SUBSTITUTING CLIMATE FOR GROUNDWATER IN AQUACULTURE: THE POTENTIAL FOR CONSERVATION IN THE SOUTHEASTERN UNITED STATES

Charles L. Wax and Jonathan W. Pote
Department of Agricultural and Biological Engineering
Mississippi State University

Introduction

One of the main environmental elements used to define the southern region of the U.S. is climate. The southeastern corner of the North American continent is characterized by the humid subtropical climate type, typified by temperate winters, evenly distributed rainfall through the year (no pronounced wet or dry period), and long, hot summers. This climatic setting is one of the most important controlling factors for man's activities within the southern region, establishing environmental conditions conducive to many uses of the natural landscape.

The southern region has traditionally been agriculturally oriented and productive. In recent years, warm water aquaculture has expanded rapidly as an alternative crop in the region and the industry has experienced phenomenal growth in the last ten years (World Aquaculture Society 1988). The heart of the industry in the U.S. is the state of Mississippi, which accounts for more than 75 percent of all domestic catfish (*Ictalurus punctatus*) production, the predominant warm water aquacultural species. According to Mississippi State University (1989) the farm raised catfish industry is the fastest growing and most profitable enterprise in Mississippi, with about 90,000 acres devoted to pond production. With a 1988 production value of $301 million, it was outranked only by cotton, timber, poultry, and soybeans in the state.

The industry has prospered in the southern region because it is water intensive and temperature dependent. In addition to the favorable temperatures in the south, groundwater, the primary source of water for the industry, is also plentiful in the region. With most places in the region receiving between 45-65" of precipitation annually, and with groundwater being relatively abundant and accessible across the region, water availability has been taken almost for granted. Recently, increased demand for groundwater, aggravated by a series of drought years, has prompted growing concern over future availability and quality of this vital natural resource, and the need for conservation of groundwater especially has become clearly focused.

A previous study (Pote et al. 1988) specifically addressed groundwater conservation in catfish production in the Mississippi Delta, where over 96% of the state's catfish production occurs. The study showed groundwater conservation potential for that particular location when a management scheme that took advantage of climatic attributes was employed. This report extends the results of the techniques established in that study for warm water aquaculture at other locations in the region in order to determine if the management scheme is uniformly applicable throughout the entire region.

Locations were chosen to evaluate the effectiveness of the scheme throughout the region by taking into account the east-west precipitation gradient and the south-north change from maritime to continental characteristics. This document addresses water use in aquaculture by reviewing sources and losses of water used in production and by developing climatological water budgets for ponds under differing climatic conditions in the region.

Background Information

Commercial warm water aquaculture in the region is practiced in levee ponds constructed on heavy clay soils with excellent water-holding capacity. A typical pond has about 17 acres of water on 20 acres of land, averaging about 4 feet in depth. Ponds are built with drains to control and adjust water level.

Although precipitation falling into ponds has the potential to supply large amounts of water, levee ponds have virtually no watersheds, so other sources of water must be available. Because of water quality advantages, groundwater is presently by far the source of choice. A well yielding 2,000-3,000 gallons per minute is adequate for four ponds of about 17 water acres each (Wellborn 1987).

The water budget for a levee pond can include these terms:

<u>Sources</u>	<u>Losses</u>
Rainfall	Evaporation
Groundwater	Seepage (infiltration)
Surface water	Overflow

While rainfall has the potential of providing up to 65" per year in some parts of the region, in practice nearly all this water is lost to overflow due to the management practice of holding pond levels at near maximum. Surface water is generally contaminated with trash fish, disease organisms, or pesticides, fertilizers, and other pollutants, and is, therefore, seldom used. Thus, owing to its purity and availability, groundwater is the primary source for warm water aquaculture.

Evaporation is a major and unavoidable loss in the production process because an open pond surface is necessary for gas exchanges as well as cultural activities such as feeding, aerating, and harvesting. Infiltration losses are minimal because leaking ponds are repaired or taken out of production in favor of better sites. Overflow losses are determined by both precipitation events and management practices.

In light of the above considerations, a realistic water budget for ponds can ignore surface water inflow and infiltration losses but must account for precipitation and evaporation. It should also be noted that pumping groundwater into the pond and removing pond water through the drains (overflow) can be used to control the pond water level.

Methods and Procedures

Site selection

Five sites were chosen for the analyses. Selection was based on the following three criteria:

1) sites were located in states that have significant aquacultural production;
2) sites had serially complete and homogeneous daily precipitation and evaporation records; and
3) sites were spatially dispersed to provide representation of the moister eastern and drier western portions of the region as well as the coastal (maritime) and interior (continental) characteristics of the regional climate.

Based on the best possible combination of these criteria, the following sites were selected: Stuttgart, AR; Stoneville, MS; LSU - Ben Hur, LA; Fairhope, AL; and Clemson, SC.

Climatological Data

Daily observations of precipitation and evaporation for the period 1962 to 1986 from the National Weather Service Cooperative Observation System were obtained from the U.S. West optical disk set, available on CD-ROM (Climatedata, 1988). The data were loaded into Lotus 1-2-3 (Lotus[R], 1986) spreadsheets for checking and quality control.

Pan evaporation is not directly comparable to true evaporative loss from the surface of a lake or pond because of different heating characteristics and differing degrees of exposure to wind and sun of evaporation pans as compared to large bodies of water. Therefore, a correction coefficient is generally used to correct measured pan evaporation to a more realistic estimate of actual evaporative loss 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; Hounam 1973; Yonts et al. 1973; Ficke 1972; Ficke et al. 1977).

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). Because the environment in which these coefficients were determined is closely related to the environments of aquacultural production ponds in the southeastern U.S., a correction coefficient of 0.8 was used in this study to correct the pan evaporation data to estimates of evaporative losses from ponds. Table 1 shows, for spatial comparison, the range of pond evaporation values thus determined from pan evaporation records for the five sites in this study.

Table 1: Summary of Average Daily Pond Evaporation Rates During Summer, Southern Region

Location	Inches
Fairhope, AL	0.18 - 0.20
Clemson, SC	0.17 - 0.19
LSU - Ben Hur, LA	0.19 - 0.23
Stuttgart, AR	0.20 - 0.24
Stoneville, MS	0.20 - 0.24

Data Analysis Techniques

Climatological Water Balance, No Management

A daily comparison of precipitation (P) and pond evaporation (E) was conducted at each of the 5 locations for the 25-year period Jan. 1, 1962 - Dec. 31, 1986, except at the LSU site where data were not available for 1962. Cumulative summation of these daily values provided patterns of pond water levels at each site, as influenced solely by daily increases or decreases from either a positive or a negative P-E, through the period.

These analyses show the pond level regimes that might be expected from a purely climatological standpoint; that is, if the daily interaction between precipitation and evaporation were the sole factors in determining pond water levels, and if no water was added from any source other than precipitation, no overflow occurred, and no loss other than evaporation was encountered. Comparison of results at the 5 sites documents the regional variation in potential for precipitation to exceed pond evaporation on a cumulative, daily basis, and, therefore, indicates the comparative advantage of different areas within the region to use precipitation in a management scheme to keep ponds filled and thereby conserve groundwater.

Climatological Water Balance, Two Management Methods

The first method of pond management consists of preventing infiltrative losses and using less or no water for flushing of ponds (McGee and Boyd 1983). The only water added is that necessary 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 precipitation to overflow. The large annual precipitation in the region as well as the 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.

The second method is the 6/3 scheme proposed by Pote et al. (1988), a management option in which the water level of the pond is allowed to drop, by evaporative loss in excess of any precipitation, a full six inches from the starting point before addition of any groundwater occurs. When groundwater is added at that point, the amount added is only enough to raise the level of the pond three inches, leaving capacity to store any precipitation which might subsequently occur. Any rainfall which raises the pond level above the starting point is assumed lost to overflow through the drain pipe. Fluctuation in pond water level allows 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.

The application of the two management systems was simulated on a daily basis by computer program for each of the five locations for the twenty-five year period 1962-1986. Daily water budgets or ponds at all 5 locations were calculated using daily precipitation and pan evaporation data. Ponds at each site were assumed full on 1 January 1962. 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 methods.

The total amount of water added under the "make-up" method was simply the summation of all daily negative P-E values for each year. Under the 6/3 scheme, the amount of water added each year was the summation of the 3 inch increments added when pond level had dropped to the 6 inch threshold. The amounts of groundwater used under both schemes during each year at each of the five sites was thereby determined and compared.

Results and Discussion

Climatological Water Balance, No Management

Water levels in ponds were assumed to be at some arbitrary gage level "0" on January 1st of the year of interest. Results show that if all precipitation was captured and retained in the pond to offset subsequent evaporation, pond levels during an average year would, at all 5 sites, rise and stay constantly above the starting level through about July 1st, and then end up at or above the starting level at year's end. Conceptually, this documents the regional climatic advantage available for aquaculture -- that even in the period of highest evaporation, rainfall is constant enough to continuously replace evaporation losses on a routine basis much of the time.

Comparison of the wettest years at each of the 5 sites shows that the daily pond levels experience a nearly continuous increase through those entire years at each location as precipitation dominated evaporation most days of the year. Furthermore, the extreme wet years show the considerable differences in pond regime as influenced by climate across the region. The Fairhope site ended its wettest year (1978) with pond levels around 54 inches above the starting level while the Stuttgart site ended the wettest year there (1974) with water only about 12 inches above the starting level -- a regional range of 42 inches.

Evaluation of the driest year at each of the five locations showed that all the pond water levels stayed at or above the starting level at all sites for the first two or three months of those years before starting to drop. Thereafter at all sites a nearly continuous decrease in pond levels was characteristic throughout the remainder of the year as cumulative P-E stayed negative day after day. Daily water level fluctuations during the average and extreme years at the Stoneville location are shown for illustration in Figure 1.

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 magnitudes found, ranging from near 60 inches at Fairhope to about 35 inches at Stuttgart. Some degree of management must be introduced to control fluctuations in water level.

Climatological Water Balance, Two Management Methods

The results of the "make-up" management scheme are not graphically dramatic on a day-to-day basis. The water level remained essentially constant, and the amounts added on a daily basis were small -- only enough to replace daily evaporation in excess of daily rainfall at the rates shown in Table 1.

The daily water level patterns created by the 6/3 management scheme for the wettest years and the years requiring the most pumping of groundwater at each of the five locations are shown in Figures 2 and 3. The days in the year when pond levels dropped to the 6-inch threshold and 3 inches of groundwater was consequently added to the ponds are marked on the date of pumping. The differences in the daily fluctuation patterns from place-to-place, the amounts of water added, and the distribution of pumping events through each of the years are evident in the Figures. These analyses illustrate clearly the effects of rainfall, pumping, and evaporation on pond water levels and documents the capability of this management scheme when the impact of annual climatic variability is most extreme.

Figure 2, the patterns of the wettest years at all locations, shows that the pond levels fell no more than one or two inches through April and overflowed on many occasions with excess rainfall. No water had to be added at either Fairhope or LSU, and only one pumping event was required at the other three sites during the wettest year. Furthermore, since only 3 inches of water was added then, the subsequent large rainfalls at each of the three sites were successfully captured and no more water was added for the rest of the year. It is apparent from these analyses that the climate in the southern region is capable of providing sufficient rainfall, in both a temporal and spatial sense, to almost completely maintain ponds within the 6-inch design limit in wet years.

Figure 3 shows how the scheme worked in the years requiring the most groundwater to maintain ponds within the 6-inch design limit at each site. Typically, these were the years at each site that had the longest strings of dry days as compared to the actual driest years, which may have had rainfall more evenly distributed and, therefore, required less pumping. With the exception of the Fairhope site, no location had overflow between the middle of April and early October. All sites 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. These analyses thus give a clear indication of how long a three-inch addition of groundwater will last against evaporative losses when no daily precipitation occurs, and thereby emphasize how much potential for conservation the capture of daily precipitation does provide.

Figure 4 displays the difference in water used in ponds at all locations during each of the 25 years when "make-up" water is used as compared to the 6/3 scheme. It can be seen that use of the "make-up" method requires a regional average of around 38 inches of groundwater each year to keep ponds full, with the exception of Fairhope where the yearly amount is about 33 inches on the average. By comparison, the amount of groundwater required to keep ponds within the design limits of the 6/3 scheme varies in any given year at different locations from zero to a maximum of 24 inches and averages under 10 inches a year regionally.

Specific figures for each site, as well as the regional average, are given in Table 2. Note that these analyses indicate an average regional reduction in the use of groundwater of more than 75 percent over the previously best conservation strategy. Furthermore, notwithstanding the spatial advantages of maritime environments or the temporal advantages of wetter years, the demonstrated potential for groundwater conservation is not limited by location in the region or by the annual climatic variability that is so common in the region.

Table 2: Twenty-five Year Averages of Annual Groundwater Use (inches), Two Management Methods, with Conservation Potential Indicated

Location	Make-up	6/3	% Conserved
Fairhope	33	4	82%
Clemson	38	9	76%
LSU-Ben Hur	38	7	82%
Stuttgart	40	12	70%
Stoneville	40	14	65%
Region	38	9	76%

Because the five sites are arranged in approximate geographic relationship to each other, regional variation in both water use requirements and potential for conservation of groundwater can also be discerned in Figure 4. For example, the regional east-west precipitation gradient can be seen in the difference in water required at Clemson as compared to Stoneville and Stuttgart. Even more pointed is the maritime-to-continental gradient that is particularly evident in the differences detected between the coastal environment represented by Fairhope and the inland locations of Stoneville and Stuttgart.

The 6-inch water level fluctuation threshold was chosen based upon discussion with producers. That amount of exposed levee bank was not considered an erosion or weed-encroachment threat. The 3-inch groundwater addition threshold was chosen based upon climatological probabilities for weekly rain amounts. There is less than a 10 percent chance of getting more than 3 inches of rain in any week during the year (Wax and Walker 1986). Other combinations -- such as 6/1, 9/3, 9/1, 12/3, or 12/1 -- could prove even more advantageous from a water conservation or economic standpoint. Further investigation by computer simulation using these other design limits may be justified.

Conclusions

It is becoming increasingly vital for warm water aquaculture producers to recognize the importance of water conservation. Ponds with high infiltration rates should either be repaired or taken out of production. The practice of flushing to maintain water quality should be eliminated. While use of "make-up" water is presently the best conservation practice employed, use of the suggested 6/3 scheme, which uses captured rainfall to offset evaporative losses, has the potential for drastically reducing groundwater use in aquaculture in the southern region. The potential average conservation of groundwater indicated by this study ranges from 65% to 82% and averages 76% regionally.

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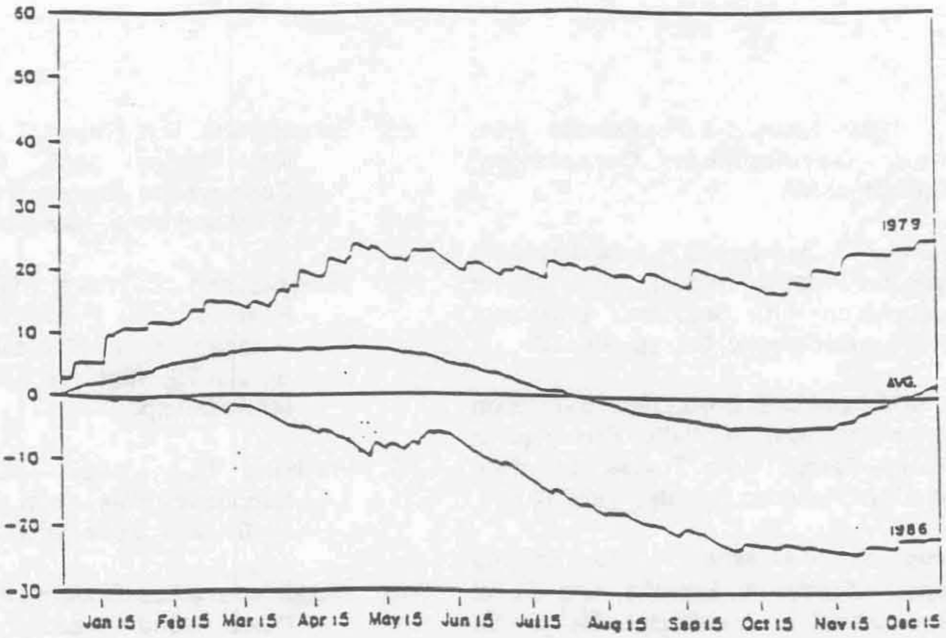

Figure 1. Cumulative P-E, Daily, Stoneville, During the Wettest Year (1979), the Driest Year (1986), and the Average Year (AVG)

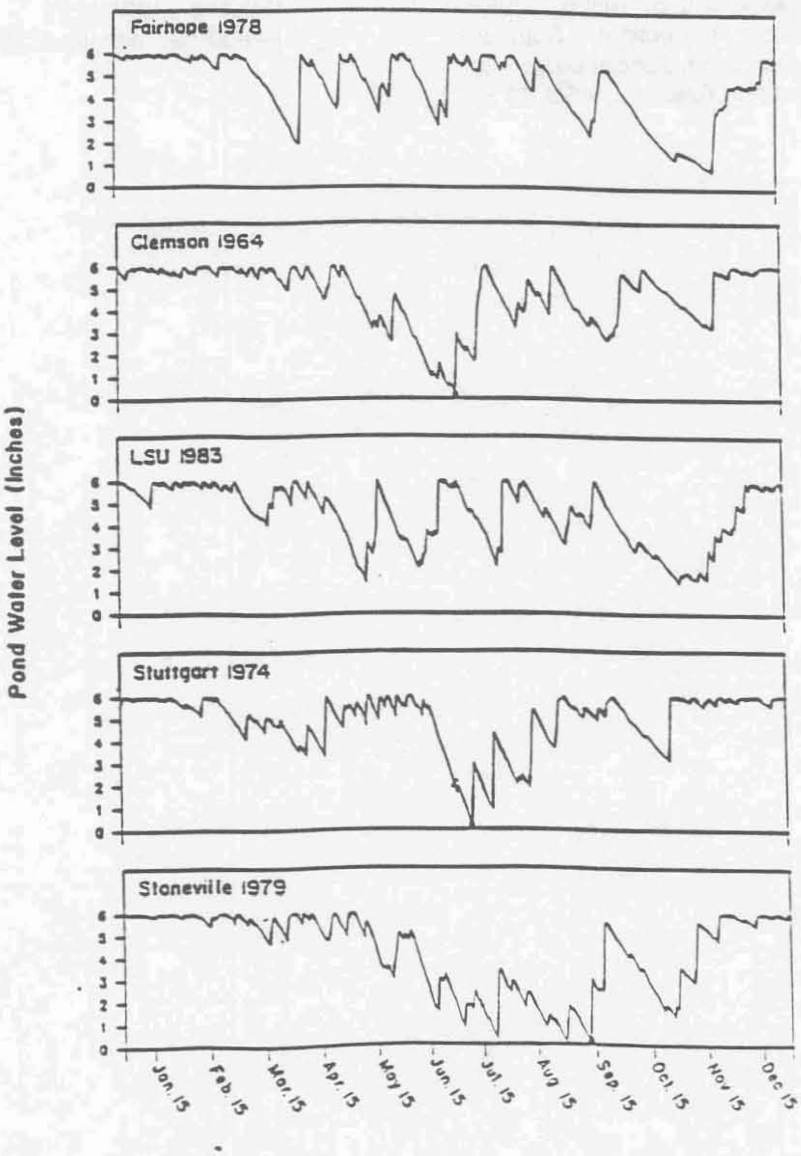

Figure 2. Daily Water Level Fluctuations, Wettest Year

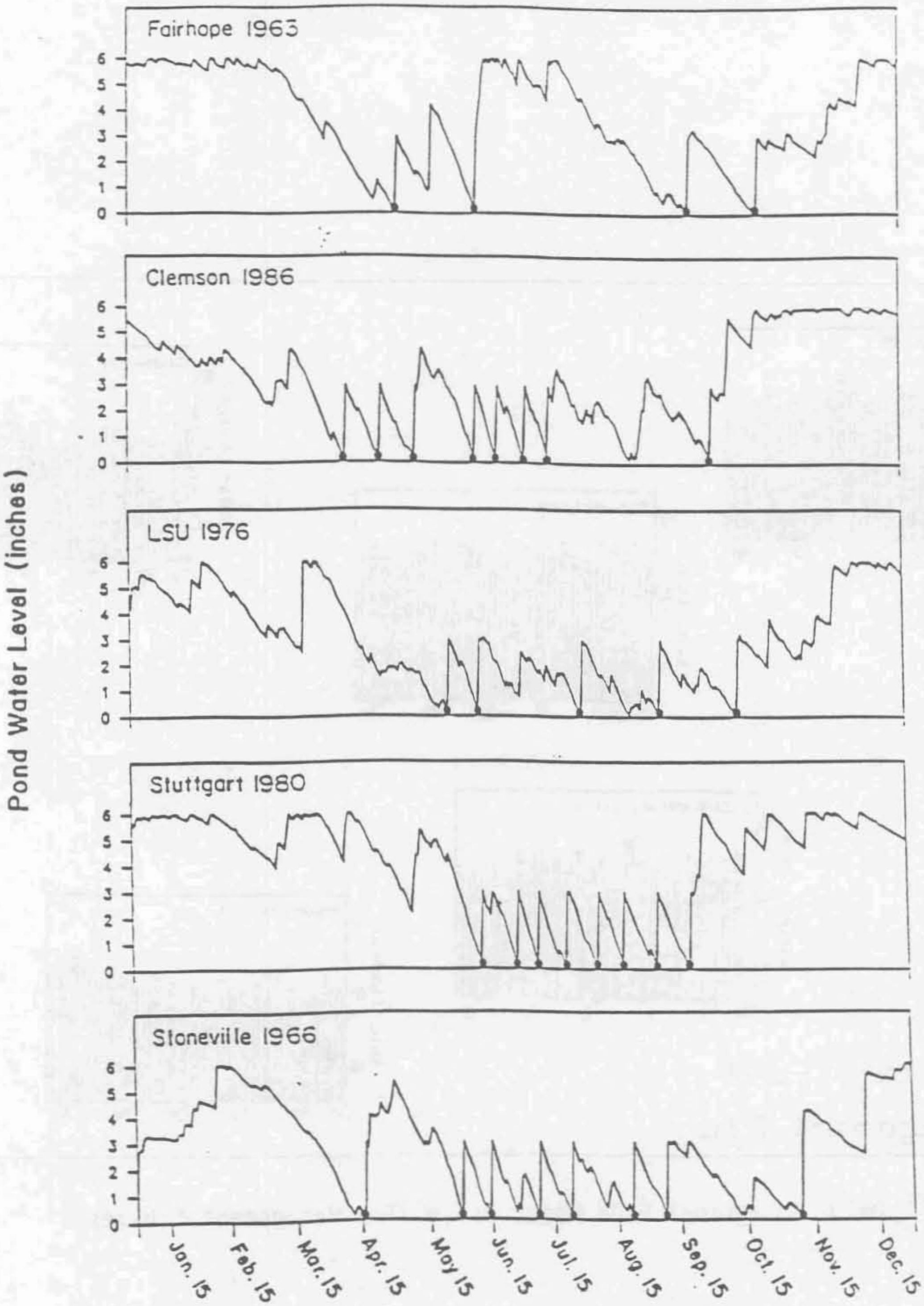

Figure 3. Daily Water Level Fluctuations, Driest Year

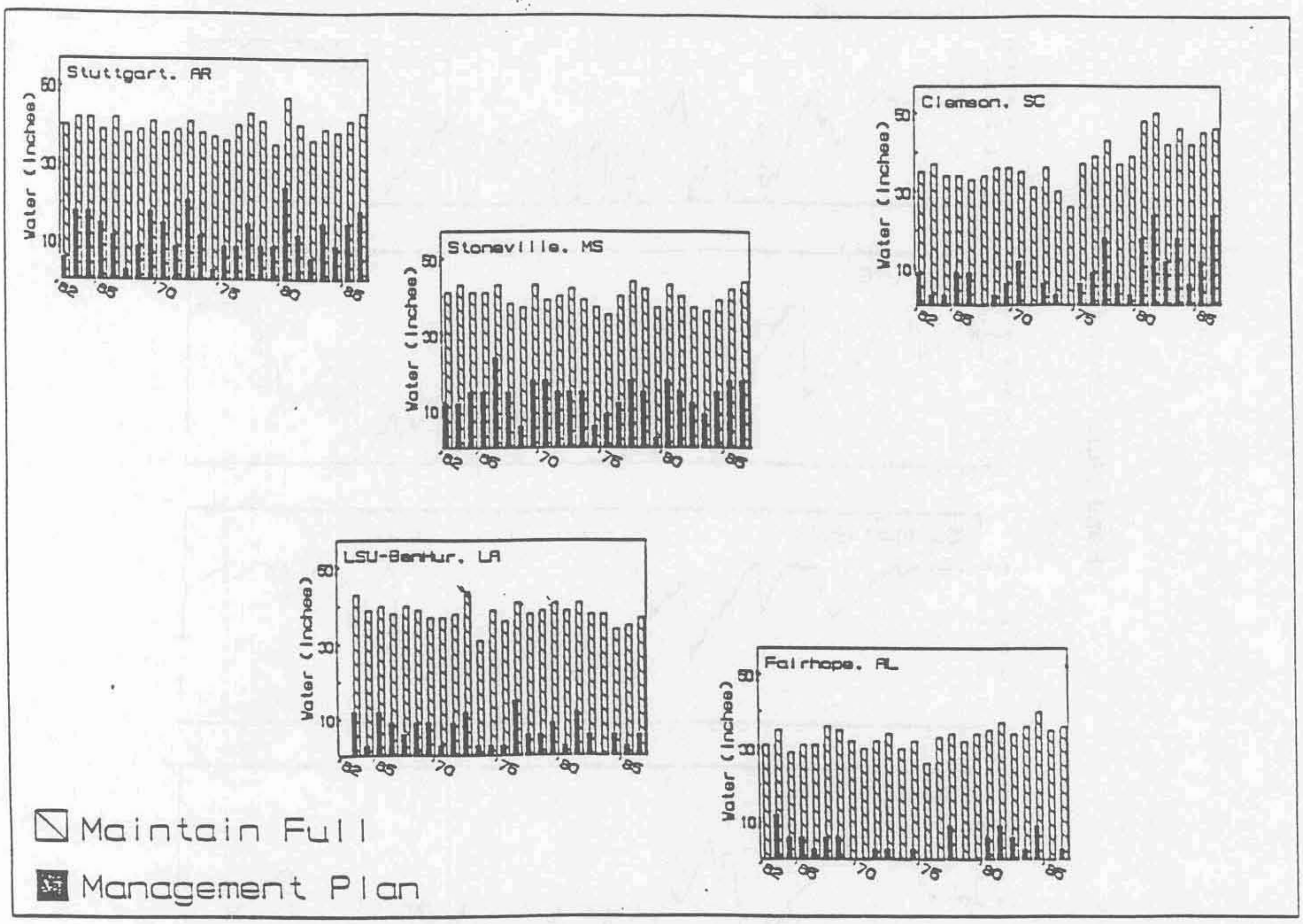

Figure 4. Regional Pond Water Usage, Two Management Schemes