phosphorous [***]	mg/l	0.8616 [a] (1.1874)	0.1102 [b] (0.1956)
Total suspended solids [***]	mg/l	0.0107 [a] (0.0104)	0.0049 [b] (0.0056)
Chlorophyll A [***]	mg/m^3	0.0280 [a] (0.0299)	0.0108 [b] (0.0130)
Phaeophytin [**]	mg/m^3	0.0162 [a] (0.0207)	0.0073 [b] (0.0118)

Legend: Means with the same letter are not significantly different at 5%; numbers in parentheses are standard deviations; ns - not significantly different at 5%; * - significantly different at 5%; ** - significantly different at 1%; *** - significantly different at 0.01%.

Table 6. Means and standard deviations of weekly readings of selected water quality variables in control ponds and ponds with standard wetlands during fall months, September 22-November 30, 1994

Variable	Unit	Control (No Wetland)	Standard (25%, 6.5 gpm)
Salinity [ns]	ppt	0.0000 [a] (0.0000)	0.0000 [a] (0.0000)
pH [***]		7.7610 [a] (0.8156)	7.0323 [b] (0.1748)
Ammonia [ns]	mg/l	0.0627 [a] (0.1176)	0.0333 [a] (0.0384)
Nitrate [ns]	mg/l	0.0760 [a] (0.1319)	0.0503 [a] (0.0566)
Nitrite nitrogen [*]	mg/l	0.0161 [a] (0.0158)	0.0093 [b] (0.0085)
Phosphorous [**]	mg/l	0.6553 [a] (0.8079)	0.2400 [b] (0.2630)
Total suspended solids [***]	mg/l	0.0383 [a] (0.0459)	0.0048 [b] (0.0058)
Chlorophyll A [***]	mg/m^3	0.0625 [a] (0.0708)	0.0160 [b] (0.0234)
Phaeophytin [***]	mg/m^3	0.0396 [a] (0.0524)	0.0084 [b] (0.0128)

Legend: Means with the same letter are not significantly different at 5%; numbers in parentheses are standard deviations; ns - not significantly different at 5%; * - significantly different at 5%; ** - significantly different at 1%; *** - significantly different at 0.01%.

Table 7. Log-linear regression results with the logarithm of individual weights in control ponds and ponds with standard wetlands as dependent variable, June 2-December 16, 1994

Variable	Control (no wetland)	Standard (25%, 6.5 gpm)
Intercept	1.8732*** (0.0850)	1.9088*** (0.0725)
Sampling date	0.0124*** (0.0003)	0.0118*** (0.0003)
R-squared	0.7808	0.8127
F-statistic	1179.17***	1440.94***
D-W statistic	1.69 nsc	1.82 nsc
Number of observation	352	364

Legend: Numbers in parentheses are standard errors; *** - significant at 0.01 %; nsc - no serial correlation; fish sampling were conducted four times: June 2-4, June 30-July 2, July 28-30 and December 13-16; fingerlings were stocked on December 16, 1993.

Table 8. Means and standard deviations of fish stocking, harvest, production, growth, and survival rate, feed fed and feed conversion in control ponds and ponds with standard wetlands, December 16, 1993-December 16, 1994

Item	Unit	Control (No Wetland) (N=3)	Standard (25%, 6.5 gpm) (N=3)
Fish stocking	lb/pond [ns]	24.7900 [a] (2.5895)	23.2667 [a] (0.1401)
	fish/pond [ns]	1250.0000 [a] (0.0000)	1252.3300 [a] (4.0415)
	lb/1000 fish [ns]	19.8300 [a] (2.0699)	18.5767 [a] (0.0777)
Fish harvest	lb/pond [ns]	765.5000 [a] (7.7781)	657.3333 [a] (49.3389)
	fish/pond [ns]	885.5000 [a] (79.9031)	867.6667 [a] (120.7905)
	lb/fish [ns]	0.9133 [a] (0.0902)	0.7633 [a] (0.0513)
Fish growth [ns]	lb/fish	0.8935 [a] (0.0885)	0.7448 [a] (0.0514)
Fish production [ns]	lb/pond	742.0000 [a] (7.0711)	634.0000 [a] (49.2747)
Fish survival rate [ns]	%	70.5000 [a] (6.3639)	69.3333 [a] (9.6090)
Feed fed [ns]	lb/pond	1714.0000 [a] (8.1853)	1708.0000 [a] (12.1244)
Feed conversion [ns]	lb of feed per lb of fish weight gained	2.3200 [a] (0.0282)	2.7033 [a] (0.1986)

Legend: Means with the same letter are not significantly different at 5%; numbers in parentheses are standard deviations; ns - not significant at 5%; n - number of ponds.

Table 9. Means and standard deviations of daily readings of dissolved oxygen and aeration time in ponds with variable wetland size and fixed flow rate by season, March 2-November 30, 1994

Variable	Unit	15%, 6.5 gpm	25%, 6.5 gpm	35%, 6.5 gpm	50%, 6.5 gpm
All seasons (March 2-November 30, 1994)					
A.M. dissolved oxygen [ns]	ppm	5.8433 [a] (1.7433)	6.0503[a] (1.5452)	5.8856[a] (1.8211)	6.1602[a] (1.8224)
P.M. dissolved oxygen [***]	ppm	8.2186 [b] (1.5217)	8.5299[a] (1.7770)	8.0583[b] (1.4516)	7.9303[b] (1.4408)
Aeration time[***]	hr/day	0.8230 [b] (3.0903)	0.5337[b] (3.0327)	0.4712[b] (3.0670)	1.7182[a] (5.4036)
Winter (March 2-Mar 19, 1994)					
A.M. dissolved oxygen [ns]	ppm	8.3545 [a] (1.2086)	8.5971[a] (0.6999)	8.9182[a] (0.4854)	8.9273[a] (0.6798)
P.M. dissolved oxygen [ns]	ppm	9.4889 [a] (0.9266)	9.2000[a] (0.7190)	9.2333[a] (0.5874)	9.3222[a] (0.5214)
Aeration time [ns]	hr/day	0.0000 [a] (0.0000)	0.0000 [a] (0.0000)	0.0000 [a] (0.0000)	0.0000 [a] (0.0000)
Spring (March 20-June 19, 1997)					
A.M. dissolved oxygen [***]	ppm	6.6493 [c] (1.3475)	6.9187[b,c] (1.2123)	7.2632[b] (1.1826)	7.6786[a] (0.8801)
P.M. dissolved oxygen [***]	ppm	8.4324 [b] (1.1981)	8.2990[b] (0.9981)	8.7691[a] (1.0910)	8.9420[a] (1.0680)
Aeration time [ns]	hr/day	0.0000 [a] (0.0000)	0.0000 [a] (0.0000)	0.0000 [a] (0.0000)	0.0000 [a] (0.0000)
Summer (June 20-September 21, 1994)					
A.M. dissolved oxygen [***]	ppm	4.5600 [b] (1.4007)	4.9652[a] (0.9798)	4.1759[c] (0.9509)	4.6193[b] (1.1966)
P.M. dissolved oxygen [***]	ppm	7.6373 [b] (1.6113)	8.2894[a] (1.9426)	7.0476[c] (1.2501)	6.9440[c] (1.1746)
Aeration time[***]	hr/day	2.3257 [a,b] (4.8635)	1.1257[b,c] (4.3655)	0.1685[c] (1.5809)	2.9473[a] (6.5377)

Fall (September 22-November 30, 1994)					
A.M. dissolved oxygen [ns]	ppm	6.3280 [a] (1.2995)	6.1690[a] (1.4250)	6.3200[a] (0.9609)	6.1385[a] (1.3533)
P.M. dissolved oxygen **	ppm	8.6236 [a,b] (1.5210)	9.0753[a] (2.2008)	8.5309[a,b] (1.3332)	7.9393[b] (1.2537)
Aeration time**	hr/day	0.0000 [c] (0.0000)	0.5370[b,c] (2.9770)	1.6893[a,b] (5.7864)	2.6698[a] (7.0130)

Legend: Means with the same letter are not significantly different at 5%; numbers in parentheses are standard deviations; ns - not significantly different at 5%; ** - significantly different at 5%; *** - significantly different at 0.01%.

Table 10. Means and standard deviations of weekly readings of selected water quality variables in ponds with variable wetland size and fixed flow rate during all seasons, March 2-November 30, 1994

Variable	Unit	15%, 6.5 gpm	25%, 6.5 gpm	35%, 6.5 gpm	50%, 6.5 gpm
Salinity **	ppt	0.7500 [a] (0.9805)	0.3500[b] (0.7293)	0.3750[b] (0.5856)	0.2250[b] (0.4229)
pH ***		6.9800 [a] (0.1884)	7.0618[a] (0.4821)	6.8505[a] (0.4305)	6.5327[b] (0.7993)
Ammonia ns	mg/l	0.0568 [a] (0.0616)	0.0412[a] (0.0467)	0.0810[a] (0.1823)	0.0604[a] (0.0969)
Nitrate ns	mg/l	0.1598 [a] (0.4638)	0.2062[a] (0.7287)	0.1604[a] (0.5001)	0.1483[a] (0.5176)
Nitrite ***	mg/l	0.0269 [a] (0.0532)	0.0047[b] (0.0064)	0.0043[b] (0.0057)	0.0092[b] (0.0201)
Phosphorous ns	mg/l	0.1772 [a] (0.2255)	0.1364[a] (0.2375)	0.1093[a] (0.3525)	0.0767[a] (0.1472)
Total suspended solids ***	mg/l	0.0149 [a] (0.0139)	0.0046[b] (0.0053)	0.0034[b] (0.0028)	0.0060[b] (0.0060)
Chlorophyll A **	mg/m^3	0.0142 [a] (0.0126)	0.0087[a,b] (0.0151)	0.0037[b] (0.0049)	0.0109[a] (0.0186)
Phaeophytin ns	mg/m^3	0.0077 [a] (0.0119)	0.0051[a] (0.0101)	0.0026[a] (0.0049)	0.0055[a] (0.0219)

Legend: Means with the same letter are not significantly different at 5%; numbers in parentheses are standard deviations; ns - not significant at 5%; *** - significant at 0.01%; **-significant at 1%.

Table 11. Means and standard deviations of weekly readings of selected water quality variables in ponds with variable wetland size and fixed flow rate during winter months, March 2-March 19, 1994

Variable	Unit	15%, 6.5 gpm	25%, 6.5 gpm	35%, 6.5 gpm	50%, 6.5 gpm
Salinity ***	ppt	1.6667 [a] (0.5773)	0.5556[d] (0.8819)	1.0000[b] (0.0000)	0.6667[c] (0.5773)
pH ***		7.2033 [a] (0.0642)	7.1156[b] (0.3298)	7.0567[c] (0.2458)	5.6267[d] (1.3096)
Ammonia ns	mg/l	0.0443 [a] (0.0237)	0.0450[a] (0.0240)	0.0168[a] (0.0029)	0.2382[a] (0.3040)
Nitrate***	mg/l	0.0575 [c] (0.0433)	0.1418[b] (0.1039)	0.0278[d] (0.0087)	0.1516[a] (0.1028)
Nitrite nitrogen ns	mg/l	0.0075 [a] (0.0025)	0.0067[a] (0.0047)	0.0049[a] (0.0016)	0.0057[a] (0.0031)
Phosphorous ns	mg/l	0.1450 [a] (0.2539)	0.0338[a] (0.1793)	0.1160[a] (0.1573)	0.1232[a] (0.1480)
Total suspended solids ns	mg/l	0.0031 [a] (0.0040)	0.0029[a] (0.0041)	0.0025[a] (0.0040)	0.0082[a] (0.0073)
Chlorophyll A ns	mg/m^3	0.0041 [a] (0.0063)	0.0025[a] (0.0040)	0.0051[a] (0.0046)	0.0415[a] (0.0623)
Phaeophytin ns	mg/m^3	- 0.0029 [a] (0.0074)	-0.0012[a] (0.0057)	-0.0046[a] (0.0051)	-0.0370[a] (0.0631)

Legend: Means with the same letter are not significantly different at 5%; numbers in parentheses are standard deviations; ns - not significantly different at 5%; *** - significantly different at 0.01%.

Table 12. Means and standard deviations of weekly readings of selected water quality variables in ponds with variable wetland size and fixed flow rate during spring months, March 20-June 19,1994

Variable	Unit	15%, 6.5 gpm	25%, 6.5 gpm	35%, 6.5 gpm	50%, 6.5 gpm
Salinity **	ppt	1.6154 [a] (1.0439)	0.7692[b] (1.0121)	0.8462[b] (0.6887)	0.5385[b] (0.5188)
pH ns		7.1285 [a] (0.1574)	7.1408[a] (0.5280)	7.2985[a] (0.4303)	7.2162[a] (0.6584)
Ammonia ns	mg/l	0.0623 [a] (0.0736)	0.0581[a] (0.0618)	0.1445[a] (0.2967)	0.0473[a] (0.0507)
Nitrate ns	mg/l	0.1397 [a] (0.1691)	0.1117[a] (0.1661)	0.1407[a] (0.2366)	0.0561[a] (0.0781)
Nitrite ns	mg/l	0.0026 [a] (0.0037)	0.0029[a] (0.0049)	0.0028[a] (0.0079)	0.0008[a] (0.0034)
Phosphorous ns	mg/l	0.1138 [a] (0.2489)	0.1087[a] (0.2514)	0.2476[a] (0.5855)	0.0502[a] (0.1893)
Total suspended solids *	mg/l	0.0048 [a] (0.0031)	0.0047[a] (0.0049)	0.0021[b] (0.0020)	0.0035[a,b] (0.0025)
Chlorophyll A ***	mg/m^3	0.0081 [a] (0.0051)	0.0023[c] (0.0024)	0.0016[c] (0.0014)	0.0059[b] (0.0050)
Phaeophytin ns	mg/m^3	0.0025 [a] (0.0044)	0.0017[a] (0.0018)	0.0013[a] (0.0012)	0.0017[a] (0.0016)

Legend: Means with the same letter are not significantly different at 5%; numbers in parentheses are standard deviations; ns - not significant at 5%; *** - significant at 0.01%; **- significant at 1%; * - significant at 5%.

Table 13. Means and standard deviations of weekly readings of selected water quality variables in ponds with variable wetland size and fixed flow rate during summer months, June 20-September 21, 1994

Variable	Unit	15%, 6.5 gpm	25%, 6.5 gpm	35%, 6.5 gpm	50%, 6.5 gpm
Salinity [ns]	ppt	0.2857 [a] (0.4688)	0.1667 [a] (0.3772)	0.1714 [a] (0.2672)	0.0000 [a] (0.0000)
pH [***]		6.8843 [a] (0.1297)	6.9981 [a] (0.6016)	6.5321 [b] (0.1056)	6.2107 [c] (0.6619)
Ammonia [*]	mg/l	0.0741 [a] (0.0687)	0.0304 [a] (0.0346)	0.0741 [a] (0.1029)	0.0542 [a] (0.0450)
Nitrate [ns]	mg/l	0.2872 [a] (0.7651)	0.4191 [a] (1.1991)	0.2907 [a] (0.8150)	0.2952 [a] (0.8688)
Nitrite [***]	mg/l	0.0646 [a] (0.0780)	0.0027 [b] (0.0043)	0.0047 [b] (0.0056)	0.0169 [b] (0.0323)
Phosphorous [ns]	mg/l	0.1724 [a] (0.2144)	0.1103 [a] (0.1957)	0.0435 [a] (0.1321)	0.0528 [a] (0.1169)
Total suspended solids [***]	mg/l	0.0143 [a] (0.0079)	0.0049 [b] (0.0057)	0.0052 [b] (0.0030)	0.0054 [b] (0.0021)
Chlorophyll A [*]	mg/m^3	0.0128 [a] (0.0109)	0.0108 [a] (0.0130)	0.0022 [b] (0.0014)	0.0096 [a] (0.0117)
Phaeophytin [ns]	mg/m^3	0.0073 [a] (0.0092)	0.0073 [a] (0.0118)	0.0048 [a] (0.0061)	0.0091 [a] (0.0046)

Legend: Means with the same letter are not significantly different at 5%; numbers in parentheses are standard deviations; ns - not significant at 5%; *** - significant at 0.01%; **-significant at 1%; * - significant at 5%.

Table 14. Means and standard deviations of weekly readings of selected water quality variables in ponds with variable wetland size and fixed flow rate during fall months, September 22-November 30, 1994

Variable	Unit	15%, 6.5 gpm	25%, 6.5 gpm	35%, 6.5 gpm	50%, 6.5 gpm
Salinity [ns]	ppt	0.0000 (0.0000)	0.0000 (0.0000)	0.0000 (0.0000)	0.0000 (0.0000)
pH [***]		6.8540 [b] (0.1235)	7.0320 [a] (0.1748)	6.6520 [c] (0.1463)	6.3670 [d] (0.1911)
Ammonia [ns]	mg/l	0.0351 [a] (0.0376)	0.0333 [a] (0.0384)	0.0275 [a] (0.0313)	0.0330 [a] (0.0465)
Nitrate [ns]	mg/l	0.0383 [a] (0.0469)	0.0503 [a] (0.0566)	0.0435 [a] (0.0451)	0.0616 [a] (0.0791)
Nitrite [ns]	mg/l	0.0116 [a] (0.0050)	0.0093 [a] (0.0085)	0.0057 [a] (0.0027)	0.0107 [a] (0.0059)
Phosphorous [**]	mg/l	0.2762 [a] (0.1999)	0.2399 [a] (0.2630)	0.0196 [b] (0.0848)	0.1305 [a,b] (0.1256)
Total suspended solids [***]	mg/l	0.0327 [a] (0.0138)	0.0048 [b] (0.0058)	0.0029 [d] (0.0019)	0.0095 [b] (0.0103)
Chlorophyll A [*]	mg/m^3	0.0274 [a] (0.0141)	0.0160 [a,b] (0.0236)	0.0085 [b] (0.0078)	0.0103 [b] (0.0080)
Phaeophytin [*]	mg/m^3	0.0184 [a] (0.0161	0.0084 [a,b] (0.0128)	0.0035 [b] (0.0038)	0.0184 [a] (0.0186)

Legend: Means with the same letter are not significantly different at 5%; numbers in parentheses are standard deviations; ns - not significant at 5%; *** - significant at 0.01%; **- significant at 1%; * - significant at 5%.

Table 15. Log-linear regression results with the logarithm of individual weights in ponds with variable wetland size and fixed water flow rate as dependent variable, June 2-December 16, 1994

Variable	15%, 6.5 gpm	25%, 6.5 gpm	35%, 6.5 gpm	50%, 6.5 gpm
Intercept	2.7070*** (0.1545)	1.9088*** (0.0725)	2.0785*** (0.2221)	1.8559*** (0.1451)
Sampling date	0.0094*** (0.0006)	0.0118*** (0.0003)	0.0111*** (0.0009)	0.0123*** (0.0006)
R-squared	0.6364	0.8127	0.6607	0.8001
F-statistic	208.29***	1440.94***	121.72***	404.31***
D-W statistic	1.94 nsc	1.82 nsc	2.01 nsc	1.93 nsc
Number of observation	121	364	129	103

Legend: Numbers in parentheses are standard errors; *** - significant at 0.01 %; nsc - no serial correlation; fish sampling was conducted four times: June 2-4, June 30-July 2, July 28-30 and December 13-16; fingerlings were stocked on December 16, 1993.

Table 16. Means of fish stocking, harvest, production, growth, and survival rate, feed fed and feed conversion in ponds with variable wetland size and fixed flow rate, December 16, 1993-December 16, 1994

Item	Unit	15%, 6.5 gpm (N=1)	25%, 6.5 gpm (N=3)	35%, 6.5 gpm (N=1)	50%, 6.5 gpm (N=1)
Fish stocking	lb/pond ***	60.1900 a	23.2667 d	26.6400 c	50.9300 b
	fish/pond ns	1250.0000 a	1252.3333 a	1250.0000 a	1250.0000 a
	lb/1000 fish ***	48.1500 a	18.5767 d	21.3100 c	40.7400 b
Fish harvest	lb/pond ns	814.0000 a	657.3333 a	718.0000 a	666.0000 a
	fish/pond ns	1225.0000 a	867.6667 a	892.0000 a	1114.0000 a
	lb/fish ns	0.6600 a	0.7633 a	0.8000 a	0.6000 a
Fish production ns	lb/pond	754.0000 a	634.0000 a	691.0000 a	615.0000 a
Fish survival rate ns	%	98.0000 a	69.3333 a	71.0000 a	89.0000 a
Fish growth	lb/fish	0.6118 a	0.7448 a	0.7787 a	0.5593 a
Feed fed ns	lb/pond	1774.0000 a	1708.0000 a	1700.0000 a	1744.0000 a
Feed conversion ns	lb of feed per lb of weight gained	2.3500 a	2.7033 a	2.4600 a	2.8400 a

Legend: Means with the same letter are not significantly different at 5%; ** - significant at 0.01%; ns -not significant at 5%; n - number of ponds.

Table 17. Means and standard deviations of daily readings of dissolved oxygen and aeration time in ponds with fixed wetland size and variable flow rate by season, March 2-November 30, 1994

Variable	Unit	25%, 3.25 gpm	25%, 6.5 gpm	25%, 13 gpm	25%, 26 gpm
All seasons (March 2-November 30, 1004)					
A.M. dissolved oxygen ***	ppm	6.5159[a] (1.3932)	6.0503[b] (1.5452)	5.9196[b] (1.8228)	5.7950[b] (1.6669)
P.M. dissolved oxygen ***	ppm	8.7684[a] (1.3455)	8.5299[a] (1.7770)	8.5849[a] (1.4739)	7.5124[b] (1.3887)
Aeration time ***	hr/day	0.0600[b] (0.9404)	0.5337[b] (3.0327)	0.1097[b] (0.7823)	1.5458[a] (5.1962)
Winter (March 2-March 19, 1994)					
A.M. dissolved oxygen ns	ppm	8.6364[a] (0.5045)	8.5971[a] (0.6999)	8.9444[a] (0.8079)	8.7455[a] (0.6846)
P.M. dissolved oxygen ns	ppm	8.9667[a] (0.5292)	9.2000[a] (0.7190)	9.1750[a] (0.7265)	9.3889[a] (0.6373)
Aeration time ns	hr/day	0.0000[a] (0.0000)	0.0000[a] (0.0000)	0.0000[a] (0.0000)	0.0000[a] (0.0000)
Spring (March 20-June 19, 1994)					
A.M. dissolved oxygen ns	ppm	7.1557[a] (0.9716)	6.9187[a] (1.2123)	7.1386[a] (1.1695)	6.7443[a] (1.1463)
P.M. dissolved oxygen ***	ppm	8.4357[b] (0.7458)	8.2990[b] (0.9981)	9.0667[a] (1.1122)	8.1853[b] (1.0303)
Aeration time ns	hr/day	0.0000[a] (0.0000)	0.0000[a] (0.0000)	0.0000[a] (0.0000)	0.0000[a] (0.0000)
Summer (June 20-September 21, 1994)					
A.M. dissolved oxygen ***	ppm	5.4534[a] (0.9752)	4.9652[b] (0.9798)	4.2432[c] (0.8420)	4.3727[c] (0.9844)
P.M. dissolved oxygen ***	ppm	8.5329[a] (1.1903)	8.2894[a] (1.9426)	7.6212[b] (1.2417)	6.6376[c] (1.3730)
Aeration time **	hr/day	0.1657[b] (1.5634)	1.1251[a,b] (4.3655)	0.3044[b] (1.2849)	1.9716[a] (5.4465)

Fall (September 22-November 30, 1994)						
A.M. dissolved oxygen **	ppm	7.0137[a] (1.3003)	6.1690[b] (1.4250)	6.5923[a,b] (1.4408)	6.3000[b] (1.2640)
P.M. dissolved oxygen ***	ppm	9.5370[a] (1.8859)	9.0753[a] (2.2007)	9.3696[a] (1.5017)	7.7214[b] (1.0074)
Aeration time ***	hr/day	0.0000[b] (0.0000)	0.5370[b] (2.9770)	0.0000[b] (0.0000)	3.4080[a] (7.7424)

Legend: Means with the same letter are not significantly different at 5%; numbers in parentheses are standard deviations; *** - significant at 0.01%; ns - not significant; ** - significant at 1%.

Table 18. Means and standard deviations of weekly readings of selected water quality variables in ponds with fixed wetland size and variable flow rate during all seasons, March 2-November 30, 1994

Variable	Unit	25%, 3.25 gpm	25%, 6.5 gpm	25%, 13 gpm	25%, 26 gpm
Salinity ***	ppt	0.1250 [b] (0.3349)	0.3500 [a] (0.7293)	0.0750 [b] (0.2667)	0.4750 [a] (0.6400)
pH ***		7.3010 [a] (0.4068)	7.0618 [b] (0.4821)	7.0632 [b] (0.4258)	6.8857 [b] (0.3466)
Ammonia ns	mg/l	0.0378 [a] (0.0502)	0.0412 [a] (0.0467)	0.0330 [a] (0.0375)	0.0545 [a] (0.0630)
Nitrate ns	mg/l	0.2410 [a] (0.7997)	0.2061 [a] (0.7287)	0.2649 [a] (0.7021)	0.1829 [a] (0.6309)
Nitrite *	mg/l	0.0081 [a,b] (0.0081)	0.0047 [b] (0.0064)	0.0054 [b] (0.0073)	0.0109 [a] (0.0147)
Phosphorous ns	mg/l	0.2169 [a] (0.3451)	0.1364 [a] (0.2374)	0.1174 [a] (0.1213)	0.1648 [a] (0.8917)
Total suspended solids ***	mg/l	0.0166 [a] (0.0111)	0.0046 [c] (0.0053)	0.0109 [b] (0.0114)	0.0027 [c] (0.0023)
Chlorophyll A ***	mg/m^3	0.0237 [a] (0.0277)	0.0087 [c] (0.0151)	0.0154 [b] (0.0122)	0.0042 [c] (0.0085)
Phaeophytin ***	mg/m^3	0.0165 [a] (0.0273)	0.0051 [b,c] (0.0101)	0.0101 [b] (0.0175)	0.0024 [c] (0.0059)

Legend: Means with the same letter are not significantly different at 5 %; numbers in parentheses are standard deviations; *** - significant at 0.01%; ns - not significant at 5%; ** - significant at 0.01%; * - significant at 1%.

Table 19. Means and standard deviations of weekly readings of selected water quality variables in ponds with fixed wetland size and variable flow rate during winter months, March 2-March 19, 1994

Variable	Unit	25%, 3.25 gpm	25%, 6.5 gpm	25%, 13 gpm	25%, 26 gpm
Salinity ***	ppt	0.0000[c] (0.0000)	0.5556[b] (0.8819)	0.0000[d] (0.0000)	1.0000[a] (0.0000)
pH ***		7.3333[b] (0.1002)	7.1156[d] (0.3299)	7.2900[c] (0.0755)	7.5600[a] (0.2551)
Ammonia ***	mg/l	0.0299[b] (0.0071)	0.0451[a] (0.0240)	0.0268[b] (0.0133)	0.0173[c] (0.0062)
Nitrate ***	mg/l	0.0418[b] (0.0101)	0.1418[a] (0.1040)	0.0332[d] (0.0059)	0.0353[c] (0.0146)
Nitrite ns	mg/l	0.0051[a] (0.0026)	0.0068[a] (0.0047)	0.0088[a] (0.0038)	0.0035[a] (0.0034)
Phosphorous ns	mg/l	0.0144[a] (0.0981)	0.0338[a] (0.1794)	0.1812[a] (0.1661)	0.1595[a] (0.2622)
Total suspended solids ns	mg/l	0.0059[a] (0.0093)	0.0029[a] (0.0041)	0.0053[a] (0.0069)	0.0043[a] (0.0044)
Chlorophyll A ns	mg/m^3	0.0028[a] (0.0023)	0.0025[a] (0.0040)	0.0020[a] (0.0068)	0.0049[a] (0.0100)
Phaeophytin ns	mg/m^3	-0.0019[a] (0.0032)	-0.0011[a] (0.0058)	0.0006[a] (0.0097)	-0.0045[a] (0.0103)

Legend: Means with the same letter are not significantly different at 5 %; numbers in parentheses are standard deviations; *** - significant at 0.01%; ns - not significant at 5%; ** - significant at 0.01%; * - significant at 1%.

Table 20. Means and standard deviations of weekly readings of selected water quality variables in ponds with fixed wetland size and variable flow rate during spring months, March 19-June 19, 1994

Variable	Unit	25%, 3.25 gpm	25%, 6.5 gpm	25%, 13 gpm	25%, 26 gpm
Salinity ***	ppt	0.3077[b] (0.4803)	0.7692[a] (1.0121)	0.1538[b] (0.3755)	1.0769[a] (0.6405)
pH **		7.4469[a] (0.1360)	7.1408[b] (0.5280)	7.5077[a] (0.4314)	7.1669[b] (0.1769)
Ammonia ns	mg/l	0.0564[a] (0.0604)	0.0581[a] (0.0618)	0.0406[a] (0.0463)	0.0416[a] (0.0468)
Nitrate ns	mg/l	0.2563[a] (0.5548)	0.1117[a] (0.1662)	0.4533[a] (0.7544)	0.1331[a] (0.2542)
Nitrite ns	mg/l	0.0051[a] (0.0115)	0.0029[a] (0.0049)	0.0027[a] (0.0051)	0.0018[a] (0.0037)
Phosphorous ns	mg/l	0.1171[a] (0.2321)	0.1087[a] (0.2515)	0.1405[a] (0.1045)	0.4450[a] (1.5499)
Total suspended solids ***	mg/l	0.0080[b] (0.0045)	0.0047[b,c] (0.0049)	0.0143[a] (0.0187)	0.0011[c] (0.0008)
Chlorophyll A ***	mg/m^3	0.0070[b] (0.0043)	0.0023[c] (0.0024)	0.0117[a] (0.0074)	0.0014[d] (0.0004)
Phaeophytin ***	mg/m^3	0.0043[a] (0.0034)	0.0017[b] (0.0018)	0.0033[a] (0.0029)	0.0001[c] (0.0009)

Legend: Means with the same letter are not significantly different at 5 %; numbers in parentheses are standard deviations; *** - significant at 0.01%; ns - not significant at 5%; ** - significant at 0.01%.

Table 21. Means and standard deviations of weekly readings of selected water quality variables in ponds with fixed wetland size and variable flow rate during summer months, June 20-September 21, 1994

Variable	Unit	25%, 3.25 gpm	25%, 6.5 gpm	25%, 13 gpm	25%, 26 gpm
Salinity [ns]	ppt	0.0714[a] (0.2673)	0.1667[a] (0.3172)	0.0714[a] (0.2673)	0.1429[a] (0.3631)
pH [**]		7.2400[a] (0.6454)	6.9981[a,b] (0.6016)	6.7514[b] (0.1264)	6.6586[b] (0.1098)
Ammonia [**]	mg/l	0.0299[b] (0.0551)	0.0303[b] (0.0346)	0.0366[b] (0.0409)	0.0898[a] (0.0842)
Nitrate [ns]	mg/l	0.4147[a] (1.2487)	0.4191[a] (1.1991)	0.3109[a] (0.9268)	0.3568[a] (1.0387)
Nitrite [***]	mg/l	0.0077[b] (0.0050)	0.0027[b] (0.0043)	0.0049[b] (0.0059)	0.0165[a] (0.0195)
Phosphorous [ns]	mg/l	0.1973[a] (0.1505)	0.1103[a] (0.1957)	0.0979[a] (0.1098)	0.0450[a] (0.1726)
Total suspended solids [***]	mg/l	0.0215[a] (0.0114)	0.0049[c] (0.0057)	0.0089[b] (0.0044)	0.0040[d] (0.0025)
Chlorophyll A [***]	mg/m^3	0.0234[a] (0.0123)	0.0108[b] (0.0134)	0.0123[b] (0.0050)	0.0076[b] (0.0134)
Phaeophytin [ns]	mg/m^3	0.0137[a] (0.0149)	0.0073[a] (0.0118)	0.0071[a] (0.0034)	0.0052[a] (0.0073)

Legend: Means with the same letter are not significantly different at 5 %; numbers in parentheses are standard deviations; *** - significant at 0.01%; ns - not significant at 5%; ** - significant at 0.01%.

Table 22. Means and standard deviations of weekly readings of selected water quality variables in ponds with fixed wetland size and variable flow rate during fall months, September 22-November 20, 1994

Variable	Unit	25%, 3.25 gpm	25%, 6.5 gpm	25%, 13 gpm	25%, 26 gpm
Salinity	ppt	0.0000 (0.0000)	0.0000 (0.0000)	0.0000 (0.0000)	0.0000 (0.0000)
pH ***		7.1870[a] (0.1933)	7.0323[b] (0.1748)	6.8540[c] (0.1049)	6.6360[d] (0.1782)
Ammonia ns	mg/l	0.0273[a] (0.0305)	0.0333[a] (0.0384)	0.0200[a] (0.0220)	0.0330[a] (0.0300)
Nitrate ns	mg/l	0.0379[a] (0.0480)	0.0503[a] (0.0566)	0.0252[a] (0.0219)	0.0486[a] (0.0512)
Nitrite ns	mg/l	0.0134[a] (0.0048)	0.0093[a] (0.0085)	0.0089[a] (0.0107)	0.0170[a] (0.0117)
Phosphorous **	mg/l	0.4350[a] (0.5726)	0.2400[a,b] (0.2630)	0.0957[b,c] (0.1500)	0.0304[c] (0.0840)
Total suspended solids ***	mg/l	0.0242[a] (0.0080)	0.0048[c] (0.0058)	0.0114[b] (0.0056)	0.0027[c] (0.0016)
Chlorophyll A ***	mg/m^3	0.0520[a] (0.0405)	0.0160[b,c] (0.0236)	0.0287[b] (0.0153)	0.0030[c] (0.0016)
Phaeophytin ***	mg/m^3	0.0419[a] (0.0431)	0.0084[c] (0.0128)	0.0261[b] (0.0299)	0.0039[c] (0.0037)

Legend: Means with the same letter are not significantly different at 5 %; numbers in parentheses are standard deviations; *** - significant at 0.01%; ns - not significant at 5%; ** - significant at 0.01%.

Table 23. Log-linear regression results with the logarithm of individual weights in ponds with fixed wetland size and variable water flow rate as dependent variable, Jun 2-Dec 16, 1994

Variable	25%, 3.25 gpm	25%, 6.5 gpm	25%, 13 gpm	25%, 26 gpm
Intercept	1.7798*** (0.1284)	1.9088*** (0.0725)	2.4160*** (0.1746)	2.4884*** (0.1576)
Sampling date	0.0123*** (0.0005)	0.0118*** (0.0003)	0.0096*** (0.0007)	0.0095*** (0.0006)
R-squared	0.8178	0.8127	0.7371	0.6604
F-statistic	498.43***	1440.94***	155.68***	202.24***
D-W statistic	1.92 nsc	1.82 nsc	2.00 nsc	1.99 nsc
Number of observation	113	364	115	106

Legend: Numbers in parentheses are standard errors; *** - significant at 0.01 %; nsc - no serial correlation; fish sampling were conducted four times: June 2-4, June 30-July 2, July 28-30 and December 13-16; fingerlings were stocked on December 16, 1993.

Table 24. Means of fish stocking, harvest, production, and survival rate, feed fed, and feed conversion in ponds with fixed wetland size and variable flow rate, December 16, 1993-December 16, 1994

Item	Unit	25%, 3.25 gpm	25%, 6.5 gpm	25%, 13 gpm	25%, 26 gpm
Fish stocking	lb/pond***	22.9900 [c]	23.2667 [c]	29.7100 [b]	54.6400 [a]
	fish/pond [ns]	1250.0000 [a]	1252.3333 [a]	1250.0000 [a]	1250.0000 [a]
	lb/1000 fish***	18.3900 [c]	18.5767 [c]	23.7600 [b]	43.7100 [a]
Fish harvest	lb/pond [ns]	715.0000 [a]	657.3333 [a]	727.0000 [a]	647.0000 [a]
	fish/pond [ns]	931.0000 [a]	867.6667 [a]	1068.0000 [a]	992.0000 [a]
	lb/fish [ns]	0.7700 [a]	0.7633 [a]	0.6800 [a]	0.6500 [a]
Fish production [ns]	lb/pond	692.0000 [a]	634.0000 [a]	698.0000 [a]	593.0000 [a]
Survival rate [ns]	%	74.0000 [a]	69.3333 [a]	85.0000 [a]	79.0000 [a]
Fish growth [ns]	lb/fish	0.7516 [a]	0.7448 [a]	0.6562 [a]	0.6063 [a]
Feed fed [ns]	lb/pond	1701.0000 [a]	1708.0000 [a]	1711.0000 [a]	1762.0000 [a]
Feed conversion [ns]	lb of feed per lb of weight gained	2.4600 [a]	2.7033 [a]	2.4500 [a]	2.9700 [a]

Legend: Means with the same letter are not statistically significant at 5%; *** - significant at 0.01%; ns - not significant at 5%; n - number of ponds.

Table 25. Means and standard deviations of electricity[1] use in control ponds and ponds with standard wetlands by season March 2-December 1, 1994

Season	Unit	Control (no wetland)	Standard (25%, 6.5 gpm)
All seasons*** (March 2-November 30, 1994)	kwh/wk	3.8718[b] (6.5932)	14.4360[a] (8.6813)
Winter months*** (March 2-March 19, 1994)	kwh/wk	0.0667[b] (0.1032)	15.6000[a] (2.5044)
Spring months*** (March 20-June 19, 1994)	kwh/wk	0.0667[b] (0.1737)	13.7026[a] (6.3025)
Summer months*** (June 20-September 21, 1994)	kwh/wk	4.6667[b] (7.3805)	16.3809[a] (10.5413)
Fall months* (September 22-November 20, 1994)	kwh/wk	8.4667[b] (7.1834)	12.4333[a] (8.9777)

Legend: Means with the same letter are not significantly different at 5 %; numbers in parentheses are standard deviations; * - significantly different at 5%; *** - significantly different at 0.01%; 1 - electricity used in water recirculation system.

Table 26. Means and standard deviations of electricity[1] use in ponds with variable wetland size and fixed flow rate by season, March 2-December 1, 1994

Season	Unit	15%, 6.5 gpm	25% 6.5 gpm	35% 6.5 gpm	50% 6.5 gpm
All seasons*** (March 2-November 30, 1994)	kwh/wk	18.2820 [a,b] (13.6314)	14.4360[b,c] (8.6813)	11.5641[b] (8.5689)	21.7692[a] (11.2253)
Winter months*** (March 2-March 19, 1994)	kwh/wk	32.6000 [a] (0.0000)	15.6000[c] (2.5044)	15.6000[d] (0.0000)	23.2000[b] (0.0000)
Spring months*** (March 20-June 19, 1994)	kwh/wk	31.2923 [a] (10.4018)	13.7026[b] (6.3025)	15.2154[b] (6.0572)	17.5846[b] (7.7194)
Summer months*** (June 20-September 21, 1994)	kwh/wk	10.3571 [b] (9.0009)	16.3810[b] (10.5413)	12.5000[b] (10.1584)	28.5000[a] (13.3114)
Fall months** (September 22-November 20, 1994)	kwh/wk	9.6000 [b,c] (7.1949)	12.4333[a,b] (8.9777)	4.7000[c] (5.9545)	17.5000[a] (8.9536)

Legend: Means with the same letter are not significantly different at 5 %; numbers in parentheses are standard deviations; *** - statistically significant at 0.01%; ** - statistically significant at 5%; 1 - electricity used in water recirculation system.

Table 27. Average electricity[1] consumption in ponds with variable flow rate and fixed wetland size by season, March 2-December 1, 1994

Season	Unit	25%, 3.25 gpm	25% 6.5 gpm	25% 13 gpm	25% 26 gpm
All seasons*** (March 2-November 30, 1994)	kwh/wk	17.2540 c (9.7702)	14.4360 c (8.6813)	44.1282 b (13.2991)	51.8974 a (21.0817)
Winter months*** (March 2-March 19, 1994)	kwh/wk	25.8000 c (0.0000)	15.6000 d (2.5044)	30.4000 b (0.0000)	35.4000 a (0.0000)
Spring months*** (March 20-June 19, 1994)	kwh/wk	20.4153 c (9.6431)	13.7026 c (6.3025)	33.4769 b (8.6801)	48.2462 a (17.4673)
Summer months*** (June 20-September 21, 1994)	kwh/wk	15.2143 b (7.5057)	16.3810 c (10.5413)	51.1421 b (12.2466)	62.8571 a (17.5668)
Fall months** (September 22-November 20, 1994)	kwh/wk	14.3000 b (12.2819)	12.4333 b (8.9777)	50.9000 a (9.8200)	44.6000 a (26.4237)

Legend: Means with the same letter are not significantly different at 5 %; numbers in parentheses are standard deviations; *** - significantly different at 0.01%; 1 - electricity used in water recirculation system.

Table 28. Results of off flavor test[1] conducted on catfish harvested in November 1994.

Treatment	Number of ponds	Mean	Standard deviation
Control vs. standard ponds [ns]			
No wetland	3	3.0000[a]	2.0000
25%, 6.5 gpm	3	3.3333[a]	1.1547
Ponds with variable wetland sizes and fixed flow rates [ns]:			
15%, 6.5 gpm	1	4.0000[a]	N/A
25%, 6.5 gpm	3	3.3333[a]	1.1547
35%, 6.5 gpm	1	4.0000[a]	N/A
50%, 6.5 gpm	1	3.3333[a]	N/A
Ponds with variable flow rates and fixed wetland sizes [ns]:			
25%, 3.25 gpm	1	2.0000[a]	N/A
25%, 6.5 gpm	3	3.3333[a]	1.1547
25%, 13 gpm	1	4.0000[a]	N/A
25%, 26 gpm	1	4.0000[a]	N/A

Legend: N/A - not applicable; ns - not significant at 5%; 1- flavor scale is from 0 (on flavor) to 4 (worst off flavor), (Rick Hood, Delta Pride Catfish, Inc., pers. comm.).

Table 29. Means and percent change of weekly readings of selected water quality variables in ponds with variable wetland sizes and fixed water flow rates during all seasons, March 2-November 29, 1994

Variable	Unit	15%, 6.5 gpm			25%, 6.5 gpm			35%, 6.5 gpm			50%, 6.5 gpm		
		Inlet	Outlet	Change	Inlet	Outlet	Change	Inlet	Outlet	Change	Inlet	Outlet	Change
Salinity	ppm	0.6250	0.6250	0.0%	0.3333	0.2833	-15.0%	0.3000	0.3250	8.3%	0.2500	0.2000	-20.0%
pH		6.1445	5.3578	-12.8%	6.6950	6.6297	-1.0%	5.8403	5.5228	-5.4%	4.8088	3.7786	-21.4%
Ammonia	mg/l	0.2911	0.2301	-21.0%	0.0508	0.0612	20.5%	0.0561	0.0485	-13.5%	0.2416	0.2953	22.2%
Nitrate	mg/l	0.3923	0.3026	-22.9%	0.2005	0.2109	5.2%	0.1395	0.1332	-4.5%	0.3130	0.8539	172.8%
Nitrite	mg/l	0.0403	0.0034	-91.6%	0.0076	0.0071	-6.6%	0.0028	0.0021	-25.0%	0.0046	0.0012	-73.9%
Phosphorous	mg/l	0.1087	0.0821	-24.5%	0.1800	0.1442	-19.9%	0.1642	0.0386	-76.5%	0.0343	0.0119	-65.3%
Total suspended solids	mg/l	0.0182	0.0032	-82.4%	0.0087	0.0081	-6.9%	0.0037	0.0027	-27.0%	0.0048	0.0031	-35.4%

Legend: Negative (Positive) change - percent reduction (increase) in concentration.

Table 30. Means and percent change of weekly readings of selected water quality variables in ponds with variable wetland sizes and fixed water flow rates during winter months, March 2-March 19, 1994

Variable	Unit	15%, 6.5 gpm			25%, 6.5 gpm			35%, 6.5 gpm			50%, 6.5 gpm		
		Inlet	Outlet	Change	Inlet	Outlet	Change	Inlet	Outlet	Change	Inlet	Outlet	Change
Salinity	ppm	0.6667	0.6667	0.0%	0.2222	0.2222	0.0%	0.6667	0.6667	0.0%	0.6667	0.6667	0.0%
pH		2.9833	2.9433	-1.3%	5.3789	5.3544	-0.5%	4.2033	4.1733	-0.7%	3.3833	3.3667	-0.5%
Ammonia	mg/l	1.4475	1.0002	-30.9%	0.1893	0.3021	59.6%	0.0274	0.0352	28.5%	0.9950	1.2203	22.6%
Nitrate	mg/l	1.6118	0.9962	-38.2%	0.1589	0.1049	-34.0%	0.0722	0.0553	-23.4%	1.3674	1.5646	14.4%
Nitrite	mg/l	0.0033	0.0029	-12.1%	0.0189	0.0188	-0.5%	0.0031	0.0041	32.3%	0.0029	0.0033	13.8%
Total phosphorous	mg/l	0.0362	0.2392	560.8%	0.2851	0.2586	-9.3%	0.0145	0.0652	349.7%	0.0580	0.0290	-50.0%
Total suspended solids	mg/l	0.0097	0.0064	-34.0%	0.0217	0.0220	1.4%	0.0044	0.0083	88.6%	0.0041	0.0065	58.5%

Legend: Negative (Positive) change - percent reduction (increase) in concentration.

Table 31. Means and percent change of weekly readings of selected water quality variables in ponds with variable wetland sizes and fixed water flow rates during spring months, March 20-June 19, 1994

Variable	Unit	15%, 6.5 gpm			25%, 6.5 gpm			35%, 6.5 gpm			50%, 6.5 gpm		
		Inlet	Outlet	Change	Inlet	Outlet	Change	Inlet	Outlet	Change	Inlet	Outlet	Change
Salinity	ppm	1.4615	1.4615	0.0%	0.7949	0.6667	-16.1%	0.7693	0.7693	0.0%	0.6154	0.4615	-25.0%
pH		5.7738	5.6046	-2.9%	6.4249	6.3651	-0.9%	5.5677	5.4762	-1.6%	4.0992	3.6084	-12.0%
Ammonia	mg/l	0.4572	0.3498	-23.5%	0.0587	0.0691	17.7%	0.0771	0.0624	-19.1%	0.4184	0.5388	28.8%
Nitrate	mg/l	0.4285	0.3186	-25.6%	0.1196	0.1410	17.9%	0.1520	0.1887	24.1%	0.3489	1.9089	447.1%
Nitrite	mg/l	0.0028	0.0018	-35.7%	0.0067	0.0061	-9.0%	0.0008	0.0006	-25.0%	0.0011	0.0010	-9.1%
Total phosphorous	mg/l	0.0167	0.1205	621.6%	0.2767	0.1843	-33.4%	0.4199	0.0635	-84.9%	0.0167	0.0685	310.2%
Total suspended solids	mg/l	0.0217	0.0018	-91.7%	0.0083	0.0072	-13.3%	0.0039	0.0023	-41.0%	0.0071	0.0009	-87.3%

Legend: Negative (Positive) change - percent reduction (increase) in concentration.

Table 32. Means and percent change of weekly readings of selected water quality variables in ponds with variable wetland sizes and fixed water flow rates during summer months, June 20-September 21, 1994

Variable	Unit	15%, 6.5 gpm			25%, 6.5 gpm			35%, 6.5 gpm			50%, 6.5 gpm		
		Inlet	Outlet	Change	Inlet	Outlet	Change	Inlet	Outlet	Change	Inlet	Outlet	Change
Salinity	ppm	0.2857	0.2857	0.0%	0.1667	0.1429	-14.3%	0.0000	0.0714	??	0.0000	0.0000	0.0%
pH		6.6814	5.3557	-19.8%	6.9452	6.7905	-2.2%	6.4050	5.8935	-8.0%	5.5321	4.1193	-25.5%
Ammonia	mg/l	0.0746	0.0971	30.2%	0.0291	0.0285	-2.1%	0.0630	0.0523	-17.0%	0.0612	0.0644	5.2%
Nitrate	mg/l	0.3573	0.3311	-7.3%	0.3971	0.4240	6.8%	0.2155	0.1731	-19.7%	0.2419	0.2993	23.7%
Nitrite	mg/l	0.1035	0.0024	-97.7%	0.0034	0.0046	35.3%	0.0029	0.0033	13.8%	0.0073	0.0001	-98.6%
Total phosphorous	mg/l	0.1383	0.0901	-34.9%	0.1056	0.1429	35.3%	0.0093	0.0155	66.7%	0.0621	0.0186	-70.0%
Total suspended solids	mg/l	0.0098	0.0028	-71.4%	0.0053	0.0059	11.3%	0.0031	0.0023	-25.8%	0.0040	0.0031	-22.5%

Legend: Negative (Positive) change - percent reduction (increase) in concentration.

Table 33. Means and percent change of weekly readings of selected water quality variables in ponds with variable wetland sizes and fixed water flow rates during fall months, September 22-November 30, 1994

Variable	Unit	15%, 6.5 gpm			25%, 6.5 gpm			35%, 6.5 gpm			50%, 6.5 gpm		
		Inlet	Outlet	Change	Inlet	Outlet	Change	Inlet	Outlet	Change	Inlet	Outlet	Change
Salinity	ppm	0.0000	0.0000	0.0%	0.0000	0.0000	0.0%	0.0000	0.0000	0.0%	0.0000	0.0000	0.0%
pH		6.8230	5.7640	-15.5%	7.0907	7.1310	0.6%	5.8950	5.4690	-7.2%	5.1460	3.6470	-29.1%
Ammonia	mg/l	0.0313	0.0295	-5.8%	0.0293	0.0246	-16.0%	0.0278	0.0291	4.7%	0.0382	0.0247	-35.3%
Nitrate	mg/l	0.0285	0.0338	18.6%	0.0430	0.0355	-17.4%	0.0369	0.0284	-23.0%	0.0494	0.0457	-7.5%
Nitrite	mg/l	0.0117	0.0070	-40.2%	0.0114	0.0085	-25.4%	0.0032	0.0018	-43.8%	0.0059	0.0023	-61.0%
Total phosphorous	mg/l	0.2088	-0.0261	-112.5%	0.1268	0.0594	-53.2%	0.0935	0.0304	-67.5%	0.0544	-0.0761	-239.9%
Total suspended solids	mg/l	0.0282	0.0046	-83.7%	0.0099	0.0084	-15.2%	0.0041	0.0020	-51.2%	0.0034	0.0051	50.0%

Legend: Negative (Positive) change - percent reduction (increase) in concentration.

Table 34. Means and percent change of weekly readings of selected water quality variables in ponds with fixed wetland sizes and variable water flow rates during all seasons, March 2-November 30, 1994

Variable	Unit	25%, 3.25 gpm			25%, 6.5 gpm			25%, 13 gpm			25%, 26 gpm		
		Inlet	Outlet	Change	Inlet	Outlet	Change	Inlet	Outlet	Change	Inlet	Outlet	Change
Salinity	ppm	0.0500	0.1000	100.0%	0.3333	0.2833	-15.0%	0.0750	0.0500	-33.3%	0.4500	0.4500	0.0%
pH		6.4988	6.4313	-1.0%	6.6950	6.6297	-1.0%	6.5610	6.4243	-2.1%	6.2543	6.3023	0.8%
Ammonia	mg/l	0.0437	0.0437	0.0%	0.0508	0.0612	20.5%	0.0331	0.0373	12.7%	0.0577	0.0517	-10.4%
Nitrate	mg/l	0.1833	0.2112	15.2%	0.2005	0.2109	5.2%	0.1370	0.1181	-13.8%	0.1924	0.1654	-14.0%
Nitrite	mg/l	0.0082	0.0082	0.0%	0.0076	0.0071	-6.6%	0.0076	0.0088	15.8%	0.0087	0.0054	-37.9%
Phosphorous	mg/l	0.2795	0.0908	-67.5%	0.1800	0.1442	-19.9%	0.1560	0.1234	-20.9%	0.0973	0.0196	-79.9%
Total suspended solids	mg/l	0.0181	0.0144	-20.4%	0.0087	0.0081	-6.9%	0.0169	0.0183	8.3%	0.0039	0.0029	-25.6%

Legend: Negative (Positive) change - percent reduction (increase) in concentration.

Table 35. Means and percent change of weekly readings of selected water quality variables in ponds with fixed wetland sizes and variable water flow rates during winter months, March 2-March 19, 1994

Variable	Unit	25%, 3.25 gpm			25%, 6.5 gpm			25%, 13 gpm			25%, 26 gpm		
		Inlet	Outlet	Change	Inlet	Outlet	Change	Inlet	Outlet	Change	Inlet	Outlet	Change
Salinity	ppm	0.0000	0.0000	0.0%	0.2222	0.2222	0.0%	0.0000	0.0000	0.0%	1.0000	1.0000	0.0%
pH		4.5900	4.5033	-1.9%	5.3788	5.3544	-0.5%	5.2733	5.2600	-0.3%	4.4000	4.3866	-0.3%
Ammonia	mg/l	0.0336	0.0327	-2.7%	0.1893	0.3021	59.6%	0.0301	0.0912	203.0%	0.0375	0.0398	6.1%
Nitrate	mg/l	0.0575	0.0523	-9.0%	0.1588	0.1049	-33.9%	0.0501	0.0463	-7.6%	0.0524	0.0554	5.7%
Nitrite	mg/l	0.0057	0.0078	36.8%	0.0188	0.0188	0.0%	0.0351	0.0351	0.0%	0.0080	0.0050	-37.5%
Phosphorous	mg/l	0.1232	-0.0072	-105.8%	0.2851	0.2585	-9.3%	0.4712	0.3262	-30.8%	0.1957	0.0724	-63.0%
Total suspended solids	mg/l	0.0160	0.0176	10.0%	0.0216	0.0219	1.4%	0.0496	0.0759	53.0%	0.0081	0.0134	65.4%

Legend: Negative (Positive) change - percent reduction (increase) in concentration.

Table 36. Means and percent change of weekly readings of selected water quality variables in ponds with fixed wetland sizes and variable water flow rates during spring months, March 20-June 19, 1994

Variable	Unit	25%, 3.25 gpm			25%, 6.5 gpm			25%, 13 gpm			25%, 26 gpm		
		Inlet	Outlet	Change	Inlet	Outlet	Change	Inlet	Outlet	Change	Inlet	Outlet	Change
Salinity	ppm	0.1538	0.3077	100.1%	0.7948	0.6666	-16.1%	0.1538	0.0769	-50.0%	1.0000	1.0000	0.0%
pH		5.9977	5.9785	-0.3%	6.4249	6.3651	-0.9%	6.4731	6.3908	-1.3%	6.0661	6.0920	0.4%
Ammonia	mg/l	0.0852	0.0832	-2.3%	0.0587	0.0690	17.5%	0.0496	0.0452	-8.9%	0.0564	0.0596	5.7%
Nitrate	mg/l	0.1178	0.1514	28.5%	0.1196	0.1409	17.8%	0.1259	0.0566	-55.0%	0.1983	0.1599	-19.4%
Nitrite	mg/l	0.0038	0.0039	2.6%	0.0066	0.0061	-7.6%	0.0041	0.0048	17.1%	0.0021	0.0041	95.2%
Phosphorous	mg/l	0.3513	0.0217	-93.8%	0.2766	0.1842	-33.4%	0.0903	0.0752	-16.7%	0.1756	0.0200	-88.6%
Total suspended solids	mg/l	0.0082	0.0078	-4.9%	0.0082	0.0071	-13.4%	0.0186	0.0202	8.6%	0.0017	0.0019	11.8%

Legend: Negative (Positive) change - percent reduction (increase) in concentration.

Table 37. Means and percent change of weekly readings of selected water quality variables in ponds with fixed wetland sizes and variable water flow rates during summer months, June 20-September 21, 1994

Variable	Unit	25%, 3.25 gpm			25%, 6.5 gpm			25%, 13 gpm			25%, 26 gpm		
		Inlet	Outlet	Change	Inlet	Outlet	Change	Inlet	Outlet	Change	Inlet	Outlet	Change
Salinity	ppm	0.0000	0.0000	0.0%	0.1666	0.1428	-14.3%	0.0714	0.0714	0.0%	0.1428	0.1428	0.0%
pH		7.0300	6.9921	-0.5%	6.9452	6.7904	-2.2%	6.7357	6.4878	-3.7%	6.5928	6.6842	1.4%
Ammonia	mg/l	0.0233	0.0241	3.4%	0.0290	0.0284	-2.1%	0.0254	0.0267	5.1%	0.0782	0.0571	-27.0%
Nitrate	mg/l	0.3811	0.4309	13.1%	0.3970	0.4239	6.8%	0.2436	0.2552	4.8%	0.3214	0.2803	-12.8%
Nitrite	mg/l	0.0091	0.0080	-12.1%	0.0033	0.0045	36.4%	0.0055	0.0059	7.3%	0.0135	0.0057	-58.0%
Phosphorous	mg/l	0.1801	0.1444	-19.8%	0.1056	0.1429	35.3%	0.1739	0.1242	-28.6%	0.0652	0.0341	-47.7%
Total suspended solids	mg/l	0.0153	0.0147	-3.9%	0.0053	0.0058	9.4%	0.0118	0.0106	-10.2%	0.0053	0.0018	-66.0%

Legend: Negative (Positive) change - percent reduction (increase) in concentration.

Table 38. Means and percent change of weekly readings of selected water quality variables in ponds with fixed wetland sizes and variable water flow rates during fall months, September 22-November 30, 1994

Variable	Unit	25%, 3.25 gpm			25%, 6.5 gpm			25%, 13 gpm			25%, 26 gpm		
		Inlet	Outlet	Change	Inlet	Outlet	Change	Inlet	Outlet	Change	Inlet	Outlet	Change
Salinity	ppm	0.0000	0.0000	0.0%	0.0000	0.0000	0.0%	0.0000	0.0000	0.0%	0.0000	0.0000	0.0%
pH		6.9790	6.8130	-2.4%	7.0906	7.1310	0.6%	6.8170	6.7280	-1.3%	6.5810	6.6190	0.6%
Ammonia	mg/l	0.0212	0.0232	9.4%	0.0292	0.0245	-16.1%	0.0233	0.0256	9.9%	0.0364	0.0372	2.2%
Nitrate	mg/l	0.0290	0.0289	-0.3%	0.0430	0.0354	-17.7%	0.0281	0.0275	-2.1%	0.0462	0.0445	-3.7%
Nitrite	mg/l	0.0133	0.0142	6.8%	0.0113	0.0084	-25.7%	0.0068	0.0101	48.5%	0.0107	0.0064	-40.2%
Phosphorous	mg/l	0.3719	0.1348	-63.8%	0.1269	0.0594	-53.2%	0.1218	0.1239	1.7%	0.0108	-0.0174	-261.1%
Total suspended solids	mg/l	0.0354	0.0213	-39.8%	0.0099	0.0084	-15.2%	0.0121	0.0094	-22.3%	0.0032	0.0022	-31.3%

Legend: Negative (Positive) change - percent reduction (increase) in concentration.

Table 39. Total initial investment in six 8-acre catfish ponds in a multi-enterprise farm in the Mississippi Black Belt Area, 1995

Item	Unit	Quantity	Unit cost ($)	Total cost ($)	Percent to total
Land	land acre	58.08	700.00	40,656	24.01%
Surveying	land acre	58.08	50.00	2,904	1.72%
Pond construction					
Earth moving	cubic yard	72,768.00	0.80	58,214	34.38%
Drainage structure	water acre	48.00	81.00	3,888	2.30%
Gravel	water acre	48.00	43.00	2,064	1.22%
Vegetative cover	land acre	5.04	107.25	541	0.32%
Sub-total				64,707	38.22%
Electrical	unit	1.00	1,300.00	1,300	0.77%
Equipment	dollar			59,745	35.29%
Total				169,312	100.00%

Source: Posadas and Dillard (1997).

Table 40. Description, number and costs of equipment for six 8-acre catfish ponds in a multi-enterprise farm in the Mississippi Black Belt Area, 1995

Item	Description	Quantity	Unit cost ($)	Total cost ($)
Tractor [1]	50-69 hp	2	20,100	4,020
Truck [1]	3/4 ton	1	13,000	1,300
Feed truck	used	1	3,400	3,400
Dissolved oxygen meter	w/ 12 ft cable	1	800	800
PTO-driven paddlewheel	w/ 540 rpm shaft	2	3,500	7,000
Electric aerator	10 hp	6	3,800	22,800
Side-mounted mower	6 ft	1	4,500	4,500
Truck-mounted feeder	4,000 lb	1	6,500	6,500
Electronic feeder scale	w/ printer	1	3,200	3,200
Feed storage bin	10 ton	1	2,200	2,200
Service building [1]	25 ft x 50 ft	1	5,000	500
Chemical boat	14 ft, 42-in bottom	1	1,425	1,425
Outboard motor	30 hp	1	1,600	1,600
Boat trailer	14-in wheels	1	500	500
Total				59,745

Legend: 1 - 10 % of annual use allocated to catfish enterprise.
Source: Posadas and Dillard (1997).

Table 41. Total and average annual costs of six 8-acre catfish ponds in a multi-enterprise farm in the Mississippi Black Belt Area, 1995

Item	Total ($)	Per pond ($)	Per water acre ($)	Per land acre ($)	Per pound ($)
Fixed costs	25,891	4,315	539	446	0.1037
Operating costs	121,021	20,170	2,521	2,084	0.4849
Total costs	146,912	24,485	3,060	2,529	0.5886

Source: Posadas and Dillard (1997).

Table 42. Total annual operating costs of six 8-acre catfish ponds in a multi- enterprise farm in the Mississippi Black Belt Area, 1995

Item	Unit	Quantity	Unit cost ($)	Total cost ($)	Percent to total
Repair & maintenance	dollar			4,308	3.6%
Fuel	dollar			4,276	3.5%
Electricity	acre	48.00	124.000	5,952	4.9%
Chemicals	acre	48.00	62.000	2,976	2.5%
Telephone	acre	48.00	5.160	248	0.2%
Water quality analysis	pond	6.00	63.000	378	0.3%
Fingerlings	piece	273,600.00	0.075	20,520	17.0%
Feed	ton	224.64	231.000	51,892	42.9%
Labor	hour	1,000.16	7.100	7,101	5.9%
Harvesting & hauling	pound	249,600.00	0.050	12,480	10.3%
Liability insurance	dollar			300	0.3%
Miscellaneous	dollar			800	0.7%
Operating interest	percent	74,063.58	10.00%	7,406	6.1%
Inventory interest	percent	23,383.33	10.00%	2,383	2.0%
Total				121,021	100.0%

Source: Posadas and Dillard (1997).

Table 43. Total initial investment in six 2-acre constructed wetlands in a multi-enterprise farm in the Mississippi Black Belt Area, 1995

Item	Unit	Quantity	Unit cost ($)	Total cost ($)	Percent to total
Land	land acre	14.52	700.00	10,164	5.09%
Surveying	land acre	14.52	50.00	726	0.36%
Earth moving	cubic yard	18,192.00	0.80	14,554	7.29%
Gravel	water acre	12.00	43.00	516	0.26%
Vegetative cover	land acre	1.26	107.25	135	0.07%
Plants & planting	plant	384,000.00	0.40	153,600	76.91%
Recycling system	pond	6.00	3,336.33	20,018	10.02%
Total				199,713	100.00%

Source: Posadas (1997).

Table 44. Description, number and cost of water recycling system in a two-acre constructed wetlands in a multi-enterprise farm in the Mississippi Black Belt Area, 1995

Item	Unit	Quantity	Unit cost ($)	Total cost ($)
6-in PVC pipe, pond-wetland	feet	240.00	2.30	552.00
4-in PVC pipe, wetland-pond	feet	100.00	1.20	240.00
6-in PVC coupling	piece	24.00	10.77	258.48
4-in PVC coupling	piece	20.00	3.40	68.00
6-in PVC ball valve	unit	1.00	273.50	273.50
1.5 HP submersible pump	unit	1.00	1,500.00	1,500.00
Outdoor wire	feet	200.00	1.20	240.00
4-in PVC swing check valve	piece	1.00	51.85	51.85
100-gal sump	piece	1.00	100.00	100.00
Metal fence post	piece	6.00	4.60	27.60
1-gal plastic bucket	piece	1.00	1.50	1.50
Screen wire	square feet	12.00	0.70	8.40
PVC cement	can	2.00	5.50	11.00
PVC cleaner	can	2.00	2.00	4.00
Total				3,336.33

Source: Posadas (1997).

Table 45. Total annual costs of six 2-acre constructed wetlands in a multi-enterprise farm in the Mississippi Black Belt Area, 1995

Item	Unit	Quantity	Unit price, cost ($)	Total cost, value ($)
Added variable costs:				
Repair & maintenance	dollar			760
Electricity used by wetland pump	kwh	27,000.00	0.0871	2,352
Labor	hour	216.00	7.10	1,534
Operating interest	percent	3,483.77	10.00%	348
Sub-total				4,993
Added fixed costs:				
Depreciation	dollar			3,522
Interest on investment	dollar			10,494
Sub-total				14,016
Reduced variable costs:				
Electricity used for pond aeration	pond	6.00	12.40	74
Operating interest	percent	55.80	10.00%	6
Sub-total				80
Net change in total costs				18,930
Net change in variable costs				4,913
Net change in fixed costs				14,016

Source: Posadas (1997).