MODELLING QUANTITY AND QUALITY OF OVERFLOW FROM AQUACULTURAL PONDS

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INTRODUCTION

Fish culture, as is true of all forms of food animal production, generates wastes. Depending upon the nature of the culture system, some or all of those wastes will be discharged into surface water supplies. Although aquaculture has developed into a significant food animal production industry in the United States, relatively little research has been conducted to describe and quantify the wastes generated during culture or to assess the effect of aquaculture waste discharge into the environment. This has led to uncertainty and concern about the extent to which waste discharge from aquaculture facilities may affect receiving bodies of water. These concerns have been exacerbated by an uncertain regulatory climate in which government agencies have at times promulgated regulations with little knowledge of the nature of aquaculture discharges or their environmental effects.

The following study was undertaken to characterize effluents from channel catfish Ictalurus punctatus culture ponds in northwest Mississippi. A climatological model of pond water budgets was used to examine the role of two different water management practices on current waste discharge produced. Combining the modelled volume of overflow with selected water quality measurements produced the data for the analyses. Average and extreme conditions were determined seasonally.

METHODS

The water quantity portion of this study was based on a water use model which has been field-verified in the Mississippi Delta (Pote, et al. 1988; Rodrique and Pennington 1992). Water discharged from catfish ponds as a result of overflow only was calculated using the following equation:

$$\underline{O}_d = \underline{L}_{(D-1)} - \underline{L}_D - \underline{P}_D - 0.8\underline{E}_D - \underline{I} + \underline{GW}_D,$$

where

$\underline{O}_D$	= overflow (cm) on day D
$\underline{L}_D$	= pond water level (cm) on day D
$\underline{L}_{(D-1)}$	= pond water level at the end of day D-1
$\underline{P}_D$	= precipitation (cm) on day D
$\underline{E}_D$	= pan evaporation (cm) on day D
$\underline{I}$	= daily infiltration loss (cm)
$\underline{GW}_D$	= ground water pumped into pond (cm) on day D

Daily observations for $\underline{P}$ and $\underline{E}$ were obtained for the period 1961-1990 from the National Weather Service Cooperative System for Stoneville, Mississippi. Stoneville is within 10km of the ponds used to obtain water quality data. Weather data were obtained from the Earth Info, Inc. optical disc set (Climatedata 1990) and were formatted into Lotus 1-2-3 (Lotus 1986) spreadsheets for inspection and quality control. The factor 0.8 was used to estimate pond evaporation from pan evaporation (Boyd 1985b) and a value of 0.04 cm was assumed for daily $\underline{I}$. The value for $\underline{I}$ was obtained from infiltration losses measured in northwest Mississippi rice fields on the Alligator and Sharkey series of Vertic Haplaquept soils (Pringle 1994), which are the soil types most commonly used for catfish pond construction in that region (Tucker 1995).

Quarterly overflow losses were determined for two pond water level management scenarios. One scenario, called the "maintain full scheme" (MF), assumed that ground water was pumped into the pond at the end of each day to replace $\underline{E}$ and $\underline{I}$. In other words, no storage capacity was maintained in the pond and any $\underline{P}$ in excess of daily $\underline{E}$ + $\underline{I}$ was lost as overflow through the drain. This scenario estimated the maximum pond overflow that could occur under a given set of climatic conditions. The other scenario, called the "6/3 scheme" (6/3) (Pote et al. 1988), is a management option designed to reduce the need for pumped water and reduce overflow volume by allowing for storage of much of the annual rainfall. In that scenario, pond water level was allowed to fluctuate with climatic conditions until pond water levels dropped to 15 cm (6 inches) below the overflow structure due to $\underline{E} + \underline{I}$ in excess of $\underline{P}$. At that time, ground water was added to raise the water level to 7.5 cm (3 inches) below the top of the drain, leaving 7.5 cm of storage capacity to capture rainfall that subsequently occurred. The 7.5 cm storage capacity was chosen because there is a 90% chance that P will be less than 7.5 cm for any week in northwest Mississippi (Wax and Walker 1986). Overflow thus occurred only during unusual precipitation events. Overflow losses were determined using weather data for the 30-year (1961-1990) average, the year with the most precipitation (1979), and the year with the least precipitation (1986).

Twenty commercial channel catfish ponds were used in the water quality portion of this study. Ten ponds were located on each of two farms in Washington County. Ponds were of the levee type, constructed on clay soils, and averaged about 7 ha in area and 1.25 m in depth. Water was supplied by wells drilled into a dolomitic limestone gravel aquifer yielding water of relatively high total hardness and total alkalinity (both 290 mg/L as $CaCO_3$). Each pond was supplied with one or two 7.5-kW electric paddlewheel aerators that were used whenever dissolved oxygen concentrations fell below 3-4 mg/L.

All ponds had been in continuous fish production, without draining, for at least 3 years at nominal stocking densities of 18,000 to 24,000 fish/ha. Fish were periodically harvested with a large-mesh seine that allowed fish smaller than about 0.35 kg to escape and remain in the pond for additional growth. Fingerlings were added to ponds once or twice a year to replace fish harvested plus estimated mortality accrued during the production period. Daily feed allowances averaged between 75 and 100 kg/ha in May through September and between 5 and 20 kg/ha in December through February. Feed allowances were intermediate in autumn and spring. Harvested fish yields per pond varied between 1800 and 8300 kg/ha per year over the duration of the study. Actual fish growth rates and net fish production could not, however, be determined with any reliability due to the inherent problems in estimating inventory in commercial ponds managed under the multiple-batch cropping system (Tucker and Robinson 1990; Tucker et al. 1993).

Eight sets of water samples were obtained from each pond over a 2-year period beginning in summer of 1991. Samples were collected between 0800 and 0900 on dates in August (summer), November (autumn), February (winter), and May (spring). On each sampling date, samples were obtained using a 2.2-L Kemmerer bottle from the surface 30 cm and the bottom 30 cm of each pond at a site adjacent to the discharge pipe. Samples were returned to the laboratory and analyses were initiated within 45 min of collection.

Total nitrogen (N) was determined by alkaline persulfate oxidation/digestion followed by cadmium reduction and diazotization (Koroleff 1983). The remaining analyses were conducted according to methods described by APHA (1989): total phosphorus (P)--persulfate digestion and ascorbic acid finish; chemical oxygen demand (COD)--dichromate digestion; and biochemical oxygen demand (BOD)--standard 5-day incubation at 20C.

Pond overflow volumes for the two water management scenarios and water quality data were then used to calculate amounts of waste nitrogen, phosphorus, and organic matter discharged from ponds as a result of overflow only. Mass discharges (in kg/ha of pond surface) were computed as the product of pond overflow volumes and overall mean concentrations of N, P, COD, and BOD for each season.

RESULTS AND DISCUSSION

Northwest Mississippi has a humid, warm-temperate climate characterized by substantial seasonal variation in climatic conditions. Winters are cool with low rates of pond evaporation (less than 0.3 cm/day); summers are hot with relatively high rates of pond evaporation (averaging over 0.5 cm/day). Greatest amounts of rainfall occur from November through May (averaging 11-14 cm/month) with lesser amounts (6-10 cm/month) occurring in more sporadic rainfall events in June through October (Wax et al. 1987; Pote et al. 1988; Tucker 1995). The widely varying climatic conditions in northwest Mississippi cause seasonal variation in both overflow volume and pond water quality.

Pond water samples collected from near the surface and bottom of each pond on a given date were nearly identical with respect to all measured variables, indicating that well-mixed water columns existed in ponds at the time of sampling. Results of paired-comparison t-tests indicated no difference ($\underline{P} \leq 0.01$) between the two samples for any variable; as such, analytical results for surface and bottom samples were averaged to obtain a single value for each pond and sampling date. Means of overflow volumes and concentrations for each water quality variable and for each season are presented in Table 1. In general, concentrations of N, P, COD, and BOD tended to be highest in the warm seasons.

The general pattern of seasonal variation in water quality is similar to that described by Tucker and van der Ploeg (1993) for commercial channel catfish ponds in northwest Mississippi. Seasonal changes in pond water quality are associated, in large part, with seasonal changes in phytoplankton biomass (Hargreaves and Tucker in press). Phytoplankton biomass is greatest during warm temperatures, seasonally high values of solar radiation, and large inputs of plant nutrients (derived from feed via fish metabolic waste), all of which support rapid rates of gross phytoplankton primary production. Most of the organic matter in channel catfish pond water consists of living phytoplankton cells and phytoplankton-derived detritus (Boyd 1985), so variables such as COD and BOD that measure the organic matter content of water vary with changes in phytoplankton biomass and are generally highest in the summer.

Temporal changes in concentrations of particulate organic matter also tend to correspond to changes in phytoplankton biomass because phytoplankton and phytoplankton-derived detritus constitute the bulk of the particulate material in catfish pond waters, except in those rare ponds with high levels of suspended clay particles (Boyd 1990). Similarly, most of the nitrogen and phosphorus in catfish pond waters is present in particulate organic matter, primarily within phytoplankton cells (Boyd 1985), so total N and total P concentrations also vary with changes in phytoplankton biomass and tend to be highest in the warmer seasons (Tucker and van der Ploeg 1993).

Under both management schemes, pond overflow due to positive $\underline{P}$ - ($\underline{E}$ + $\underline{I}$) was greatest in the winter and spring (Table 1) except in the driest year on record (1986) when no overflow occurred all year. Managing water levels in ponds to maintain a minimum storage capacity of 7.5 cm (6/3 scheme) greatly reduced overflow volumes compared to ponds managed without storage (MF scheme), particularly in the summer and autumn (Figure 1). In an average year, managing water levels in ponds for storage capacity reduced overflow to about 30% of that from ponds managed with no storage capacity (32 cm vs 103 cm). More importantly, overflow was reduced in the average summer to about 8% of that in ponds managed without storage (4 cm vs 44 cm). In exceptionally dry years, there was no overflow due to positive $\underline{P}$ - ($\underline{E}$ + $\underline{I}$) from ponds managed to maintain storage.

Waste discharge (in kg/ha of pond surface) as a result of pond overflow only is shown in Table 2. Although overall average concentrations of all four water quality variables were highest in the summer (Table 1), waste discharge quantity was strongly influenced by overflow volume, which in contrast was lowest in the summer. On the other hand, greatest quantities of waste were discharged in the winter when pond overflow was greatest, but concentrations were lowest (Table 2; Figures 2-5). Since managing ponds to maintain storage capacity reduced overflow, large reductions in waste discharge resulted from use of the 6/3 scheme, particularly during the summer months. In an average year, annual discharge of N, P, and organic matter in ponds managed to maintain storage capacity was only about 30% of that from ponds not managed to maintain storage capacity. Even in exceptionally wet years, waste discharge was considerably lower in ponds managed to reduce overflow, and no waste was discharged from managed ponds in exceptionally dry years (Figures 2-5).

Managing pond water levels to reduce overflow volume is particularly significant in the summer months because that is when catfish pond water quality is poorest and streamflows in northwest Mississippi are at their annual minimum. The coincidence of seasonally poorest effluent quality and lowest rates of dilution after discharge suggests that summertime would be the season when pond discharge would have the greatest potential effect on receiving stream water quality (Pote et al. 1988; Tucker and Lloyd 1985). In an average year, managing ponds to maintain storage capacity reduced N discharge from 10.7 to 0.9 kg/ha, over 91% (Figure 2); P discharge from 0.9 to 0.1 kg/ha, over 88% (Figure 3); COD from 172 to 14 kg/ha, over 91% (Figure 4); and BOD from 41 to 3 kg/ha, over 92% (Figure 5) during the critical summer period. No N, P, or organic matter was discharged from ponds during the summer as a result of positive $\underline{P}$- ($\underline{E}$ + $\underline{I}$) in the wettest and driest year of the record (Figures 2-5).

CONCLUSIONS

The quantity of waste discharged from aquaculture ponds can be reduced in four ways: (1) decrease waste production within the pond by reducing the amount of feed added, by increasing retention of feed nutrients by fish, or by reducing the amount of nitrogen and phosphorus in the feed; (2) increase the rate of in-pond loss processes for nitrogen, phosphorus, and organic matter to reduce concentrations of those substances in the pond before discharge; (3) treat wastes using standard post-discharge wastewater treatment technology; and (4) reduce discharge volume. All of these options have been the subject of research, but the practical application of most approaches is questionable.

Reducing overflow volume by maintaining storage capacity in ponds appears to be a simple and highly effective technique for reducing waste discharge. As this study has shown, the product of overflow volume and nutrient concentration can estimate total waste discharge by seasons. Summer values prove to be most critical and although nutrient concentrations are high, the overlow volume is low, thereby mitigating potential impact of the effluent. The study showed that use of the 6/3 scheme reduced total waste discharge during the summer by an average of about 90% for all water quality variables studied.

In addition to the environmental benefits accruing from reduced waste discharge, maintenance of storage capacity in ponds also helps conserve ground water resources by dramatically reducing the need for pumped water to maintain pond water levels during fish culture (Pote et al. 1988). If storage capacity is available, rainfall is captured in the pond rather than lost as overflow, and the stored water helps offset evaporative and infiltration losses. Further reduction in waste discharge could be achieved by not draining ponds annually for harvest (Hollerman and Boyd 1985; Seok et al. 1995), a practice that is universally used in Mississippi channel catfish farming.

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Table 1. Seasonal overflow volume (cm) and water quality concentration (mg/L) data.

6/3 Management	SP	SU	FA	WI
Average	8.71	1.42	3.10	19.43
Dry Year	0	0	0	0
Wet Year	23.37	0	2.95	34.77
Maintain full				
Average	30.51	17.42	23.24	33.15
Dry Year	19.02	12.14	19.76	13.00
Wet Year	50.75	23.75	35.48	43.76
Average water quality				
Total N	4.84	6.12	6.54	5.3
Total P	0.34	0.52	0.30	0.34
COD	73	98	71	74
BOD	14.8	23.6	11	12.8

Table 2. Waste discharge (Kg/ha) resulting from pond overflow.

TOTAL N	SP	SU	FA	WI
Avg Yr 6/3	4.2	0.9	2.0	10.1
Dry Yr 6/3	0	0	0	0
Wet Yr 6/3	11.3	0	1.9	18.1
Avg Yr MF	14.7	10.7	15.2	17.2
Dry Yr MF	9.7	7.4	12.9	6.8
Wet Yr MF	24.6	14.5	23.2	22.8
TOTAL P				
Avg Yr 6/3	0.3	0.1	0.2	0.7
Dry Yr 6/3	0	0	0	0
Wet Yr 6/3	0.8	0	0.1	1.2
Avg Yr MF	1.0	0.9	0.7	1.1
Dry Yr MF	0.6	0.6	0.6	0.4
Wet Yr MF	1.7	1.2	1.1	1.5
COD				
Avg Yr 6/3	64	14	22	143
Dry Yr 6/3	0	0	0	0
Wet Yr 6/3	171	0	21	257
Avg Yr MF	223	172	165	245
Dry Yr MF	139	120	140	96
Wet Yr MF	372	235	252	323
BOD				
Avg Yr 6/3	13	3	3	25
Dry Yr 6/3	0	0	0	0
Wet Yr 6/3	35	0	3	45
Avg Yr MF	45	41	25	42
Dry Yr MF	28	28	22	17
Wet Yr MF	75	56	39	56

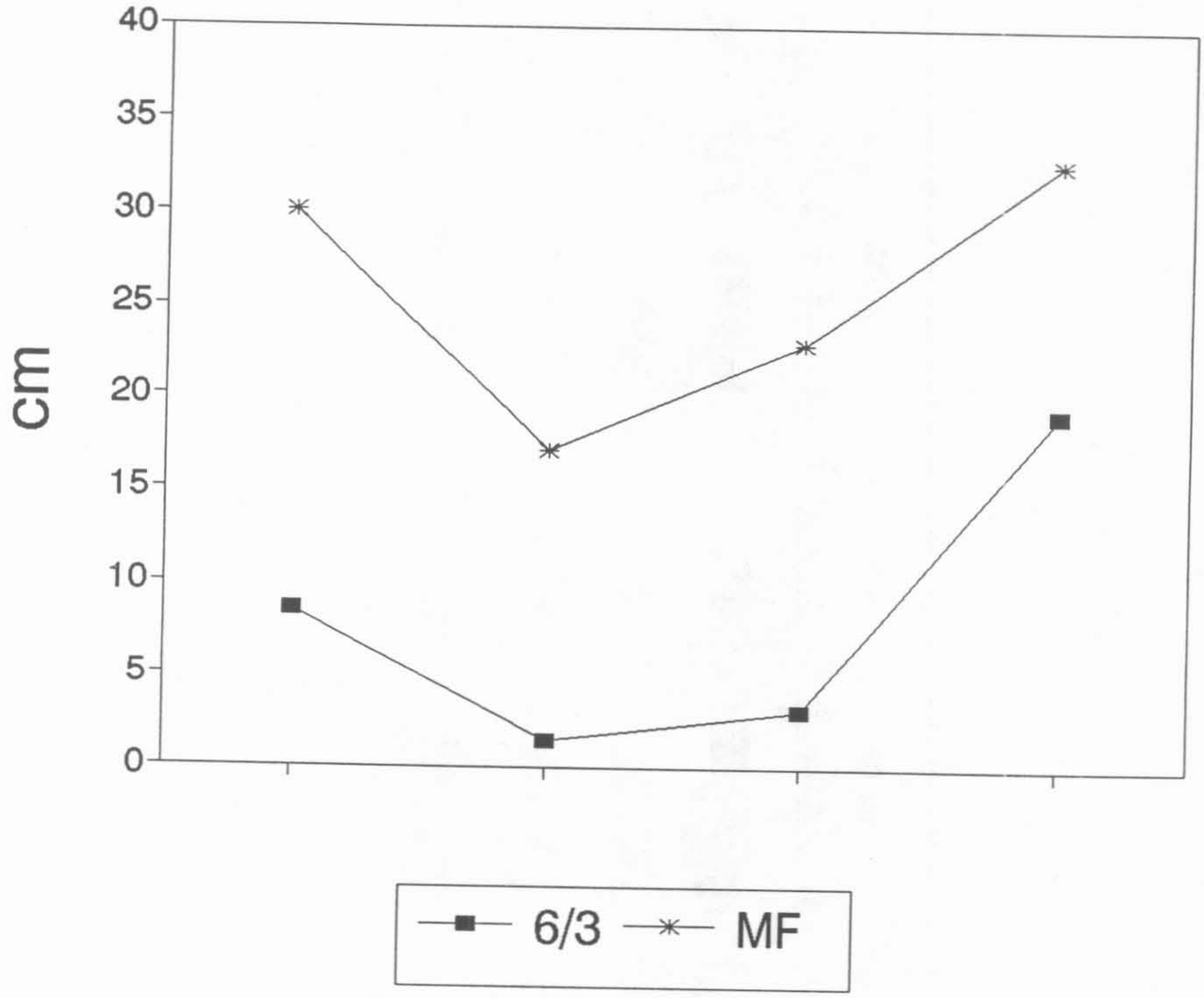

Figure 1. Seasonal Average Pond Overflow, Two Management Schemes

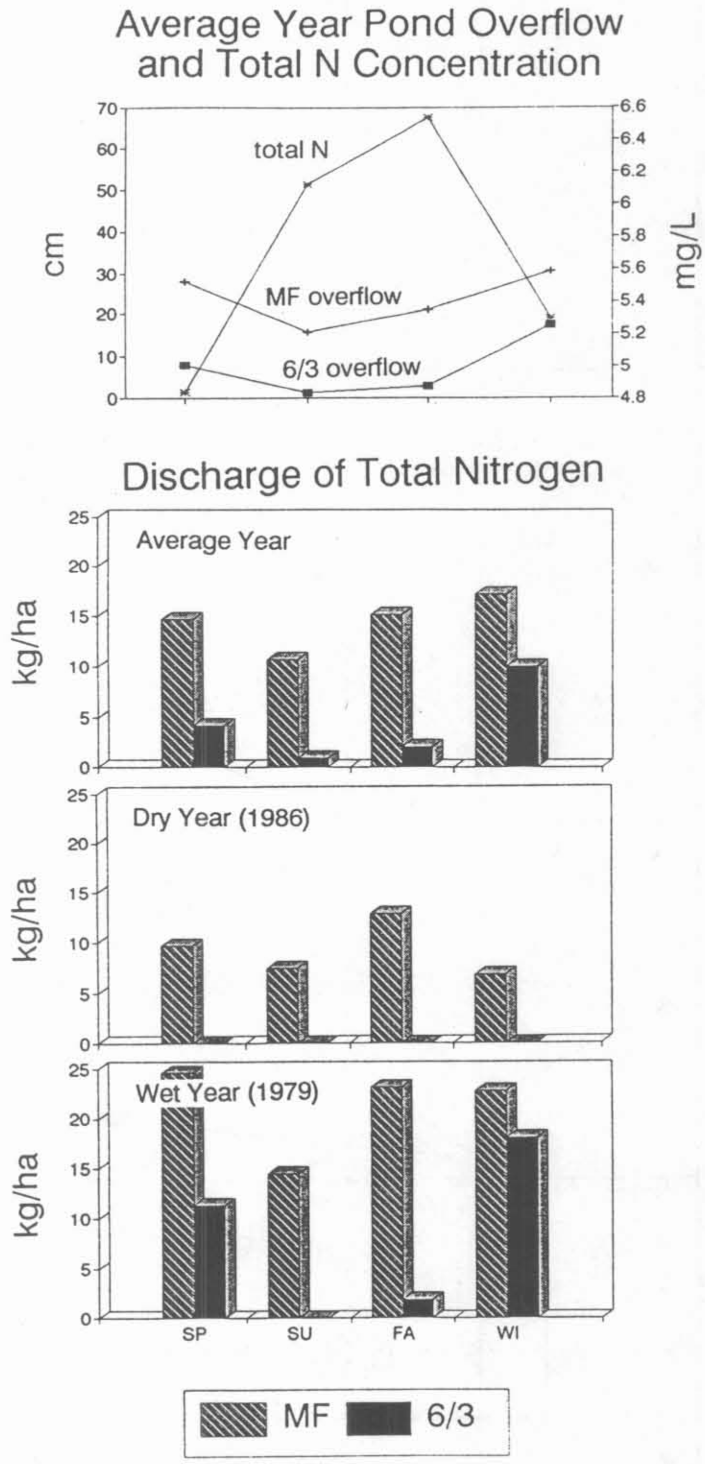

Figure 2. Seasonal comparison of Total N concentration with overflow and resulting discharge, two management schemes

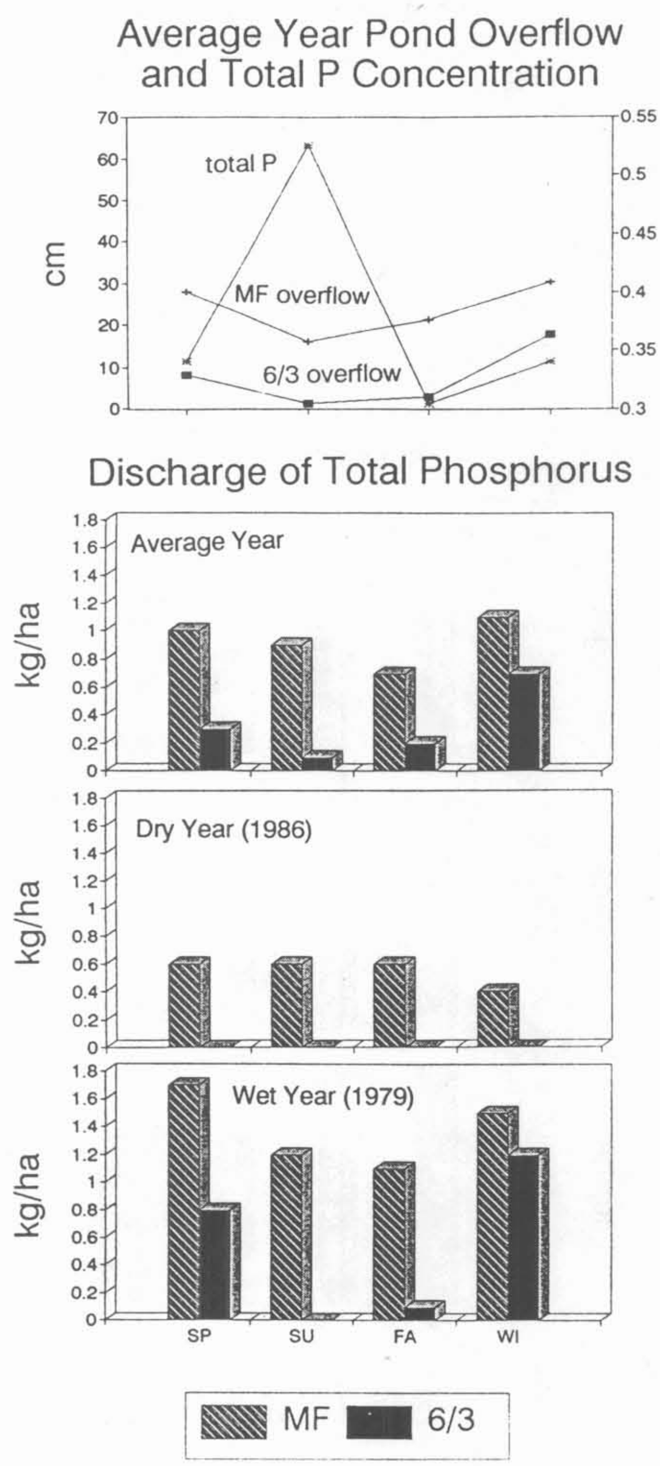

Figure 3. Seasonal comparison of Total P concentration with overflow and resulting discharge, two management schemes

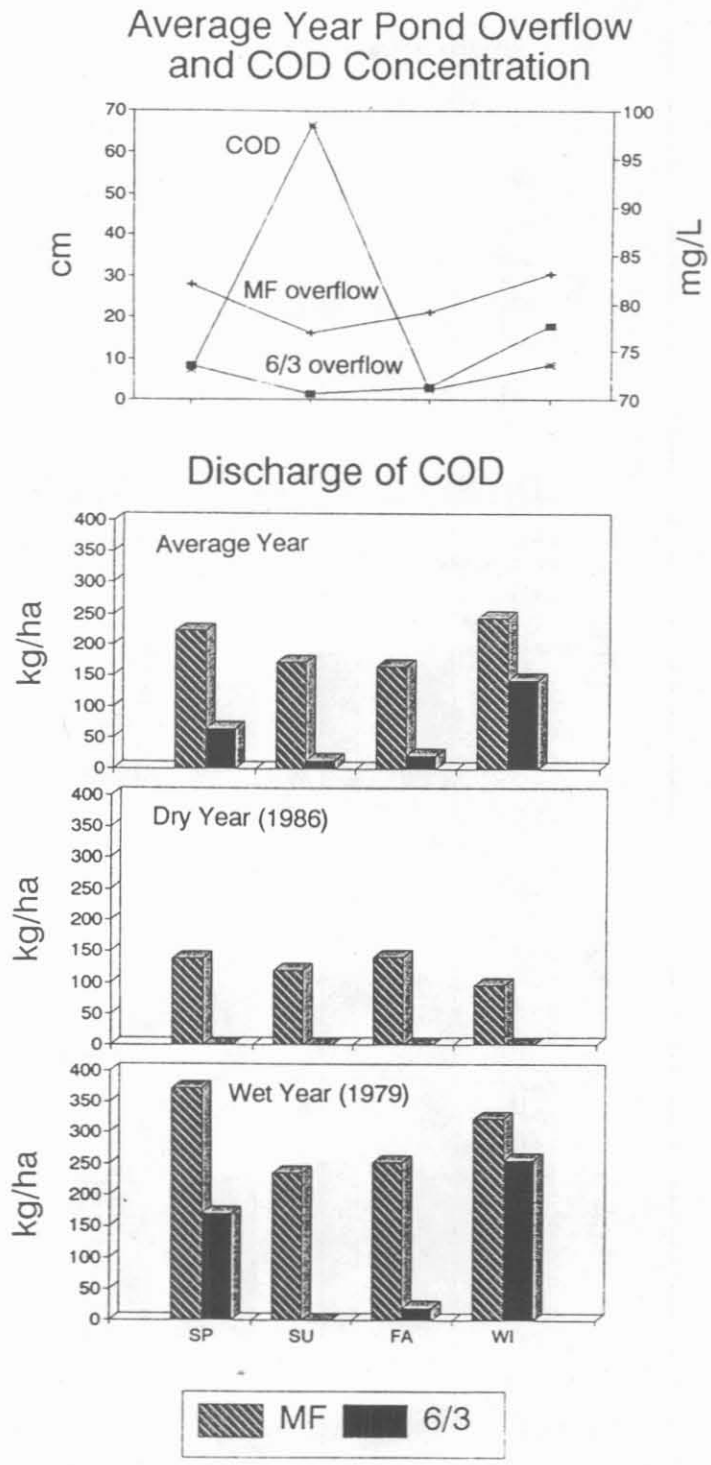

Figure 4. Seasonal comparison of COD concentration with overflow and resulting discharge, two management schemes

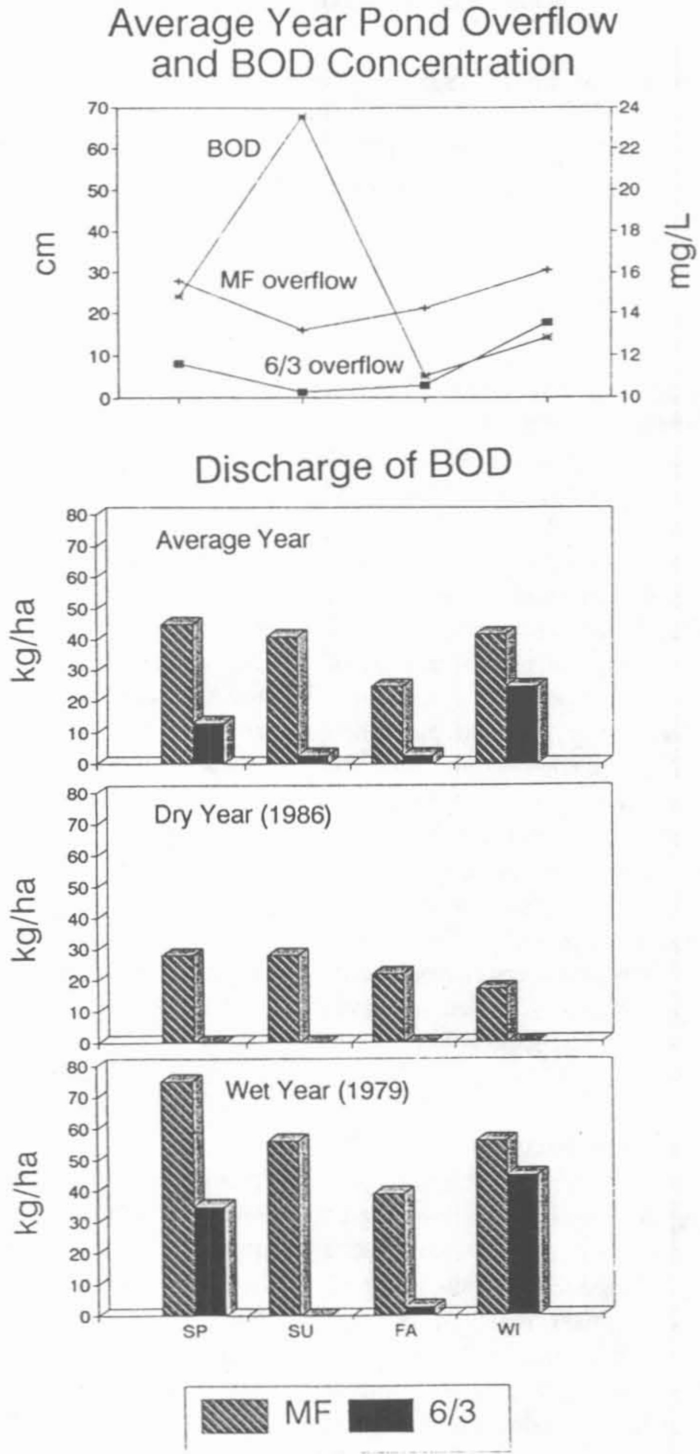

Figure 5. Seasonal comparison of BOD concentration with overflow and resulting discharge, two management schemes