INCLUDING THE EFFECTS OF SOLAR ACTIVITY FOR MORE EFFICIENT WATER MANAGEMENT: AN APPLICATION OF NEURAL NETWORKS

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ABSTRACT

Lake Okeechobee is the second largest freshwater lake, by area, lying wholly within the boundaries of the United States. The competing objectives associated with the water management of this large body of water are becoming increasingly challenging to satisfy. This is in part due to rapid development of the region as well as an ever growing awareness of the needs and sensitivities of the natural ecosystems within the region. The findings of this report demonstrate the advantages of having more flexible water management rules that recognize natural climate variability as it occurs on seasonal to decadal time scales. The variability of climate identified with solar activity, El Nino events, and changes in the strength of the Atlantic Ocean thermohaline current, are integrated with the aid of a neural network to make six month inflow forecasts for Lake Okeechobee. By incorporating the hydrologic forecast into the Lake operational rules, it is demonstrated that the objectives of water management can be more proficiently satisfied. Temporal distribution and strength of solar activity as indicated by geomagnetic disturbances and sunspot activity are demonstrated to be important inputs for the seasonal hydrologic forecast for Lake Okeechobee.

Key words: inflow forecast, climate variability, efficient water management, geomagnetic activity, sunspots, neural network.

1. INTRODUCTION

Lake Okeechobee is the "liquid heart" of southern Florida. The surface area of the Lake is approximately 1970 km^2 and has a storage capacity over 4×10^9 m^3 in which excess water may be stored during the wet periods for subsequent use by agricultural and municipalities during drier periods. It is also an important source of water for the vast wetlands to its south known as the Everglades. Due to the potential for heavy rains and severe tropical storms in south Florida, water levels must be carefully monitored to ensure that they do not rise to levels that threaten the structural integrity of the levee system surrounding the Lake. The natural ecosystems within the Lake and those located within the downstream wetlands and estuaries are also very sensitive to the temporal and spatial distribution of releases from the Lake.

Zhang and Trimble (1996 a , b) developed a methodology for predicting Lake Okeechobee inflows from solar and global indices with the application of an artificial neural network. The current paper reports on the refinement of the earlier approach and a demonstration of the improved water management efficiency that may be achieved by including the forecast in Lake Okeechobee operational guidelines.

2. CLIMATE SHIFTS AND WATER MANAGEMENT

Weather forecasting is the science of predicting the likely future sequence of weather events. Weather systems are governed by complex interactions of dynamic and physical 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.

Climate forecasting is the science of predicting shifts in atmospheric conditions that may persist for months, years or even decades. A shifted climate may be recognized as a persistent change in the expected mean and extremes of meteorological variables. Regional water management systems that include large lakes and reservoirs with extensive tributary and water use basins have amplified hydrologic response to relatively small shifts in climate. With the significant advances in climate research in recent years, climate based operational rules have emerged as a desirable mechanism for more proficiently meeting the increasingly challenging competing regional water management objectives. Ramusson and Arkin (1993) emphasized the necessity for having a global perspective in order to understand persistent shifts of regional climate.

3. VALUABLE INDICATORS FOR FLORIDA

Indeed, a large portion of the variations of south Florida's climate and hydrology has been found to be associated with solar and large-scale global processes. Associations between climates at distant locations of the world are known as teleconnections. These teleconnections tend to be most easily recognized by somewhat cyclic anomalies of atmospheric and oceanic variables. The detailed description of all these anomalies is beyond the scope of this report. However, a few global and solar indices are readily available that provide useful information for forecasting regional hydrologic conditions within Florida.

3.1 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 periods actually vary between 9 and 14 years. Periods tend to be shorter when the magnitude of the sunspot maximum is larger and longer when the magnitude of the sunspot peak is smaller. The 20th century has been a period with very high solar activity with a corresponding shorter than average cyclic period of 9.7 years (Friis-Christensen and Lassen, 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 that indicates a significant portion of the earth's climate variability is associated to variations of solar activity, the exact mechanisms of these associations are not completely understood. The changes in the ultraviolet energy flux that occurs across the outer bounds of the Earth's atmosphere during the variation of sunspot activity appears to be too small to account for the observed climatic fluctuations. Willet (1953, 1987) has elaborated that short bursts of ultraviolet and corpuscular energy emitted from the sun may penetrate the geomagnetic field and upper atmosphere allowing strong spot heating of the Earth's atmosphere and disruption of the zonal weather circulations. This, he contended, allows such activity to contribute significantly to climate fluctuations without appreciable longer term changes in energy flux. The aa index of geomagnetic activity was taken by Willet to be the best indicator of short term solar energy fluctuations. This index, as does sunspot activity, follows an approximate 11-year cycle, but generally lags the sunspot cycle and contains many more perturbations.

Research of Labitzke and van Loon (1989, 1992, 1993) provide more recent evidence that an important connection exists between solar cycles and the Earth's climate. Haigh (1996) has successfully simulated observed shifts of the subtropical westerly jets and changes in the tropical Hadley circulation that appear to fluctuate with the 11-year solar cycle. Photo-chemical reactions in the stratosphere are included in the model that enhance the effects of the variations of the solar irradiance. Even a small shift in the strength and positioning of these global scale climate systems may have potentially significant effects on Florida's climate. Balliunas and Soon (1996) concluded from long term solar records that solar-brightness variations can explain the majority of the past record of terrestrial global temperature fluctuations. They indicated that the variable length of the solar magnetic cycle correlates nearly perfectly with the 11-year moving average of global temperature since 1750. Reid and Gage (1988), Reid (1991) , and White (1996) reported on the similarities between secular variations of solar activity and that of the global sea surface temperature.

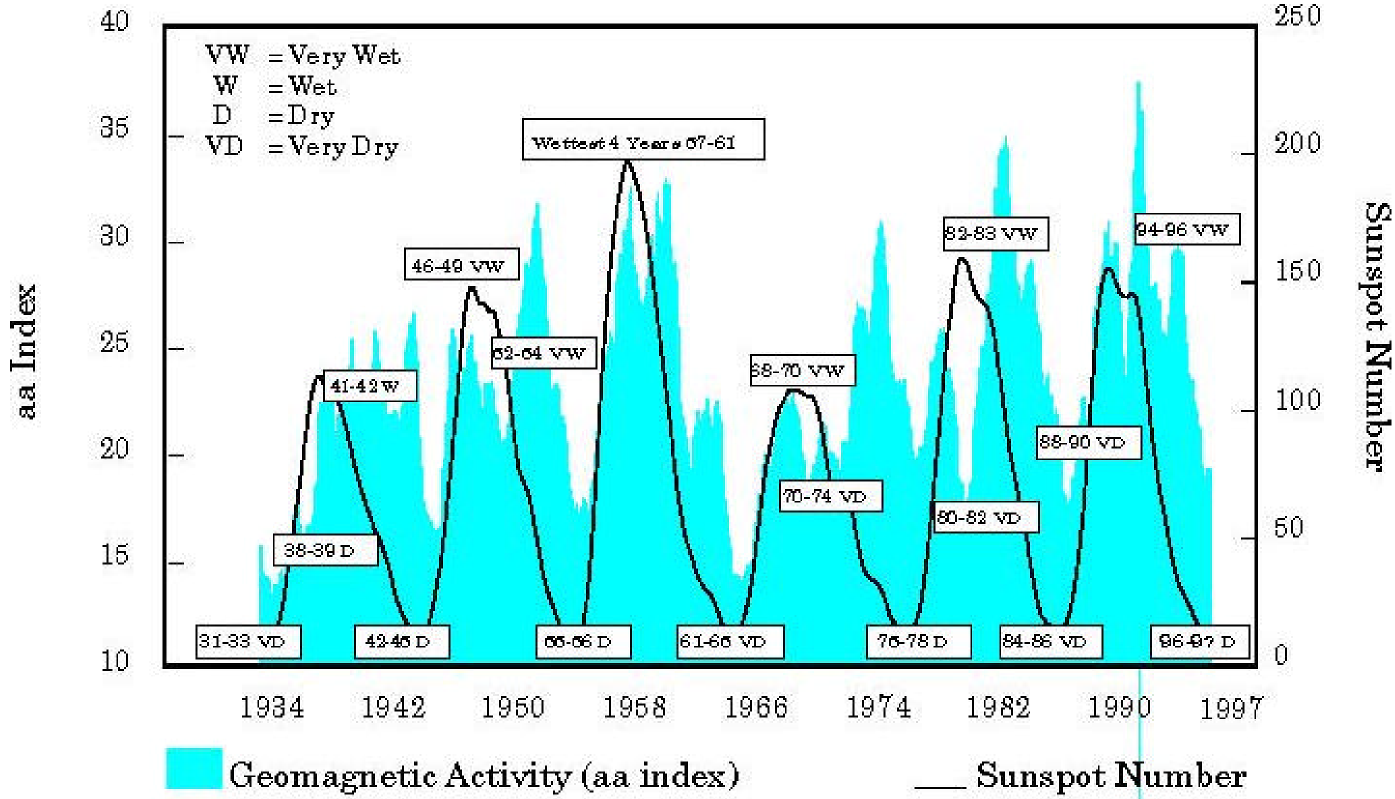
In summary, solar activity affects the Earth and its atmosphere in many ways over different time scales. These may be broken down into the following categories:

1. Short duration solar eruptive phenomena,
2. The 11- and 22- year sunspot cycle,
3. Longer solar cycles

All three of these categories appear to contribute significantly to climate variations in south Florida.

Figure 1 labels the most significant anomalies in the Lake Okeechobee inflow record compared to that of solar activity as estimated by the sunspot number and geomagnetic activity. These anomalies are defined in terms of water years which extend from June of the first year through May of the following year. Each water year is classified based on the magnitude of the inflow volume for illustration purposes. The inflow term includes surface inflows plus the volume of net rainfall that falls directly on the Lake. Years with annual inflows less than 3.5×10^9 (2.5×10^9) m^3 are classified as being dry (very dry), while inflows greater than 6×10^9 (7×10^9) m^3 are classified as being wet (very wet). When a period of several wet or dry years are in sequence, the period is labeled according to the wettest or driest year of each sequence.

Large Lake inflows that occurred during the periods of 1946-1949, 1952-1954, 1957-1961, 1982-1983 and 1994-1996 appear to have been closely associated with solar eruptive phenomena. Sporadic solar activity that occurs during the sunspot maximum (e.g. 1969-1970) appear to be more closely associated with large inflow events than those that occur at low sunspot activity (e.g. 1942-1945 and 1961-1963). Extended dry periods are more likely to be associated with minimums of either geomagnetic activity or minimums of the 11-year sunspot cycle. On a longer time scale, decadal



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.

variations of Lake Okeechobee inflows appear to be related to the magnitude of the 11-year solar cycles.

3.2 El Nino - Southern Oscillation

The El Nino-Southern Oscillation (ENSO) is a complex interaction of oceanic and atmospheric processes in the tropical Pacific. This system of processes is associated with climate anomalies world-wide. The Floridian climate has its most significant statistical association with the ENSO process during the winter months. During periods of persistent above normal ocean temperature along the equatorial Pacific Ocean (El Nino event) greater than normal winter rainfalls are expected in Florida. Likewise, during persistent periods of below normal ocean temperature in the same region of the Pacific Ocean (La Nina event) less than normal winter rainfalls are normally experienced in Florida (Hanson and Maul, 1991). 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 (SSTA) because it has a much longer period of historical record available. The sea surface temperature (SST) record for El Nino events is available beginning in 1950 while the SOI period of record begins prior to 1900. This longer period of record is particularly valuable for analyzing the relationship of the variations of the Floridian climate and hence hydrology to various global atmospheric-oceanic conditions.

3.3 Atlantic Ocean Thermohaline Current (AOTC)

Broecker (1991) outlined the theory of the great ocean conveyor. This is a global system of ocean currents that is driven by density differences caused by variations in salinity and temperature. Broecker hypothesized that variations of these currents may cause abrupt shifts to the global climate. Gray et al (1997) recognized the importance multi-decadal shifts of the Atlantic Ocean portion of the global ocean conveyor may have on tropical activity and climate fluctuations. The strong phase of the current is associated with an increased number of more intense tropical storms and less numerous ENSO events.

Florida experienced much wetter conditions and more intense tropical storms prior to 1970, the last period the AOTC was recognized as being in the strong phase prior to 1994. The 1970-1993 is the period reported by Gray et al for which the AOTC has been reported as being in a weak phase. They suggest that the general strength of this current may be estimated by subtracting South Atlantic Ocean SSTA from North Atlantic Ocean SSTA averaged over broad regions of each ocean basin. When the North Atlantic Ocean is experiencing warm anomalies and the South Atlantic Ocean cool anomalies, the AOTC is described as being in a stronger phase. When the anomalies reverse themselves, the current is described as being in a weaker phase.

Evidence suggests that the AOTC has recently reentered the strong phase of the conveyor current. This would indicate more intense tropical activity and very wet conditions may be on the horizon for Florida. This statement is supported by recent SSTA and more frequent intense Hurricanes within the Atlantic Ocean Basin. The North Atlantic Ocean SSTA minus the SSTA has recently became positive for the first time in 25 years (during the 1994-1995 water year). The magnitude of the difference in anomalies normally range between 0.3 to 0.5 degrees. The value remained continually positive from 1930 through 1969 and continually negative between 1970 and 1994. Gray et al's 1997 report covers past variation of the strength of the AOTC and the effect this variation had on the climate regime of the Atlantic Ocean basin.

3.4 Predicting Regional Climate Shifts

Successful interpretation of the effects that large-scale global and solar processes have on regional climate anomalies requires that the interactions of these processes be considered. A detailed visual inspection of historical data reveals some potentially useful relationships. These relationships are discussed in the following sub-sections.

3.4.1 Interaction of ENSO Events and Solar Activity

El Nino events that occurred during the peak solar activity have more pronounced rainfall anomalies (greater increases in rainfall) in Florida. The El Nino events of 1957-1958, 1982-1983, and the 1990s are primary examples of this type of episode. The 1965-1966, 1972-1973, 1977-1978 and 1986-1987 events are examples of moderately strong El Nino's events that had less extreme affect on Florida's rainfall and hydrology. These events occurred within periods of lesser solar activity.

Enfield and Cid (1991) presented evidence that when solar activity is strong, El Nino-Southern Oscillation (ENSO) events, are spaced farther apart with periodicity being strongly influenced by the Sun. During weaker solar activity the events occur closer together and are more influenced by the internal dynamics of the ENSO system. Mendoza et al (1991) reported on the increased likelihood of ENSO events during particular phases of the 11-year solar cycle. It appears very plausible that solar activity influences Florida's climate indirectly by its influences on the periodicity and onset of El Nino events.

3.4.2 Interaction AOTC and Solar Activity

Hydrologic drought in Florida tend toward periods of minimum solar activity and the periods shortly thereafter. This relationship exists even during strong phase of the AOTC. The 1996-1999 period is a period to be cognizant of the increased potential for drought due to the phase of the solar cycle. The exact timing of these events depends on the phase and strength of the El Nino. Even if a strong El Nino event does occur, it generally has less effect on Florida's rainfall during periods of lesser solar activity. Once this potentially dry period passes, south Florida appears headed to a climate regime similar to that which existed from 1940 through 1960. This forecast is based on the return to the strong phase of the AOTC as reported by Gray et al and a general consensus that solar cycle 23 should continue the recent trends of strong to very strong sunspot cycles that have occurred during the middle and latter part of the 20th century (Joselyn et al, 1996). This shift in climate regime will make the 1994-1995 seemingly very large inflow event a much more common occurrence.

When considered jointly, the AOTC and long term level of solar activity appear to account for a significant portion of the multi-decadal variability of Florida's climate.

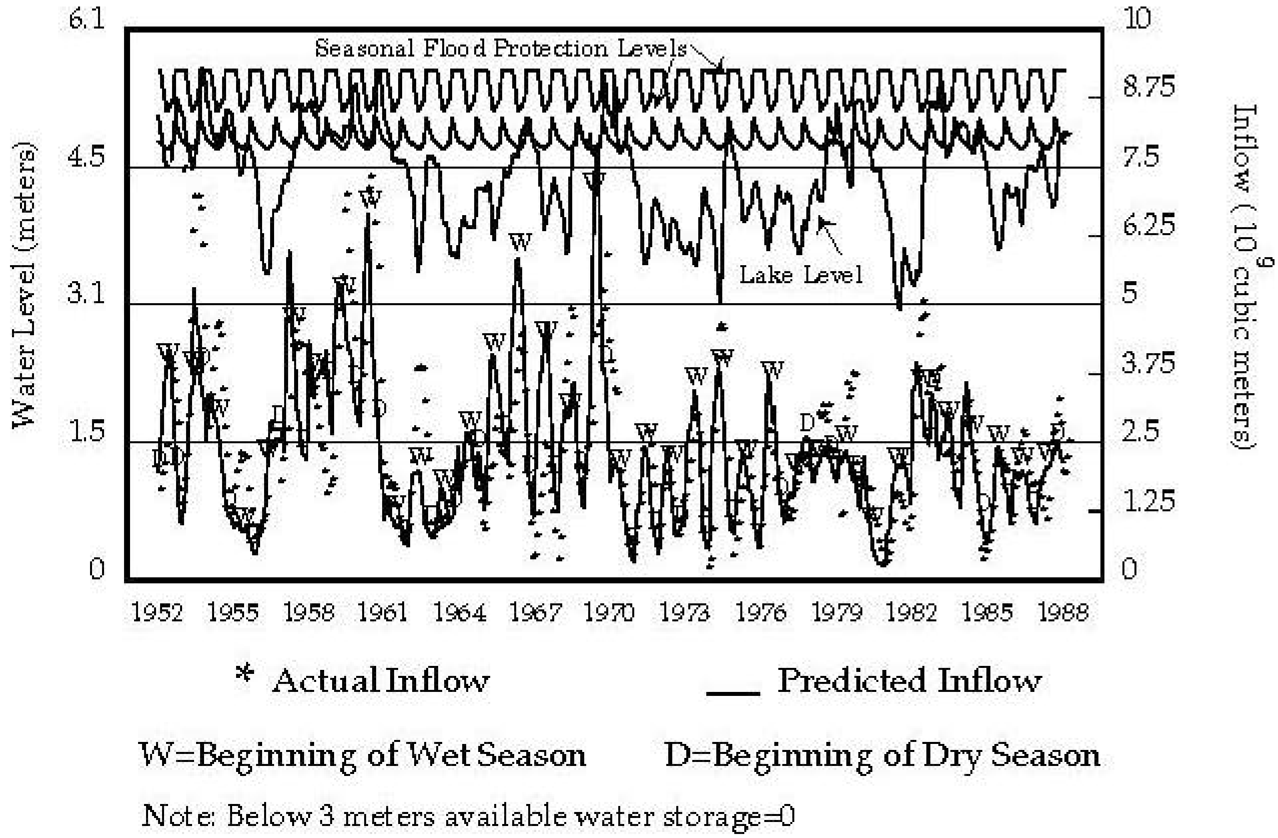
4. FORECASTING LAKE OKEECHOBEE INFLOWS

The ability to forecast climate shifts that affect a full range of water management objectives is very desirable. However, the complexity of the solar-terrestrial and oceanic-atmospheric interaction make the ability to forecast regional climate anomalies by more traditional statistical methods difficult. This paper applies an artificial neural network for predicting Lake Inflows.

4.1 Neural Networks

Neural networks have received attention from many professions. In water resources and hydrology, several applications may be cited (Karunanithi, 1994; Smith and Eli 1995; Crespo and Mora, 1993; Grubert, 1995; Raman and Sunilkumar, 1995; Derr and Slutz, 1994). Appealing aspects of neural networks are their applicability to complex non-linear problem sets, their adaptiveness to adjust to new information and their ability to make predictions from inputs in which the relationships between the predictors and the predicted are not completely understood. 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. This is the methodology selected for making the inflow forecast.

The most significant adaption to the original methodology developed by Zhang and Trimble (1996 a, b) was the inclusion of the strength of the AOTC as a predictor of Lake Okeechobee inflow. In addition, a logarithmic transformation of Lake Okeechobee inflow was made to reduce the skewness of the data set. After an extensive effort was performed which involved the evaluation of different network configurations, the configuration with 7 input neurons, 14 hidden layer neurons and one output neuron was selected for making the inflow forecast.



4.2 Data for Training and Testing

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

1. the Southern Oscillation Index (SOI),
2. the sunspot number,
3. trend in sunspot number,
4. maximum sunspot number of each cycle,
5. geomagnetic index,
6. AOTC index, and
7. the month of the year.

Indices were smoothed with a six month running average. Therefore, each of the indices used for the inflow predictions was the average value of that index during the previous six month period. Two exceptions to the smoothing were made. The first exception was the AOTC index which was simply input as a step function. The strong state of the current was input through 1970 and after 1993. The period between 1970 through 1994 was defined as being in the weak state based upon on-going research (Gray et al, 1997).

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 11-year cycle for the rising phase of the sunspot cycle. Forecasts are available from various sources including NASA. On the declining phase the actual maximum sunspot number may be used.

Estimated 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 from data collected by the South Florida Water Management District (SFWMD). A complete data set of climate indices and Lake inflows from 1933 through 1996 is available for training and testing each neural network configuration.

Table 1 illustrates an abbreviated annual summary of climate indices and inflow volumes.. The solar and ENSO indices are reported in terms of .5 unit normal deviates. The AOTC index is depicted as a step function with a strong phase (+) and a weak phase (-). The season of the year that solar disturbances and global climate anomalies occur is very important as to how they effect on Florida's climate. Although some of the useful information may be diminished considering only annual values, it is believed that insight to the complex relationships that exist between of the patterns of climate indices and the Lake inflow may be obtained from Table 1.

4.3 Training Period

The period of March, 1933 through February, 1988 was selected as the training period. The results of a sector of the training period is illustrated in Figure 2. The lower half of these plots illustrate the predicted inflow and the actual inflow versus time. The right axis is the scale that represents the inflow volumes. The two repetitive lines near the top of the plot represent the seasonal schedules (meters) at which special operations are required to control water levels for flood protection. Intermediate releases are required when water levels exceed the lower schedule. When water levels reach the upper line, up to maximum capacity discharges are required. These larger discharges are highly undesirable due to the adverse impacts they have on downstream ecosystems. The remaining line represents the Lake water level with the current operational schedule in place. The available water for consumptive purposes is very limited when the Lake water level is below 3 meters relative to National Geodetic Vertical Datum (NGVD). The NGVD datum was adopted by the United States in 1929 and is synonym for the 1929 local mean sea level datum.

The drought periods that are acknowledged by water managers in south Florida as being exceptional for Lake Okeechobee include: the mid- 1950s, the early to mid- 1960s, and extended periods of the 1970s and early 1980s. Extremely wet periods include: 1953-1954, 1957-1961, 1968-1970 and 1982-1983. The coefficient of determination for the actual versus trained inflows was 0.50. Upon closer inspection of Figure 2, it may be recognized that the predicted transition from a high-to -low or a low-to-high inflow regimes generally precede the actual occurrence of the event. This is likely due to the absence of local antecedent hydrologic conditions being input to the neural network. The potential of this predictor becomes more clear upon recognizing that: 1. the inflow transitions are forecasted well in advance of the water level response and 2. exceptional wet (W) and dry (D) season inflows (e.g. wet seasons 1955; dry season 1982).

Table 1. Annual Lake Inflow Versus Averaged Annual Values of Climate Indices [Each Symbol +/- .5 unit normal deviate]

Water Year [June-May]	Sunspot Number	Geo-- Magn. [aa]	ENSO Index [-SOI]	AOTC Index	Lake Inflow [m^3 10^6]	Rank
1959-1960	+++	++		+	9558	1
1947-1948	++			+	9382	2
1953-1954	--		++	+	9252	3
1960-1961	+	++++	-	+	8752	4
1969-1970	+	-	+	+	8179	5
1982-1983	+	++++	+++	-	7875	6
1957-1958	++++	++		+	7756	7
1994-1995	-	++	+++	+	7064	8
1995-1996	--			+	6407	9
1968-1969	+			+	6333	10
1948-1949	++			+	6156	11
1941-1942		+	++	+	6080	12
1992-1993	+	+	++++	-	5831	13
1945-1946	-	--	-	+	5705	14
1933-1934	--	--	+	+	5644	15
1940-1941			+	+	5472	16
1954-1955	--	--		+	5268	17
1951-1952		++		+	5268	18
1934-1935	--	-----		+	5258	19
1949-1950	++			+	5164	20
1936-1937		--		+	5045	21
1978-1979			+	-	4989	22
1939-1940				+	4978	23
1952-1953		++		+	4961	24
1974-1975	-	++	---	-	4939	25
1979-1980	++			-	4654	26
1965-1966	--	----	++	+	4619	27
1935-1936	--	---		+	4519	28
1983-1984		+++	++++	-	4438	29
1991-1992	++	++++	++	-	4342	30
1962-1963	-		--	+	4322	31
1958-1959	++++	++	+	+	4281	32
1956-1957	++		---	+	4247	33
1966-1967	-	--	+	+	4194	34
1987-1988	-	-	++++	-	4080	35
1986-1987	--			-	4023	36
1946-1947		+		+	3954	37
1937-1938	+	-		+	3945	38
1990-1991	++	++	+	-	3811	39
1932-1933	-	-		+	3771	40
1977-1978	-	-	++	-	3577	41
1943-1944	--		-	+	3404	42
1971-1972		-	----	-	3322	43
1942-1943	-			+	3276	44
1976-1977	--		-	-	3101	45
1950-1951			---	+	3042	46
1985-1986	--			-	3032	47
1964-1965	--	--	-	+	3018	48
1989-1990	+++	++	--	-	3001	49
1975-1976			----	-	2879	50
1967-1968		-	-	+	2812	51
1981-1982	++			-	2715	52
1963-1964	-		---	-	2710	53
1955-1956	-	--	---	+	2710	54
1973-1974	-	+	-	-	2681	55
1972-1973		-	+	-	2662	56
1944-1945	--	--		+	2638	57
1993-1994		+	+++	-	2618	58
1938-1939	+		-	+	2600	59
1988-1989			--	-	2572	60
1931-1932	-	--		+	2379	61
1984-1985	-	++		-	2322	62
1996-1997	--	-	-	+	2321	63
1970-1971	+	-		-	2044	64
1961-1962				+	2014	65
1980-1981	+++	--		-	1100	66

4.4 Testing Period

Figure 3 illustrates the results for the testing period. The very low inflow period of 1988 through early 1989, the very large inflow period of 1994 and 1995 and finally the transition back to drier than normal conditions in 1996 were all successfully predicted. An over prediction of the 1989 inflows was most likely related to the depleted storage of the regional system that had to be replenished before tributary basin runoff could be generated into the Lake. However, this was a first sign that the climate would soon be entering a transition back to a wetter regime. This forecast should be very valuable for water managers who are responsible for equitably and efficiently distributing water supply during periods with limited supply and illustrates that the inflow forecast may be even more valuable for water management than a statistical goodness of fit measure between the predicted and actual inflow would indicate.

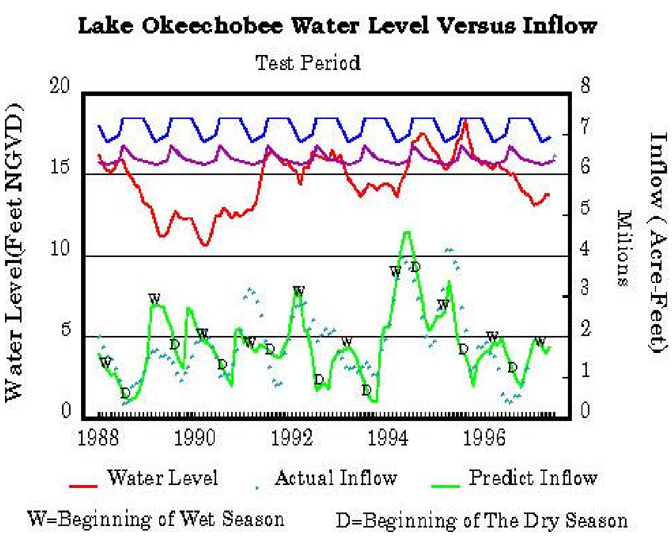
Figure 4 illustrates a scatter plot of the predicted inflows versus actual inflows for the testing period. The coefficient of determination for this period was equal to 0.48. This is especially significant when it is considered that no regional hydrologic input is included in the predictor. The test period

included the same tendency as the training period for the predicted inflow to precede the timing of occurrence of the actual inflow. Again it is suspected that the antecedent hydrologic conditions is the major reason for this tendency.

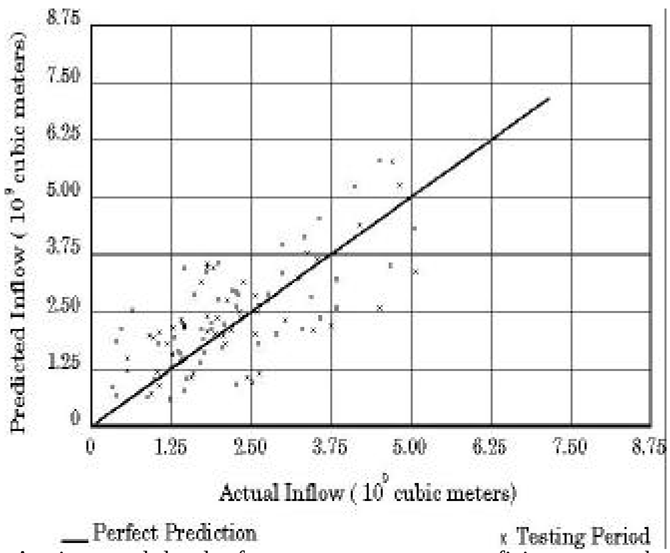
5. PERFORMANCE OF PROPOSED SCHEDULE

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 (SFWMD, 1997). 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 nearly 20000 km^2 with a mesh of 1746 cells. Lake Okeechobee is modeled separately from the grid mesh as a flat pool-lumped reservoir
system. The model 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 facilities are also simulated.

The proposed climate based operational schedule is evaluated by comparing its simulated performance to that of the current schedule. Climate based operational guidelines were developed for five distinct categories of inflow based on climate conditions ranging from dry (with the expected next six month inflow being less than 1.9 x 10^9 m^3) to very wet (with the next six month inflows expected to be greater than 3.8 x 10^9 m^3) conditions. More details of these guidelines are included in a recent in



SFWMD Special Report (Trimble et al, 1997).



An increased level of water management proficiency may be achieved for Lake Okeechobee by incorporating a climate based operational schedule. Simulated water deliveries to the Everglades natural wetlands were increased from 6 x 10^9 m^3 to 8 x 10^9 m^3 while at the same time increasing the volume of water supply needs met by approximately 1 x 10^9 m^3. By reducing large discharges to tidewater, the associated objective of reducing adverse impacts to the ecosystems of downstream estuaries is accomplished.

6. SUMMARY

This report presents the summary of the basis for the recommendation of a Lake Okeechobee operational schedule being considered by the South Florida Water Management District for implementation. The theme of this schedule is increased operational flexibility. Operational guidelines are suggested that are not only a function of the existing regional hydrologic conditions but also projected Lake inflow. The inflow estimates are computed from solar and global climate indices. Although a general hypothesis is available to describe the physical mechanism for these inflow forecast, the actual complex interaction of these processes is not completely understood. Regardless of this shortcoming, the computational power of artificial neural networks for recognizing patterns of climate and solar indices that

produce extreme inflow events is demonstrated. These inflow forecasts provide a mechanism for regional water managers to identify the general state of the global climate and its potential to produce extreme regional hydrologic events within south-central Florida. With this information it is illustrated that water management can be accomplished with more proficiency.

The recent advances that have been made in understanding and predicting solar activity on different time scales (Wu et al, 1997; Ashmall and Moore, 1997) and the continual efforts being made to better understand how this solar activity affects variations of the Earth's climate (e.g. Svensmark and Friis-Chritensen, 1997) holds great promise for developing more proficient regional water management in the near future.

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