EVALUATION OF A CONSTRUCTED WETLAND'S EFFECTS ON REMEDIATION OF WATER QUALITY IN A RECIRCULATING CATFISH AQUACULTURE POND

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INTRODUCTION

Some impediments to further development of intensive aquaculture enterprises in the southeastern U.S. relate to: 1) availability of adequate supplies of good quality water, and 2) management efforts to reduce water quality problems both within fish production ponds and in waters discharged from culture systems. The following concerns are apparent and undoubtedly will become more pronounced in the future:

1. Present reliance on considerable quantities of groundwater in some areas of Mississippi is beginning to have a serious impact on availability and quality of water for other human needs.

2. Semi-closed systems result in effluents with high concentrations of BOD, suspended solids, nitrogen, and phosphorus. Such water is typically added to natural drainage ways, resulting in detrimental ecological impact.

3. Traditional aquaculture practices cannot be implemented in some regions where adequate groundwater supplies are limited even if other culture conditions (i.e., climate, topography, geological considerations, etc.) are favorable. Reuse of water in these areas is essential for effective increase in aquaculture activities and for reductions in nutrients, solids, and BOD in water that escapes from the system.

Such concerns have prompted some aquaculturists to evaluate alternative approaches to intensive catfish production. For example, in some systems in our region, fish are cultured intensively using protocols which are generally similar to those used elsewhere in the southeast but 1) the primary water resource is surface runoff instead of shallow or deep wells that predominate in other areas, and 2) water from the culture pond (which contains fish excretory wastes, other metabolites, uneaten food, suspended solids, etc.) is passed through constructed wetlands containing floating and emergent vegetation rather than being discharged into natural waterways. The treated water is then reused in the intensive culture system.

The utility of constructed wetlands in water purification is well established in the literature and does not need to be reviewed extensively here. The scientific principle of vascular plant utilization in water treatment is that plants and associated microflora grow cooperatively in such systems; microorganisms living on and around the plant root systems contribute to many of the water treatment processes. In turn, plants themselves aid in the processes of water treatment both through mechanical means and absorption of nutrients (Wolverton 1987). Ultimately, water treated by constructed wetlands may be purified to such an extent that it is nearly potable.

Many water contaminants have been shown to be reduced during passage of water through artificial marsh systems (Stowell et al. 1979). These include solids, organics, phosphorus, bacteria, viruses, and other nutrients. Clearly, reduction of these materials in aquaculture operations could be of significant benefit to culturists. Moreover, additional benefits could also be realized as a result of water reuse in aquaculture. For example, reuse could result in both reduced demands on aquifers and reduced detrimental ecological impacts on drainage ways that would ordinarily receive aquaculture effluents.

The overall objective of our study was to evaluate the performance of a constructed wetland as a water treatment biofilter for a recirculating catfish aquaculture pond. Two systems were evaluated during our work. The first is a system which was built in 1989; the plants in the constructed wetland were already established when we began our monitoring program in 1990. The second system was built in 1990, but the constructed wetland was not completed until 1991 and the macrophytes did not become well established in the wetland until recently. In this paper, we report on only the first system.

MATERIALS AND METHODS

Overview

Several tasks were undertaken to: 1) evaluate water quality and sediment composition within the production pond, and 2) assess filter performance in improving water quality.

1) Sediments in both the production pond and constructed wetland were analyzed periodically for total phosphorus and total kjeldahl nitrogen.

2) Physicochemical conditions of water in the pond and constructed wetland were analyzed periodically during a three-year monitoring period. Parameters consistently evaluated throughout the study included total phosphates, total ammonia nitrogen, total solids, and chemical oxygen demand. Numerous additional water quality parameters of interest to the culturist were also monitored, but will not be reported here.

3) On several sampling occasions, we quantified total aerobic bacteria to determine the extent to which bacteria are removed by the constructed wetland.

The system we studied is a four-acre production pond (average depth ~4 ft) which has two half-acre constructed wetland filter cells (average depth ~1 ft) associated with it. When constructed, the wetland cells were planted with several species of macrophytes (*Eichornia crassipes*, *Panicum hemitomum* and *Panicum repens*); at the time the study was initiated, in August 1990, some of the plants within the system were already well-established.

Sampling Protocols and Specific Methodologies

Sediment Analyses. Sediment samples were obtained near the middle of the production ponds as well as near the inlet and outlet ends of the constructed wetlands. Owing to considerable between-site heterogeneity with respect to bottom type, we used several methods to secure bottom mud from the upper 2-5 cm. Although a coring device and an Ekman grab sampler were used whenever possible, some samples were collected by hand in the constructed wetlands due to the prevalence of gravel. All samples were analyzed by an analytical services company for total kjeldahl nitrogen (TKN) and total phosphorus in accordance with 40 CFR 136 and amendments. In this paper, we report only on results of sediment analyses obtained during the first two years of our investigation.

Water Chemistry Analyses. Water samples were obtained near the middle of the production pond. Water samples within the constructed wetland were obtained directly from the influent water and also at the effluent ends of the filters. All samples were collected in bottles and processed within 24 h. Water quality parameters were analyzed using various techniques. Hach kits were used to determine COD, total phosphate and ammonia nitrogen; tests were conducted in accordance with the recommendations of the manufacturers of the test kit. COD was analyzed using the reactor digestion method with potassium dichromate as the oxidizing agent and dichromate ion ($Cr_2O_7^{2-}$) as the electron acceptor. Total phosphate was determined using the acid persulfate digestion method. Ammonia nitrogen was determined by the Nessler method. Total solids were analyzed in accordance with Standard Methods (APHA 1975).

Microbial Investigation. In May of both 1991 and 1992 and during the third year of this investigation, we evaluated the effectiveness of constructed wetlands in reducing microbial populations in the pond water. The samples were obtained in sterile containers from the influent and effluent ends of the constructed wetland associated with the production pond. Additional samples were obtained from the influent and effluent waters of a constructed wetland associated with an on-site catfish hatchery. Total aerobic bacteria enumerations were made using Petrifilm™ Aerobic Count plates following the manufacturer's recommendations. A quantitative plating method was used. This procedure consisted of diluting the organisms in the water sample in a series of sterile water blanks. Dilutions were carried out to 10^{-10}. Plates were incubated at room temperature for 48 hours and total numbers of bacterial colonies were counted. All colonies were enumerated, regardless of size.

RESULTS AND DISCUSSION

Sediment Analyses

Results of the sediment analyses for total phosphorus are provided in Figure 1. Phosphorus levels within the production pond sediments generally increased during the study, reaching levels approximating 200 mg/g on the last two sampling occasions. Although the levels of phosphorus in the constructed wetland were much higher than the levels measured in production pond sediments on most occasions, sediment phosphorus levels appear to fluctuate with season. Despite an initial increase in phosphorus levels from August 1990 to June 1991, levels thereafter decreased until the last sampling date in June 1992, when levels were near those of June 1991 (influent end of the wetland) and much lower than the previous year at the effluent end. The latter result is compatible with the hypothesis that once the macrophytes became well-established in the wetland, they were able to mobilize phosphorus which had been sequestered in the wetland sediments.

As with the phosphorus data, results for sediment TKN content (Figure 2) suggest that the levels within the production pond sediments are trending upward with time.

Also, on all sampling occasions except February 1992, TKN values in the sediments of the constructed wetland were dramatically higher than those in the production pond. On most occasions, TKN near the effluent end of the wetland was greater than that near the influent end, which may suggest that much of the organic nitrogen in the wetland in autochthonous. Clearly, considerable plant biomass is produced and accumulates within the wetland during the active growth season. In winter, such material decreases in concentration as abundant rainfall flushes the material from the wetland.

Water Chemistry Analyses

Ammonia concentrations measured in the wetland influent and effluent water are shown in Figure 3. Shortly after our study was initiated in August 1990, a serious deterioration in water quality occurred due to the abrupt die-off of a dense phytoplankton population. An ammonia spike followed and some fish mortality occurred. Ammonia subsequently declined but increased again during late summer 1991. Critical months for management of ammonia concentrations in ponds utilizing constructed wetlands are likely to continue to be in the late summer and autumn, as is generally the case for traditional catfish aquaculture in our region. An important point to note is that severity of the late summer increase in ammonia declined during the course of our investigation. We consider it likely that this is due to the establishment of plants within the constructed wetland. When we initiated the work, macrophytes were only beginning to become established, but by the end of our monitoring, dense stands of macrophytes were well-established.

An important conclusion of our study is that the constructed wetland is beneficial in removing ammonia from the water column. With few exceptions, ammonia concentrations are lower in water leaving the constructed wetland filter than concentrations in the water entering the constructed wetland. The result recorded in October 1992 is noteworthy. The recirculating pumps had recently been turned off for the duration of the year, although some production pond water was flowing into the wetland. The influent water exhibited a low ammonia concentration, but water near the effluent end of the wetland had a very high concentration, undoubtedly due to production of ammonia within the wetland which was accompanying decomposition of plant material near the end of the plant growing season. This finding suggests that it would be unwise to recirculate water from the wetland to the production pond after the plant growing season, since such a practice could actually add ammonia to the production pond.

Results obtained from August 1990 to June 1992 demonstrate that wetland filtration can be a significant factor in reducing the level of chemical oxygen demand (COD), total phosphate, and total suspended solids in catfish pond water. The effectiveness of the wetland filters appears to be dependent on its flora and its age.

Chemical oxygen demand represents the amount of oxygen required to oxidize all of the organic matter to carbon dioxide and water. Hence, COD serves as an indicator of a water sample's organic content. Water entering the constructed wetland generally exhibited a higher concentration of COD than water leaving the wetland (Figure 4). Based on these results, we conclude that an established wetland filter plays a role in reducing the organic load of catfish pond water.

A water quality parameter most dramatically affected by wetland filtration was total phosphate. There was a consistent reduction in the total phosphate content of the water during the study as a result of passage through the constructed wetland (Figure 5). The percentage reduction in total phosphate was generally above 35%. Clearly, significant removal of phosphate from the water column occurs; yet as mentioned earlier, there is no clear-cut accumulation of phosphorus in the constructed wetland sediments. Again, we suspect that the plants within the wetland are responsible for much of the reduction in phosphate from the production pond water. Although total phosphate levels fluctuated during the study, no clear temporal pattern is evident. Total phosphate was high during late 1990, during mid- to late summer 1991, and in spring 1990.

The constructed wetland also had a dramatic effect on suspended solids within the water column; there was a consistent reduction in total solids. The percentage reduction ranged from 14 to 62% with an average of 40% (Figure 6). Substantial effects such as these would be of benefit to the culturist since phytoplankton, bacteria, excess food, fish feces, and sediment settling at a location remote to the production pond itself would lessen the rate at which filling-in of the pond occurs. Also, while such materials accumulate within the constructed wetland, decomposition processes occurring within the wetland rather than the production pond itself would be unlikely to contribute to deterioration in pond water quality. However, the process would also contribute to accelerated filling-in of the wetland itself. Indeed, we noted considerable sedimentation within the wetland during the course of our investigation, suggesting that after a few years of operation, efforts would need to be directed toward removing the sediments. Based on our observations, we suspect that restoration would probably be necessary within 5-8 years after implementation of the constructed wetland.

Microbiological Analyses

In May 1991, total aerobic bacterial counts in the hatchery effluent were 10,000 - 18,200 organisms/ml whereas counts in the hatchery influent (the recirculated water after treatment within the constructed wetland) were only 1,490 - 1,670 organisms/ml. In May 1992, counts for the hatchery effluent and influent were 10,600 - 20,700 and 1,200 - 1,320 organisms/ml, respectively. Bacterial counts in samples obtained from the influent and effluent of the constructed wetland during the third year of the study confirm that significant reductions in aerobic bacteria occur as a result of filtration by the constructed wetland. Often, reductions were nearly an order of magnitude. Such effects certainly contribute to an overall improvement in water quality. Also, it may be possible that such reductions in numbers of water-borne bacteria could be beneficial during periods of disease outbreaks. However, our study was not designed to address this possibility.

CONCLUSIONS

The results of this project suggest that the use of recirculating surface water and constructed wetlands for water quality control are attractive and viable strategies for catfish aquaculture in areas where available groundwater is limited, expensive to pump, or must otherwise be conserved. Furthermore, such systems reduce the production of effluent water with high concentrations of nitrogen, phosphorus, COD, and suspended solids associated with more traditional catfish aquaculture practices.

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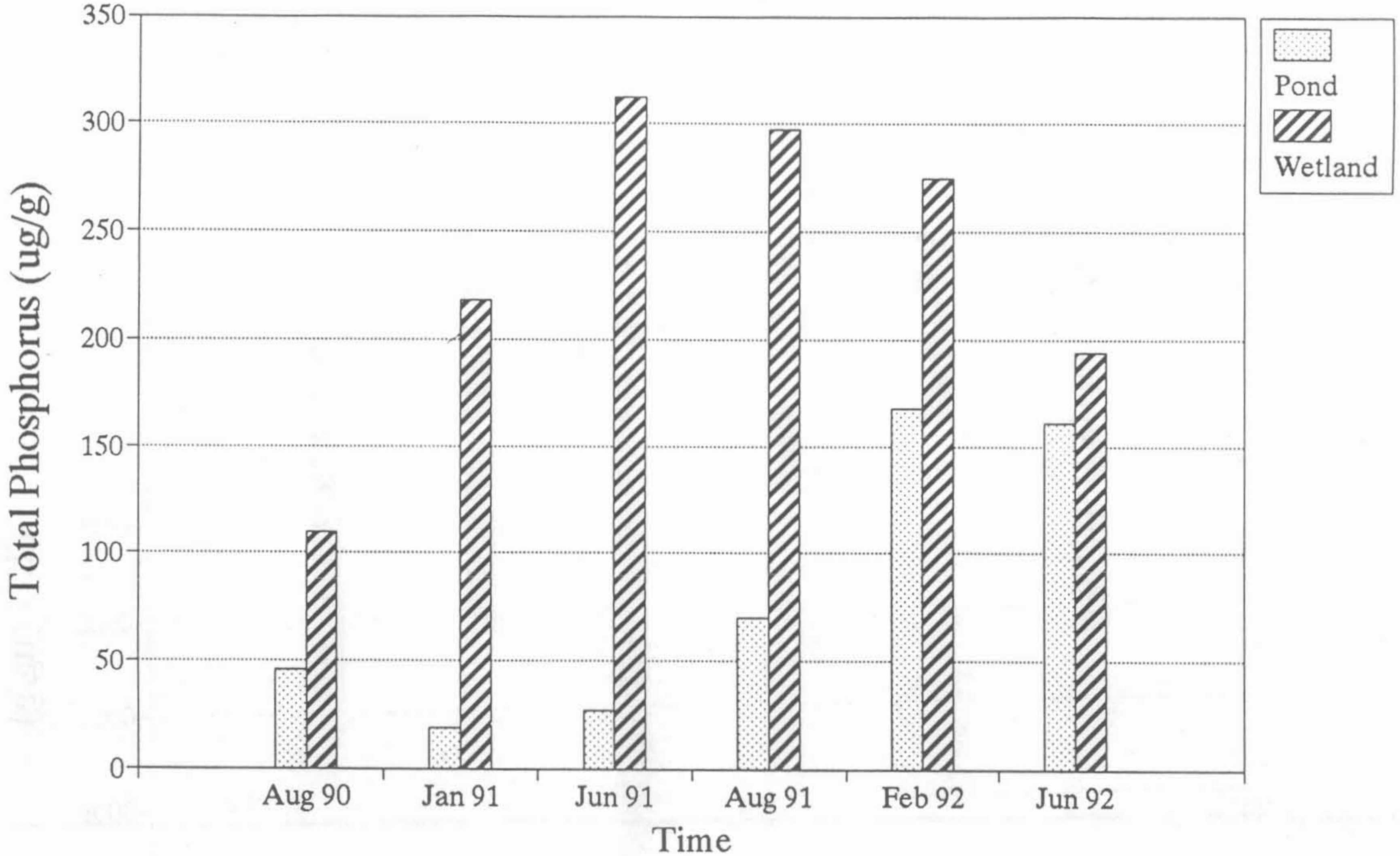

Figure 1. Concentrations of total phosphorus measured in the sediments of a catfish production pond and sediments of a constructed wetland used to treat the pond water.

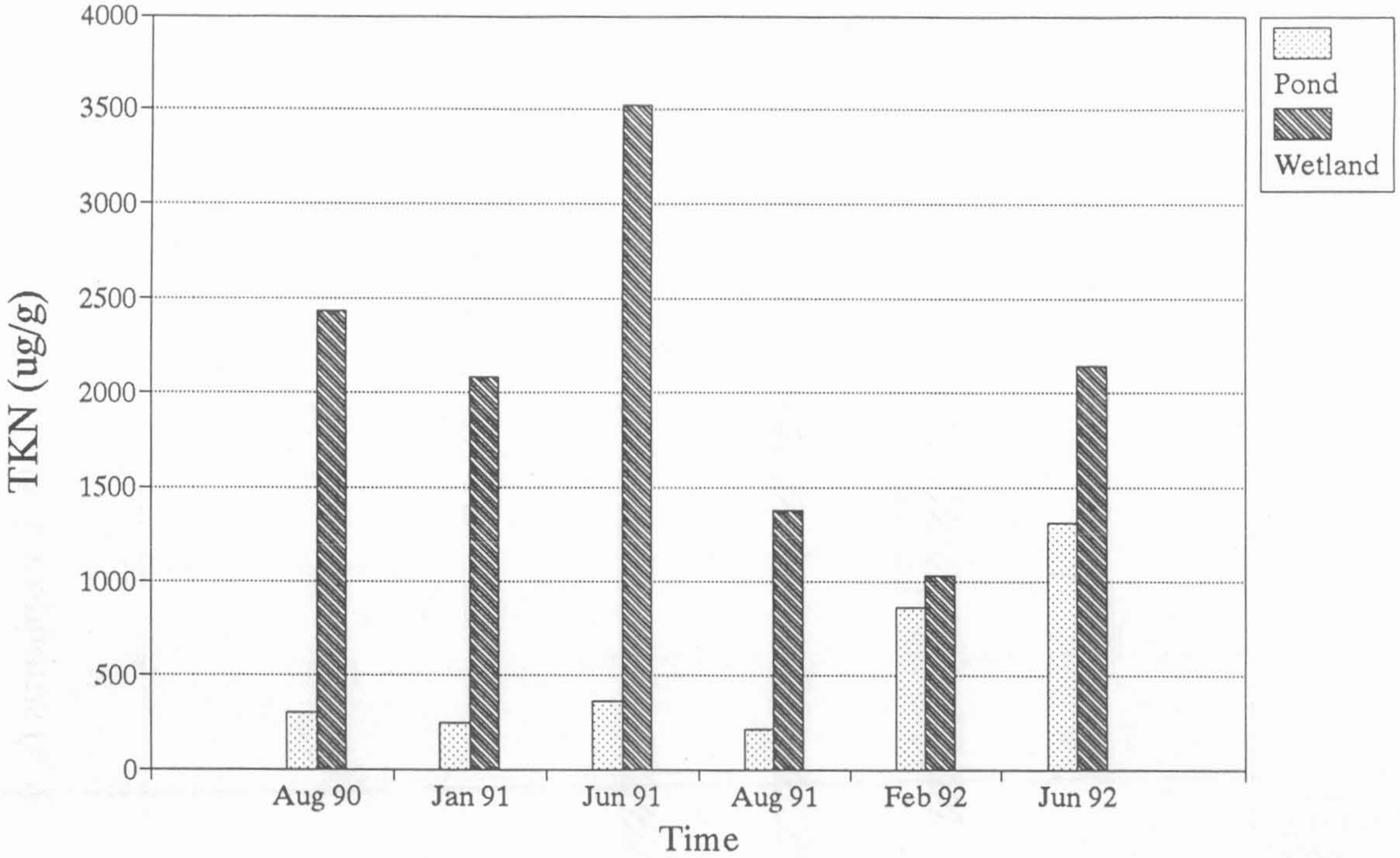

Figure 2. Concentrations of total kjeldahl nitrogen in the sediments of a catfish production pond and sediments of a constructed wetland used to treat the pond water.

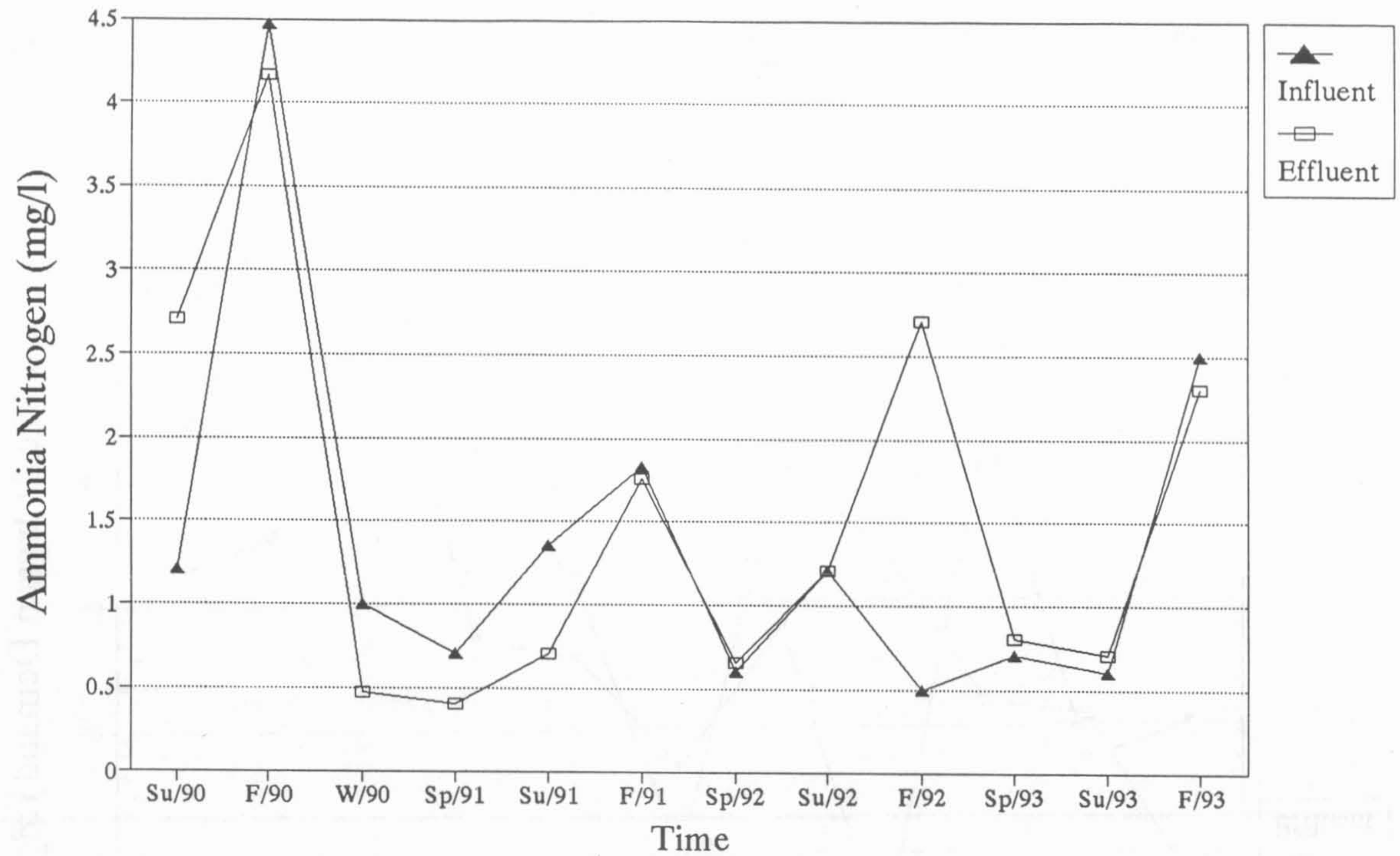

Figure 3. Concentrations of total ammonia nitrogen measured in catfish production pond water entering (influent) and leaving (effluent) a constructed wetland used to treat the pond water. Sp, Spring; Su, Summer; F, Fall; W, Winter.

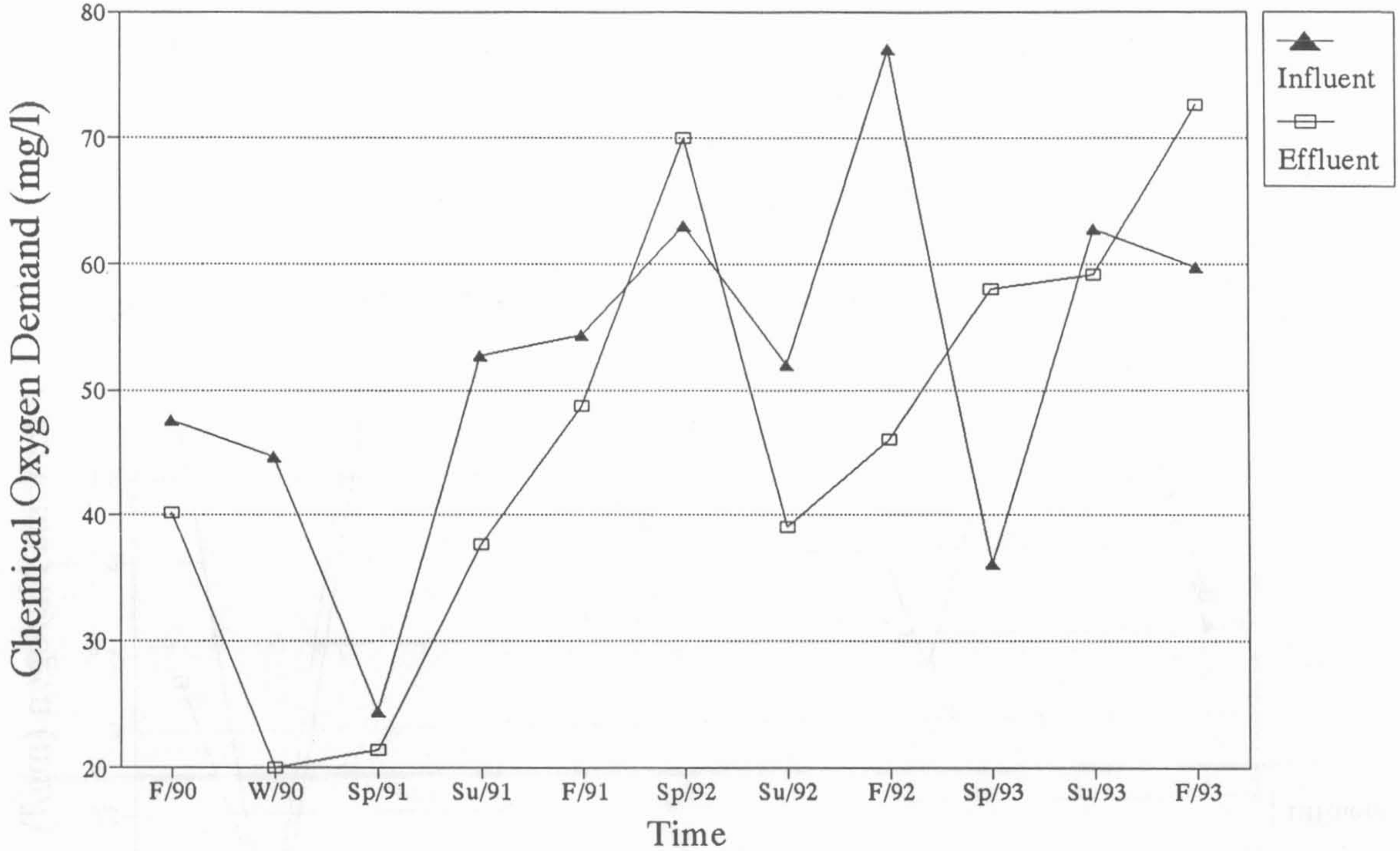

Figure 4. Concentrations of total chemical oxygen demand (COD) measured in catfish production pond water entering (influent) and leaving (effluent) a constructed wetland used to treat the pond water. Sp, Spring; Su, Summer; F, Fall; W, Winter.

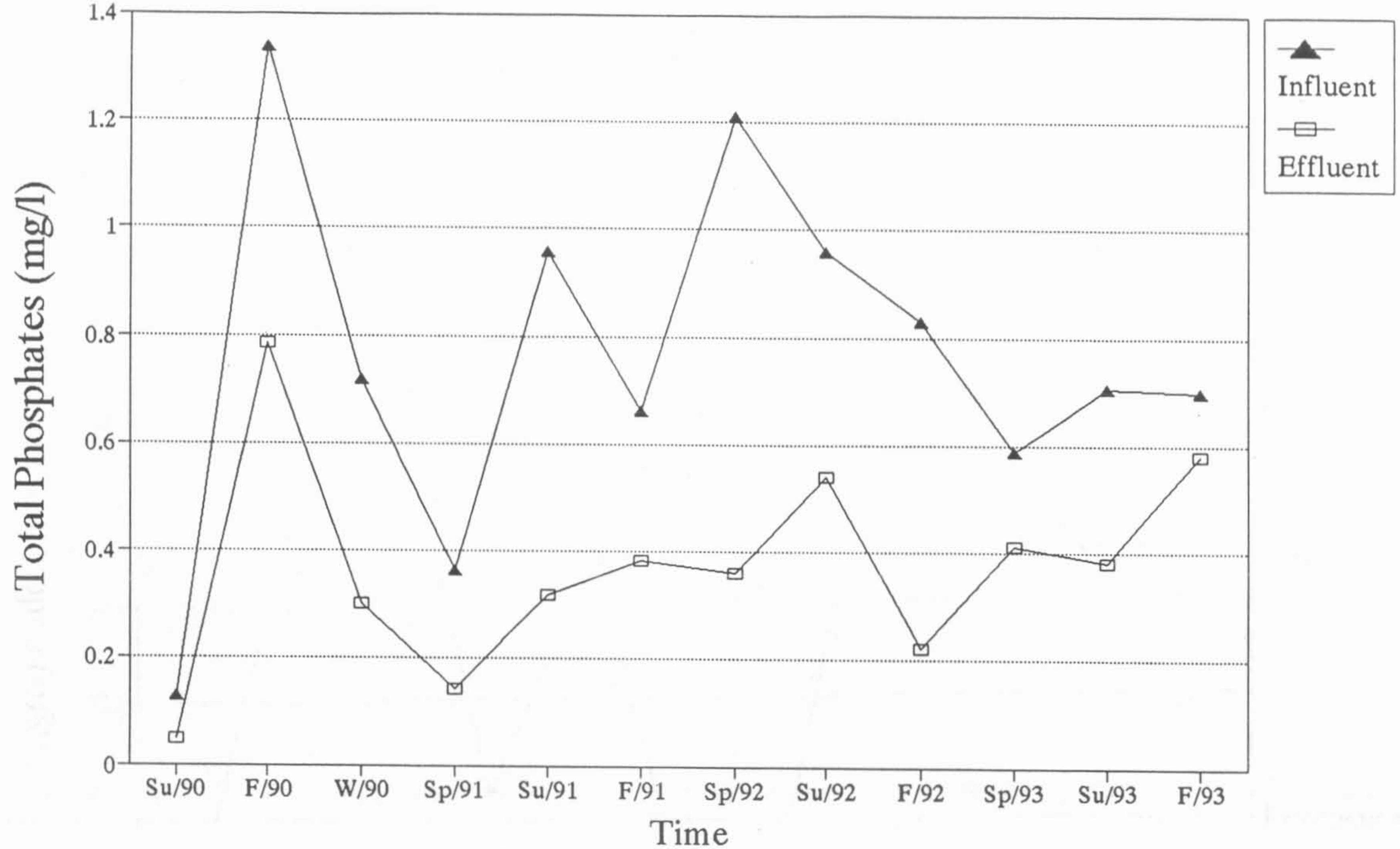

Figure 5. Concentrations of total phosphates measured in catfish production pond water entering (influent) and leaving (effluent) a constructed wetland used to treat the pond water. Sp, Spring; Su, Summer; F, Fall; W, Winter.

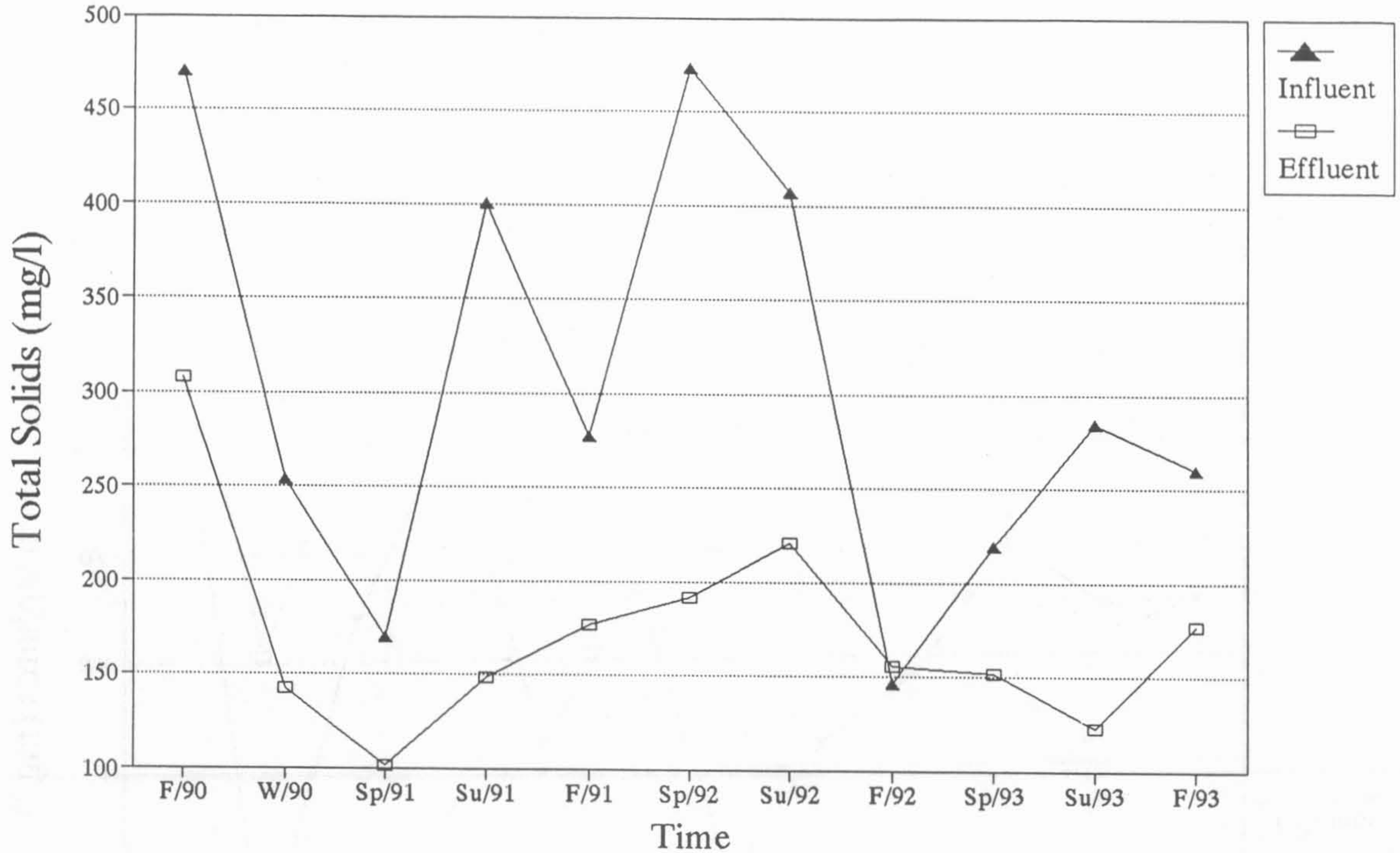

Figure 6. Concentrations of total solids measured in catfish production pond water entering (influent) and leaving (effluent) a constructed wetland used to treat the pond water. Sp, Spring; Su, Summer; F, Fall; W, Winter.