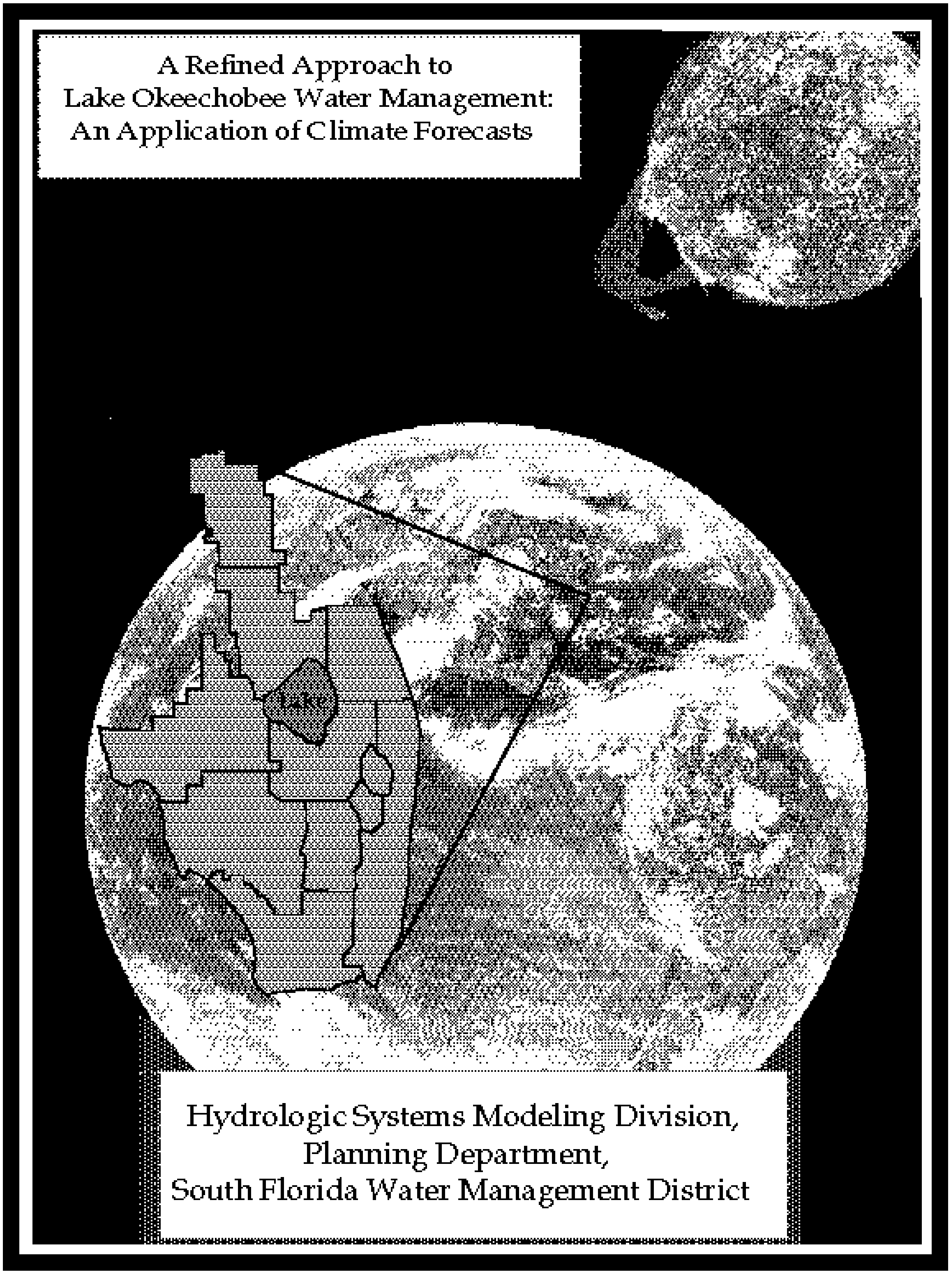
Special Report

A Refined Approach to
Lake Okeechobee Water Management:
An Application of Climate Forecasts



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A Proposal of the Hydrologic Systems Modeling Division,

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Executive Summary

The purpose of this report is to present the basis for a refined operational schedule for managing Lake Okeechobee water levels and discharges. The theme of this proposed operational schedule is towards increased operational flexibility. Recent breakthroughs in the diagnostics of climate variability on seasonal to decadal time scales provide a valuable mechanism for the advancement of the level of proficiency of regional water management. This potential for advancement results from increased lead times of forthcoming climate anomalies that may persist for extended periods. These anomalies may occur in the form of long term departures from average climate conditions and/or a distinct change in the likelihood of occurrence of extreme events. When these anomalies are recognized as being associated with larger scale prolonged climate phenomena, the advantages of an adaptable operational schedule are significant. This opportunity for increasing the efficiency of the regional hydrologic system is very timely considering the challenges that we face in managing our future water resources in south and central Florida.

In this report, the performance of the proposed operational schedule which incorporates a six month lead inflow forecast is compared to that of the current operation schedule with the application of the District's South Florida Water Management Model Version 3.2 (Hydrologic System Modeling Division, 1998). In addition to the increased flexibility incorporated into the operational rules of the intermediate zones, the proposed schedule permits excess water to be discharged from the Lake at lower water levels when large inflows are expected, based on current and projected hydrologic conditions. The Lake Okeechobee inflow forecast is computed

applying a methodology developed by Zhang and Trimble (1996) which uses global climate indices that are made available by the National Oceanic and Atmospheric Administration (NOAA).

The contents of this report include:

1. A brief introduction to several issues associated with Lake Okeechobee water management;
2. A discussion of the application of recent advancements that have been made in the field of climate diagnostics to water management;
3. A description of key climate indices that provide valuable lead time on forthcoming hydrologic conditions for south Florida;
4. An explanation of how these indices are transformed into operational forecasts;
5. Delineation of the proposed refinements to the Lake operational schedule;
6. Guidelines for application of more flexible operational rules;
7. Review of the simulated performance of the refined schedule compared to the current schedule;
8. Recommendations

The results of this analysis indicate that the operational schedule for Lake Okeechobee can be refined to increase the likelihood for most proficiently fulfilling the objectives of managing the Lake water levels and discharges. It is envisioned that with future advances in the understanding of climate fluctuations, that more flexible operational rules proposed will lead to even greater benefits for regional water management in south Florida.

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I. Introduction

Lake Okeechobee is the second largest freshwater lake lying wholly within the boundaries of the United States. It's location in south Florida is illustrated in Figure 1. This body of water benefits south Florida by storing enormous volumes of water during wet periods for meeting environmental, urban and agricultural needs during subsequent dry periods. However, extended periods of high water levels within the Lake have been identified as being stressful to the Lake littoral zone. In addition, south Florida's potential for heavy rains and severe tropical storms requires that water levels in the lake be carefully monitored to ensure that they do not rise to levels that would threaten the structural integrity of the levee system surrounding the Lake. Therefore when water levels in the lake reach certain elevations designated by the operational schedule, discharges are made through the major outlets to control excessive buildup of water in the Lake. The timing and magnitude of these releases are not only important for preserving the flood protection of the region, but also for protecting the natural habitats of downstream estuaries and Everglades.

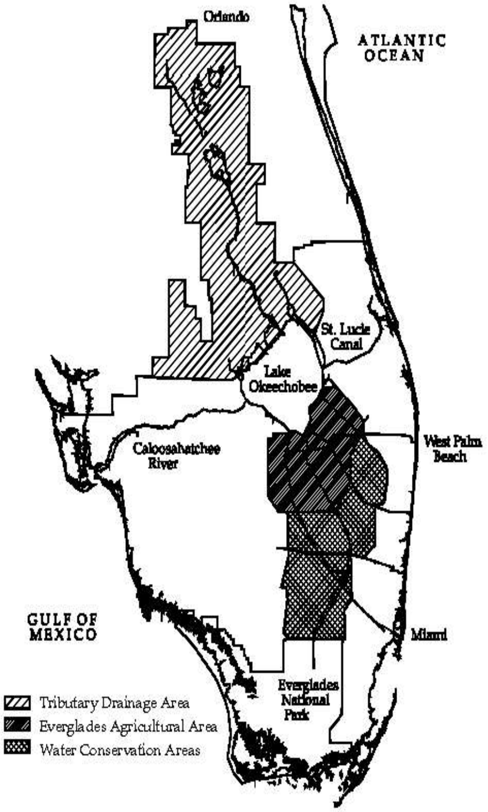


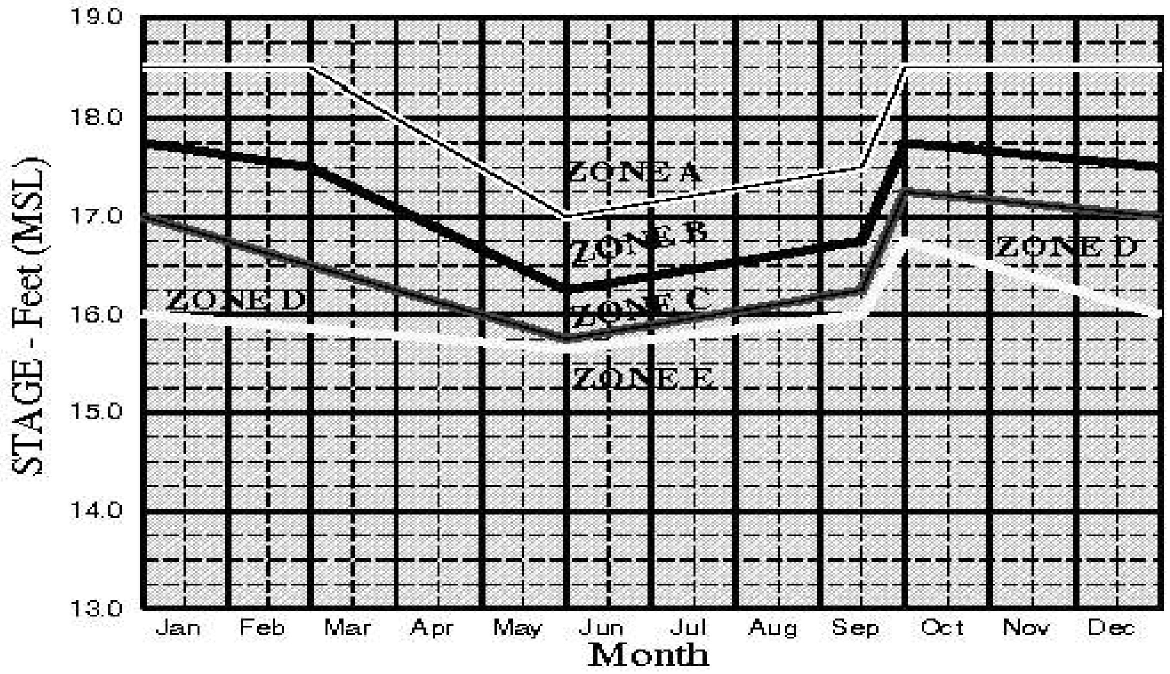
Figure 1. Location of Lake Okeechobee within the South Florida Water Management District

In summary the competing objectives associated with managing the lake water levels include:

1. Providing adequate flood protection for the regions surrounding the Lake,
2. Meeting the water use requirements of the agricultural and urban areas dependent on Lake Okeechobee for water supply,
3. Preserving the biological integrity of the estuaries downstream of the Lakes two major outlets to tide,
4. Supplying water to the remnant Everglades as part of the effort to restore more natural hydroperiods within this region,
5. Preserving and enhancing the lake's littoral zone which provides a natural habitat for fish and wildlife,
6. Serving the recreational needs of south Florida,
7. Providing navigational waterways.

The current schedule that is utilized for operational decisions appears in Figure 2. This schedule was officially adopted by the United States Army Corps of Engineers in December 1994 after a two year trial period. It is an adaptation of the preceding schedule that was originally made operational in 1978. The chief rationale for the implementation of the current operational schedule was to minimize the environmental impacts to the downstream estuaries from large flood control discharges of excess Lake Okeechobee water without negatively affecting the other objectives associated with Lake Okeechobee water management (Trimble and Marban, 1988; 1989). The current schedule was developed primarily considering only the most recent hydrologic conditions and the season of the year. The reliability of climate forecasts and the relationship between local Florida hydrology and global climate fluctuations was regarded as, at best, only fair during the development phase of the current operational schedule. With the recent advances in the diagnostics and predictability of prolonged climate shifts, it is clearly appropriate that this new information should be assimilated into the operational rules of the south Florida regional hydrologic system. Lake Okeechobee, with it's large tributaries and water use basins, is ideal for this application. The most substantial value of the implementation of a climate-based operational schedule is to alert water managers of the increased likelihood of extreme regional hydrological events, so performance may be improved for such events. Improved overall performance during less extreme hydrologic events will also be demonstrated.

Lake Okeechobee Regulation Schedule



	Release Through Outlets as Indicated		
Zone	Agricultural Canals to Water Conservation Areas[2]	Caloosahatchee River at S-77[2]	St. Lucie at S-80 including runoff from C-44 Basin

A	Maximum practicable releases	Up to maximum capacity	Up to maximum capacity
B[1]	Maximum practicable releases	6500 cfs	3500 cfs[3]
C[1]	Maximum practicable releases	up to 4500 cfs	up to 2500 cfs[3]
D	Maximum practicable releases	Maximum non-harmfull, discharges to estuary when stage rising	Maximum non-harmfull, discharges to estuary when stage rising
E	None	None	None

Figure 2. Current Operational Schedule

II. Climate Fluctuations and Regional Water Management

Weather forecasting is the science of predicting the likely future sequence of weather events. Weather systems are governed by complex interactions of physical and dynamic processes which are very sensitive to a diverse array of atmospheric variables. Small differences in these variables at one moment of time can eventually lead to large variations in the atmospheric behavior at a later time. The limited availability of high quality fine resolution meteorological data for atmospheric models bounds the lead time that can be produced with weather forecasts. Typically such forecasts are considered reliable for only a few days and seldom longer than a few weeks.

Regional water management systems that include large lakes and reservoirs with extensive tributary and water use basins require longer lead forecasts so that operators can make significant adjustments early enough to minimize adverse impacts to sensitive ecological systems, while maintaining adequate levels of flood protection and water supply. For Lake Okeechobee, even small deficits or surplus in rainfall are accentuated due to the large areal expanse that directly contributes to fluctuations in the Lake storage. This amplification of the Lake hydrologic response significantly narrows the window of opportunity for operational decisions. With the significant advances in climate research in recent years, climate forecasting has emerged as a plausible mechanism for improved water management. Climate forecasts predict shifts in atmospheric conditions that may persist for months, years or even decades. Figure 3 illustrates the time scales of climate variability. These will be discussed further in the following section.

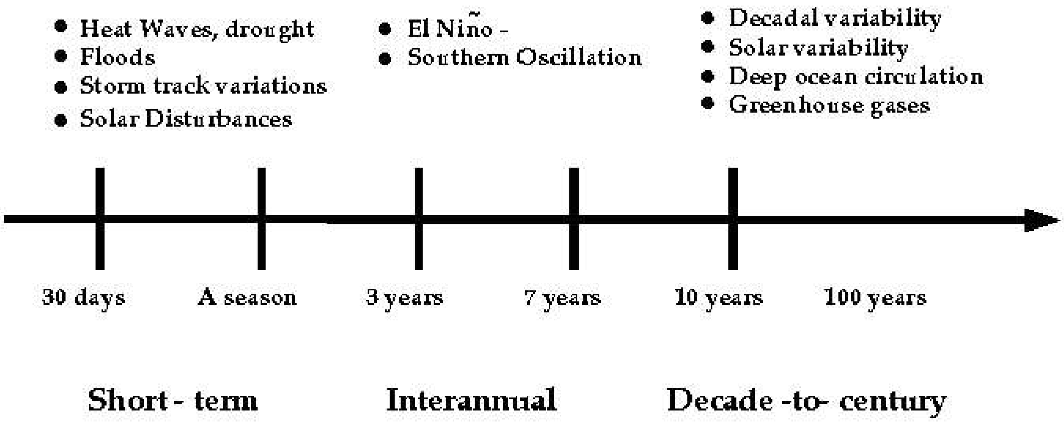


Figure 3. Time Scales of Climate Variability (Adapted from Randall M. Dole, 1977)

Figure 4 illustrates an example of a probability distribution of hydrologic events for normal climate conditions and the distribution for a shifted climate. A shifted climate may be recognized locally as a persistent change in the expected mean and extremes of rainfall events over prolonged periods. This information is of limited value for water management because it doesn't give an indication of why the anomaly is occurring or when it might end.

NOAA Environmental Research Laboratories
Climate Diagnostics Center

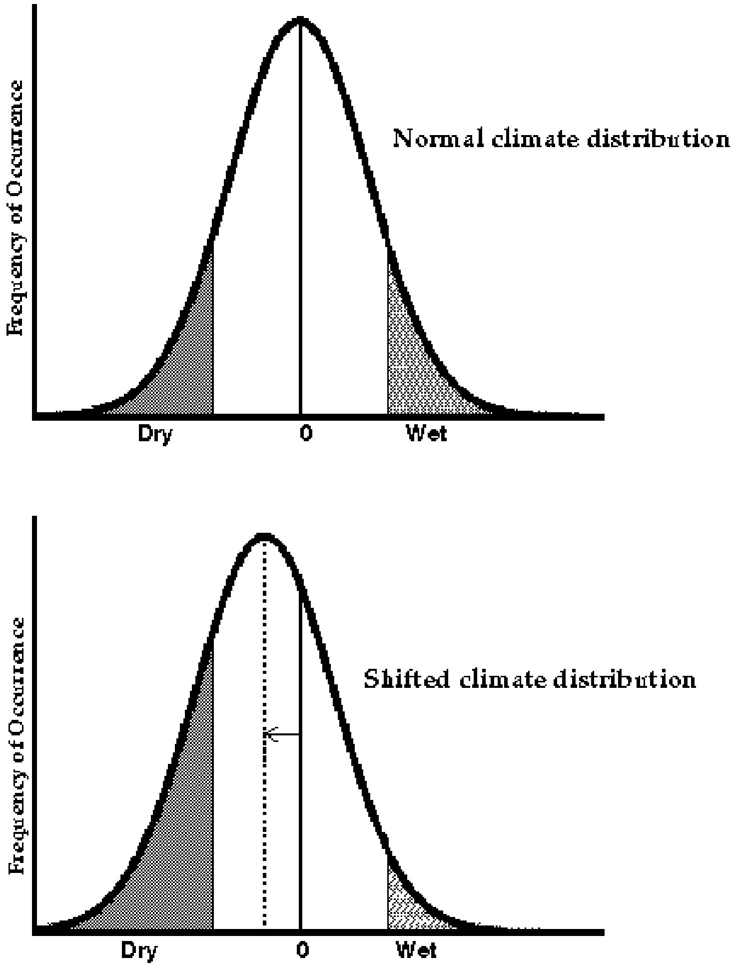


Figure 4. Probability of Extreme Regional Hydrologic Conditions with a Normal and a Shifted Climate (Randall M. Dole, 1977)

A rainy weather event in the domain of a climate shift towards drier conditions may be mistaken for a return to more normal or even wetter than normal climate conditions, if it is just perceived from a local perspective. However, it becomes of great significance for water management when the local climate anomaly is recognized as being associated with other larger (continental or global) scale climate events. Ramusson and Arkin (1993) emphasized the necessity for having a global perspective of the state of the climate in order to understand persistent shifts of regional climate.

The recognition of a shift in climate towards drier conditions, with less severe storms should enable water managers to refine operational rules to keep water in storage for longer periods. One example of such a climate shift occurred in south Florida nearly 25 years ago and has lasted more than two decades. This period was marked by the rearrangement of the Atlantic Ocean thermohaline current (Gray, Sheaffer and Landsea, 1997). Associated climate shifts occurred globally during this same period. One of the most notable was a significant decrease in rainfall in the region of Africa's Sahel and the subsequent expansion of the Sahara desert. The concurrent climate shift that occurred in south Florida had similar, though a less severe, reduction of rainfall. An important feature of the more recent climate regime is the reduction of intense tropical activity along the southeast coast of the United States. Figure 5 illustrates the decadal downward shift of tropical activity that occurred about 1970.

Until very recently the association between these climate anomalies was not widely recognized. In south Florida, Shih (1983) reported that the net decrease of averaged annual rainfall District wide from pre- to post- 1970 was on the order of 5 inches. Chin (1993) of the University of Miami in an analysis supported by University of Florida, the United States Department of the Interior and the South Florida Water Management District confirmed the continuance of the lower annual rainfall totals with his analysis of more recent rainfall data through the year 1990. The most significant decrease of rainfall was during the wet season months of June and October. Figure 6 illustrates the decadal shifts of Lake Okeechobee inflows that have occurred due to climate shifts.

During the post-1970 period, late winter and spring discharges of excess water were made to tide-water on a number of occasions. The releases made in the spring of 1980, 1984 and 1988 were followed by extended dry periods that necessitated special governmental actions related to water management including a special order for water supply backpumping of runoff from the Everglades Agricultural Area to the Lake Okeechobee. The 1980 and 1988 flood protection releases were followed by extended periods of mandatory regional water supply cutbacks. If these extended dry periods had been predicted at that time, along with recognition that south Florida was in a climate regime of less wet season rainfall and a significantly reduced likelihood of intense hurricanes, the excess water could have been safely retained during these spring months. The stored water supply could have been used during the very dry subsequent conditions to supply irrigation needs and/or enhancing hydro-patterns in the Everglades. This hindsight is especially clear since these releases to tide-water were made during the non-tropical season when no imminent threat of hurricane surge existed.

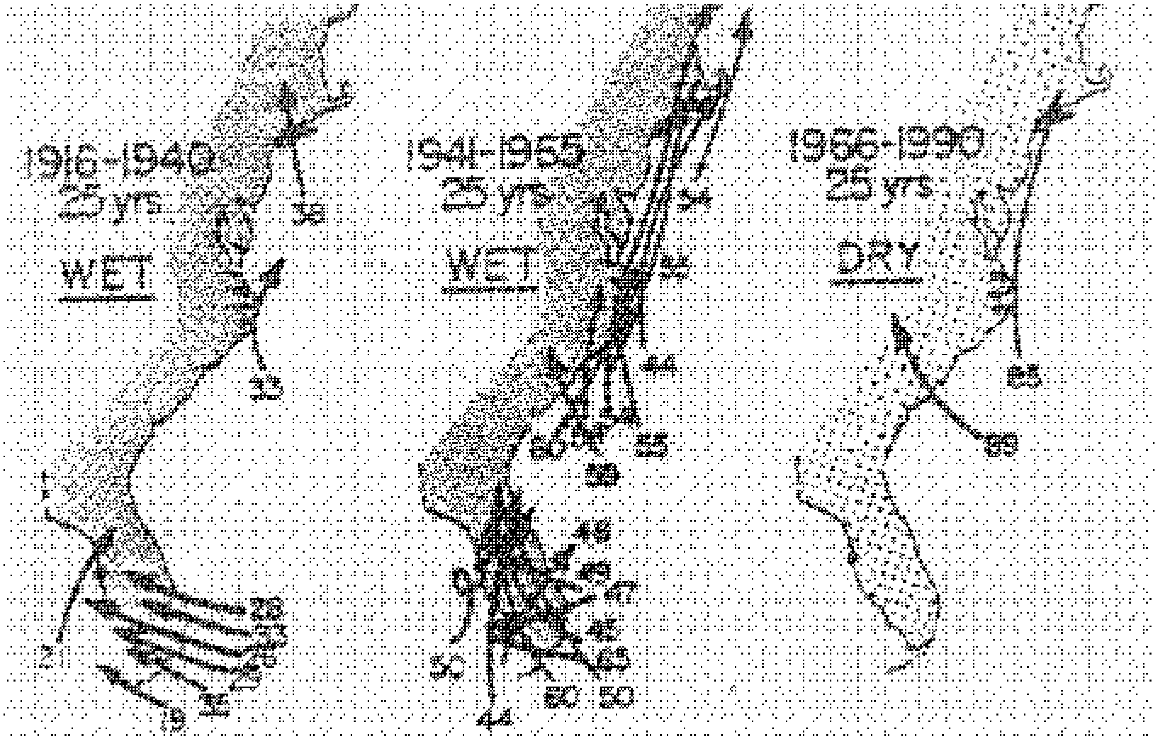


Figure 5. Contrast of land falling intense hurricanes on the East Coast of the United States during two 25 year periods, 1916-1940 and 1941-1965, when the Sahel Area of West Africa was relatively wet, versus intense landfalling hurricanes during 25 years (1966-1994) when it was dry. Numbers plotted by each track indicate the year of the storm. Printed by permission of Gray, Shaeffer and Landsea, 1997

With the large strides that have been made in recent years in the understanding of global climate fluctuations and how they relate to regional climate anomalies such as those of south and central Florida, the time has come to develop more flexible operational rules that take advantage of this knowledge base. During periods of more active and severe tropical activity and a lower drought frequency, similar to those we have experienced in 1995 and 1996 and years prior to 1960, it would be advantageous to make releases from the Lake to tide-water at lower water levels. This would not only improve flood protection but would minimize the impact to the Lake littoral zone and downstream estuaries.

Intuitively, when a shift in the climate has been recognized and the causes of this shift are understood, an appropriate adjustment in the operational rules should be made to increase the likelihood of better meeting the competing objectives of managing Lake Okeechobee water levels. Vital research being completed by a number of NOAA and international research centers have allowed great strides to be made in the field of climate forecasting. These efforts have tremendous potential for increasing the efficiency of water management. The following section discusses the climate fluctuations, including the Atlantic Ocean thermohaline circulation referenced in this section, that may give valuable lead time for water managers.

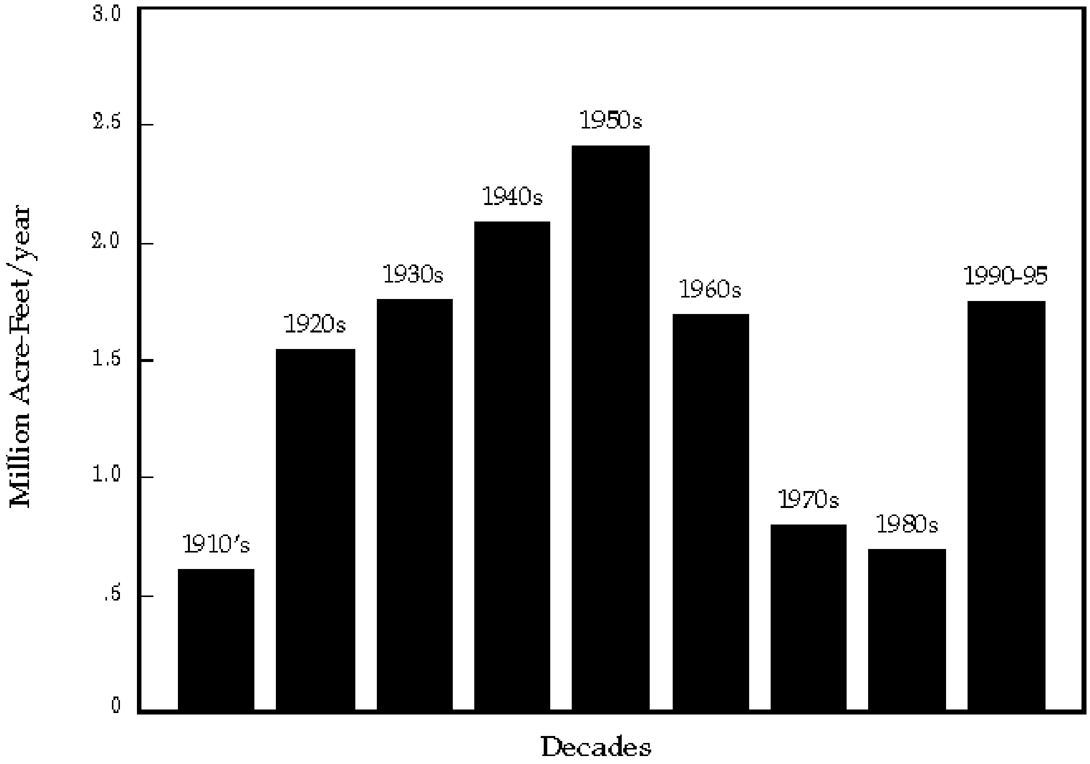


Figure 6. Decadal Variations of Lake Okeechobee Inflow

III. Valuable Indices for South Florida Regional Water Management

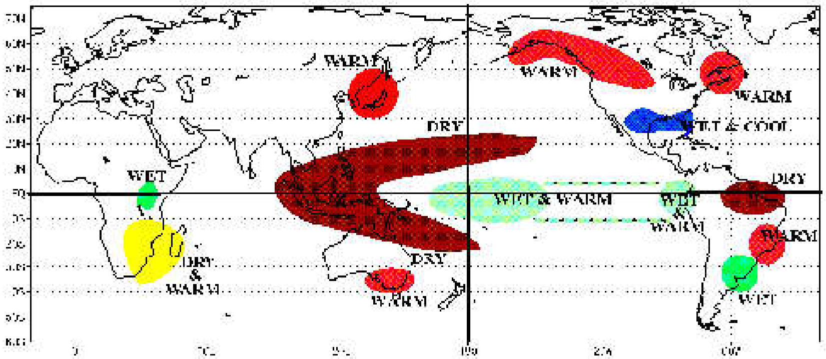
Indeed, a large portion of the variations of south Florida's climate has been found to be associated with large-scale global atmospheric and oceanic changes that occur at distant parts of the world. Teleconnections between climates at distant locations of the world are indicated by the statistical association between the climate variables at these locations. The teleconnections tend to be most easily recognized by the cyclic anomalies of atmospheric and oceanic variables. Several offices of the National Oceanic and Atmospheric Administration including the National Center of Environmental Prediction- the Hurricane Research Division, the Climate Analysis Center and the Climate Diagnostics Center, are involved with research to increase the understanding of global oceanic and atmospheric teleconnections. The description of these research projects is beyond the scope of this analysis. However, particular climate indices are readily available that summarize the general state of the global atmospheric and oceanic systems. Many of these provide useful information for forecasting Florida's regional hydrologic conditions.

a) El Nino - Southern Oscillation Index

El Nino events originally only referred to sea surface temperature anomalies that occurred along the equator within the Pacific Ocean. However, the El Nino-Southern Oscillation (ENSO) is now recognized as complex interaction of ocean and atmosphere processes in the tropical Pacific. The Southern Oscillation was first detected in the late 19th century by Sir Gilbert Walker who pioneered the application of statistical methods for comprehending the relationship of climate fluctuations that occur synchronously at distant points of the world. His efforts were directed towards better grasping the reasons for the variability of India's monsoon after two catastrophic droughts and famines occurred in the years 1877 and 1899.

In his endeavor, Walker discovered a seesaw like relationship in the atmospheric pressures between the subtropical Pacific and the India Oceans. His statistical studies also found significant correlation between ocean temperature and rainfall fluctuations across the Pacific Ocean with this phenomenon. Walker published a series of papers between 1923 and 1937 in which he documented the relationship that exists between the India's monsoon and global climate fluctuations on an interannual basis (Golnaraghi and Kaul, 1995). However, because of the lack of previous scientific evidence of such teleconnections between climates in different parts of the world, the interest in his work gradually faded until the occurrence of an exceptionally strong ENSO event that occurred during the autumn and winter of 1957-1958.

Figure 7a. El Nino Climate Teleconnections:
December - February



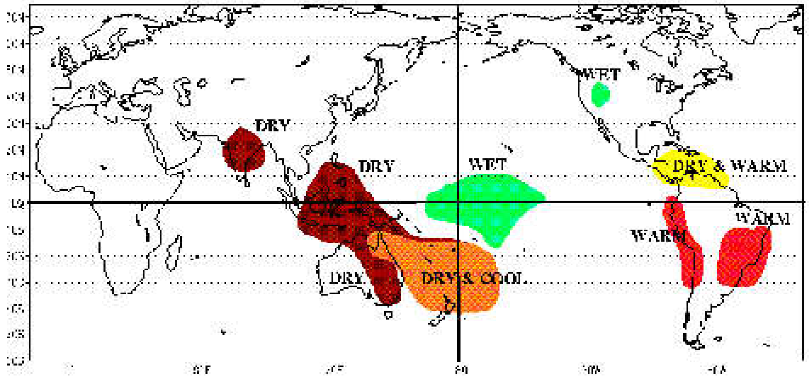


Figure 7b. El Nino Climate Teleconnections:
June - August

Figure 7a,b. El Nino Climate Teleconnections

ENSO has been recognized for it's associations with many global climate anomalies. Figures 7 a and b illustrate many of the most significant anomalies associated with the warm phase of El Nino. The Florida climate has the greatest statistical association with the ENSO process during the winter months. The warm phase of the ocean temperature anomalies (El Nino) have been identified with greater than normal winter rainfalls while the cold phase of ocean temperature anomalies (La Nina) have been identified with drier than normal winter rainfalls in Florida (Hanson and Maul, 1991). The winter rainfall anomalies associated with El Nino events have been generally reported to be 50 percent above the normal winter rainfall totals.

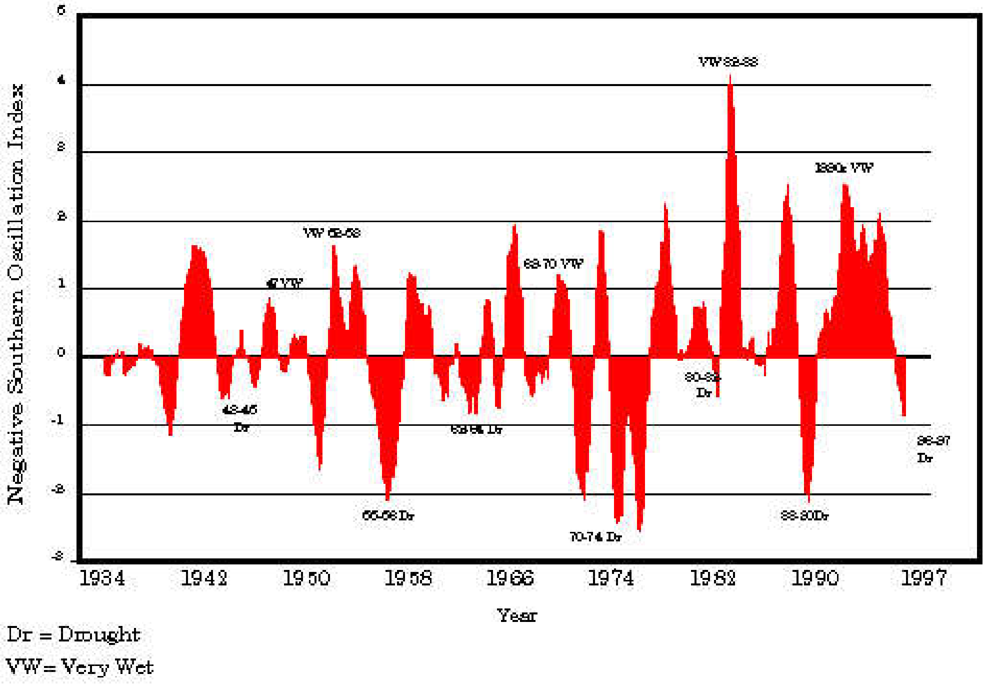


Figure 8. El Nino-Southern Oscillation Index (-SOI) and Notable Lake Okeechobee Inflow Events

The Southern Oscillation Index (SOI) computed from the sea level pressure anomalies is used as an indicator of the strength and phase of the ENSO. The SOI was selected over sea surface temperature anomalies because it has a much longer period of historical record available. The sea surface temperature record for El Nino events is available beginning in 1950 while the SOI pressure record begins prior to 1900. This longer record is very valuable for developing a relationship between the ENSO process and the Florida hydrology for a large variety of global atmospheric conditions. Figure 8 illustrates notable Lake Okeechobee inflow events versus major ENSO events. The air pressure anomalies associated with the SOI are normally opposite in sign of the sea surface temperature anomalies associated with El Nino. Since the ENSO events are more commonly recognized by the sea surface anomaly, the negative SOI index is plotted in Figure 8. Therefore a positive plotted value (a computed negative value for SOI) is associated with a warm El Nino event and a negative plotted value (a computed positive value for SOI) is associated with a cold El Nino event. Figure 9a illustrates an example of the sea surface anomaly along the Peruvian Coast during the 1982-1983 El Nino event (warm sea surface temperature anomaly). During this same period much above normal rainfall persisted for several months in Florida. This excess rainfall required large discharges from Lake Okeechobee to tide-water. Figure 9b illustrates it's counterpart, the La Nina event (cold sea surface anomaly) that occurred in 1989 at which time Florida had an extended period of below normal rainfall.

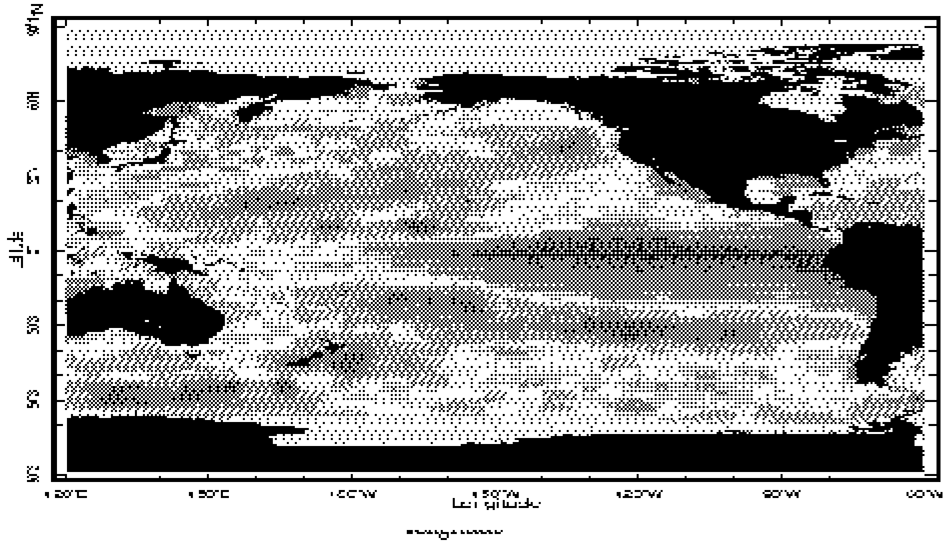


Figure 9a. Warm Sea Surface Temperature Anomaly Associated with 1982-1983 El Nino (Florida in a Wet Condition)

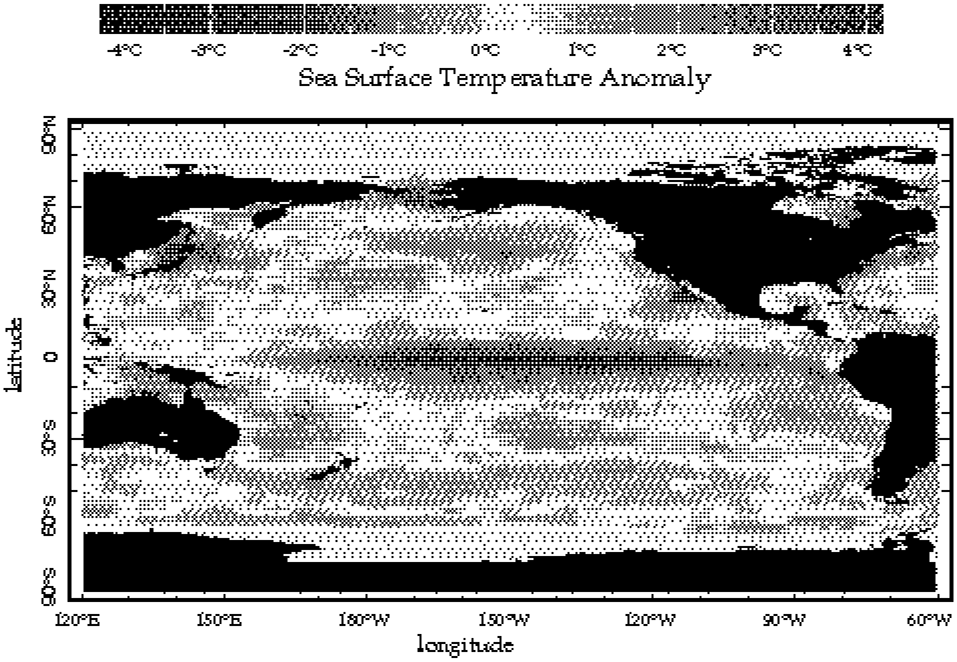


Figure 9b. Cold Sea Surface Temperature Anomaly Associated with 1989 La Nina (Florida in Drought Condition)

Figure 9a,b. Sea Surface Temperature Anomalies

Finally, the El Nino-Southern Oscillation influences global weather year round as is illustrated in Figure 7. In many regions, a statistical connection with this ENSO process may not occur. This does not mean that the ENSO doesn't influence that regional climate. It may be that it doesn't always influence that climate in the same way all the time. It may depend on the state of other large scale atmospheric systems that influence the climate of that region. Research indicates, for example, that hurricanes are about half as likely to make landfall on the United States during tropical seasons associated with the El Nino warm sea surface temperature anomaly (O'Brien et al, 1995). Therefore, though there may not be a statistical link between Florida and the phase of ENSO in the summer rainfall, it still obviously has an influence on Florida's climate. Therefore, if the ENSO conditions are taken into consideration along with other large scale climate systems that affect the region, it is likely to provide additional useful information about the status of Florida's climate even in seasons relationship hasn't been shown to be statistically significant.

b) Solar Indices

Certain global climate and oceanic fluctuations that occur with a regular frequency appear to have their origins associated with solar activity. Solar sunspot activity displays a cyclic pattern with an approximate periodicity of 11 years. The period actually vary between 9 and 14 years. Periods tend to be shorter when the peak of the sunspot activity is more pronounced, and they tend to be longer when the peak is less pronounced. The 20th century has been a period with very high solar activity with a corresponding shorter than average cyclic period of 9.7 years (Christensen and Lasen, 1991). Between each cycle there is a reversal in the direction of the sun's magnetic field. Therefore conditions begin a new cycle about once every 22-years. This cycle is known as the Hale cycle.

In spite of increasing statistical evidence of a relationship between solar sunspot cycles and the earth's climate fluctuations in certain parts of the world, no completely acceptable theory has been introduced which explains how the small changes in the ultra-violet energy flux across the outer bounds of the earth's atmosphere due to sunspot cycles can be translated into climatic fluctuations. Willet (1953, 1987) has elaborated that solar eruptive phenomena such as solar flare activity cause disturbances of the geomagnetic field, and the temperature and wind fields of the upper atmosphere. This strong spot heating of the atmosphere disrupts the zonal weather circulations allowing such activity to contribute significantly to climate fluctuations without appreciable changes in energy flux. The aa index of geomagnetic activity was taken by Willet to be the best long term indicator of solar eruptive phenomena. This index also follows an approximate eleven year cycle, but generally lags the sunspot cycle and contains many more perturbations.

Research of Labitzke and van Loon (1989, 1992, 1993) of the National Center of Atmospheric Research provide additional evidence that an important connection exists between solar cycles and the earth's climate. Enfield and Cid (1991) presented evidence that when solar activity is strong, El Nino events are spaced farther apart with periodicity being strongly influenced by the sun. During weaker activity the events are closer together and more influenced by the internal dynamics of the southern oscillation system. Mendoza et al (1991), reported that two-thirds of El Nino events occur on the descending branch of the eleven year solar cycle. Reid and Gage (1988) and Reid (1989) reported on the similarities between the 11-year running means of monthly sunspot numbers and the global sea surface temperature.

More recently, Warren B. White, the Director of Scripps Institution of Oceanography and D. L. Cayan (1996) reported on the 'remarkable similarity' between sea surface temperature variations and the intra (11 year) - and the inter (22 year) - decadal fluctuations in solar activity during the last four centuries. Haigh (1996), successfully simulated observed shifts of the subtropical westerly jets and changes in the tropical Hadley circulation that appear to fluctuate with the solar cycle. These simulations included photo-chemical reactions in the stratosphere that enhanced the effects of the variations of the solar irradiance energy. Even a slight shift in the strength and positioning of these climate systems would have significant effects on Florida's climate.

Balliunas and Soon (1996) concluded that from long term solar records that solar-brightness variations can explain the majority of the past record of terrestrial global temperature fluctuations. In September 1996, Baliunas submitted testimony to the Senate Committee on Energy and Natural Resources Senate indicating that to present 'no evidence can be found in the observations of the global temperature for a dangerous warming derived from human actions'. Further, he indicated that 'the variable length of the solar magnetic cycle correlates nearly perfectly with 11 -year moving average of global temperature since 1750. This document is included in Appendix A.

Lean and Rind (1995) provide an excellent overview of the relationship of climate variability to fluctuations in solar activity. The reader who is interested in further discussions on the current understanding of this relationship should refer to Appendix B. Their discussion explains the difficulty in isolating the effects of natural climate variability from those of anthropogenic effects. In this proposal, only variables that appear (from historical records) to have significant correlation with Florida's past climate variations are considered. The period of record with increased greenhouse gases in the atmosphere is considered too short for determining the effects of increased greenhouse gases on climate variability. In summary, solar activity affects the earth and it's atmosphere in many ways over different time scales. These may be broken down into the following categories:

1. Solar eruptive phenomena,
2. The 11 - and 22 - year sunspot cycle,
3. Long-term secular changes of sunspot cycle amplitude.

The various time scales of solar activity that interact with the earth are illustrated in Figure 10a.

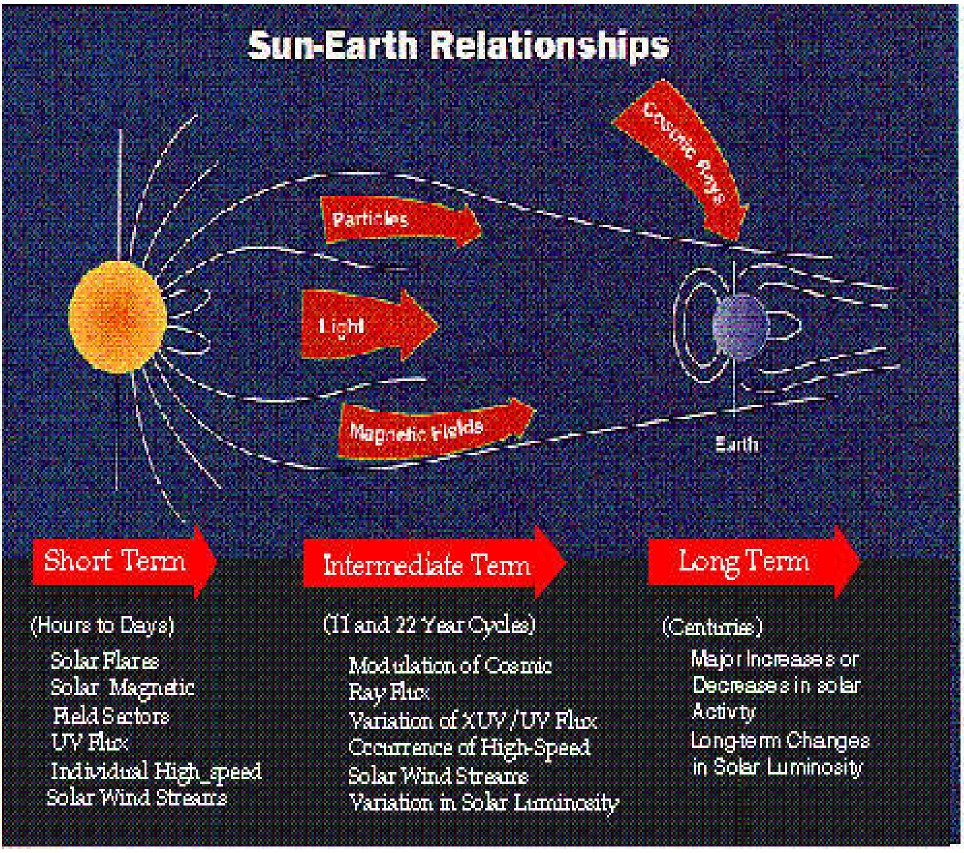
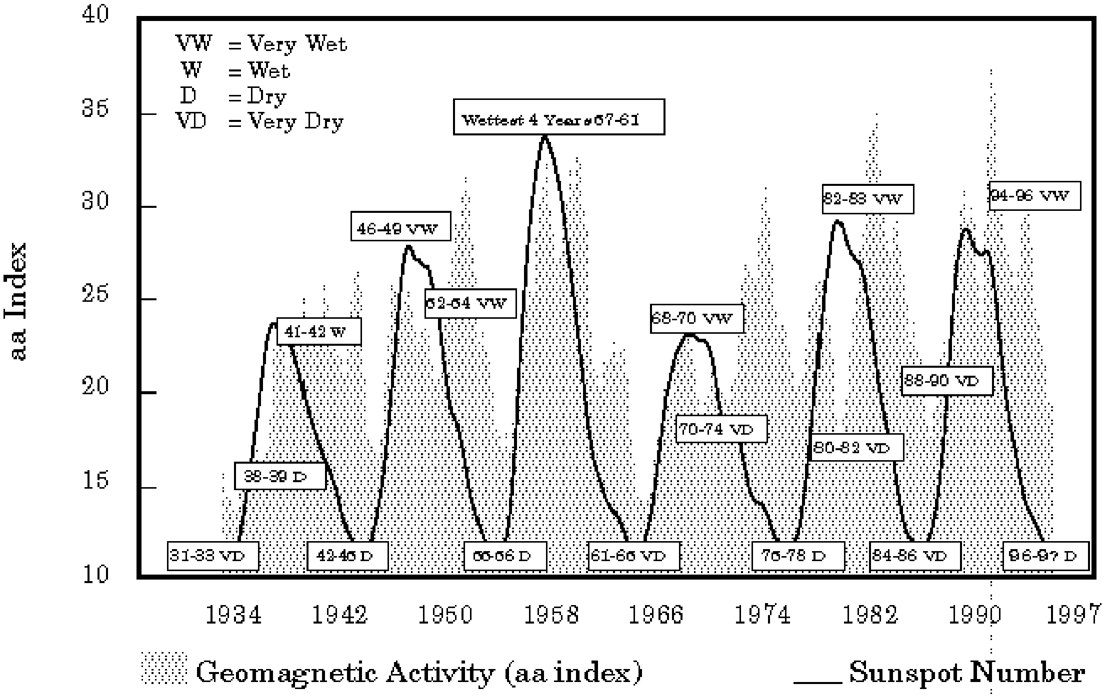


Figure 10a. Sun-Earth Relationship (Courtesy of NASA)

All three of the above categories appear to contribute significantly to climate variations. Figure 10b illustrates the solar activity as recognized by the geomagnetic index and the sunspot number. Also illustrated in this figure are important climate anomalies that occurred in south Florida. Sporadic solar activity may be represented by peaks in the geomagnetic activity. Very wet periods within southern Florida occurred during the periods of 1930, 1947, 1952-1953, 1957-1960, 1982-1983 and the 1990's correspond with large geomagnetic disturbances that occurred. Droughts that are related to the 11 year solar cycle include the mid-1940s, mid-1950s, early 1960s, 1970s, and 1980s. These droughts are clearly clustered near minimums of solar activity as best represented by the geomagnetic index.



Note: Wet and dry period labels are only positioned to indicate the apparent association of these events with the 11-year solar cycle and geomagnetic activity. The magnitude of Lake Okeechobee inflow for each year appear in Table 1.

Figure 10b. Solar Activity and Notable Lake Okeechobee Inflow Events

On a decadal time scale, variations of Lake Okeechobee inflows closely resemble those of the sun from 1900 through 1970. About 1970 a major rearrangement of the currents of the Atlantic Ocean is hypothesized to be the major cause of a climate break in south Florida (Gray et al,1997). This aspect will be discussed in the next section. However, after this period, wetter conditions still appear to be associated with high geomagnetic activity while droughts occur after lulls in geomagnetic activity. Since periods of high and low solar activity can be measured and somewhat reliably predicted, periods of the increased likelihood of droughts or extreme wetness may also be predicted. On a final note, the NOAA Climate Analysis Center currently uses solar cycle data in their seasonal winter forecast (Coffey, Erwin, and Hanchett, 1997).

c) Atlantic Ocean Conveyor Current Index

Southern and Central Florida have experienced marked decadal fluctuations in climate conditions during the 20th century. Drainage of wetlands and land use changes affecting the local 'rainfall machine' during the decades of the 1960's, 1970's and 1980's have been suggested as the cause for this downward trend in rainfall (Gannon,1978, Pardue et al, 1983 and others). It is now apparent that the largest portion of the decadal rainfall variations are associated with global fluctuations of climate. This deduction became more apparent upon reviewing similarities of Florida's rainfall trends and anomalies to those that have occurred with climate variables and ocean currents of other regions of the world, as reported by Gray et al (1997).

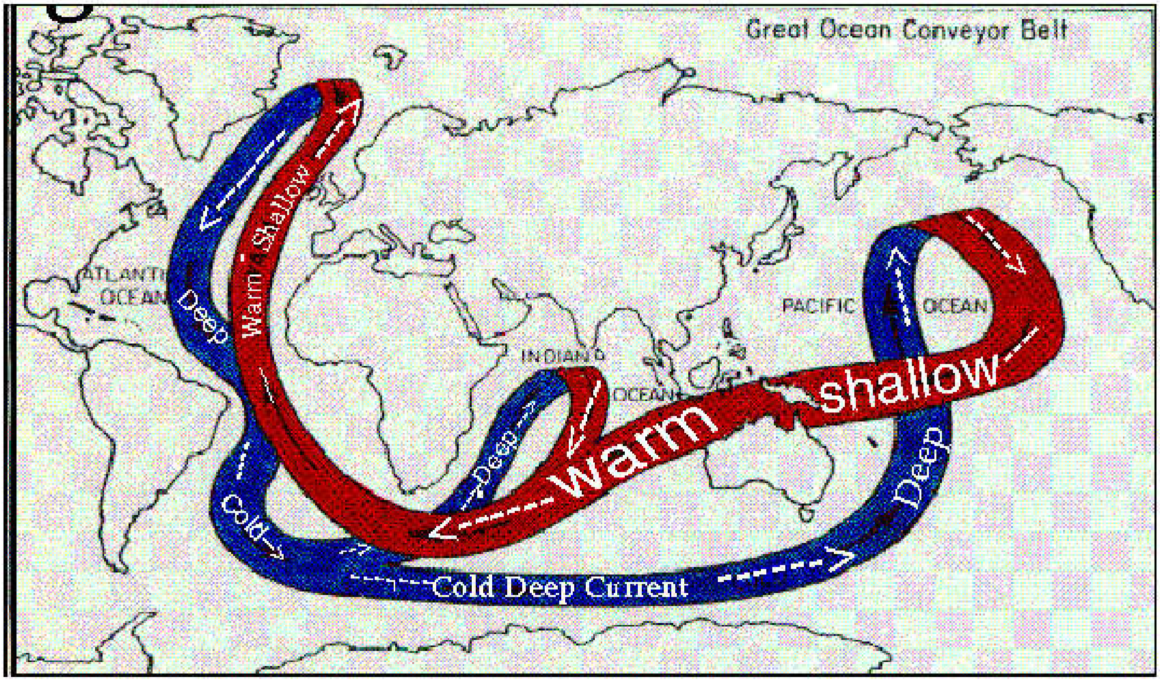
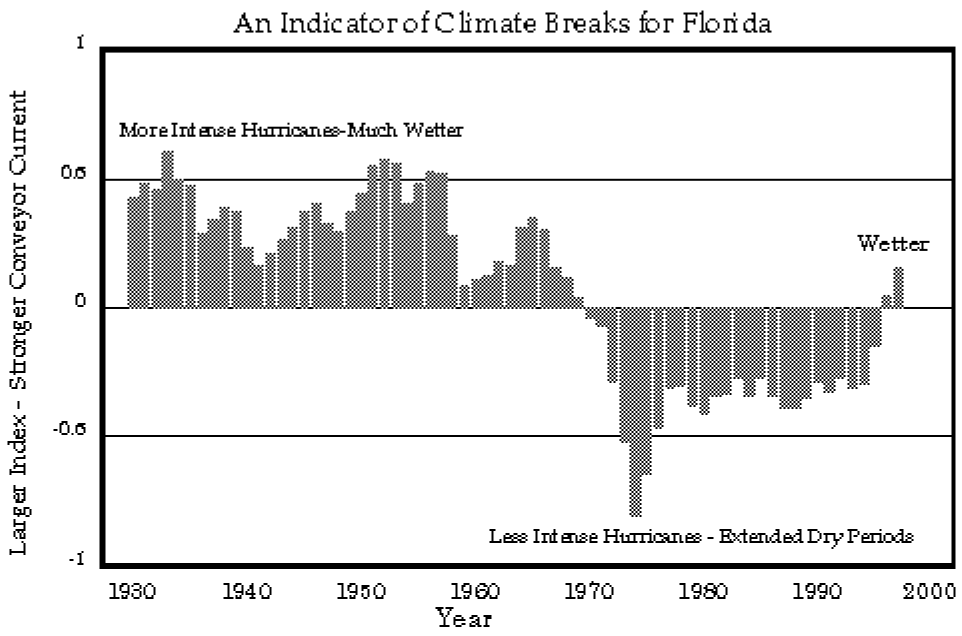


Figure 11. Schematic Diagram of the Global "Conveyor Current": Depicting the Global Thermoline Circulation (Broecker, 1978)

In the late 1980s, Wallace S. Broecker (1991) of Columbia University outlined the theory of the great ocean conveyor - a global system of ocean currents that may have abrupt affects on the global climate. Figure 11 illustrates a simplified view of this system of currents. Gray et al (1997) recognized the importance that multi-decadal shifts of the Atlantic Ocean sector of this current may have on tropical activity and global climate fluctuations. Strong phases of the current are associated with increased, more intense tropical activity and weaker, less numerous El Nino's. Locally, Florida experienced much wetter conditions and more intense tropical storms prior to 1970, the last period the Atlantic Ocean Conveyor was recognized as being in the strong phase.

Although this ocean current is driven by complex processes involving salinity and thermal gradients, Gray et al suggested the general strength of this current may be estimated by subtracting South Atlantic sea surface temperature anomalies from North Atlantic sea surface temperature anomalies averaged over broad regions of the ocean basin. When the North Atlantic Ocean is experiencing warm anomalies and the South Atlantic Ocean cold anomalies the current is described as being in a stronger phase. When the anomalies reverse themselves, the current is described as being in a weaker phase. Figure 12 illustrates a smoothed index computed from the sea surface temperature anomalies. Data were obtained and averaged over the appropriate sections of the ocean basin with the aid of an internet tool and data sources (Integrated Global Ocean Services System and the Global Ocean Surface Temperature Atlas) made available by the Lamont-Doherty Earth Observatory of Columbia University. The anomalies of this index follow closely with hydrological anomalies that have occurred in Florida. The break in the Florida rainfall characteristics as reported by Shih is coincident with the abrupt change of the index to a negative number. Evidence suggests that we may be currently reentering the strong phase of the conveyor current. This would indicate much more intense tropical activity and very wet conditions in Florida. The stronger circulation is hypothesized by Gray et al to be associated with weaker less frequent ENSO events and stronger more active Atlantic Basin tropical activity than we have experienced since 1970.



North Atlantic Minus South Atlantic Sea Surface Temperature Anomaly
Computed as suggested by Gray, Landsea et al (1996)

Figure 12. The Atlantic Ocean Conveyor Index

d) Relationship to Florida's Climate

In reviewing the large scale forcing mechanisms affecting Florida's climate, it is first useful to consider one mechanism at a time before addressing the complexities of their interactions. The following are the primary forcing mechanisms considered to be strongly associated with Florida's climate:

i) Florida rainfall has been significantly tied to *El Nino-Southern Oscillation Events;*

ii) Florida rainfall fluctuations are tied to *solar activity*. High solar activity generally signals wetter events in Florida, while major droughts generally occur near minima of solar activity. In most past solar-climate analysis, sunspot data was most often used as the chief indicator of solar activity. Geomagnetic disturbances associated with electromagnetic and solar flare activity appear to be even more important for forecasting the likelihood of extreme wet periods and extended droughts. This activity is more irregular than sunspot activity, but it appears to give more valuable lead time for predicting potential extreme wet or dry events in Florida.

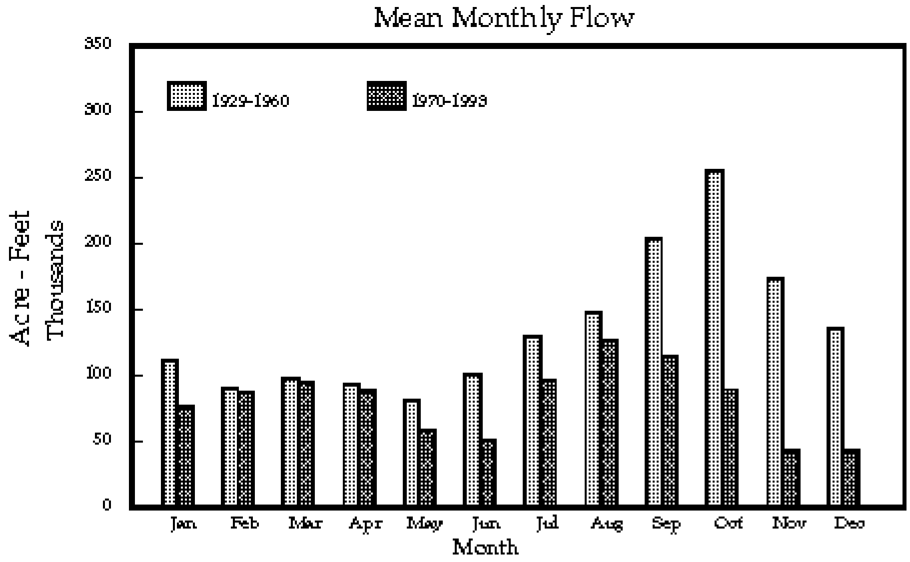
iii) The strong phase of the *Atlantic Ocean Conveyor (thermohaline) Current* is

> associated with more frequent and intense tropical activity and much wetter conditions in Florida during the tropical season. The weak phase of this current is associated with more frequent and persistent droughts

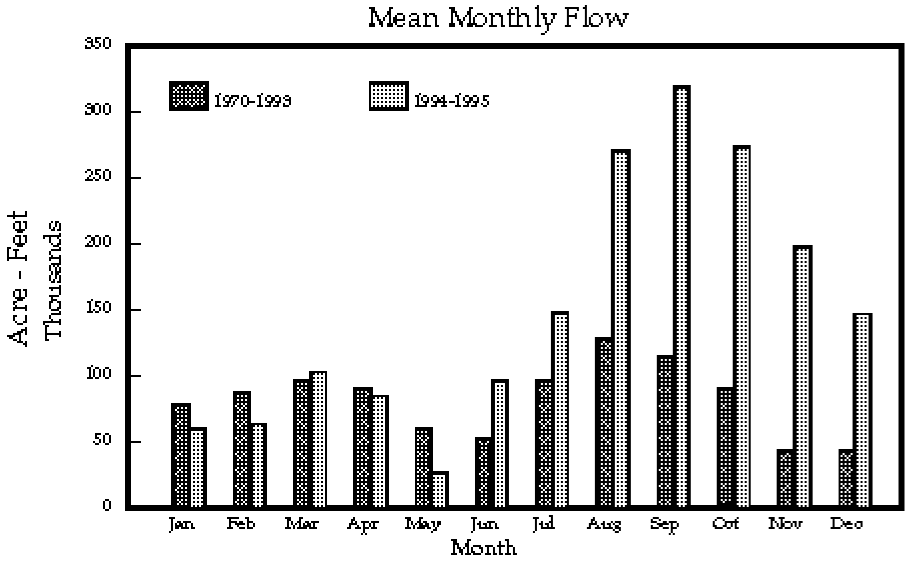
There are two major climate shifts that are believed to be associated with the strong phase of the Atlantic Ocean thermohaline current that are especially pertinent to Florida's hydrology. The first is a shift to higher frequency and stronger El Nino-Southern Oscillation (ENSO) events; and the second is the less intense tropical activity. Within the region of Florida, the increased ENSO activity is associated with more winter and early spring wetness and less summer and autumn rainfall. Gray et al (1997) has indicated that evidence suggest that the Atlantic Ocean thermohaline current has been in a strengthening state since about 1994. Figure 13a and 13b compare Lake Okeechobee mean monthly S-65E inflows for the following three periods:

1. 1929 - 1960 (strong Atlantic ocean thermohaline current);
2. 1971 - 1993 (weak Atlantic ocean thermohaline current);
3. 1994 - 1995 (strengthening Atlantic thermohaline ocean current);

The inflow at S-65E represents about two-thirds of the Lake Okeechobee surface water inflows. It is obvious from this record that the mean monthly inflow hydrograph for the period of 1971-1993 deviates significantly from the characteristics of the inflow hydrograph of the other two periods. The total inflow for the period from 1971 through 1993 is nearly half of that of the other two periods illustrated. A major portion of the reduction of the inflow came during the tropical season.



a. 1929-1960 versus 1970-1993



b. 1970-1993 versus 1994-1995

1929-1960 Annual Avg. 1616596 Acre-Feet
1970-1993 Annual Avg. 856619 Acre-Feet
1994-1995 Annual Avg. 1794234 Acre-Feet

Figure 13. Comparison of S-65E Mean Monthly Flow

e) Interactions and Variability of Large Scale Processes

Successful interpretation of the relationship of large-scale global processes with regional climate anomalies requires that the interactions of the effects of the different global processes on

Florida's weather be considered. A detailed visual inspection of historical data reveals some potentially useful relationships. A summary of these relationships are listed as follows:

> i) Kripalani and Kulkarni (1997) suggested that droughts and floods in India may be best understood when considered in light of both the El Nino events and solar activity. Their paper described decadal shifts in precipitation that were remarkably similar to those of Florida. These shifts were for extended periods of below normal rainfall during the years from 1895 through 1930 and above normal rainfall during the years from 1930 through 1963, and again after 1990.
>
> In Florida, strong El Nino (warm) events that occur during a periods of high solar activity appear to produce consistently wet conditions in Florida while strong La Nina conditions together with low solar activity appear to consistently produce the most significant droughts. When signals are mixed with either a strong warm ENSO event and low solar activity or a cold ENSO event together with high solar activity are periods of greatest uncertainty regarding the predicted inflows to Lake Okeechobee.
>
> ii) A strong *Atlantic Ocean Conveyor current* is believed to be associated with weaker and less frequency of *ENSO* events. This in part explains why the efforts of Sir Gilbert Walker faded for so many years. The conveyor current was in it's strong phase from the late 1920s through the mid-1960s. His papers on the Southern Oscillation were published just as the strong phase of the conveyor current was beginning. Subsequently this was the beginning of the period of less frequent and weaker El Nino-Southern Oscillation events. Florida hydrology was much more affected by Atlantic basin tropical events than by ENSO events during these periods. Extended dry periods or droughts occur with the minimum of solar activity even during strong conveyor currents. Considering that the minimum of the 11-year sunspot cycle occurred during the late spring of 1996 and that geomagnetic disruptions were very low as of time of publication, are indicators of the increased possibility of drought during this period. In particular, the three water years beginning in June 1996 and lasting through May 1999 is a period to be especially aware of potential drought. The exact timing of drought depends on the phase and strength of the El Nino. Once this potentially dry period passes, south Florida appears headed to a climate regime similar to that which existed from 1940 through 1960. This type of climate regime will make the 1994-1995 large inflows a much more common occurrence.
>
> iii) When considered jointly, the *Atlantic Ocean Conveyor Current* and *solar activity* best explain multi-decadal variability of Florida's climate. As just discussed, the conveyor current was in a strong phase from the late 1920s to 1969, which is indicative of a likelihood for wetter conditions for Florida. The pattern of consecutive larger inflows to the Lake are strongly correlated with the increase of solar activity during the period from the 1930s through the 1950s (see Figure 6 versus Figure 10b). The reduction of inflow during the period of the 1960's could also logically be explained by a sudden drop of solar activity. However, the continued lower inflows during the 1970's and 1980s are better explained by the concept of the weakening Atlantic Conveyor Current. This hypothesis is strengthened by the similarities in Florida's Hydrology to the Atlantic Ocean Conveyor since the very dry period in Florida from 1971-1974 occurred precisely during the weakest phase of the conveyor current. During the 1980s, very low decadal inflows again appear to be associated with the conveyor currents. The wetter conditions

in the early 1990s were initially associated with strong ENSO and solar activity. During the latter part of 1994-1995, the intensifying conveyor current appears to be contributing significantly to the wetter climate regime in Florida.

IV. Forecasting Lake Okeechobee Inflows

The ability to forecast climate shifts that affect a full range of water management objectives is very desirable. Solar activity and global atmospheric and oceanic teleconnections appear to be likely contributors to climate variability in Florida. An overview of the apparent relationships was presented at the Southeast Regional Workshop on Climate Variability and Water Resources which was sponsored by the National Aeronautics and Space Administration (NASA), the United States Geological Survey (USGS), and NOAA. The complexity of the solar-terrestrial and oceanic-atmospheric interaction make the ability to forecast regional climate anomalies by more traditional statistical methods difficult. In this proposal, the application of artificial neural network technology was adapted from Zhang and Trimble (1996) to forecast variability in Lake Okeechobee inflows. This application was presented at the Second International Workshop on Artificial Intelligence Application in Solar-Terrestrial Physics (July, 1997).

i) Overview of Neural Network Methodology

A neural network is a computational method inspired by studies of brain and nerve systems of biological organisms. A typical neural network consists of a group of inter-connected processing units which are called neurons. Each neuron makes an independent computation based upon a weighted sum of its inputs and passes the results to other neurons in an organized fashion. A neural network is a parallel, distributed information processing structure consisting of processing elements interconnected via unidirectional signal channels. Each processing element has a single output connection that branches out into many collateral connections with other neurons. The processing element can be of any mathematical type desired.

Neural Network systems can acquire, store and utilize experiential knowledge (Pandya and Macy, 1996). Appealing aspects of neural networks are the applicability to complex non-linear problem sets and adaptiveness to adjust to new information. Neural networks have received attention from many professions. In water resources and hydrology, several applications may be cited (Karunanithi et al, 1994; Smith and Eli 1995; Crespo and Mora, 1993; Grupert, 1995; Raman and Sunilkumar, 1995; Derr and Slutz, 1994).

Among the variety of neural network paradigms, back-propagation is the most commonly used and has been successfully applied to a broad range of areas such as speech recognition, autonomous vehicle control, pattern recognition and image classification. The knowledge required to map the input patterns into an appropriate classification is embodied by the weights. Initially the weights appropriate to a given problem domain are unknown. Until a set of applicable weights is found, the network The has no ability to deal with the problem. The process of finding a useful set of weights is called training. Training begins with a set of inputs that produces a known outcome. By systematically adjusting the networks weights through the back-propagation algorithm, the neural network becomes able to produce the output within a acceptable degree of error. If the neural network is trained with a configuration that adequately represents the relationship between the input and output, the neural network should than be able to predict the outcome from a new data set with no additional training.

Thus, we see that the application of a neural network to a recognition problem involves two distinct phases. During the training phase the network weights are adapted to reflect the problem domain. In the second phase, or prediction phase, the weights have been frozen and the network when presented with test or real time data will predict the outcome. Figure 14a and 14b illustrate a schematic of the training phase and testing (or predicting) phase of a neural network application.

Data must be normalized and than 'squashed' so that all values are between 0 and 1 before application. Pandya and Macy (1996) offer an excellent text for those interested in obtaining a more thorough understanding of this methodology and it's algorithms.

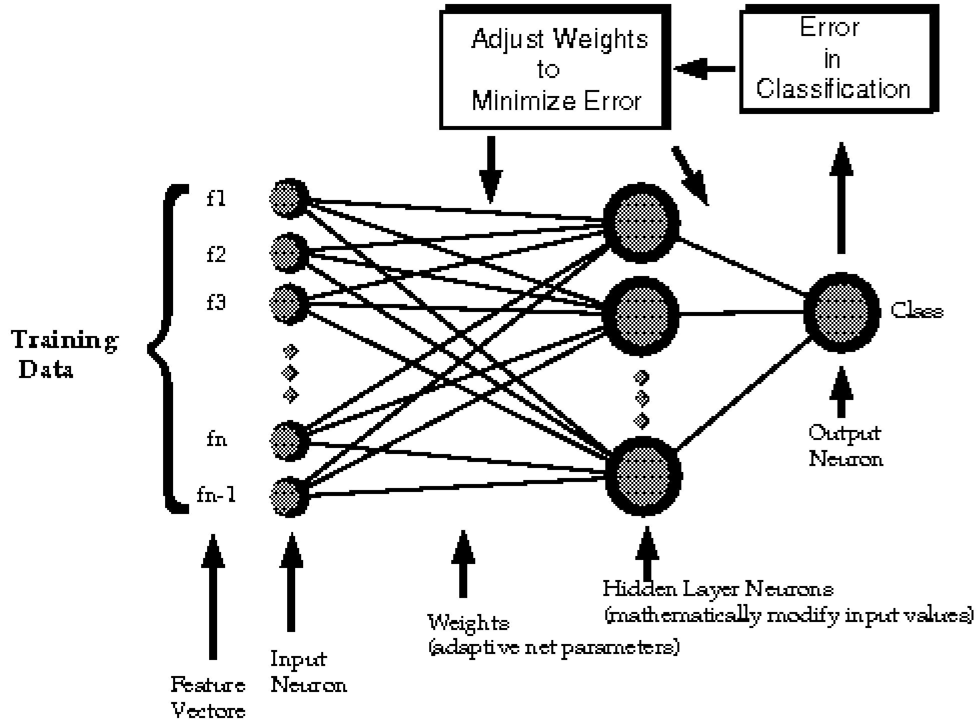
ii) Data for Training and Testing

Seven parameters were processed for predicting Lake Okeechobee inflows. These include:

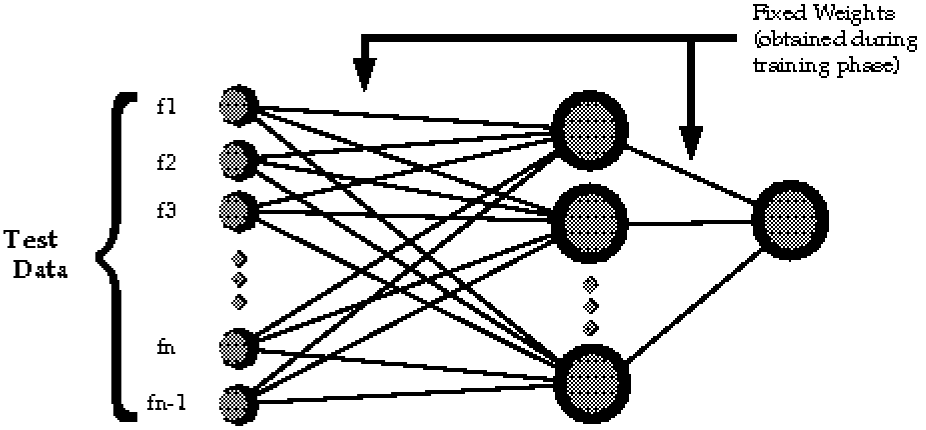
1. the Southern Oscillation Index,
2. the sunspot number,
3. trend in sunspot number,
4. maximum sunspot number of each cycle,
5. geomagnetic index,
6. Atlantic Ocean thermohaline index and
7. the month of the year.

Indices were smoothed with a six month running average. Therefore the index used to compute the next six month inflow was an average value of a particular index from the previous six month period. Two exceptions to the smoothing were made. The first exception was the Atlantic Conveyor index which was simply input as being in a strong state up to 1970 and after 1993. The period between 1970 through 1994 was defined as a weak state based upon on-going research posted on Colorado State University Tropical Forecast Internet site (Gray et al, 1996).

The second exception is the maximum sunspot number of the current cycle. During the training and testing periods the actual value was used. During the period the neural network is used for hydrologic predictions, it is planned to use the forecast of the forthcoming eleven year cycle for the rising phase of the sunspot cycle. Forecast are available from various sources including NASA. On the declining phase the actual maximum sunspot number may be used.



The Training Phase



The prediction phase

Figure 14. Conceptual Schematic of the Training and Prediction Phases of a Neural Network (Pandya and Macy, 1996)

Computed Lake inflow values were obtained from the United States Army Corps of Engineers Rules Curve and Key Operating Manual prior to 1965 (USACE,1978). After 1964 the values were computed by the SFWMD. The values are computed from the change in storage of the

Lake. Added to this value are estimated historical outflows and long term monthly average evapotranspiration. These computed values appear in Appendix C. A complete data set of climate indices and Lake inflows from 1933 through 1996 is available for training and testing each neural network configuration. The period from 1933 until 1987 was applied for training the network and the period between 1988 and 1996 for testing the network.

iii) Training

An extensive effort was performed which involved the evaluation of different neural network configurations and data smoothing techniques. Presentation of all these configurations is beyond the scope of this report. The best predictor to date of Lake inflow is the configuration with seven input neurons, 14 middle layer neurons and one output neuron. The results of the training period appears in Figure 15. The ability of this configuration of a neural network to recognize patterns of climate parameters associated with extended dry periods is realized. These periods include the mid- 1950's, early 1960's, early 1970's and early 1980's as illustrated in the figure. From visual inspection this network configuration slightly overestimates El Nino effects prior to 1965 and underestimates the effects after this period. This is likely associated with the manner the Atlantic Ocean thermohaline index is represented in the model. There are a few years that the prediction of Lake inflows peak and decline slightly early. This may be associated with the fact that the local antecedent hydrologic conditions in Florida are not input to the neural network . The large inflow prediction in 1948 is currently under investigation. However, with the operational plan that is being proposed the impact of this overestimation will be minimal since all periods with greater than 3 million acre-feet inflow are treated the same.

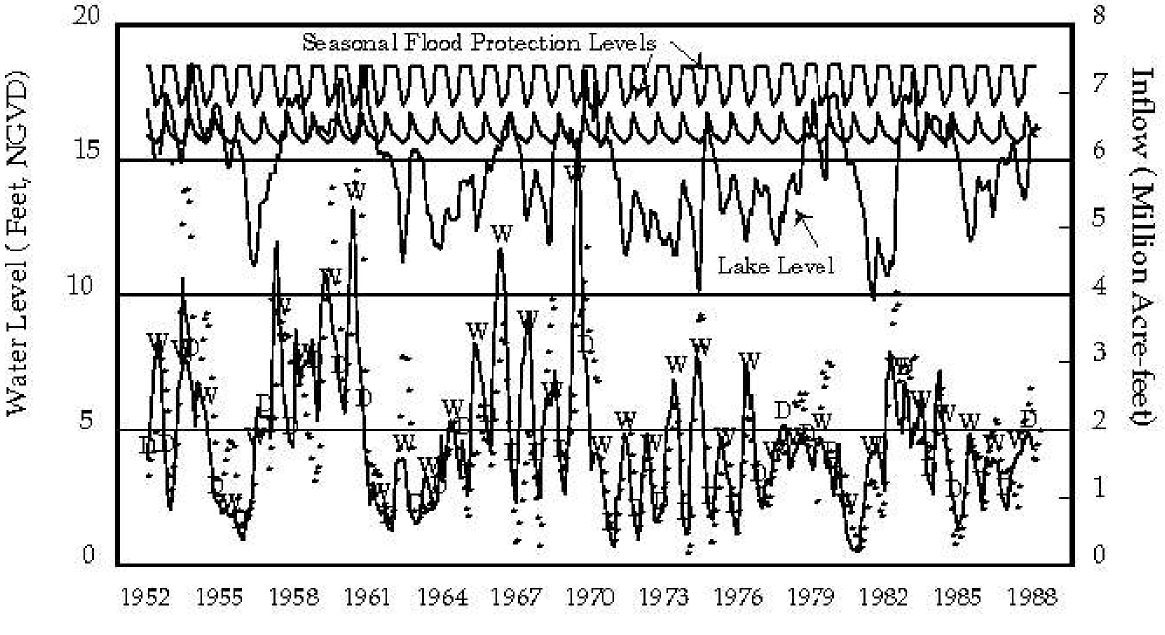


Figure 15. Lake Okeechobee Water Levels and Predicted Six Month Inflow - Sector of Training Period

iv) Prediction or Test Period

Figure 16 illustrate the results of the testing period. The neural network successfully predicted the drier period of 1988 and 1989, the very wet period of 1994 and 1995 and the return to drier to normal conditions in 1996. However, it didn't adequately predict the 1991 wet period. One possible explanation for this shortcoming may be related to the 1991 eruption of Mt. Pinatuba. The Atlantic Ocean thermohaline circulation appeared to be strengthening during the 1989-1991 period. However, this strengthening appeared to regress after the volcano. One hypothesis that may be suggested is that the current did briefly reach a strengthened state early in 1991 but then regressed to the weaker state after the eruption Mt. Pinatuba. One of the documented effects of this eruption was to rather abruptly lower the earth's air surface temperature by 0.5o C. By 1995 the global air surface temperature had recovered (Hansen et al,1996).

The possibility that the Atlantic Ocean Conveyor may have gone through a transition as hypothesized above is supported by a comparison of the sequence of Atlantic Ocean sea surface temperature salinity anomalies during this period. The northern hemisphere summer North Atlantic Ocean sea surface temperature anomaly was consistently greater than that of the South Atlantic for the first time since the 1960's. The representation of the state of Atlantic Ocean Conveyor thermohaline current for predicting Lake Okeechobee Inflows is still being investigated.

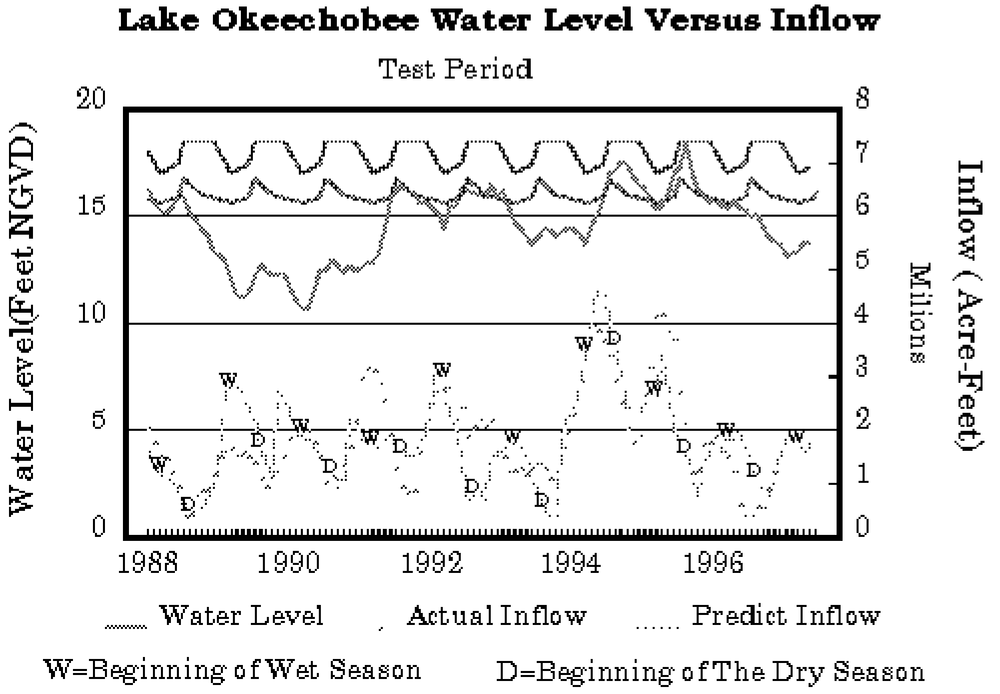


Figure 16. Lake Okeechobee Six Month Inflow - Test Period

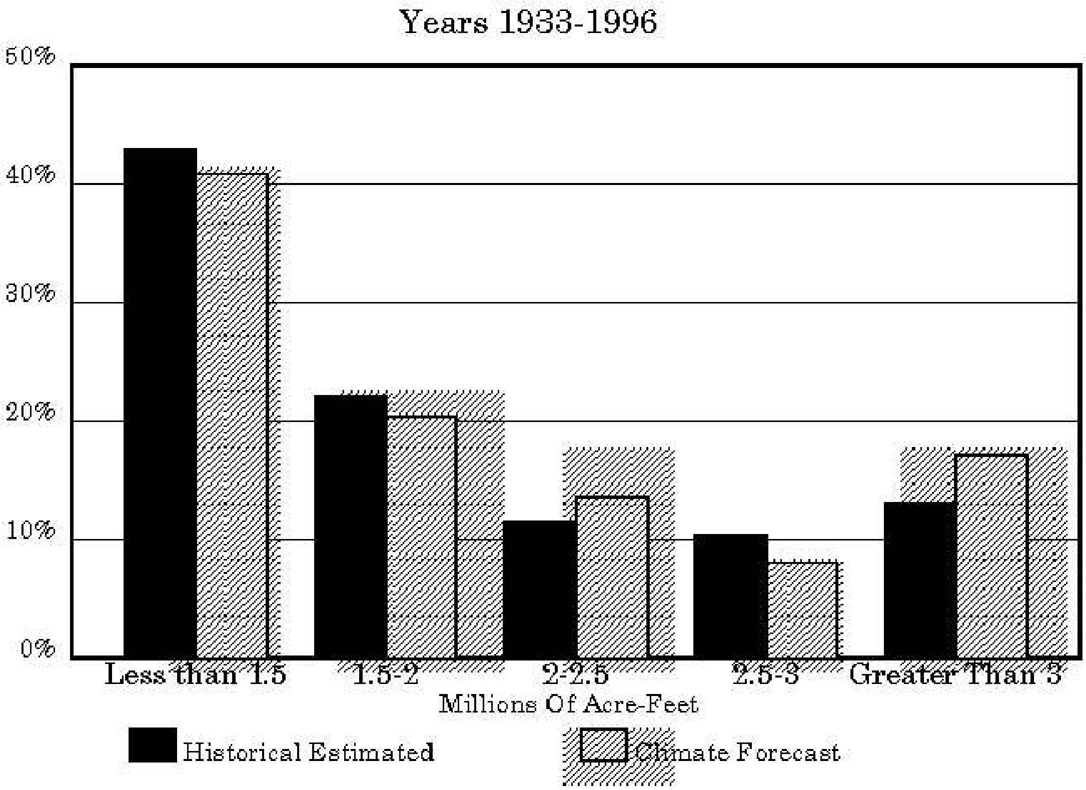
It is hoped to improve the sensitivity of the forecast to intermediate states of this current. To date consideration was only given to two phases of this current - strong and weak.

The period from 1991 through the latter part of 1995 was one of an extended El Nino, and high solar activity. In addition, although vacillating at times, a general tendency of a strengthening Atlantic Ocean Thermohaline current has been occurring over the past several years. This strengthened thermohaline current is recognized as one that is shifted towards the likelihood of a wetter climate regime for Florida. The shorter-term shift towards a drier climate that occurred in late 1995 was successfully predicted by the neural network model. This drier period was associated with the minimum of the 11- year solar cycle and also a weak La Nina condition. The effect of the lull in solar activity should persist for 2 to 3 years only being interrupted by the occurrence of an ENSO event. Indications for a more extended period are that very wet conditions may persist for Florida after the drier conditions of the next year or two. This forecast is based on solar activity that is expected to stay at or near record activity levels during the next 11- year solar cycle. In addition, the Atlantic Ocean thermohaline current appears to be shifting towards the stronger phase. This combination of high solar activity and strong Atlantic Ocean thermohaline current more closely resembles those associated with the Florida climate conditions that existed for the period from the 1940s through 1960s.

v) Summary of Predictions -

Figure 17 delineates categories of the forecasted versus the actual six month inflows for the period of record. The predicted six month inflows for each month from 1933 through 1996 are included in tabular form in Appendix D. As a continuous time series, the predicted input accounts for 65 percent of the actual variability that occurred during the training period. The standard error of estimate was about 650 thousand acre-feet. During the testing period the predicted values explained 38 percent of the actual variation with a standard error of estimate of 670 thousand acre-feet.

Part of the explanation for the decrease in the correlation may be the increased spikiness in the ENSO and geomagnetic activity. Since the model contains no information about the local hydrology, it responds too quickly to the spikes of solar and global scale climate activity. In fact the correlation of the 6 month predicted inflow with the actual inflow summed over 2 to 8 months in the future is better. The percent of variation explained by the predicted values increases to 46 percent while the standard error is reduced to 650 thousand acre-feet. It is planned eventually to include local hydrologic conditions as input to the neural network. Table 1 summarizes the variance and standard error for the training and application periods for forecast made each month of the year. Scatter plots for each month of the forecasted inflow versus that which actually occurred appear in Appendix E.



Includes Effects of RF but not ET

Figure 17. Histogram of the Forecasted Versus Actual Six Month

Table 1. Variance and Standard Error of Six Month Forecast				
	Training Period (1933-1987)		Test Period (1988-1996)	
Month	Variance r2	Standard Error (1000 AF)	Variance r2	Standard Error (1000 AF)

January	.53	477	.06	387
February	.50	527	.22	296
March	.53	557	.33	485
April	.54	646	.49	576
May	.58	738	.61	682
June	.52	848	.57	797
July	.60	747	.58	797
August	.70	629	.37	996
September	.67	634	.31	889
October	.73	496	.37	704
November	.77	359	.38	559
December	.74	344	.13	471

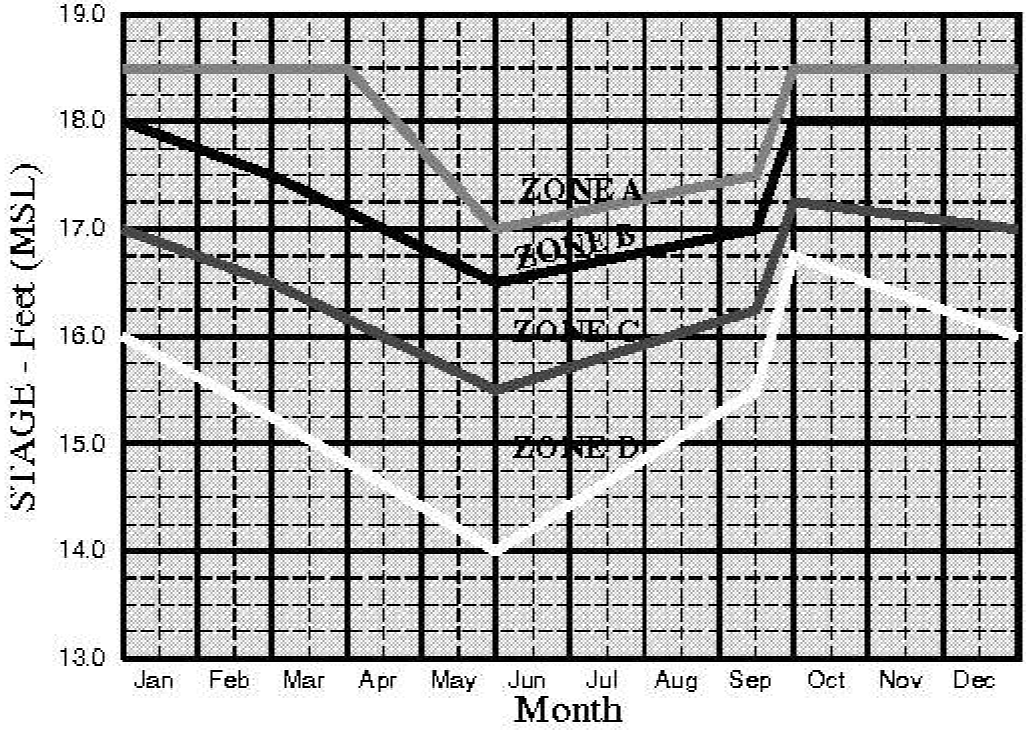
V. Description of Proposed Refinements to Regulation Schedule

Recent Lake operational schedules (1971-1997) contain a clause indicating that adjustments to the operational rules may be implemented for the purpose of increasing benefits and minimizing impacts to the hydrologic system. The 1970 schedule, and most of those prior to 1970, allowed adjustments for discharges based on weather forecasts. However, rarely in the last 25 years have outflows differed from those explicitly stated on the operational schedule. This may be due, at least in part, to the following factors:

1. The reliability of the past extended-period weather and runoff forecasts were only fair at best.
2. Changes in the likelihood of extreme regional events were not well understood.
3. Systems operators have too many complex and competing water management objectives on different scales including those related to environmental enhancement and protection, water supply needs and providing flood protection. During periods with large excessive amounts of water, operators have little time to analyze and consider 'on the fly' adjustments to the Lake operations unless the advantages are very obvious.

With the recent strides made in the understanding of climate variations on different time scales, the proposed lake operational schedule offers guidelines for refined water management practices for Lake Okeechobee. Figure 18 illustrates the proposed Water Supply and Environmental (WSE) operational schedule. Adjustments to discharges for each zone of the schedule are based on climate forecasts and hydrologic conditions. Table 2A defines the actual guideline for categorizing future 6-month inflow conditions. These volumes include surface inflows and rainfall that falls directly into the Lake. The effects of ET loses have not been included. Table 2B includes other useful guidelines that are associated with this proposed operational schedule.

Table 2A. Guidelines for Application of WSE Operational Rules				
Condition	Dry	Normal	Wet	Very Wet
6 Month Lake Inflow Forecast (Million Acre-feet)	0.0-1.5	1.5-2.0	2.0-2.5	2.5



Releases Through Outlets as Indicated			
Zone	**Agricultural Canals to WCAs[1]**	**Caloosahatchee River at S-77[1,2,4]**	**St. Lucie Canal at S-80[1,2,4]**
A	Pump Maximum Practicable	Up to Maximum Capacity	Up to Maximum Capacity
B[3]	Maximum Practicable Releases	Normal to Wet: Up to 6,500 cfs	Normal to Wet: Up to 3,500 cfs

		Dry: Up to Maximum Pulse Release	Dry: Up to Maximum Pulse Release
C[3]	Maximum Practicable Releases	Wet: Up to 4,500cfs	Wet: Up to 2,500cfs
		Dry to Normal: Up to Maximum Pulse Release	Dry to Normal: Up to Maximim Pulse Release
D[3]	As needed to enhance natural hydroperiods in the Everglades	Very Wet: Pulse release	Very Wet: Pulse release
		Dry to Normal: none	Dry to Normal: none

Figure 18. Proposed Regulation Schedule (WSE)

Table 2B. Other Important Operational Guidelines
<u>Zone A</u> i) During the Hurricane season (June through October) Zone A discharges are initiated promptly as the Lake water level enters this Zone.
ii) During the dry season (November through May) discharges are only increased as necessary to lower water levels back to Zone B in a reasonable time frame. These releases may be needed to avoid prolonged stress on the levee system.
iii) Regulatory discharges to WCAs should be pumped at S-7 and S-8
<u>Zone B</u> i) During wet season when S-65E flows exceed 7500 cfs revert to wet condition regulatory discharge mode. Continue these flows until S-65E flows decline to less than 1000 cfs, or when water levels fall to Zone C
ii) During the dry season when S-65E flows exceed 5000 cfs revert to wet condition regulatory flows. Continue until S-65E declines to less than 1000 cfs, or when water levels fall to Zone C
iii) Regulatory discharges to WCAs should be pumped at S-7 and S-8
iv) Discharges to tide may be up to maximum capacity as necessary to prevent water levels from exceeding 18.5 feet, NGVD for prolonged periods.

Zone C

i) During wet season when S-65E flows exceed 10000 cfs revert to wet condition regulatory discharge mode. Continue these flows until S-65E flows decline to less than 1000 cfs, or when water levels fall to Zone D

ii)During the dry season when S-65E flows exceed 7500 cfs revert to wet condition regulatory flows. Continue until S-65E declines to less than 1000 cfs, or when water levels fall to Zone D

iii) Flows should be pumped when necessary to minimize impacts to coastal estuaries.

Zone D Pump flow to WCAs when necessary to minimize the impacts to coastal estuaries.

Water Conservation Areas

Discontinue regulatory releases from the Lake to the WCAs when they exceed the maximum of their upper respective flood discharge schedules by more than .25 feet.

A key feature of the WSE schedule is the lower operational zone, labeled Zone D. This zone allows the operational flexibility to deliver water to the Everglades at lower lake water levels which serves relieve stress on the Lake littoral zone while enhancing Everglades hydroperiod. If very wet conditions exist or are expected over the next six months, pulse releases may be initiated to tide-water in Zone D.

The WSE schedule allows dry season discharges to tide-water to be gradually increased as necessary (up to the discharge rate recommended for the specific zone) to control water levels. This practice does not impact flood protection since there is no threat of hurricane surge during the dry season. The large outlet capacity virtually assures the ability to lower the water levels before the arrival of the hurricane season. This practice will allow more water to be kept in the regional system for water supply and hydroperiod restoration. Figure 19a compares the mean and maximum historical inflows and net rainfall to the available outlet capacity for indicated month to the end of the dry season. This figure clearly illustrates the large additional available outlet capacity available even during the wettest year of record.

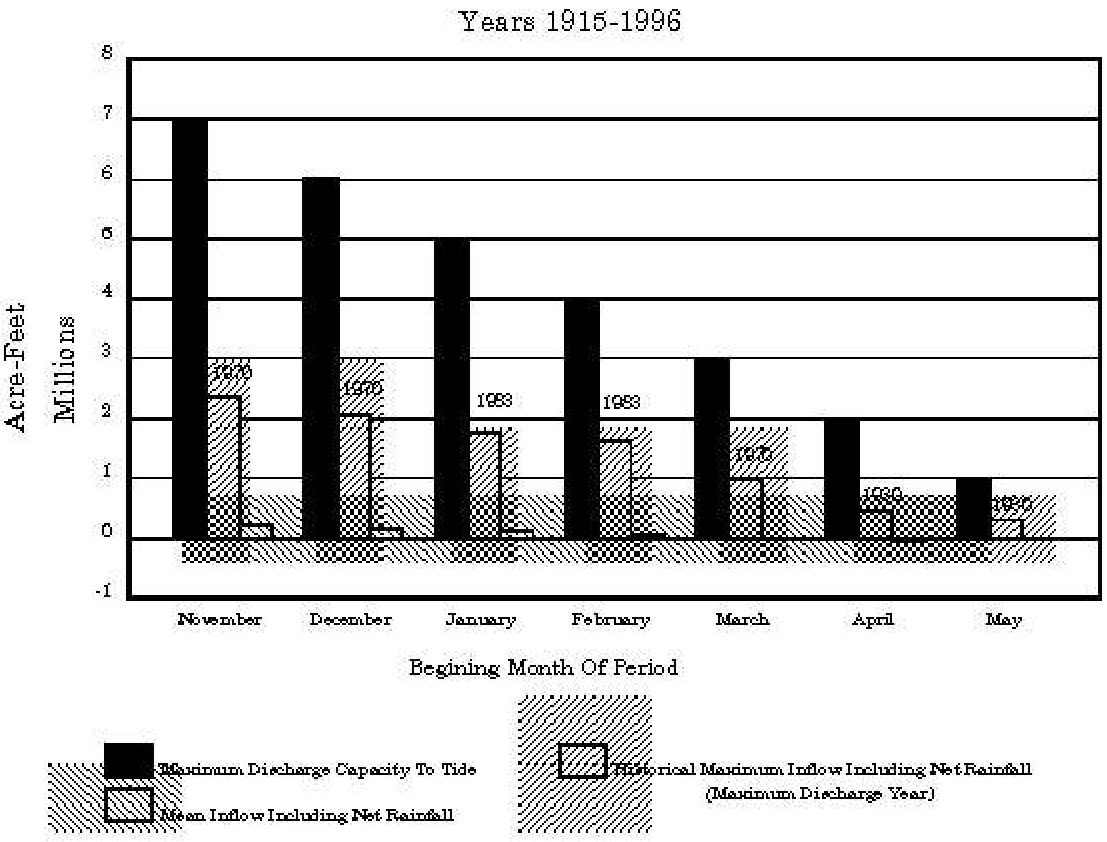
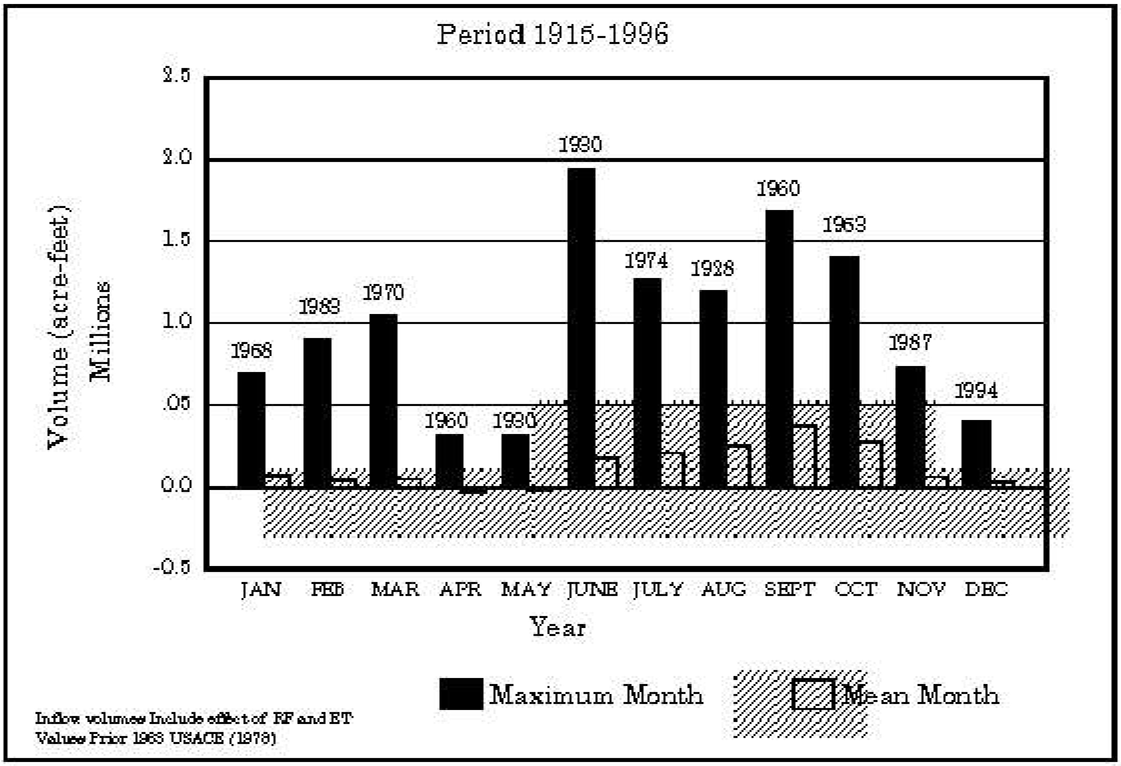


Figure 19a. Maximum Dry Season Historical Inflow Versus Outlet Capacity to Tidewater

Figure 19b illustrates the mean and maximum Lake inflow for each month of the year. With the conveyance capacity from the Lake to tide-water being approximately 1 million acre-feet, the window of opportunity for lowering Lake levels during April and May is again clearly depicted. It should also be noted that all maximum years during November through March occurred during El Nino warm anomalies. The effects of El Nino events on Florida hydrology diminishes by April. The remainder of the maximum inflow months, with the exception of July of 1974, occurred during a period of a strong Atlantic Ocean thermohaline current . The years 1930, 1953, 1958, 1960, 1974, 1983 were associated with a highly perturbed geomagnetic field. The year 1994 was moderately perturbed, while 1928 and 1987 were average and weakly perturbed geomagnetic fields respectively.



Inflow volumes Include effect of RF and ET
Values Prior 1963 USACE (1978)

Figure 19b. Historical Mean and Maximum Monthly Lake Okeechobee Inflow

a) Flood Protection

The levee system surrounding Lake Okeechobee ranges from 32 to 45 feet (NGVD), making it very unlikely for overtopping of the levee system by excess storage alone. However, large wind tide-waters caused by sustained hurricane-force winds could overtop the levees under specific conditions. Table 3 summarizes estimates of the effect of wind tide-waters on the Lake stage at the downwind shoreline given the initial flat pool average Lake level and a 100 mile per hour wind.

Table 3. Estimated Wind Tide-water With A 100 Mile Per Hour Wind			
Lake Water Level (feet,NGVD)	Average Depth of water (feet)	Wind Tide-water (feet)	Lake Stage at Downwind Shoreline (feet,NGVD)
12.0	6.5	14.6	26.6
14.0	8.5	13.7	27.7
16.0	10.5	12.9	28.9

17.0	11.5	12.7	29.7
18.0	12.5	12.5	30.5
19.0	13.5	12.2	31.2
20.0	14.5	12.0	32.0
25.6	20.1	10.4	36.0

The levee design and flood regulation of water levels for Lake Okeechobee are based on a combination of hydrologic and meteorologic conditions. Most notably are the maximum probable hurricane with winds of 145 miles per hour with a pool elevation of 17.5 feet: a standard project hurricane on a 100 year, 30-day average lake stage of 21.2 feet, or a moderate hurricane on a 30-day average water level of 23.5 feet. Due to the potential of severe damage and loss of life that may occur with such events, it is important that these criteria are not relaxed. For the purposes of this analysis, it means assuring that water levels do not exceed those of the current schedule during the peak of the hurricane season, August 1st to September 15th.During very active tropical seasons, to ensure the flood control capability is not reduced, the WSE operational schedule permits releases to be made to tide-water at lower levels than the current schedule.

With improved climate forecasts, regulatory discharges may be initiated earlier when it is recognized that a shift in the climate towards a wetter regime has occurred. Current weather and hydrologic conditions would always carry the highest priority with matters related to flood protection. One useful indicator of the current hydrologic conditions is the S65-E structure inflows from the Kissimmee River Basin. During the wet season (May 15th to October 15th) when these flows exceed 7500 cubic feet per second, wet conditions are initiated when water levels are in Zone B, and regardless of the climate forecast. This continues until S-65E inflow falls below 1000 cfs. In the dry season because of declining schedules the wet condition should be assumed once the flow exceeds 5000 cfs and again continues until the flow declines to below 1000 cfs.

b) Water Supply

During the period from 1970-1990, the south Florida climate has shifted to a regime of below average rainfall characterized by prolonged dry periods. This regional climate shift has coincided with many other global climate shifts. It was also marked by very distinct anomalies in the sea surface temperature and salinity in the Atlantic Ocean. This climate regime contains stronger and more frequent El Nino events, a lesser number of intense Atlantic Basin hurricanes and drier wet season months. In fact many of Florida's drought periods during this period were largely a result of rainfall deficits during the wet season (including 1980-82 and the 1988-1990 droughts). With the increased urban development in Florida and the large volumes of water needed for hydroperiod restoration, water resources must be managed as frugally as possible.

One potential opportunity that exists for delaying large discharges to tide-water is during the winter and early spring months since there is no threat of hurricane surge at this time. The water can be released to the Water Conservation Areas if storage is available, or released in smaller minimum impact discharges to the estuaries. This action is especially recommended for years that it is recognized that climate conditions are entering a dry regime. As indicated in the earlier section related to flood protection, there is an ample time window in April and May to make releases to tide-water, if they are required, to lower the Lake level prior to prior to the hurricane season.

c) Environmental Enhancement

The lower zone of this schedule is designed to allow greater volumes of water to be released southward to the Everglades. These releases have the potential to improve Everglades hydroperiod, reduce the need for undesirable flood control releases through the estuaries to tide-water, and lessen the stress to the littoral zone. From an environmental perspective it appears very favorable. The potential benefits for the littoral zone would be best realized during the pre-1960 conditions when Lake inflows were large (and predicted to be large) for long durations during this period. Appendix C and D contain the actual and predicted monthly inflows to the Lake Okeechobee inflows.

VI. Simulated Performance of the Current Versus the WSE Schedule

The performance of the proposed Lake Okeechobee climate-based operational schedule is compared to that of the current operational schedule with the application of the South Florida Water Management Model (SFWMM). This integrated surface water-groundwater model was designed as a tool to aid water managers in the analysis of complex regional hydrologic issues. The model domain includes a region of southern Florida that covers 7600 square miles with a mesh of 1746 - 2x2 mile cells. Lake Okeechobee, which covers 728 square-miles, is modeled as a flat pool - lumped reservoir system. The SFWMM is a continuous simulation model with a time step of one day. Key processes simulated include: overland and groundwater flow, infiltration, percolation, canal routings, levee seepage, canal-groundwater seepage and groundwater pumpage withdrawals. Operational rules for all the major water control structures and pump stations are also simulated.

The simulated response of the 1990 physical hydrologic system, operational rules and water demands is referred to as the '1990 base condition'. The simulated response of the 2010 physical hydrologic system, operational rules and water demands that are expected to be constructed by 2010 are referred to as the '2010 base condition'. Both base conditions assume that the current Lake Okeechobee operational rules are in effect. The period of hydrologic analysis includes the sequence of rainfall and climate conditions that occurred during the 31-year period from January 1965 through December 1995.

The WSE schedule is evaluated by comparing its performance to that of the current operational schedule. The implementation of the WSE operational guidelines is the only difference in this model simulation when compared to the 1990 base simulation. The performance measures discussed in this report include the primary measures developed for the Lower East Coast Regional Water Supply Plan. For a more detailed look at a larger set of performance measures compared with additional proposed schedules see the report entitled: *Simulations of Alternative Operational Schedules for Lake Okeechobee* (Neidrauer, Trimble and Santee, 1997). The Lake Okeechobee stage hydrographs for each schedule for 1990 conditions appear in Figure 20.

Figure 21 illustrates the multi-objective trade-off analysis associated with current schedule compared to the WSE schedule for 1990 and 2010 conditions. The purpose of this analysis is to compare how well the two operational schedules meet the primary objectives for managing Lake water levels and discharges. These objectives include: 1. maximize water supply, 2. maximize Everglades hydropattern enhancement, 3. minimize harmful impacts of large freshwater discharges to the estuaries, and 4. to minimizing the number of undesirable water level events for the Lake littoral zone. There are four axes in the plot, one for each of the performance measures referenced above. The trade-off plot is designed such that a better performance for a particular objective is plotted further from the origin. Generally, the larger the rectangle the better the performance of a schedule.

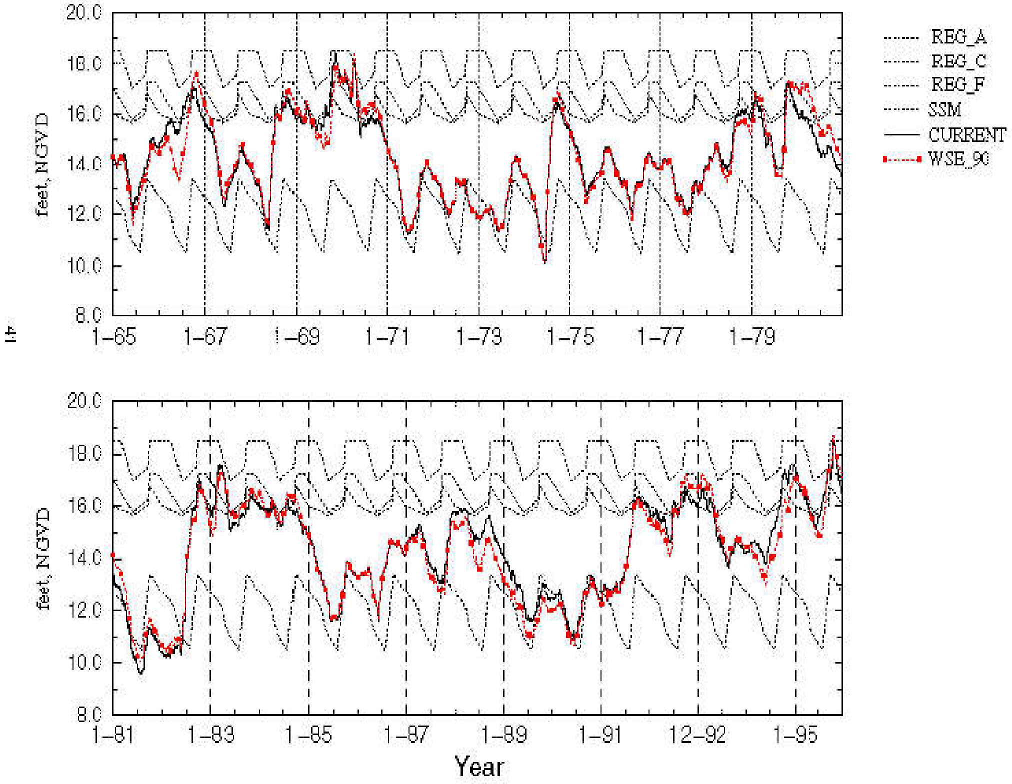


Figure 20. Comparison of Lake Okeechobee Water Level Hydrographs

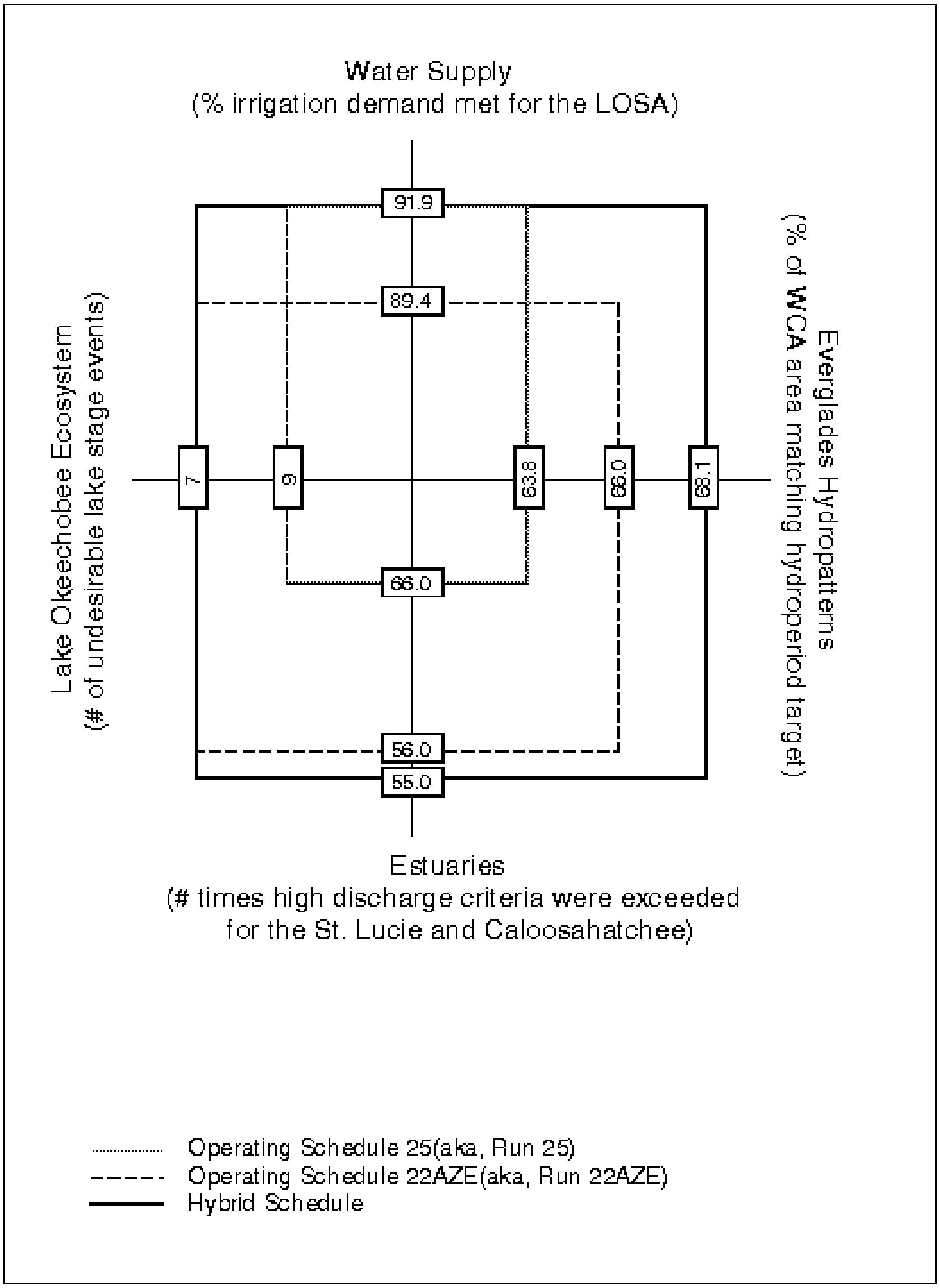


Figure 21. Multi-Objective Trade-Off Analysis

Very often, however, the improvement in the performance of one objective, is associated with a decline in performance for another objective. Thus the terminology of a trade-off analysis was derived. Flood protection was not directly included on the trade-off plot because it was considered as a constraint. That is, the level of flood protection would not be compromised from that provided by the current schedule. The performance of the proposed operational schedule for flood protection is included in the discussion that follows.

Figure 21 illustrates the performance and the associated trade-offs that exist for the current and proposed WSE operational schedule assuming that all other conditions are the same as the 1990 conditions. In addition, Figure 21 illustrates the performance of the WSE operational schedule assuming conditions are equivalent 2010 condition. The future condition was included in this trade-off analysis to illustrate the shift in the ability of the regional hydrologic system to meet water management objectives under future 2010 conditions. Emphasis in this analysis focuses on the 1990 conditions. For a complete summary of the performance of the current and proposed schedules for the 1990 and 2010 conditions the reader is referenced to the report by Neidrauer, Trimble and Santee (1998).

a) Water Supply

i) Lake Okeechobee

The 1990 simulation results indicate that for the Lake Okeechobee Service Area, volumetric water use requirements satisfied remained unchanged with the WSE operational schedule implemented(91.9 percent satisfied overall). This was accomplished by discontinuing or reducing flows to tide-water during the dry season after a shift to a drier climate regime has been recognized. Prior to wetter periods water levels in the Lake were lowered by discharging water southward when desirable for the Everglades or to tidewater in low impact discharges to tidewater. The flexibility of the WSE schedule allowed water to be kept in the regional hydrologic system just prior to the droughts of the early 1970s and 1980s.

The advantages of applying operational flexibility was exemplified by the actual water management decisions that were made in early May, 1970. While the Lake water level was still in an intermediate zone that normally would call for moderate releases to tide-water, releases were ceased based on the 30 day below normal rainfall forecast (Koperski, 1970). It was estimated at the time of the decision that over two hundred thousand acre-feet of water could be saved by this action. The most remarkable feature of this exceptional action in operations is that it occurred immediately after a period that large discharges were made to tide-water. These releases were associated with a very active tropical season followed by El Nino event that produced exceptionally large inflows in late March and early April. The system operators of that period should be applauded especially considering that they took this action during a period when flood control must have been a priority issue. The period from the summer of 1970 through the spring of 1974 turned out to be one of the most extended dry periods on record in south Florida.

ii) Lower East Coast Service Areas

The Lower East Coast benefits by the WSE operational plan in two ways:

1. less frequent water use cutbacks that were initiated based on low Lake water levels;

2. a greater backup supply of water if a more prolonged or severe drought occurs than is represented in the relatively short (31-year) rainfall record used in these hydrologic simulations.

b) Flood Protection

The maximum water level during the peak the hurricane season, August 1st through September 15th, was not significantly changed. The maximum water level during this period is the most critical for flood protection because of the threat of large storm surge that exist from severe hurricanes. It is especially important to note that prior to the peak of the two most active tropical storm seasons of the analysis period (1969 and 1995), the climate-based schedule called for discharges to tide-water in Zone D prior to the peak of the hurricane season. These discharges were made in the form of minimum-impact pulse discharges and were based on forecasted six month inflow conditions that were very wet. During the peak of these two most active hurricane seasons, the climate-based schedule provided better flood protection than the current schedule. During this period it had 11 less days in which the Lake water level was over 16.5 feet NGVD. With the current schedule the number of days 16.5 feet were exceeded totaled 57 while with the WSE schedule the number was only 46. It is recognized that for real-time water management decisions, the short-term and seasonal tropical predictions would be consulted regularly.

c) Flows to the St. Lucie and Caloosahatchee Estuaries

The WSE schedule reduces the number of times that harmful discharges would be made to the St. Lucie estuary from 30 to 24 times and to the Caloosahatchee estuary from 36 to 31. The measures that were used to represent harmful discharges were mean monthly flows greater than 2500 cfs and 4500 cfs into the St. Lucie and Caloosahatchee estuaries, respectively. With the recent emphasis on retaining water in the regional hydrologic system for water supply and hydroperiod restoration, it may be expected that less frequent and less harmful discharges would be necessary. Consistent with this expectation, simulated regulatory discharges to tide-water were decreased by over 5 million acre-feet over the 31 year simulation period.

d) Everglades Performance Measures

Hydroperiod of the Everglades improved with the WSE operational schedule. However, it is expected that even further improvement may be possible during wet periods if the operational schedules of the Water Conservation Areas incorporated an option to discharge to tide-water if water levels are projected to reach undesirable high levels based on the six month climate forecast. With the increased reliability of climate and weather forecasts, the concept of more flexible schedules can eventually be used to enhance the Everglades hydroperiods even further.

e) Lake Okeechobee Littoral Zone

The number of instances of less desirable lake water level events decreased from 9 to 7. With data supporting the fact that the Florida climate has been in a multi-decadal period with below normal rainfall, and evidence suggesting that the climate may soon (if it hasn't already) be returning to a significantly wetter regime (Gray et al, 1997), the advantages of the WSE schedule will become more clearly evident in the future decades. Trimble and Marban (1988) illustrated that with the current operational schedule, that water levels may stay above 15 feet NGVD for several years at a time during the climate regime that existed prior to 1960. With the WSE schedule, releases may be made to the Everglades at water levels as low as 13.5 feet, NGVD (Zone D of the WSE schedule). During very wet periods, releases may also be made to tide-water in Zone D. With the proposed climate index that appears in Appendix D, conditions would be defined as being very wet for a significant portion of sixty percent of the years between 1940 through 1960. The proposed schedule recognizes the needs for making releases to tide-water during these periods for the health of the littoral zone. During the simulation period of 1965 through 1995, early releases were made to tide-water in 1966 and 1994. These early releases enabled the water levels of the Lake to drop to 15 feet both of these years. With the current operational schedule water levels stayed well above 15 feet, NGVD during 1966.

A closer look at the simulated Lake water level hydrograph in Figure 20 illustrates that during several occasions through the SFWMM simulation period (1965-1995), the Lake water level rose during the winter and spring months. Included among these years are: 1965-1966, 1969-1970, 1977-1978, 1978-1979, 1982-1983, 1986-1987, 1992-1993. All of these events except the 1978-1979 were recognized El Nino events. From a global impact perspective, the 1982-1983 ENSO event was the largest and most devastating ENSO event of the century at the time of occurrence and had world-wide adverse environmental and societal impacts associated with it. It caused weather-related disasters on almost every continent. Australia, Africa and Indonesia suffered droughts, dust storms, and brush fires. Peru was hit with the heaviest rainfall in recorded history (11 feet in areas where 6 inches was the norm). Some rivers carried 1,000 times their normal flow (Amaral, 1995). The 1990-1995 El Nino was recognized as the longest El Nino on record (Trenberth and Hoar, January 1996). This El Nino Event has an estimated return period of once every two thousand years. The 1997-1998 El Nino was similar in magnitude as the 1982-1983 El Nino event. Understanding that these periods were very unusual climate periods, indicates that this period would have been a naturally stressful period for the Lake's littoral zone habitat regardless of operational schedule. A certain segment of this stress is associated with climate variability and not the Lake Okeechobee operational schedule.

f) Recreational Use of Lake

There will be significant benefit for the navigational and recreational industries as boating activities will not be constrained by low levels as often. The simulation results for proposed climate based schedule under current conditions indicate the elimination of days in which Lake Okeechobee water levels decline below 10 feet NGVD during the analysis period.

g) Summary

The proposed WSE schedule performs equal or better than the current schedule for all the performance measures under the 1990 conditions. Figure 21 illustrates the trade-off that exists between schedule. There is a marked shift in performance under the projected 2010 condition. The simulations indicate greater water shortages will exist with future conditions along with lesser high water stress on the littoral zone habitat. This shift is associated with increased water demand for the 2010 conditions and not the proposed schedule (Neidrauer et al, 1997).

In summary, the proposed WSE schedule by far out performs the current schedule assuming the 1990 regional hydrologic system and conditions and a repeat of the 1965-1995 rainfall regime. This period was a very exceptional period from a climate perspective when compared to periods prior to 1960. A climate break that likely occurred in the late 1960's was characterized by two distinct features:

1. Markedly diminished Lake inflows,

2. A greater proportion of Lake inflows occurred during the winter and spring months (It is normally considered advantageous to the littoral zone of the Lake to have declining water levels during the late winter and spring months).

During the simulation period, even though there were undesirable littoral zone events simulated with the current operational schedule, the water levels during this period were not as stressful as they could have been. Extended periods of below normal inflows generally kept water levels in the desirable range for the littoral zone habitat. The shift of the seasonal inflow and water level hydrographs that occurred to the Lake for the period analyzed was associated with a climate shift that favored less summer and autumn rainfall (associated with tropical activity) and more winter and spring rainfall (associated with El Nino). These regional climate shifts are associated with natural on-going global climate shifts and not with Lake Okeechobee operational schedules. It's likely that ecosystems that prefer declining water levels during the winter and spring would have experienced the stress associated with rising water levels even under natural conditions. On the other hand, during climate regimes like those which occurred prior to 1960, the proposed operational schedule would take advantage of climate forecasts to relieve unnatural stress to the littoral zone by passing water south earlier when the Everglades needs the water, and to tide-water by way of low impact releases during very wet periods.

In conclusion, the WSE operational schedule is the first such schedule developed for Lake Okeechobee that takes into account the several different time scales of climate fluctuations that south Florida experiences. The dynamic nature of the schedule has built-in provisions that allows for a shift water management priorities to occur during the observed shifts in climate. Therefore during periods that favor extended drier climate regimes, emphasis may be shifted towards retaining the water supply and hydroperiod restoration objectives, while for wetter climate regimes emphasis may be shifted towards flood protection and the estuary and littoral zone ecosystems. This schedule offers the opportunity for improving the overall proficiency of Lake Okeechobee and regional water management in South Florida.

VII. Summary

Recent breakthroughs in the diagnostics of climate variability on seasonal to decadal time scales provide a valuable mechanism for the advancement of the level of proficiency of regional water management. The potential for advancement results from increased lead times of forthcoming climate anomalies that may persist for extended periods. A large portion of south Florida's climate and associated regional hydrologic variability is related to the variability of solar, atmospheric and oceanic processes that occur at great distances from Florida. The physical and dynamic mechanisms for these associations are not always well understood. Fortuitously, a few very meaningful associations have been identified that provide valuable lead times for forecasting shifts and variations in Florida's climate from variations of larger-scale processes. One example of the correlation is that which exist between the El Nino - Southern Oscillation and Florida's winter rainfall. This teleconnection alone provides valuable lead times of likely deficits or excesses of water availability that may occur during the southern Florida dry season (November-May).

The recent unveiling by Gray, et al, of the significance that multi-decadal variations of the Atlantic Ocean thermohaline current has on the intensity and frequency of tropical activity has especially important implications for Florida's regional hydrologic system. The weak phase of the ocean current is associated with extended periods of below normal rainfall, less tropical activity and more frequent and stronger El Ninos; while the stronger periods are associated with extended periods of above normal rainfall and more intense tropical activity. Currently Florida appears to be returning to much wetter climate conditions similar to those that existed from 1930 through 1960.

The solar activity contributes to climate fluctuations by the cyclic variations of irradience energy within its 11-year and longer cycles. This variability causes small shifts in global scale atmospheric systems that tend to have significant impacts on regional scale climates at the fringes of these systems. In addition, solar eruptions in the form of solar flares and electro-magnetic disturbances affect the climate over shorter time periods. The solar activity is most useful when considered with the other two processes. Figure 22 summarizes the multi-decadal variations of average annual flows that are associated with the with the solar activity and the Atlantic Ocean conveyor thermohaline current. The solar activity and the Atlantic Ocean Conveyor current explain a significant amount of the multi-decadal variations in the Lake inflows. The Atlantic Ocean conveyor variations occur in the form of giant steps between weak and strong phases after staying in one phase several decades at a time. Inflows to Lake Okeechobee drop off dramatically when the current is in a weak state.

The results of this analysis demonstrate that by integrating the effects of large atmospheric and oceanic processes have on Florida's climate, that the accuracy and certainty of climate forecasts can be significantly increased. This integration is achieved with the application of an artificial neural network system. This type of system, inspired by the function and adaptiveness of the brain, is a powerful tool for pattern recognition and is especially useful for learning and estimating non-linear cause and effect relationships. With this new tool that estimates Lake Okeechobee 6-month inflows, guidelines are established in form of a new Lake Okeechobee operational schedule to improve the proficiency of water management.

The results of this analysis indicate that the proposed operational schedule can better meet the objectives of managing the Lake water levels and discharges. This is demonstrated with the multi-objective trade-off plot illustrated in Figure 21. Noteworthy improvements of system performance during specific periods include:

1. Flood Protection - during the peak of the two most active tropical seasons 1969 and 1995, water levels were simulated to be lower than the current operational schedule. Discharges were made based on the criteria of the proposed operational schedule to lower the Lake water levels.

2. Water Supply - just prior to the two most severe and prolonged drought of 1970-1974 and 1980-1982, discharges to tide-water were discontinued because of dry climate forecasts. The flexibility of the proposed operational schedule reduces the risk of large water supply cutbacks.

3. Littoral Zone - An increase in the overall performance over the current schedule. The proposed schedule simulated 1966 and 1994 discharges to tide-water to lower the Lake water levels below 14 feet (NGVD) during the dry season. Such actions are not considered under the current operational schedule.

4. Hydroperiod Restoration - over the simulation period more than 3 million acre-feet of additional water was routed to the Everglades rather than to tide-water. This has great potential for hydroperiod restoration.

5. Estuaries - as a direct result of number 4 above, a lesser volume of emergency flood control releases are required through the estuaries.

Water managers typically operate a hydrologic system to reduce the possibility of system failure (Orlovski et al, 1984). This is consistent with the actions taken in 1 and 2 for flood protection and water supply. This concept also applies to the natural ecosystems of the Lake. For example, under the climate regime prior to 1960 very wet conditions existed for several years at a time. During these periods the proposed schedule would call for discharges to tide-water in the form of low impact discharges through the estuaries for Lake water levels as low as 14 feet NGVD. Whereas, the current operational schedule would allow water levels to remain above fifteen feet for several years at a time.

During extended drier climate regimes, the available water resources must be managed very prudently so that challenges of having sufficient water for droughts can be successfully met. As discussed throughout this report, Florida climate anomalies are most often the result of shifts in global atmospheric circulation. This is a concern because small shifts in the global climate can have large effects on the regional water supply. Florida is located along the latitudes of the great world deserts. Our proximity to the Africa desert is illustrated in Figure 23. Lamb (1977) provided evidence that global decadal shifts in mean atmospheric circulations that were associated with the expansion of the Africa Sahara desert are the same mechanism that caused the extended droughts in Florida during the early 1970s.

Potentially, climate shifts may revert Florida's climate back toward a drier climate regime for many years at a time. Probably more severe droughts will occur than we experienced in the most recent decades. If prudence is not adopted with retaining our water resources in the regional hydrologic system during times of excess, the risk of a severe hydrologic drought that will cause huge economic losses and severely impact the Everglades increases significantly.

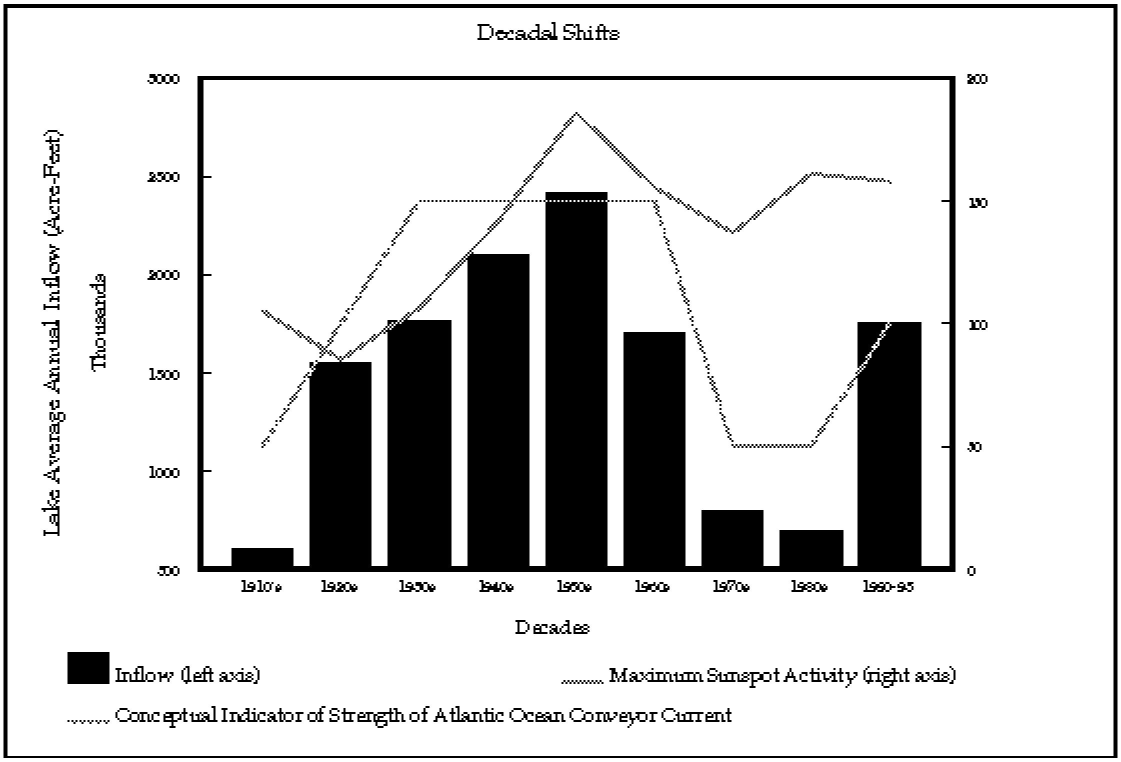


Figure 22. Lake Okeechobee Inflow Versus Solar and Global Indices

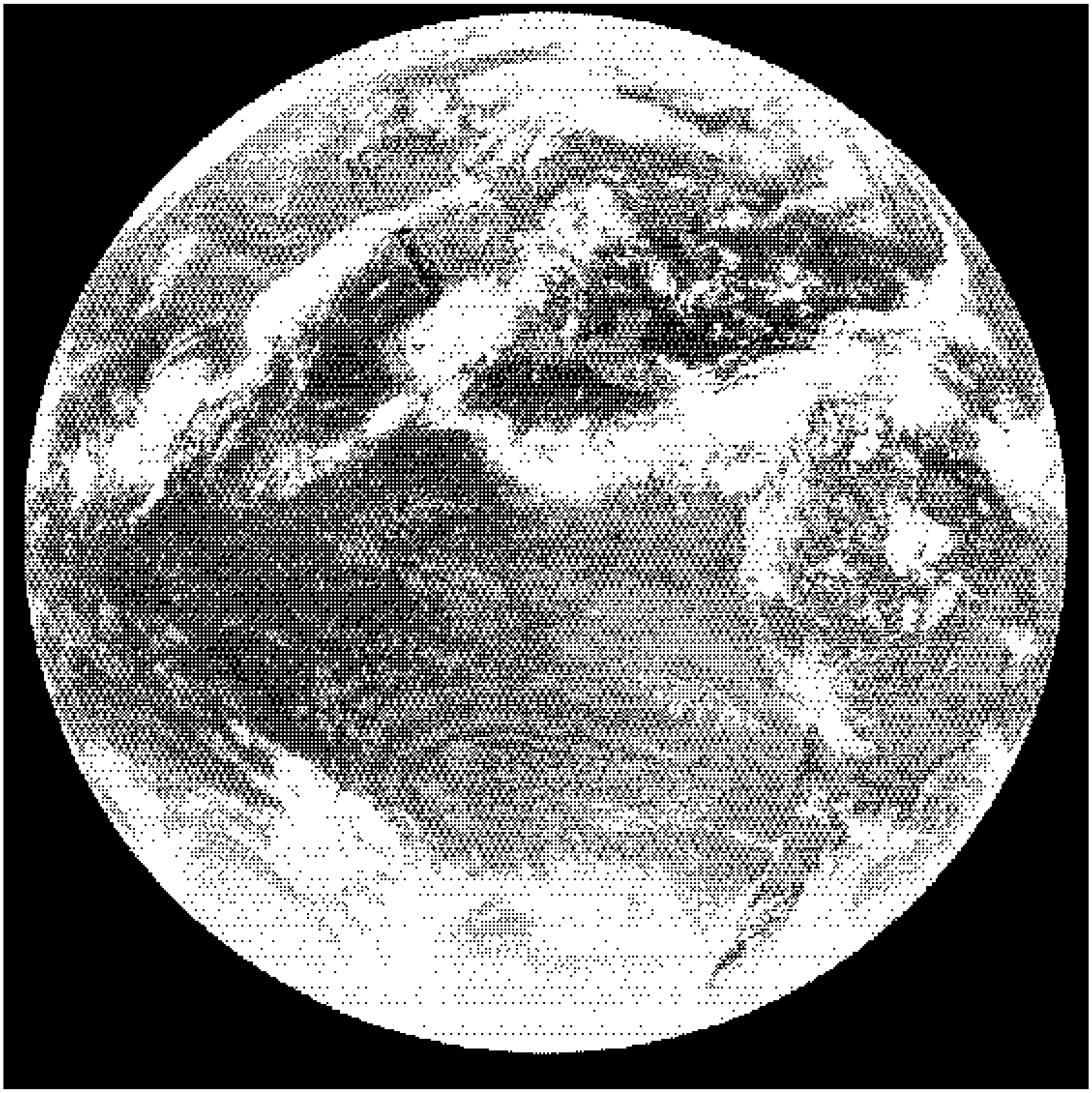


Figure 23. Our Global Neighbors

(This image of the Earth is printed with the kind permission of R. Kohrs and D.W. Sanderson of the Space and Engineering Center, the University of Wisconsin-Madison. It was developed from infrared imaginary received from the Geostationary Operational Environmental Satellite 6 on 21 September 1986.)

VII. Conclusions and Recommendations

This report presents the basis for the recommendation of the Lake Okeechobee operational schedule being proposed by the Hydrologic Systems Modeling Division for implementation. The theme of this schedule is increased operational flexibility. Operational guidelines are suggested that are not only a function of the existing system-wide hydrologic conditions but also climate-based hydrologic forecast. The forecast enable water management to be accomplished in a more proficient manner. Additional characteristics that are inherent to the schedule include:

1. Water releases from the Lake to the Everglades may be initiated at lower Lake stages to reduce stress to the Lake littoral zone habitat.
2. In the new lowest zone, during very wet climate forecast, releases may be initiated to tide-water. This has the potential for reducing stress to the littoral zone, reducing the need for larger releases that would be stressful to the estuaries, and also improving flood protection.
3. Keeping the upper line of the schedule at 18.5 feet, NGVD until April 1st. This will reduce the need for making very large releases in spring months without significantly affecting flood protection.

In the long term, the proposed operational schedule has the best potential to help meet the challenges of water management in south Florida in the realm of a shifting climate regime. It is the only schedule ever developed for the Lake that is flexible enough to adequately perform for the full range of water management objectives and the full spectrum of climate regimes that the region of south and central Florida may encounter. The increasing needs for additional water resources for hydroperiod restoration and a growing population require the most prudent management of our water resources. This effort is complicated by a continual shifting of global climate regimes that has significant impacts on Florida's climate. However, the recent advances in the state of the art of climate forecasting has transformed water management-climate related questions from 'should climate forecasts be applied ' to 'why the climate forecasts were not considered' (Glantz, 1993).

There is a strong likelihood based upon ongoing research that the recent wet years may become more the norm in the near future. Operating under the new proposed schedule would have significant benefits for the littoral zone under such a climate regime. This schedule would also be beneficial for flood protection as was demonstrated. A dynamically based schedule with flexible operational guidelines is the best approach to meet the challenges of regional water management in South Florida. It is recommended that this more dynamically based schedule be considered for implementation based on its greater proficiency of performance in meeting the objectives of water management over alternative schedules that are more static in nature.

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Finally, the many state universities and national and international climate agencies and weather services that made their research and expertise available on-line have made it possible to complete the climate research associated with this project in a expedient fashion.

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Appendices

Appendix A

Please see the following paper titled 'Uncertainties inClimate Modeling: Solar Variabilty and other Factors' by Sallie Baliunas

http://www.marshall.org/baliunas.html

Appendix B

Please see the following paper titled 'The Sun and Climate' by Judith Lean and David Rind

http://gcrio.ciesin.org/CONSEQUENCES/winter96/sunclimate.html

Appendix C

Lake Okeechobee Historical Inflows-Totals for the Next Six Months (Million Acre-Feet)

YEAR	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
1933	- -	- -	- -	- -	- -	- -	- -	- -	2.5	1.9	1.3	1.3
1934	1.8	2.5	3.1	3.4	3.6	3.4	2.9	2.2	1.5	0.9	0.9	0.8
1935	1.0	1.1	1.3	2.0	2.1	2.1	2.0	1.9	2.0	1.7	1.4	1.5
1936	2.4	2.5	2.5	2.7	2.7	2.7	1.9	1.7	1.5	1.4	1.5	1.4
1937	1.6	1.8	1.9	1.9	2.1	2.3	2.3	1.9	1.8	1.6	1.1	0.9
1938	0.9	1.2	1.2	1.4	1.6	1.5	1.3	1.0	0.8	0.5	0.5	0.6
1939	0.8	1.3	2.0	2.5	2.8	2.8	2.7	2.3	1.9	1.6	1.3	1.2
1940	1.5	1.6	1.8	2.4	2.4	2.3	2.1	2.3	2.2	1.6	1.9	2.1

1941	2.2	2.7	2.6	2.9	2.9	2.9	2.8	2.3	2.2	2.2	2.0	2.0
1942	2.6	2.7	2.6	2.5	2.2	2.0	1.3	1.1	0.8	0.6	0.6	0.7
1943	0.7	1.0	1.4	1.6	1.9	2.0	1.9	1.6	1.3	1.0	0.8	0.7
1944	0.8	0.9	1.2	1.3	1.5	1.5	1.5	1.5	1.2	1.0	0.7	0.7
1945	0.8	1.2	1.6	2.7	3.3	3.5	3.4	3.0	2.7	1.8	1.1	1.1
1946	1.3	1.4	1.6	1.8	1.9	1.8	1.6	1.3	1.1	1.4	1.4	1.4
1947	2.0	2.7	3.3	4.3	5.3	5.7	5.3	5.0	4.6	3.2	2.3	1.9
1948	1.7	1.5	1.7	2.9	3.9	4.2	4.3	4.2	3.7	2.3	1.2	0.8
1949	1.0	1.3	1.9	2.7	3.1	3.3	3.2	2.9	2.2	1.5	1.0	0.9
1950	0.6	0.8	1.0	1.0	1.6	1.6	1.5	1.4	1.2	1.2	0.8	0.9
1951	1.1	1.4	1.7	1.9	3.1	3.2	3.1	2.7	2.6	2.5	1.1	1.1
1952	1.2	1.4	1.6	1.8	3.0	3.0	2.9	2.8	2.5	2.2	1.2	1.0
1953	1.3	1.7	2.3	3.6	4.9	5.4	5.4	5.3	4.8	3.6	2.3	2.1
1954	2.6	2.9	3.2	3.5	3.6	3.4	2.6	2.1	1.7	1.2	0.9	0.8
1955	1.2	1.4	1.6	1.7	1.7	1.6	1.2	0.9	0.7	0.5	0.5	0.6
1956	0.6	0.7	0.8	1.1	1.8	1.8	1.8	1.9	1.9	1.9	1.3	1.6
1957	1.9	2.1	2.5	3.3	3.5	3.2	3.3	3.7	3.3	2.9	2.9	3.1
1958	2.9	2.6	2.7	2.4	2.1	1.8	1.8	1.5	1.1	1.3	1.3	1.6
1959	2.6	3.3	3.8	4.3	5.2	5.5	4.7	4.1	3.9	3.4	2.6	2.3
1960	2.5	2.8	3.3	4.8	5.6	5.7	5.3	5.1	4.4	2.8	1.6	1.4
1961	1.4	1.2	1.3	1.2	1.2	1.0	0.8	0.7	0.5	0.5	0.6	0.7
1962	1.1	1.6	2.1	2.9	3.0	2.9	2.5	2.0	1.6	0.7	0.5	0.6
1963	0.8	0.7	0.6	0.7	0.8	0.7	0.8	1.0	1.2	1.2	1.4	1.5
1964	1.5	1.5	1.6	1.9	2.0	1.8	1.6	1.3	1.2	1.0	0.7	0.6
1965	1.0	1.3	1.5	1.5	2.1	2.2	1.8	1.7	1.7	1.7	1.4	1.5
1966	2.0	2.4	2.9	3.2	3.4	3.2	2.6	2.0	1.3	0.7	0.2	0.2
1967	0.5	0.8	1.1	1.4	1.8	1.8	1.5	1.2	0.9	0.6	0.2	0.5
1968	1.7	2.8	3.0	3.4	3.8	3.7	2.4	1.5	1.3	1.5	1.3	1.4
1969	1.8	1.9	2.4	2.1	3.4	3.6	3.6	4.1	3.8	4.6	3.3	3.0
1970	2.9	2.6	2.6	1.5	1.4	1.3	1.0	0.6	0.5	0.4	0.2	0.4
1971	0.6	1.0	1.1	1.8	2.0	2.0	1.8	1.5	1.2	0.6	0.5	0.7
1972	1.2	1.3	1.4	1.5	1.3	1.1	0.6	0.5	0.5	0.8	1.0	1.1
1973	1.3	1.6	1.9	2.2	2.3	2.0	1.8	1.4	0.9	0.3	0.1	0.2
1974	0.6	2.0	3.1	3.5	3.6	3.5	3.1	1.6	0.6	0.2	0.2	0.5
1975	0.7	1.0	1.2	1.6	1.9	1.7	1.4	1.0	0.9	0.5	0.3	0.7
1976	1.2	1.4	1.8	2.0	2.0	1.7	1.3	1.4	1.0	0.8	0.8	0.8
1977	0.9	0.7	0.9	1.2	1.3	1.4	1.6	1.7	1.7	1.5	1.5	1.5
1978	1.4	1.7	2.3	2.2	2.4	2.3	2.2	2.4	1.8	1.6	1.4	1.7
1979	1.6	0.8	0.8	2.2	2.7	2.5	2.6	2.9	2.8	1.6	1.3	1.2
1980	1.2	1.2	1.2	1.2	0.9	0.8	0.7	0.4	0.3	0.1	0.1	0.1
1981	0.3	0.4	0.7	1.1	1.1	1.1	1.0	0.9	0.7	0.6	0.8	1.1
1982	2.2	3.0	3.4	3.7	3.9	3.7	2.6	2.1	2.5	2.8	2.8	2.7
1983	2.9	3.0	2.3	1.7	1.7	1.7	1.7	1.6	1.5	1.6	1.6	1.9
1984	1.8	2.4	2.5	2.2	1.7	1.6	1.4	0.7	0.3	0.2	0.4	0.3
1985	0.4	0.6	0.9	1.5	1.8	1.6	1.5	1.5	1.5	1.0	0.7	0.8
1986	1.2	1.6	1.8	1.9	2.0	2.0	1.6	1.4	1.2	1.2	1.3	1.3
1987	1.3	1.1	0.9	0.7	1.0	1.9	2.0	2.0	2.3	2.5	2.1	1.5
1988	1.4	1.7	1.9	1.6	1.4	1.4	1.1	0.8	0.2	0.3	0.7	0.7
1989	0.8	1.0	1.4	1.5	1.6	1.4	1.4	1.4	1.3	1.0	0.8	1.0
1990	1.1	1.4	1.8	1.8	2.1	1.9	1.6	1.4	0.9	1.0	1.0	1.2
1991	1.6	2.0	2.9	3.0	3.0	2.8	2.4	1.8	1.2	0.8	0.7	0.8
1992	1.5	1.8	2.4	2.7	2.7	2.7	2.1	2.3	1.8	1.9	2.1	2.0
1993	2.1	1.5	1.4	1.2	1.1	1.2	1.0	1.2	1.3	1.2	1.0	1.0
1994	1.6	1.8	2.2	2.8	3.3	3.8	3.7	3.6	3.3	2.8	2.4	1.9
1995	1.7	1.8	2.6	3.1	4.0	4.0	3.7	3.6	2.6	2.0	1.1	1.2
1996	1.7	1.6	1.7	1.5	1.4	1.1	0.5	0.3	0.3	0.4	0.4	0.8

Appendix D

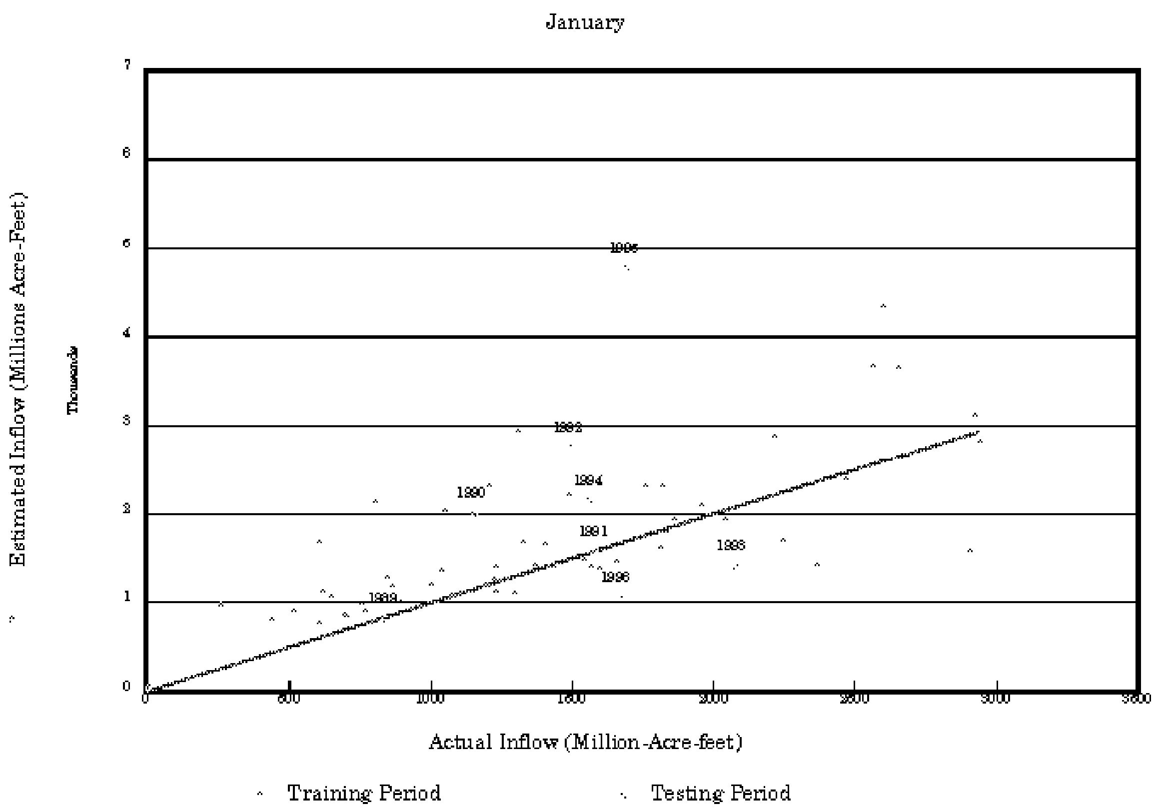
Lake Okeechobee Inflow Forecast-Totals for Next Six Month (Million Acre-feet)

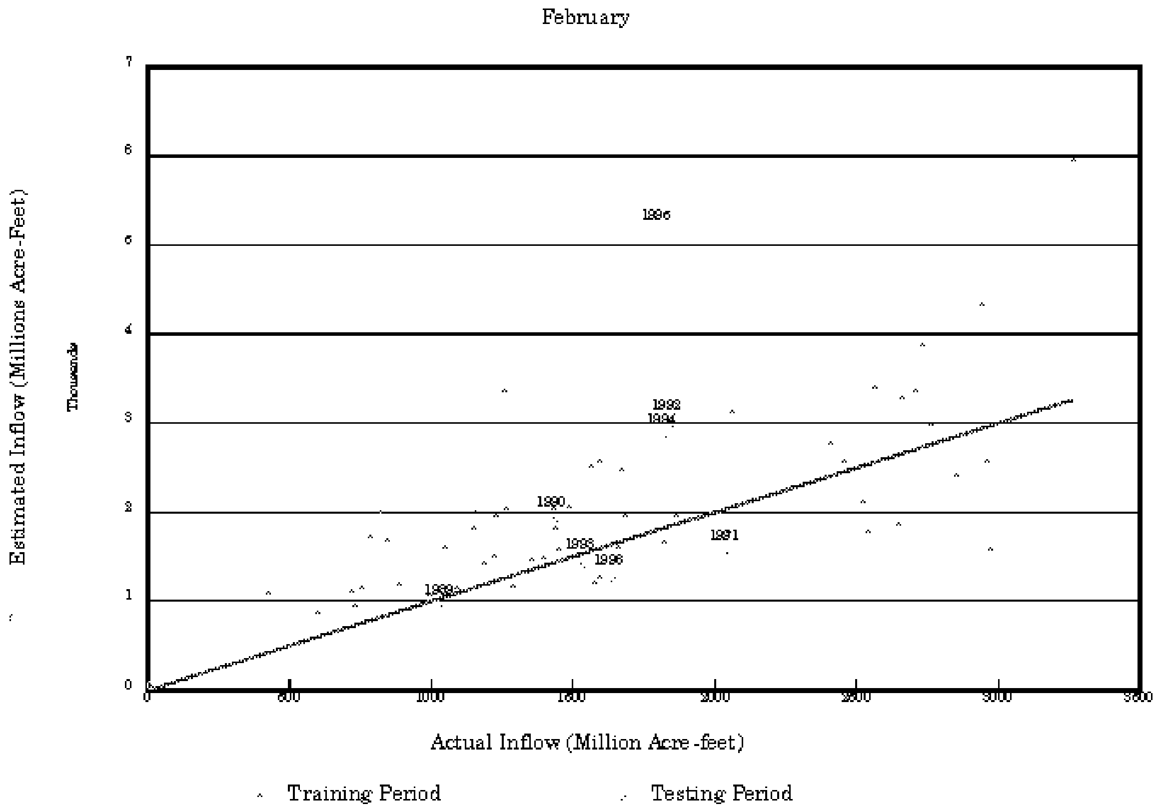
YEAR	J	F	M	A	M	J	J	A	S	O	N	D
1933	- -	- -	- -	- -	- -	- -	- -	- -	2.4	1.2	1.2	0.9
1934	1.7	2.0	2.2	2.3	2.4	2.7	2.9	2.7	2.1	1.5	1.1	0.8
1935	1.3	1.7	2.0	1.8	1.9	2.4	2.5	2.5	2.5	1.9	1.3	0.9
1936	1.3	1.7	1.9	2.1	2.4	2.4	1.9	1.4	1.3	1.2	1.2	1.1
1937	1.3	1.6	2.0	2.3	2.4	2.4	2.2	2.2	1.4	1.1	1.1	1.2
1938	1.1	1.9	2.0	1.9	2.4	2.4	2.6	2.5	1.7	1.5	1.3	1.0
1939	2.1	2.0	2.2	3.0	4.3	3.8	2.6	2.1	2.0	2.1	2.4	1.7
1940	2.1	2.4	2.5	4.4	3.5	3.5	3.0	3.2	3.3	3.4	3.0	2.5
1941	2.8	3.2	4.1	4.2	3.7	3.2	3.2	2.5	2.9	2.8	2.6	2.3
1942	3.6	3.3	3.2	3.2	3.1	2.9	1.8	1.4	1.0	0.9	0.7	0.6
1943	0.8	1.5	2.3	2.5	2.8	2.8	2.4	2.0	1.5	1.3	1.1	0.9
1944	0.9	1.1	1.5	2.1	2.5	2.1	1.6	1.4	1.3	1.2	1.0	0.9
1945	1.2	1.9	2.5	3.1	3.3	3.0	2.8	2.3	2.0	1.6	1.3	1.1
1946	1.2	1.8	2.7	2.1	2.0	1.8	1.8	1.8	1.8	1.6	1.4	1.2
1947	2.0	3.8	5.2	5.2	5.1	5.4	4.9	4.0	3.3	3.3	2.8	2.3
1948	1.4	2.0	3.3	6.4	4.3	5.6	6.0	4.3	4.4	2.7	2.1	1.6
1949	1.9	3.3	4.7	5.8	7.7	10.3	8.7	4.6	3.4	1.8	1.7	1.2
1950	1.0	1.6	1.9	2.2	1.9	2.0	2.3	2.3	2.0	1.4	1.2	1.3
1951	1.0	1.5	2.0	2.6	2.9	2.9	3.0	4.6	4.5	2.9	1.9	1.4
1952	2.2	2.0	1.8	1.9	2.0	3.0	3.4	3.1	2.5	1.9	1.2	0.9
1953	1.6	2.4	3.6	5.0	5.6	7.0	5.2	4.6	5.1	4.8	3.8	2.2
1954	3.6	4.3	3.6	2.6	2.3	2.7	2.2	1.7	1.5	1.1	1.0	0.9
1955	1.3	1.4	1.3	1.3	1.4	1.3	1.4	1.1	1.0	0.8	0.7	0.7
1956	0.7	1.1	1.2	1.2	1.5	1.8	2.2	1.8	1.7	1.6	1.5	1.5
1957	1.9	3.1	4.3	4.6	4.9	4.5	4.8	4.5	3.9	4.0	3.4	2.9
1958	3.0	3.3	3.2	2.8	3.0	3.5	4.0	3.9	3.7	2.8	2.4	2.2
1959	4.3	5.9	5.9	5.6	6.3	5.1	5.3	4.7	3.2	3.8	3.3	2.6
1960	2.3	2.4	3.2	3.9	4.4	4.5	4.0	3.8	3.5	2.9	1.8	1.8
1961	1.4	1.4	1.5	1.1	1.1	0.8	0.8	0.6	0.6	0.6	0.6	0.6
1962	1.0	1.2	1.6	2.4	2.2	2.2	2.2	1.2	0.8	0.7	0.7	0.8
1963	0.9	0.9	0.9	0.9	1.1	1.0	1.1	1.0	0.9	1.2	1.2	1.3
1964	1.4	1.6	1.9	3.0	2.1	2.0	1.7	1.5	1.4	1.3	0.9	0.6
1965	1.1	1.4	1.9	2.1	2.1	2.2	2.2	2.1	2.0	2.0	1.6	1.6
1966	1.9	2.5	3.0	3.7	3.9	3.4	3.3	2.1	1.4	0.9	0.6	0.5
1967	0.9	1.6	2.2	2.4	2.5	2.2	1.9	1.3	1.1	1.0	0.9	0.9
1968	2.3	2.9	3.5	3.0	2.7	2.8	2.8	2.3	1.7	1.4	1.3	1.2
1969	1.6	1.9	2.4	2.6	3.0	3.3	4.1	3.9	2.8	3.4	3.1	2.2
1970	1.5	1.8	1.9	1.6	1.3	1.1	0.9	0.7	0.5	0.5	0.5	0.5
1971	1.0	1.0	1.3	1.5	1.7	1.7	1.5	1.2	0.9	0.6	0.5	0.5
1972	1.1	1.1	1.2	1.1	1.0	0.9	0.8	0.7	1.0	0.9	0.9	0.8
1973	2.9	2.5	2.0	1.9	1.8	1.7	1.6	1.3	0.7	0.5	0.4	0.4
1974	1.6	1.7	2.0	2.5	2.5	2.3	1.8	1.2	0.6	0.4	0.3	0.2

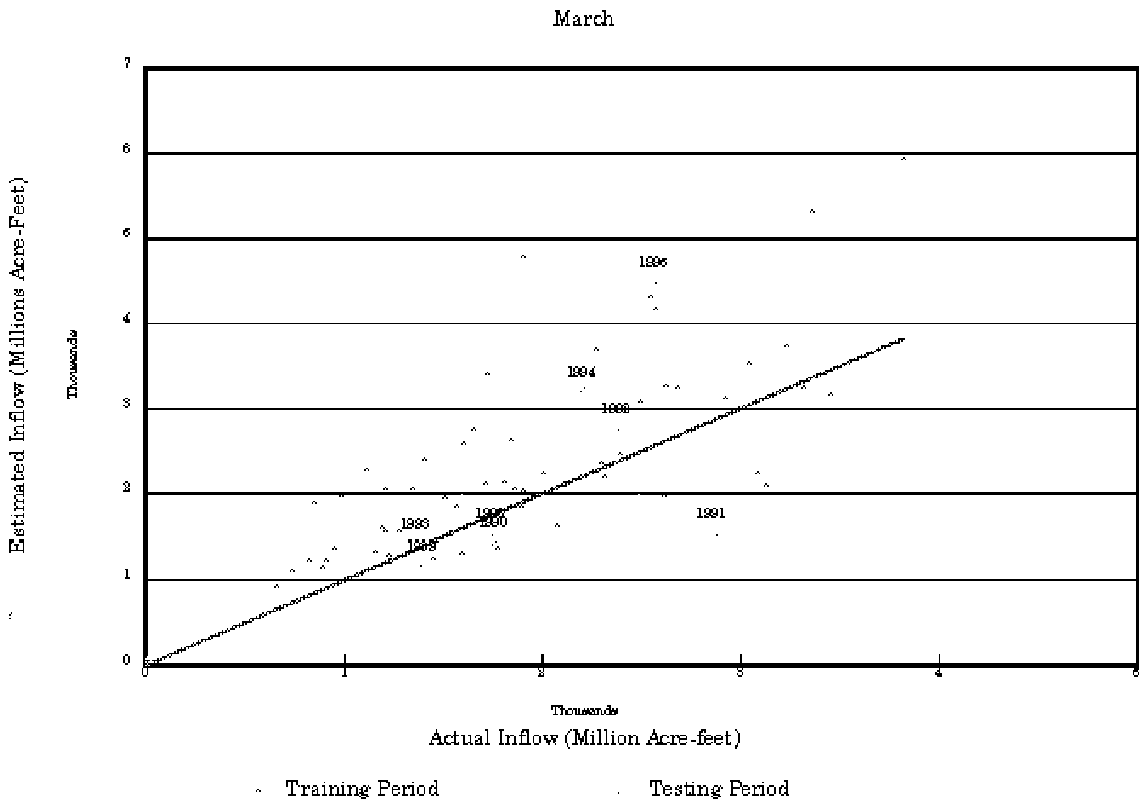
1975	0.8	1.0	1.2	1.3	1.6	1.2	1.0	1.2	1.0	0.7	0.6	0.6
1976	1.1	1.4	2.0	2.6	2.3	1.9	1.6	1.5	1.3	0.9	0.8	0.8
1977	1.0	1.1	1.1	1.1	1.2	1.4	1.5	1.5	1.6	2.0	2.3	2.1
1978	1.6	1.9	2.1	2.3	2.4	2.3	2.4	2.7	1.7	1.5	1.9	2.0
1979	1.3	1.9	1.8	2.1	2.4	2.5	2.7	2.8	2.2	1.8	1.8	1.5
1980	1.2	1.3	1.5	1.4	0.9	0.6	0.4	0.2	0.2	0.2	0.3	0.2
1981	0.9	1.0	1.0	1.0	1.2	1.3	1.4	1.6	1.4	1.2	1.0	0.8
1982	1.6	1.5	3.1	3.4	3.3	2.8	1.7	2.1	2.4	2.1	2.2	2.0
1983	2.8	2.5	2.3	1.9	1.7	1.6	1.6	1.8	1.7	0.8	1.3	1.0
1984	2.3	2.7	3.0	2.1	1.8	1.6	1.2	1.1	0.8	0.8	0.5	0.4
1985	0.7	0.8	1.3	1.4	1.7	1.5	1.4	1.3	1.2	1.2	1.0	0.9
1986	1.1	1.2	1.3	1.3	1.4	1.4	1.4	1.3	1.0	1.0	0.9	0.9
1987	1.0	1.1	1.2	1.3	1.5	1.7	1.8	1.8	1.8	1.8	1.8	1.6
1988	1.3	1.6	1.8	1.7	1.6	1.5	1.5	1.3	1.0	1.0	1.1	1.1
1989	0.8	0.9	1.1	1.4	1.4	1.5	1.7	1.6	1.6	1.2	0.9	0.7
1990	2.0	1.8	1.4	1.1	1.2	1.3	1.3	1.0	0.9	0.8	0.6	0.4
1991	1.5	1.5	1.5	1.6	1.4	1.2	1.6	1.2	1.0	1.0	1.1	1.1
1992	2.7	2.9	2.7	2.3	1.9	1.9	2.2	2.7	1.0	0.6	0.6	0.5
1993	1.4	1.4	1.4	1.4	1.5	1.7	1.8	1.2	0.8	0.4	0.3	0.2
1994	2.1	2.8	3.2	3.2	3.1	2.9	2.5	1.9	1.9	3.3	3.8	2.8
1995	4.7	5.1	4.5	4.3	5.8	5.6	4.4	2.1	1.3	1.0	0.9	0.6
1996	1.0	1.2	1.5	1.5	1.4	1.3	1.5	1.4	1.3	1.0	0.9	0.8

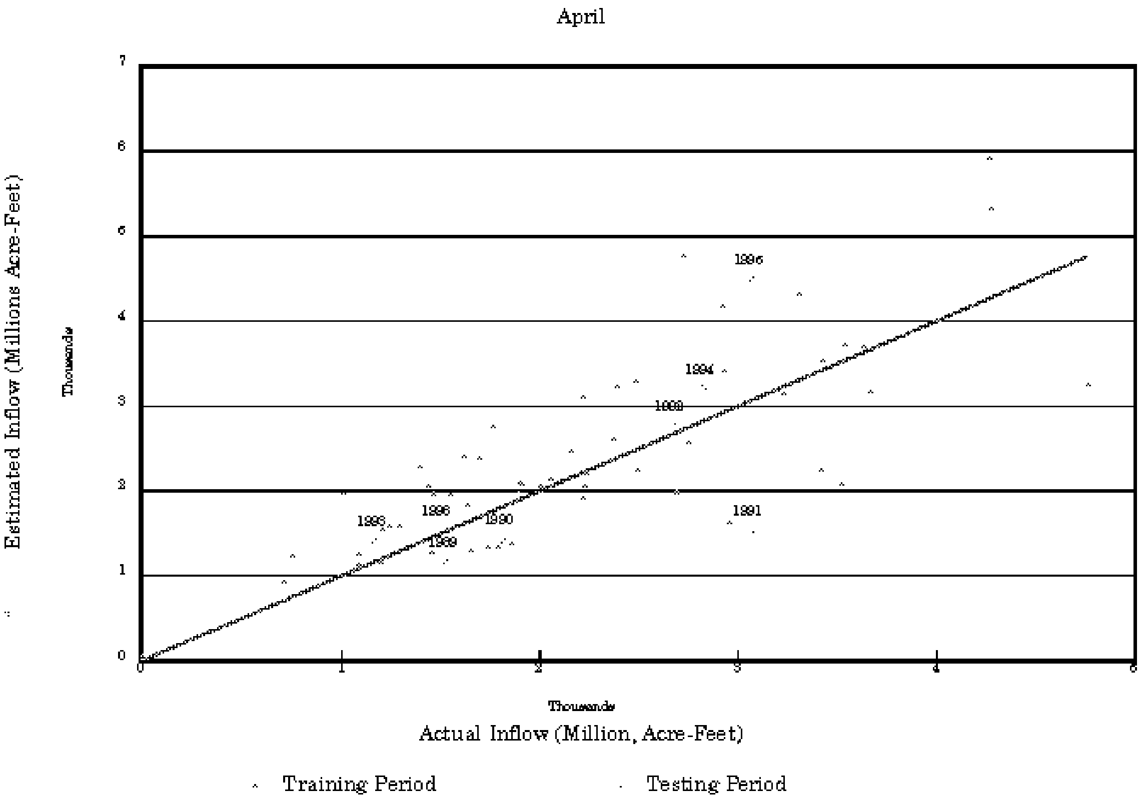
Appendix E

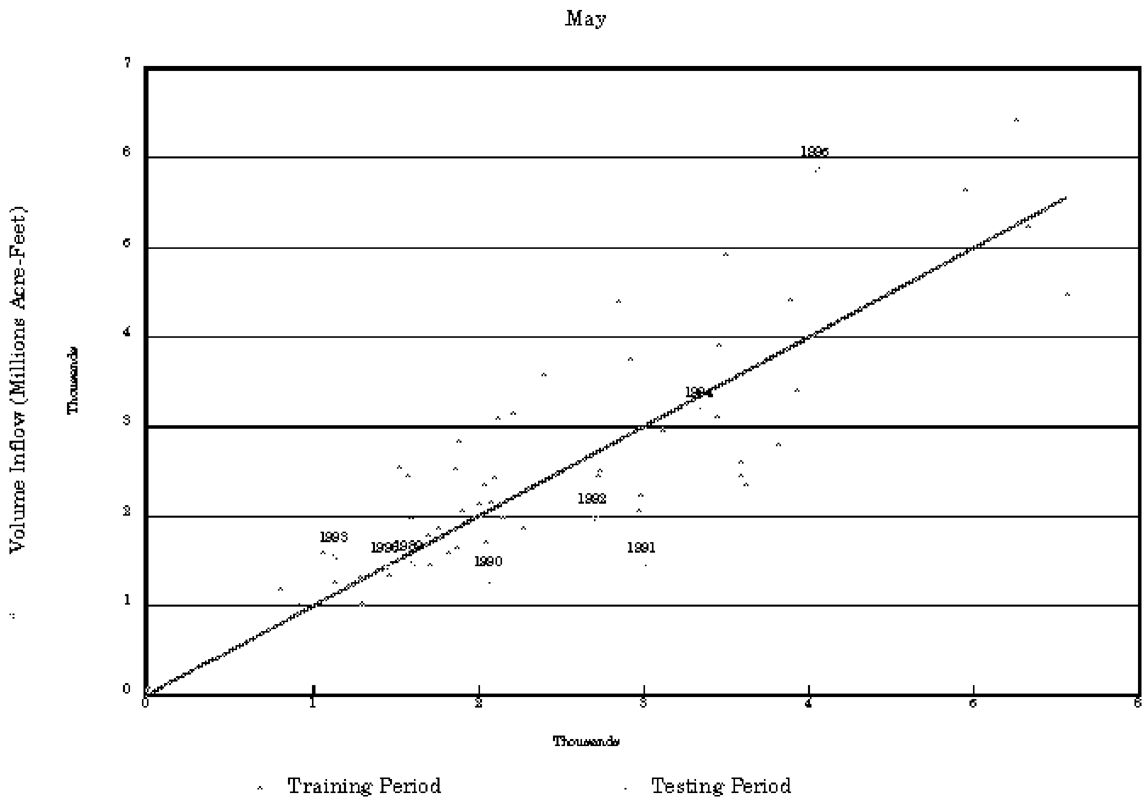
Lake Okeechobee Next Six Month Inflows (January through December)

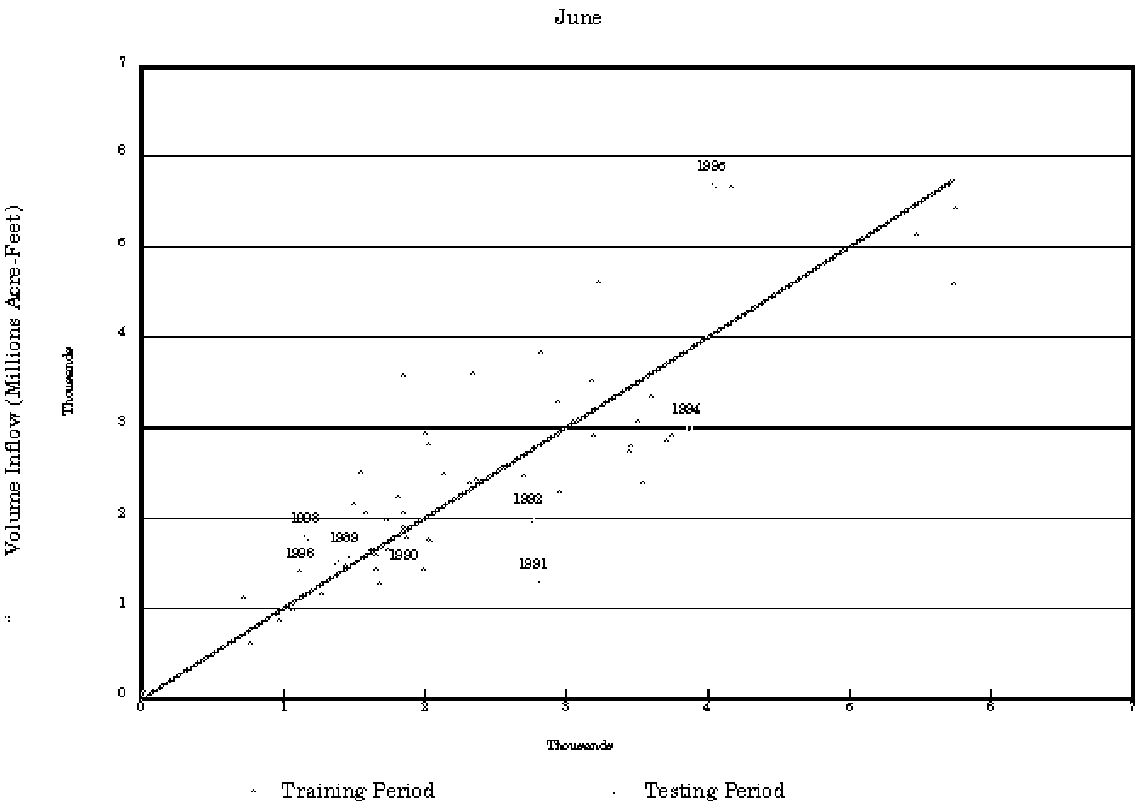

January
Estimated Inflow (Millions Acre-Feet)
Thousands
7
6
5
4
3
2
1
0
0
500
1000
1500
2000
2500
3000
3500
Actual Inflow (Million-Acre-feet)
1995
1992
1994
1990
1991
1993
1996
1989
Training Period
Testing Period


February
Estimated Inflow (Millions Acre-Feet)
Thousands
0
1
2
3
4
5
6
7
0
500
1000
1500
2000
2500
3000
3500
Actual Inflow (Million Acre-feet)
1995
1992
1994
1990
1993
1996
1991
1989
Training Period
Testing Period

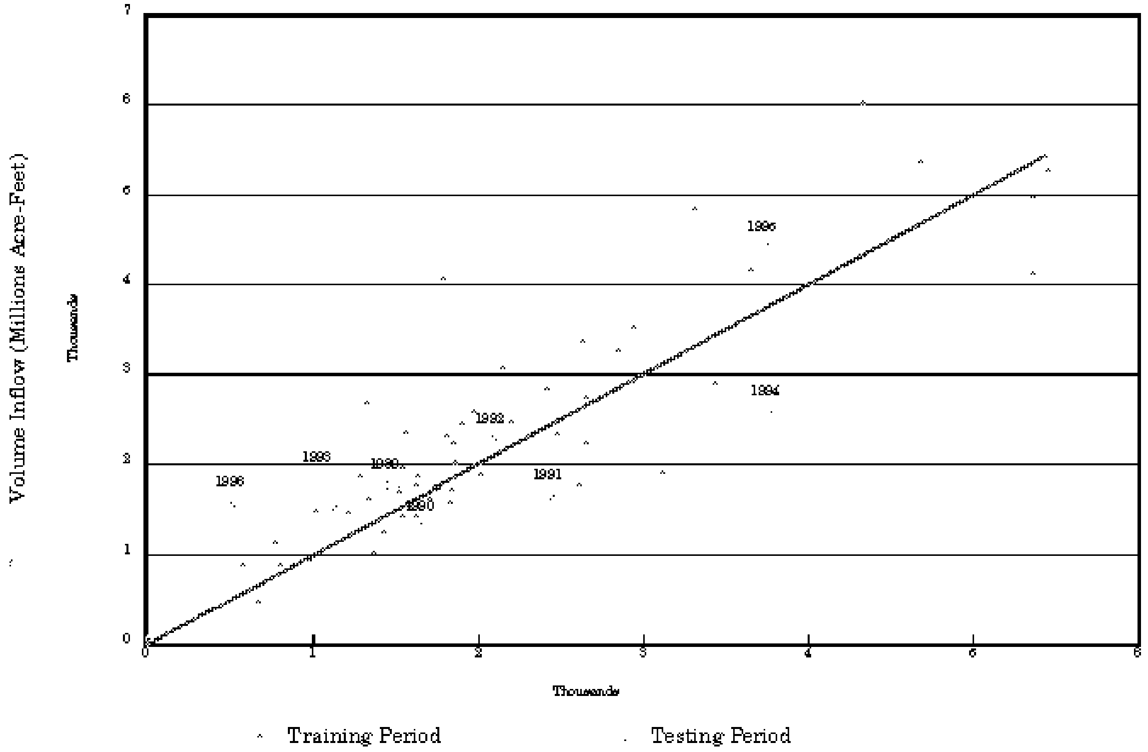

March
Estimated Inflow (Millions Acre-Feet)
Thousands
7
6
5
4
3
2
1
0
0
1
2
3
4
5
Thousands
Actual Inflow (Million Acre-feet)
1995
1994
1992
1993
1989
1992
1990
1991
Training Period
Testing Period


April
Estimated Inflow (Millions Acre-Feet)
Thousands
0
1
2
3
4
5
6
7
0
1
2
3
4
5
Thousands
Actual Inflow (Million, Acre-Feet)
1996
1994
1993
1998
1996
1990
1989
1991
Training Period
Testing Period

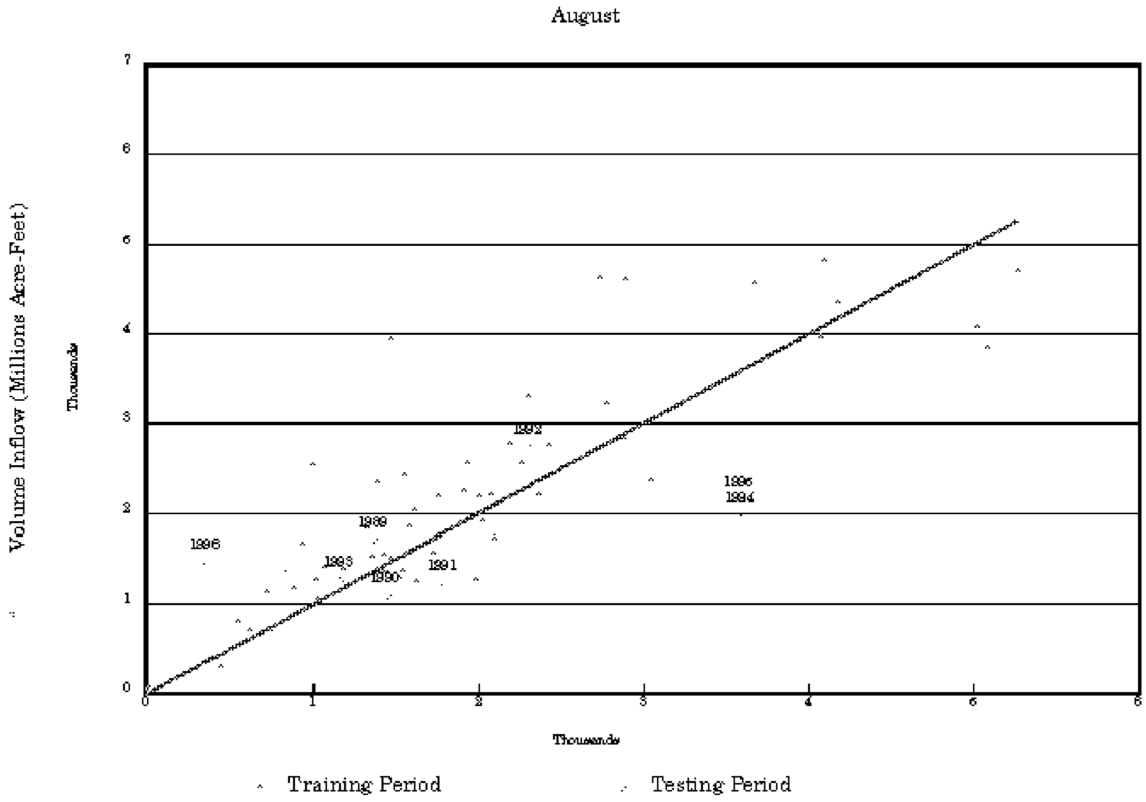

May
Volume Inflow (Millions Acre-Feet)
Thousands
7
6
5
4
3
2
1
0
0
1
2
3
4
5
6
Thousands
1995
1994
1992
1993
1996
1989
1990
1991
Training Period
Testing Period

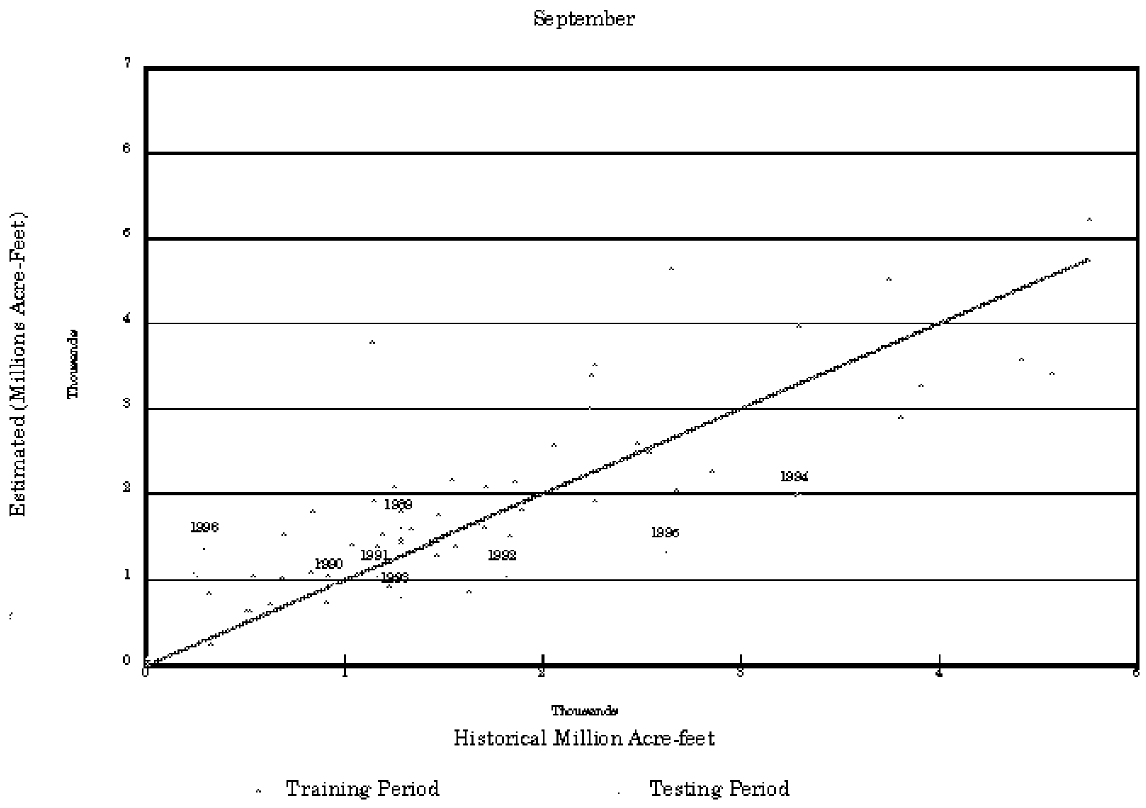

June
Volume Inflow (Millions Acre-Feet)
Thousands
7
6
5
4
3
2
1
0
0
1
2
3
4
5
6
7
Thousands
1995
1994
1992
1993
1989
1996
1990
1991
Training Period
Testing Period

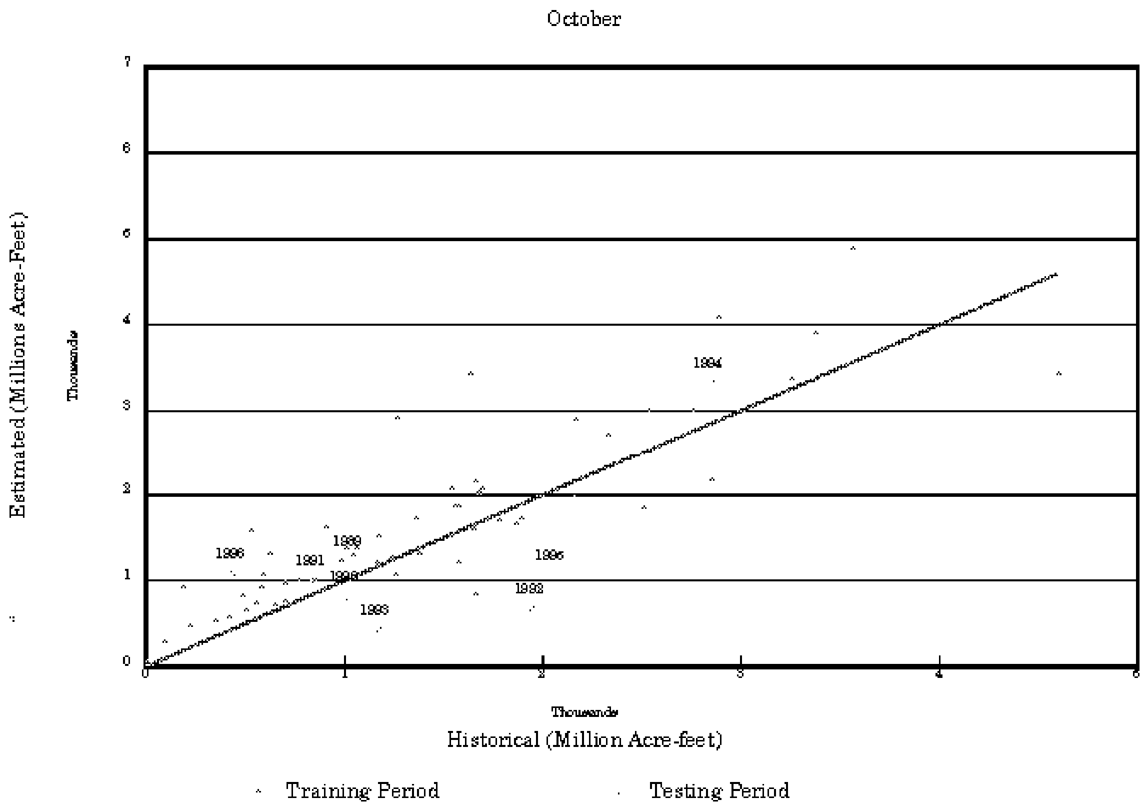
July

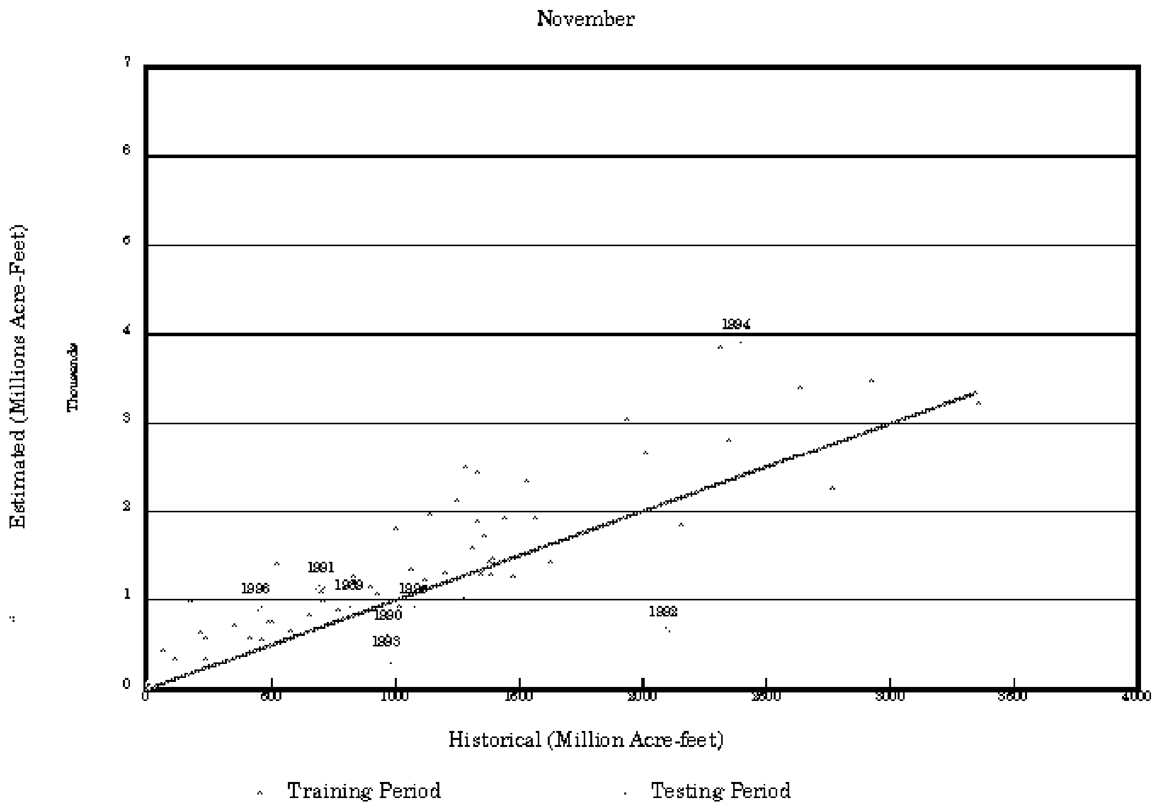


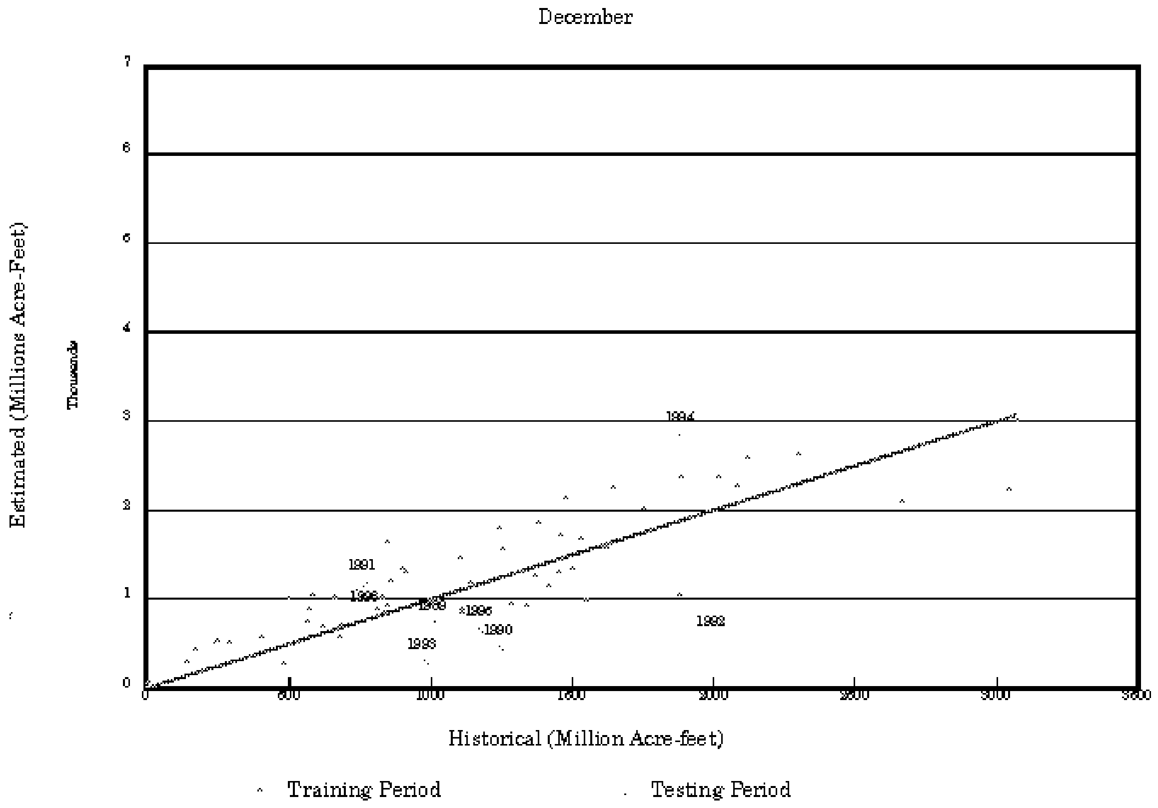
Volume Inflow (Millions Acre-Feet)
Thousands
7
6
5
4
3
2
1
0
0
1
2
3
4
5
6
Thousands
1996
1993
1989
1990
1992
1991
1995
1994
Training Period
Testing Period


August
Volume Inflow (Millions Acre-Feet)
Thousands
7
6
6
4
3
2
1
0
0
1
2
3
4
6
6
Thousands
1996
1993
1989
1990
1991
1992
1995
1994
Training Period
Testing Period


September
Estimated (Millions Acre-Feet)
Thousands
0
1
2
3
4
5
6
7
0
1
2
3
4
5
Thousands
Historical Million Acre-feet
1996
1989
1990
1991
1993
1992
1995
1994
Training Period
Testing Period


October
Estimated (Millions Acre-Feet)
Thousands
0
1
2
3
4
5
6
7
0
1
2
3
4
5
Thousands
Historical (Million Acre-feet)
1996
1991
1989
1998
1993
1995
1992
1994
Training Period
Testing Period


November
Estimated (Millions Acre-Feet)
Thousands
7
6
5
4
3
2
1
0
0
500
1000
1500
2000
2500
3000
3500
4000
Historical (Million Acre-feet)
1994
1991
1996
1989
1995
1990
1993
1992
Training Period
Testing Period

December
Estimated (Millions Acre-Feet)
Thousands
7
6
5
4
3
2
1
0
0
500
1000
1500
2000
2500
3000
3500
Historical (Million Acre-feet)
1994
1991
1996
1989
1995
1990
1993
1992
Training Period
Testing Period