EFFECTS OF INFILTRATION ON A CLIMATOLOGICAL PLAN TO CONSERVE GROUNDWATER IN AQUACULTURE

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INTRODUCTION

Aquaculture is a rapidly growing industry in the U.S. In the state of Mississippi alone, over 40,000 water hectares (100,000 acres) are devoted to catfish farming (Brunson 1991). As a very visible user of groundwater, conservation is imperative to this industry.

At present, a large segment of the aquaculture industry in the United States is centered in the Southeast Region. One of the climate characteristics of that region is fairly evenly distributed monthly rainfall rates year-round. Consequently, there is a potential to use this rainfall to offset pond water losses. Pote et al. (1988) utilized a precipitation/evaporation model to develop a method called the "6/3 Scheme" which employed this principle.

In its early history, aquaculture ponds were placed on soils which had such low infiltration rates that their usefulness for row crop production was limited. Ponds in these areas have minimal infiltration losses. Now, the profits from catfish farming commonly exceed those of other row crops such as soybeans. As a result, some soils where ponds are now being installed have infiltration losses which cannot be considered negligible.

A predictive model which allows for the possibility of infiltration losses is necessary to analyze the long-term impact of various water conservation management practices. This study compares the effects of rainfall, evaporation, and infiltration on the groundwater pumping requirements for soils of both low and intermediate infiltration rates. Both the common "Maintain Full Method" and the new "6/3 Scheme" are examined as management options to conserve groundwater.

PROCEDURES

Data Acquisition

Daily observations of precipitation (P) and pan evaporation (PE) for the period 1961 to 1990 from the National Weather Service Cooperative Observation System for Stoneville, MS were used. These were obtained from the Earth Info, Inc. optical disk set (Climatedata 1990). The data were formatted into Lotus 1-2-3 (Lotus 1986) spreadsheets for inspection and quality control.

Since pan evaporation (PE) is not directly comparable to true evaporative loss from the surface of a lake or pond, a coefficient is generally used to correct measured pan evaporation to a more realistic estimate of actual evaporative loss (E) from ponds or lakes. In early studies (Schwab et al. 1955) a constant coefficient of about 0.7 was used to convert pan evaporation to evaporation from large reservoirs. However, in more recent years it has been determined that the relationships vary from month-to-month and possibly from location-to-location (Kohler et al. 1955, 1959; Ficke 1972; Hounam 1973; Yonts et al. 1973; Ficke et al. 1977; Farnsworth et al. 1982; Farnsworth and Thompson 1982; McCabe and Muller 1987).

In a study conducted on a small, shallow pond near Auburn, AL, pan-to-pond coefficients were found to range from 0.72 in March to 0.90 in September, with an average of 0.81 for all months (Boyd 1985). The environment in which these coefficients were determined is closely related to the environments of aquacultural production ponds in the Mississippi Delta region; therefore, a correction coefficient of 0.8 was used in this study to correct the pan evaporation data to estimates of evaporative losses from ponds (E).

Infiltration estimates (I) were based on Stone and Boyd's (1989) study of fishponds in Alabama. In an analysis of 70 ponds, the infiltration rates ranged from 2.3 cm/day (.9 in/day) to less than zero with a median and mode value of 0.20 cm/day (.079 in/day). Pringle (1990) found an average I of .03 cm/day (.01 in/day) for rice fields in the Mississippi Delta. In this study, it was assumed that I in production ponds would range from 0 cm/day to 0.20 cm/day. Ponds with a high infiltration rate are generally repaired or taken out of production.

Data Analysis Techniques

Evaluation of the daily amounts of water added to ponds by P and lost from ponds by E provides an accounting of water level fluctuations resulting from climatic processes. Such an atmospheric water balance approach was used here, by computer simulation, to assess the impact of climatic variability (seasonally and annually) with the objective of determining the effectiveness of a management plan which takes advantage of regional climatic characteristics.

Initially, the analyses assumed no infiltration (I=0). First, a scenario of uncontrolled pond levels was used to assess the regional potential of climate as a viable factor in pond water supply ("no management" simulation). Then, two management schemes, ("maintain full" and "6/3" simulations), which make different use of the climatic potential were analyzed to compare the consumption of groundwater under each scheme. These simulations appropriately model water consumption in ponds with negligible infiltration. To complete the analysis by including I, these three analyses were repeated with an estimated daily water loss due to I of 0.2 cm/day (.079 in/day).

These six simulations were performed on a daily basis by computer program for the 30-year period 1961-1990. Ponds were assumed full on 1 January, 1961. For each subsequent day, both the net P-E and the water level as a result of that value were calculated and pumped water was added as indicated under each of the management schemes. Then, for each day the net P-E-I and the water level as a result of that value were calculated and pumped water was again added as indicated under each of the management schemes.

Simulations With No Infiltration

No Management Simulation: A daily comparison of precipitation (P) and pond evaporation (E) for the 30-year period produced daily values of P-E in an electronic spreadsheet year-by-year. Cumulative summation of these daily values provided patterns of pond water levels, as influenced solely by daily increases or decreases from either a positive or a negative P-E, through the period.

For perspective, the patterns of the average year, the wettest year, and the driest year were isolated. The average year was computed as the mean of the 30 P-E values for each day through the year. The extreme years were analyzed using actual, not averaged, daily P-E values for the given year. The daily water level patterns during the selected years were then graphed by cumulative addition of daily P-E values through each of the years.

This analysis shows the pond level regimes that might be expected from an uncontrolled, purely climatological standpoint; that is, if the daily interaction between P and E were the sole factors in determining pond water levels and if no water was added from any source other than P, no overflow occurred and no loss other than E was encountered. Results document the regional potential for P to exceed E on a cumulative, daily basis, and therefore indicate the extent to which P can be used to keep ponds filled and thereby conserve groundwater.

Maintain Full Simulation: The second simulation of pond water levels consists of adding water needed each day to keep the ponds full after evaporative losses -- commonly referred to as "make-up" water. This is presently the most common conservation practice. However, this system practices complete control over pond water levels, allowing no fluctuation and therefore losing most P to overflow. The large annual P as well as the initial daily P-E analyses clearly show that there is rainfall which can be captured during some part of each year for use in lieu of pumped water. Use of "make-up" water to constantly hold the pond at capacity guarantees loss of some or all of that rainfall by leaving no room for storage.

In the electronic spreadsheet the daily value of P-E was subjected to a logic statement that separated negative and positive values. Positive values were assumed to represent a loss to overflow. Negative values indicated drops in water level and it was assumed that pumping of groundwater would be used to make up this difference. The amount of groundwater used under this scheme was thereby determined -- daily, annually, and in long-term averages.

6/3 Simulation: The third simulation of pond water levels is the 6/3 scheme, a management option in which the water level of the pond is allowed to drop by evaporative loss in excess of any P (negative P-E) a full 15 cm (6 inches) from the starting point before addition of any groundwater occurs. Fifteen cm was chosen as a maximum fluctuation amount acceptable to producers because of erosion by waves. When groundwater is added at that point, the amount added is only enough to raise the level of the pond 7.5 cm (3 inches), leaving a 7.5 cm capacity to store any P which might subsequently occur. The 7.5 cm capacity was chosen because there is a 90 percent chance that P will be less than 7.5 cm for any given week (Wax and Walker 1985).

Any rainfall which raises the pond level above the starting point is assumed lost to overflow through the drain pipe. In other words, the water level of the pond is allowed to fluctuate with positive or negative P-E to the extent that groundwater is added only when the water level drops 15 cm below the drain, and even then there is capacity to store a 7.5 cm rainfall.

This scheme takes advantage of the natural processes, using fluctuation in pond water level to allow a single rainfall event to compensate for several days of evaporative losses, thus decreasing the need for groundwater pumping. This management strategy lies between no control and complete control of pond water levels.

This simulation was accomplished by a logic statement which examined the daily computations of water level. Values over the starting level (15 cm) were assumed lost to overflow and the level was reset to 15. When the water level fell to 15 cm below the starting point, the simulation added 7.5 cm and continued from that level. The amount of groundwater added each year was thus calculated as the summation of these 7.5 cm increments.

Simulations With Infiltration

Each of the three simulations described above were re-done, this time with an infiltration loss of 0.20 cm (0.079 inches) added to the daily water balance computation (P-E-I). Results of the second set of simulations are used to model water use in ponds with known losses to infiltration as well as to compare the climatic advantage for ponds under the three schemes with and without infiltration.

RESULTS AND DISCUSSION

No Management Simulations

Figure 1a shows what might be expected if water levels are determined only by the interaction of P and E. If all precipitation was captured and retained in the pond to offset subsequent evaporation, pond levels during an average year would rise during the period January-April to about 20 cm (8 inches) above the starting level, then fall back to that starting level by about the middle or end of July. From that time until the end of October, the pond level would fall to about 15 cm (6 inches) below the starting level, then begin to rise again as average precipitation becomes greater than average evaporation. The pond would return to its original level around the middle of December during the average year.

During the wettest year (1979), a nearly continuous increase in pond levels occurred through the entire year as precipitation dominated evaporation most of that year. Pond levels in 1979 are shown in Figure 1a to reach near 64 cm (25 inches) above the starting level by year's end as cumulative P-E stayed positive and filled the pond day after day. In 1986 (the driest year), a nearly continuous decrease in pond levels was characteristic as cumulative P-E stayed negative day after day, and the water level dropped to near 64 cm below the starting point by the end of the year (Figure 1a).

Three generalizations about the water level regimes emerged from these analyses: 1) precipitation is much more dominant than evaporation in causing dramatic water level fluctuations; 2) the temporal distribution of rainfall events, as opposed to dry days, is much more dominant in determining climate-controlled water levels of ponds; and 3) the daily interaction of the climatic variables is more important in pond management than annual total amounts.

Figure 1b shows the effect of including I (0.20 cm/Day) in the "no management" water level model. The results show that even in a wet year (1979) there is a net loss of water from ponds by year's end. In the driest year (1986), I losses coupled with E losses caused pond levels to drop continuously through the year to nearly 130 cm (50 inches) below the starting point. The average year shows a slight net gain through March, then a constant loss the remainder of the year as P does not routinely replace losses from both E and I. Comparison of Figures 1a and b shows that, in general, I causes an additional water loss of about 75 cm (30 inches) in the course of any given year, regardless of climatic condition.

Obviously, water level fluctuations to the extent outlined above under a "climate control only" scheme cannot be tolerated in conventional warm water aquacultural ponds. Levees cannot economically be constructed high enough to allow for changes in storage of the magnitude shown in Figure 1, nearly 64 cm (25 inches) above and below the starting point with no I, and approaching 38 cm (15 inches) above and 150 cm (60 inches) below the starting point with I included. Some degree of management must be introduced to control fluctuations in water level.

Two Management Methods

<u>Maintain Full Simulations:</u> The results of the maintain full management scheme simulations, both with and without I, are not graphically dramatic on a day-to-day basis. The water level remained essentially constant,

and the amounts of groundwater added on a daily basis ("make-up") were small -- only enough to replace daily E in excess of P and to replace losses to I. Daily E averaged between 0.56-0.61 cm (0.22-0.24 inches) during the summer season at Stoneville, and daily I was a constant 0.2 cm. Annual total amounts of groundwater required for this management method ranged from 91 to 114 cm (36 to 45 inches) without I and from 147 to 175 cm (58 to 69 inches) with I during the 30-year period.

6/3 Simulations: The daily water level patterns created by the 6/3 management scheme without I for the wettest year (1979) and the driest year (1986) showed the following results. Through May of 1979 the pond fell no more than 2.5 cm (one inch) and overflowed on many occasions with excess rainfall. Pumped water had to be added only one time, mid-September, to keep the water level within the selected limits of fluctuation (15 cm). Since only 7.5 cm of water were added then, a subsequent large rainfall on September 22 was successfully captured, and no more groundwater was added for the rest of the year. It is apparent from this analysis that the climate in the southern region is capable of providing sufficient rainfall to almost completely maintain ponds without I within the 15-cm design limit in wet years.

The analysis also illustrated that during 1986, a year in which evaporation dominated precipitation, water overflowed only once (mid-June) but had to be added six times during the year to maintain the water level within the selected limits. Ponds required repetitive additions of groundwater in an almost systematic sequence since no significant rainfall events occurred over such long time periods during the part of the year when evaporation rates were highest and most constant. This analysis thus gave a clear indication of how long a 7.5 cm addition of groundwater would last against evaporative losses when no daily precipitation or I occurs and thereby emphasized how much potential for conservation the capture of daily precipitation does provide. The analysis further revealed that, even in the extreme dry years, all required pumping was limited to the time period between early April and late October in ponds without I losses.

Results of the simulation for the 6/3 management scheme for the extreme wet and dry years when I is included are shown in Figure 2. It can be seen that, during the wettest year, pond levels stayed within the design limits without any pumping through the end of June. After that, groundwater was added on five occasions -- five times the amount required in ponds without I. All pumping was required between late June and mid-October and no loss to overflow occurred after early May. The figure also shows that, during the driest year, no overflow occurred at all and groundwater was added fifteen times -- about three times the amount required in ponds without I. It can also be seen that pumping was required in all but the three winter months. Both the increased number of pumpings required and the extended period of time when groundwater additions are needed indicate the increased water use in ponds with I.

COMPARISONS

These analyses found the differences in water used in ponds each of the 30 years when "make-up" water was used as compared to the 6/3 scheme, for both I and no-I simulations. Results showed that use of "make-up" water required around 101 cm (40 inches) each year without I and 163 cm (64 inches) with I to keep ponds full. The water required to keep ponds with no I within the design limits of the 6/3 scheme varies from 0 to 61 cm (24 inches) and averaged 33 cm (13 inches) a year. Note that this was a reduction of 68 percent over the "maintain full" strategy in ponds without I. Water required for the 6/3 scheme with I varied from 38 to 114 cm (15 to 45 inches) and averaged 76 cm (30 inches) per year, a 53 percent reduction over the "maintain full" scheme in ponds with I.

Figure 3 summarizes the full impact of the potential for groundwater conservation with use of the 6/3 management option as compared to the "maintain full" management scheme. In the figure, the top curve represents the total amount of groundwater used over 30 years under the "maintain full" scheme in ponds with I -- the worst-case scenario. The bottom curve represents the same figures of water use under the 6/3 scheme in ponds without I -- the optimum management situation. Over 30 years, the "6/3" scheme used in ponds with no I saves 2050 cm (808 inches) of water over the "maintain full" scheme in those same ponds. The figure also shows that the "6/3" scheme, even in ponds with I, uses almost 762 cm (300 inches) less water than the "maintain full" scheme in ponds without I. The 6/3 scheme in ponds with I saves 2540 cm (1000 inches) of water as compared to the "maintain full" scheme in those ponds. The 6/3 scheme limits losses to about 1270 cm (500 inches) of water over 30 years in ponds with I as compared to ponds with no I. Therefore, notwithstanding the temporal sequence of wet and dry years, the demonstrated potential for groundwater conservation with use of the 6/3 scheme is not negated by losses to I or limited by the annual climatic variability that is so common in the region.

SUMMARY AND CONCLUSIONS

Table 1 summarizes the amount of water saved by employing the "6/3" management option as versus the "maintain full" system in ponds with and without I. In ponds with no I, the simulation showed an average 68 percent conservation of water used over the 30 year period. In ponds with I of .2 cm/day, the simulation showed an average 53 percent savings of groundwater.

In a period when it is increasingly vital for catfish producers to recognize the importance of water conservation, the 6/3 scheme should be considered as a simple yet highly effective management strategy. By making use of the normally abundant rainfall in the region, the information presented here shows that even in ponds with moderate infiltration, the 6/3 management option has the potential for conserving over half of the water commonly used in catfish ponds.

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Table 1. Summary of potential annual groundwater conservation (cm) by using the 6/3 Scheme as compared to Maintain Full (MF), in ponds with infiltration (I) and with no infiltration (NI).

	MF	6/3	Amnt. Saved	Percent Saved
NI	102	33	69	68
I	163	76	86	53

Figure 1. Cumulative P-E in the wettest year (1979), the driest year (1986), and the average year (AVG) without infiltration (a) and with infiltration (b).

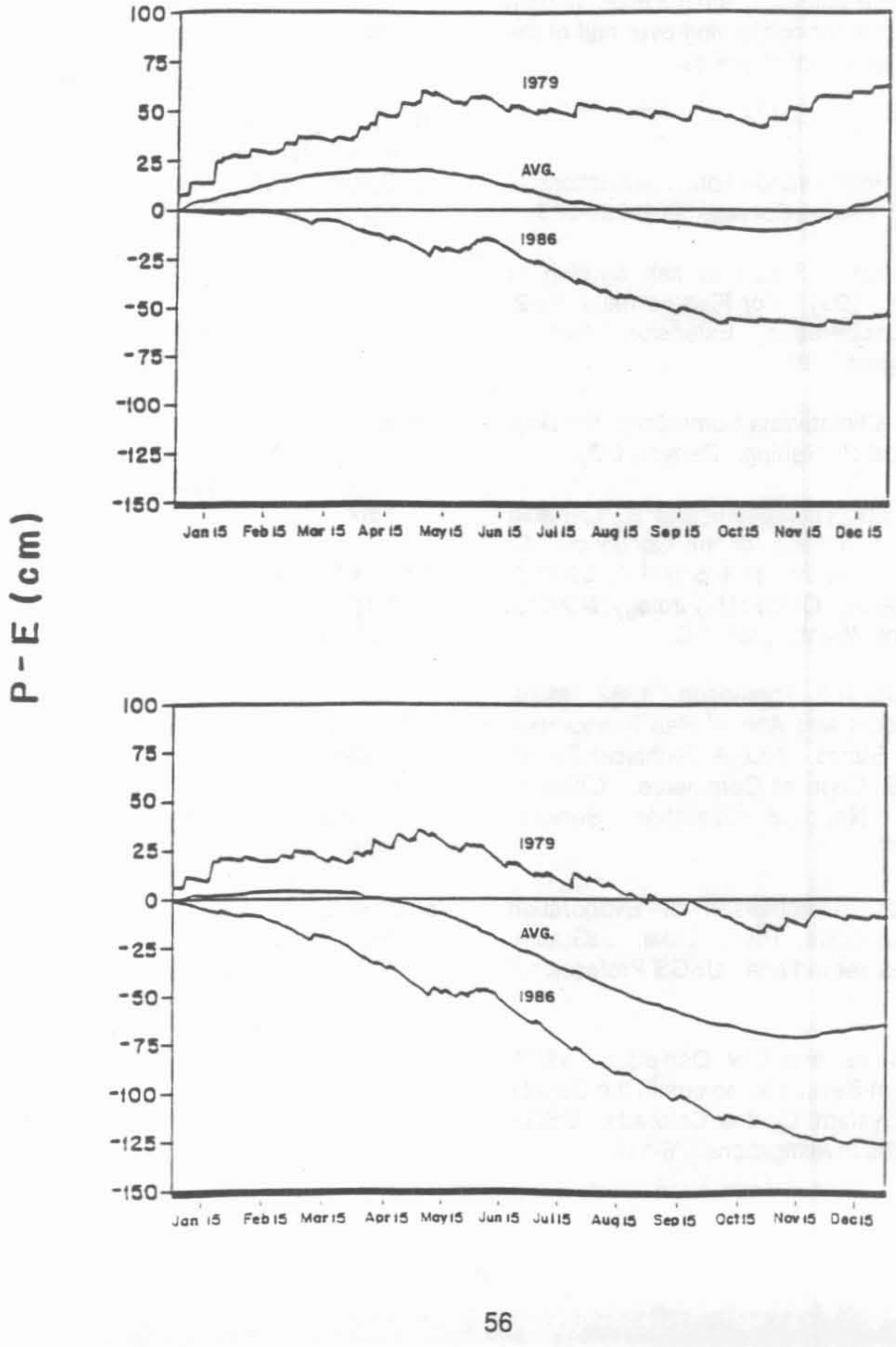

Figure 2. Daily water level fluctuations, extreme years, in ponds with infiltration.

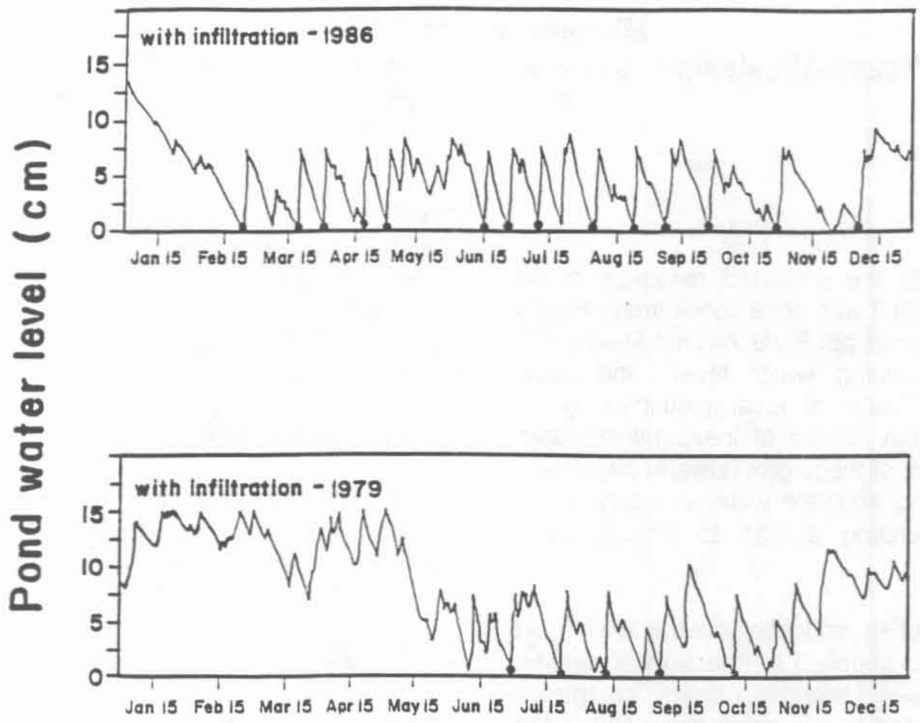

Figure 3. Total cumulative 30-year annual water use using two management methods, with and without infiltration