Use of Climate Outlook for Water Management in South Florida, USA

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ABSTRACT: Longer-lead (seasonal and multi-seasonal) climate forecasts can significantly benefit the operation of regional water management systems that include lakes and storage reservoirs for flood control, water supply, energy, and environmental enhancement. In South Florida, the water management system is extremely complex. Management of this system requires a multi-objective approach that considers water supply for urban and agricultural users in the region, and the restoration of the Everglades system. Recent advances in computer technology and the improved understanding of the global climate phenomena are providing valuable seasonal and multi-seasonal climate outlooks which can be incorporated into operational planning of the regional systems. Artificial Neural Network models have been used to predict inflow volumes to Lake Okeechobee, the primary storage in the system, using selected climatic indicators. A risk-analysis technique known as Position Analysis is used to evaluate the seasonal and multi-seasonal performance of the water management system with and without climate forecasts.

INTRODUCTION

Regional water management systems that include large lakes and storage reservoirs with extensive tributary and water use basins can significantly benefit from longer lead forecasts with lead times of several months to multiple seasons. Such forecasts will allow the water managers to make significant adjustments early enough to minimize adverse impacts to sensitive ecological systems, while maintaining adequate flood protection and water supply (Trimble et al., 1997). Recent advances in the understanding of the global climate linkages ("teleconnections") and the innovative research on linking external influences on earth's climate have the potential for providing valuable seasonal and multi-seasonal climate outlook forecasts and associated probabilities. Although such longer-lead climate forecasts have a high uncertainty, they provide additional information for water managers who constantly have to assess the effects of current operational decisions on future water conditions of natural and human systems.

This paper provides a brief summary of the recent attempts to incorporate climate outlook forecasts into the management of the water resources systems in South Florida. First, a brief description of the South Florida system and the critical water management issues are discussed. Next, a brief description of the current state of knowledge in predicting climate shifts that affects South Florida hydrology is provided. Neural network models are used to understand the relationship between the climatic indices and the major

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inflows into the system. This is followed by a discussion of the "Position Analysis" tool that allows the water managers to use computer simulating models for forecasting risks associated with a specific operating plan over a period covering one or more seasons. Finally, how the climate outlook has been incorporated into an operational schedule is presented.

SOUTH FLORIDA SYSTEM

Drainage of the Everglades in South Florida, for the purpose of land reclamation, began in the middle 1800's and has evolved into an extensive and complex network of lakes, impoundments known as Water Conservation Areas, canals, levees and numerous water control structures (Figure 1). The heart of the present-day system is Lake Okeechobee, the second largest fresh water lake located contiguously within the United States. The Kissimmee River and Fisheating Creek provide most of Lake Okeechobee inflows. The system includes approximately 1400 miles (2250 km) each of both levees and canals, more than 200 water control structures and 18 major pump stations. Lake Okeechobee has two outlets, the Caloosahatchee River to the west and the St. Lucie Canal to the east, which discharge through the tidal estuaries to the ocean. Four major canals (West Palm Beach, Hillsboro, North New River and Miami) convey water supply to the Lower East Coast (LEC) and flood control releases from Lake Okeechobee to the south. These canals traverse the Water Conservation Areas (WCAs) and capture excess runoff from the Everglades Agricultural Area (EAA). The 5 WCAs, WCA-1, WCA-2A, WCA-2B, WCA-3A and WCA-3B, work as shallow, above the ground impoundments. The rich soils in the EAA, located in between Lake Okeechobee and the WCAs, are used for production of sugar cane, sod and winter vegetables. Lake Okeechobee supplies water to both the EAA and the communities around the Lake (Lake Okeechobee Service Areas, LOSA). An important feature of south Florida hydrology is the continuous interaction between highly transmissive ground water system and surface water.

The water control system of south Florida is complex, not only in its configuration, but also in its operation. Conflicting water needs necessitate the use of appropriate water management decision tools. The ability to look into probable future responses of the system, given the current state and future climatic forecasts, is a valuable tool for managing this complex water resources system.

CLIMATE INDICATORS AND OUTLOOKS

Associations between climate variations (anomalies) at distant locations of the world are known as teleconnections. The most well-known teleconnections are those associated with the regional climate variability world-wide to that of the El Nino-Southern Oscillation (ENSO) phenomenon. The signature of an El Nino event is the occurrence of very warm ocean waters at low latitudes located off the west coast of South America. This region of the ocean normally has cooler sea surface temperatures due to the upwelling of the ocean. The Southern Oscillation is the measure of sea level atmospheric pressure difference between Darwin, Australia (western Pacific) and Tahiti (eastern Pacific). There is a strong connection between EL Nino and the Southern Oscillation and the combined event is known as ENSO. The warm phase of ENSO is generally known as

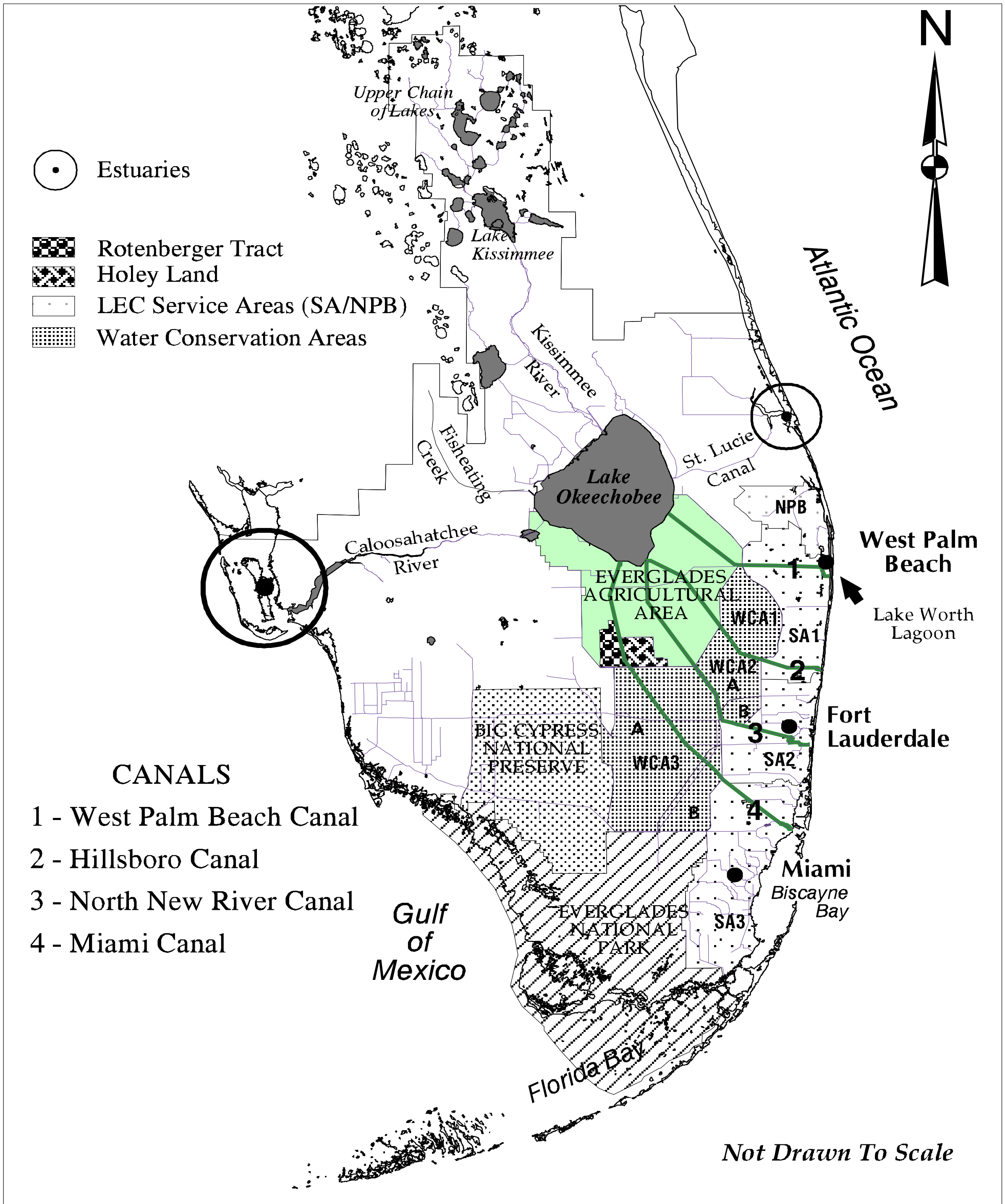

Figure 1. The current South Florida water control system.

"El Nino" and the cold phase is called "La Nina." El Nino events have been blamed for droughts in countries from India to Australia, floods from Ecuador to New Zealand, and fires in the West Africa and Brazil (Golnaraghi and Kaul, 1995). It has also been linked to climate of specific regions of North America (Piechota and Dracup, 1996) and in particular to rainfall and drought events in the state of Florida (Hanson and Maul, 1991).

Recent research (Zhang and Trimble, 1996; Trimble et al, 1997; Trimble and Trimble, 1998) has revealed other climate indicators that may be useful for predicting south Florida hydrology. These include:

- Solar sunspot activity and fluctuations in geomagnetic field (Labitzke and van Loon, 1993, Willet, 1953)
- Atlantic Ocean Thermohaline current (Gray et al, 1997)
- Pacific Decadal Oscillation (Mantua et al., 1997)

The current research (Trimble et al, 1998) has shown a significant potential for using ENSO and the other indices listed above for predicting net inflow volumes into Lake Okeechobee (for example see Figures 2 and 3). Clearly, scientists are far from understanding the physical processes that explain teleconnections. In this efforts, Artificial Neural Network (ANN) models have been employed for predicting net inflow volumes into Lake Okeechobee using ENSO and other climatic indices (Zhang and Trimble, 1996; Trimble et. al, 1997; Trimble and Trimble, 1998). The period of March 1952 through March 1988 was selected for "training" the ANN model (Figure 4). The model was tested for the 1989-1997 period (Figure 5). Figure 6 illustrates the scatter plot of the predicted inflows versus actual inflows for the testing period. The coefficient of determination for this prediction was equal to 0.48.

The South Florida Water Management District (SFWMD) employs the "Climate Outlook" produced by the National Oceanic and Atmospheric Administration (NOAA) Climate Prediction Center (CPC) and other experimental forecasts to aid operational planning efforts. The predictions of precipitation and temperature updated every month by CPC include a one-month outlook for the next month and 13 three-month outlooks going into the future in overlapping fashion in one-month time steps (http://www.cpc.ncep.noaa.gov/products/predictions)

POSITION ANALYSIS

Seasonal and multi-seasonal operational planning of major water resources systems require a careful evaluation of future likely scenarios of water and environmental conditions that influence management objectives. It is a common practice to employ computer simulation models for determining likely outcomes of both short and long-term management options. Position analysis (Hirsh, 1978; Smith et al., 1992; Tasker and Dunne., 1997; Cadavid et al., 1999) is a form of risk analysis that can forecast risks associated with a specific operating plan for a basin over a period of many months conditioned on current state (eg. reservoir storages) of the system. It relies on the generation of large number of possible traces (season or multiple seasons in length) of the hydrologic variable of interest (eg. reservoir stages, flows) using the same initial conditions. It should incorporate a broad range of meteorological conditions that may occur in the future but cannot be forecast accurately. Future likely meteorological conditions may be derived using (a) such methods as extended streamflow prediction

(Day, 1985), (b) historical data; and (c) stochastic simulation models (Tasker & Dunne, 1997).

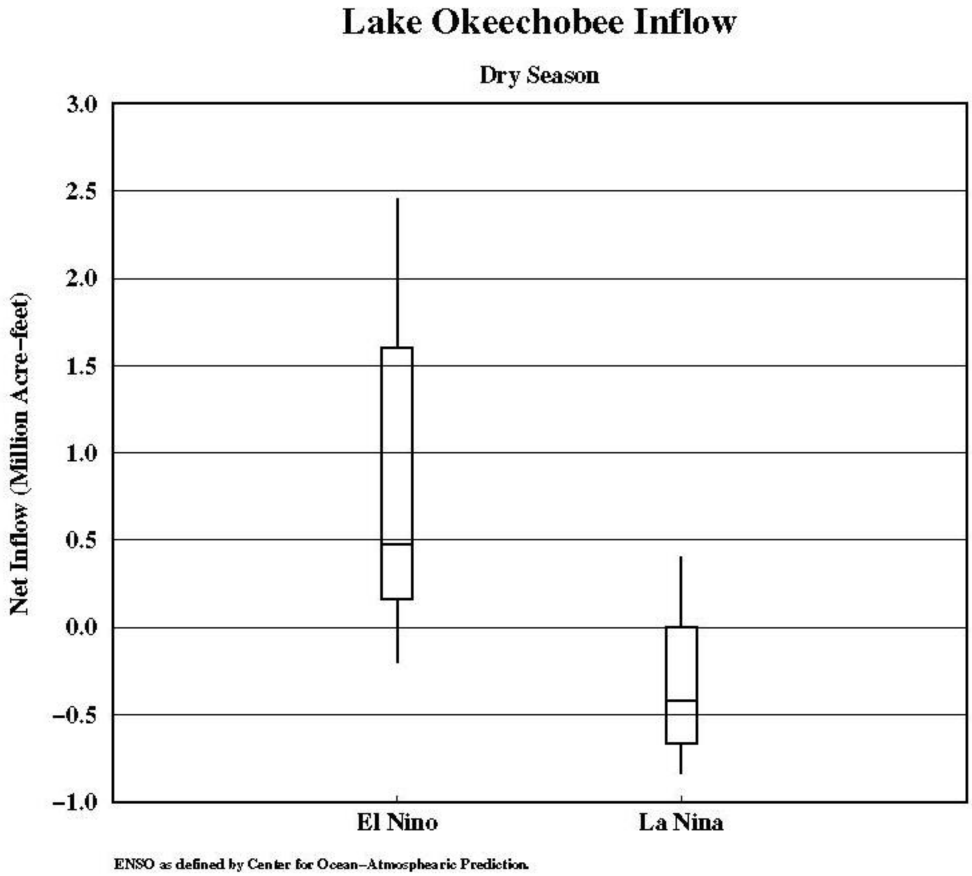

Figure 2. Box & Whisker plots of Lake Inflows during El Nino and La Nino conditions in the Pacific

Cadavid et al (1999) defined the terms Conditional Position Analysis (CPA) and the Unconditional Position Analysis (UPA) depending on whether the estimated risks incorporate climate outlook or not (eg. La Nina conditions that affect the likely inflows to the reservoir system). The methodology adopted for CPA (Cadavid et al., 1999) follows a procedure described by Croley (1996). The objective of the CPA is to estimate the risks of the future response of the system given both the current state and the future climate forecast. Croley's method includes an optimization procedure which provides a set of weights for different traces and these weights reflect information provided by the climate forecasts. For example, if an El Nino condition is predicted and the larger reservoir inflows are possible during this condition, the traces that are associated with El Nino years would have larger weights. A typical stage percentile probability plot resulting from the Conditional Position Analysis (CPA) of Lake Okeechobee is shown in Figure 7.

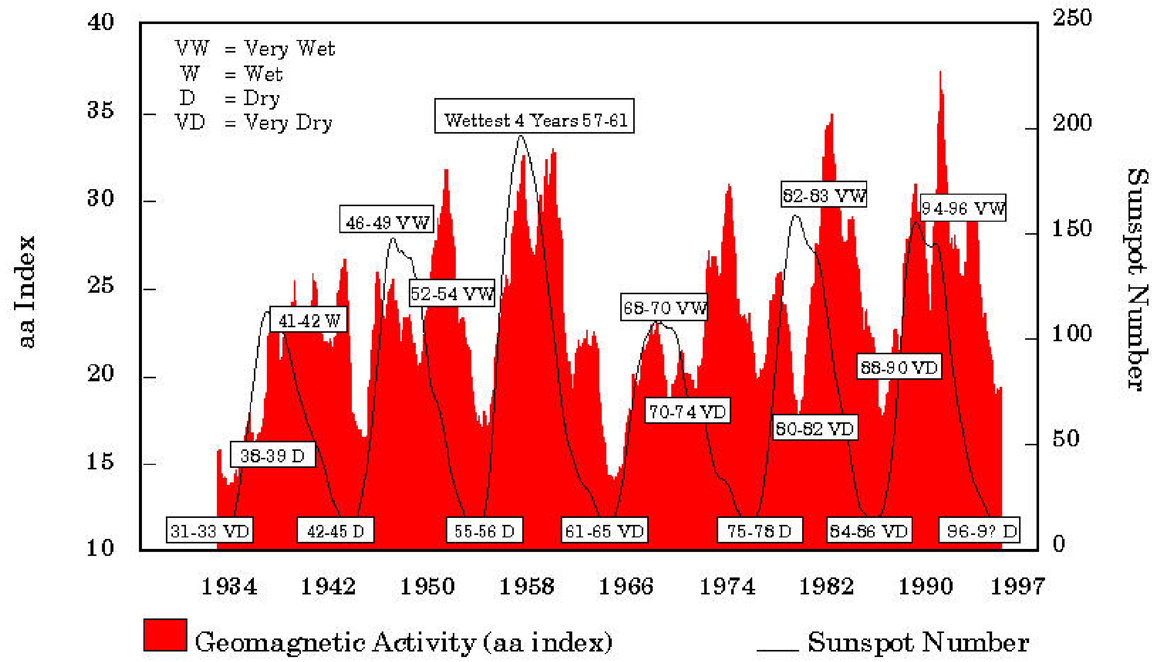

Figure 3. Solar activity and notable Lake Okeechobee Inflow periods

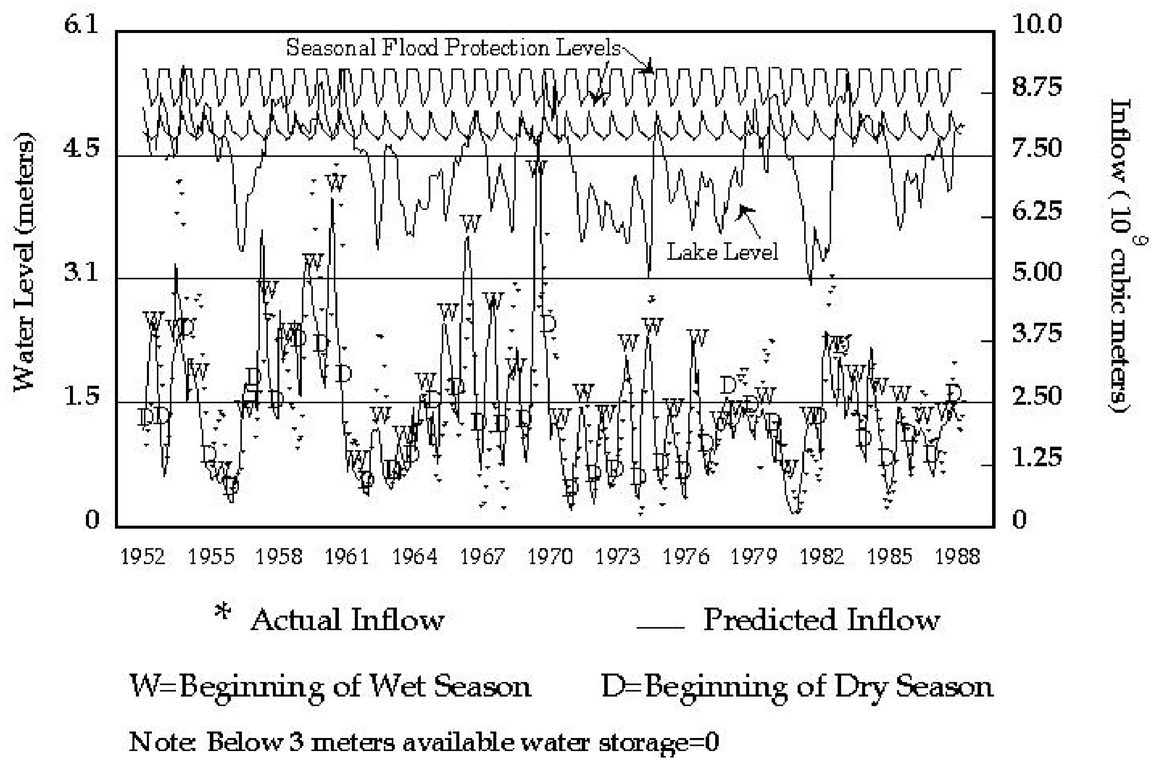

Figure 4. Comaparison of acutual and predicted Lake Okeechobee inflows for the training period of the neural network model

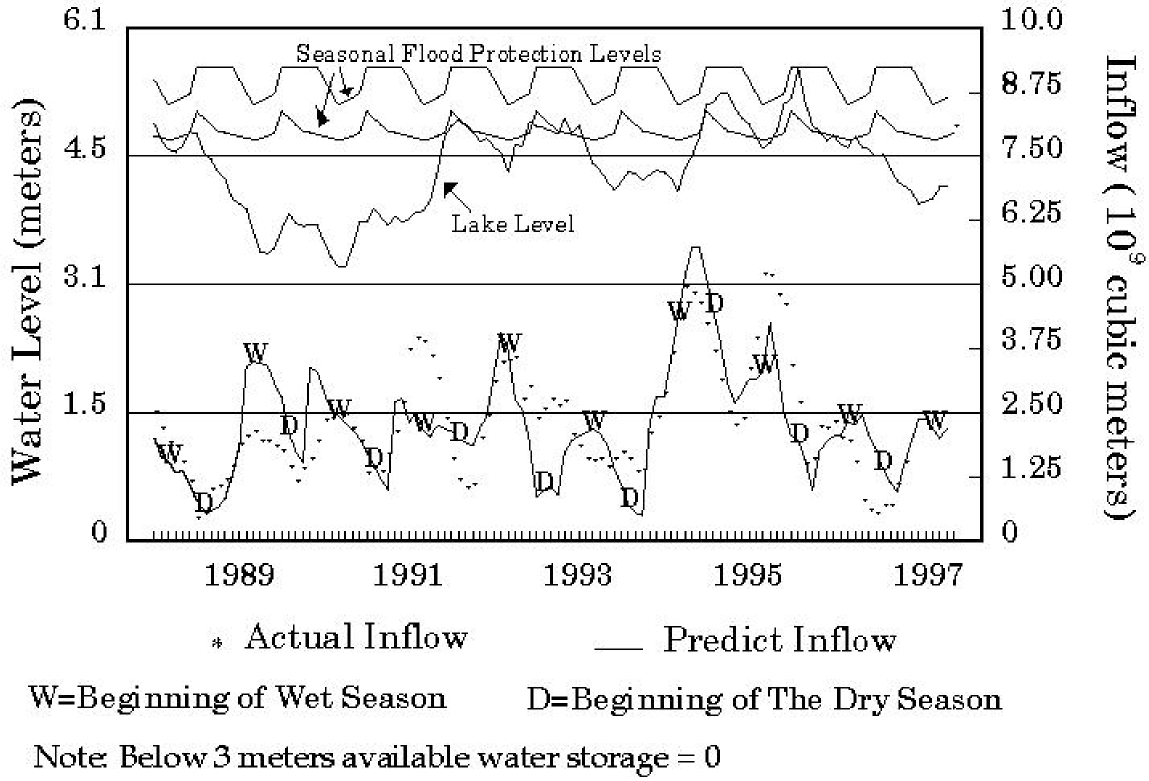

Figure 5. Comaparison of acutual and predicted Lake Okeechobee inflows for the testing period of the neural network model

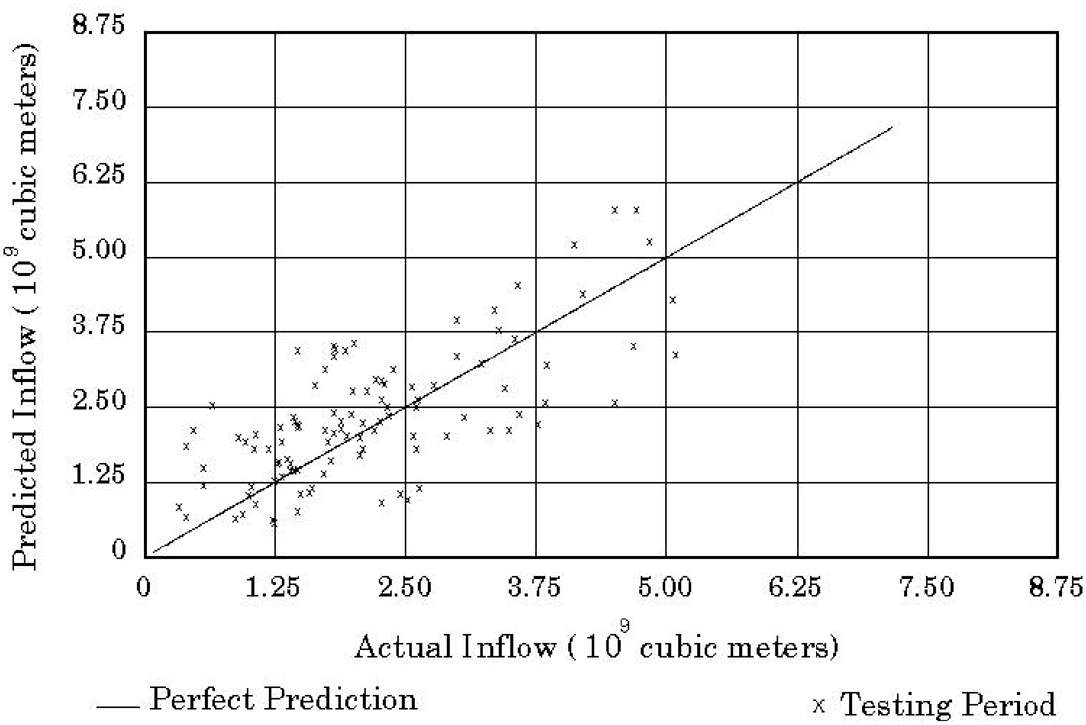

Figure 6. Comparison of acutal and predicted Lake Okeechobee inflows from the ANN model

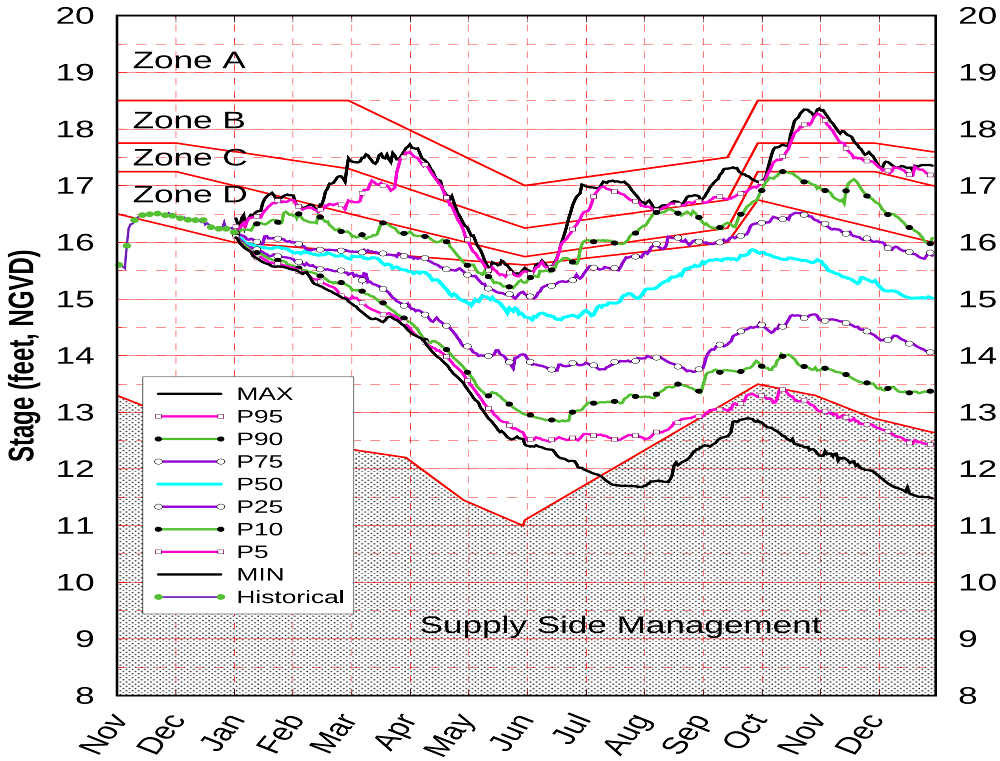

Figure 7. Lake Okeechobee Conditional Position Analysis (CPA) stage initialized to 16.7 ft. on 01/01/1999. The traces correspond to stage percentiles (eg. P95 is the 95th percentile) computed from CPA traces.

CLIMATE OUTLOOK IN OPERATING RULES

The climate outlooks have also been incorporated into the operational rules of Lake Okeechobee. Traditional rule curves (or regulation schedules) for reservoir operations are "static" in the sense that operational decision are made only when the reservoir stage crosses a predetermined curve. SFWMD is adopting a "dynamic" regulation schedule for Lake Okeechobee known as WSE which incorporates not only the seasonal and multi-seasonal climate outlooks, but also the near term (two-week) forecasts of tributary inflows into the lake (http://www.saj.usace.army.mil/h2o/lib/documents/WSE/). The new schedule consists of two parts: (a) A set of regulation schedule lines which define different operational zones (Figure 8) ; and (b) Decision trees that specify the operational decisions based on forecasts of inflows and climate outlook (Figure 9). The climate based operational guidelines as incorporated into the WSE are emerging as a highly desirable approach for Lake Okeechobee water management.

Overall operational strategy was simulated to improve for five major competing water management objectives as illustrated in Figure 10. This improvement was estimated for the climatolgical regime that existed during the period 1965-1995 by the following performance measures : 1) a decrease by 3 in the undesirable Lake Okeechobee water level events for the Lake littoral zone, 2) an increase by approximately 4 percent of the Lake Okeechobee Service Area water supply needs being met during drought years, 3) improved hydro-pattern for the Everglades, 4) a decrease in the number of times undesirable high discharge criteria were exceeded for the estuaries and 5) Lower Lake water levels during the peak of the Hurricane season.

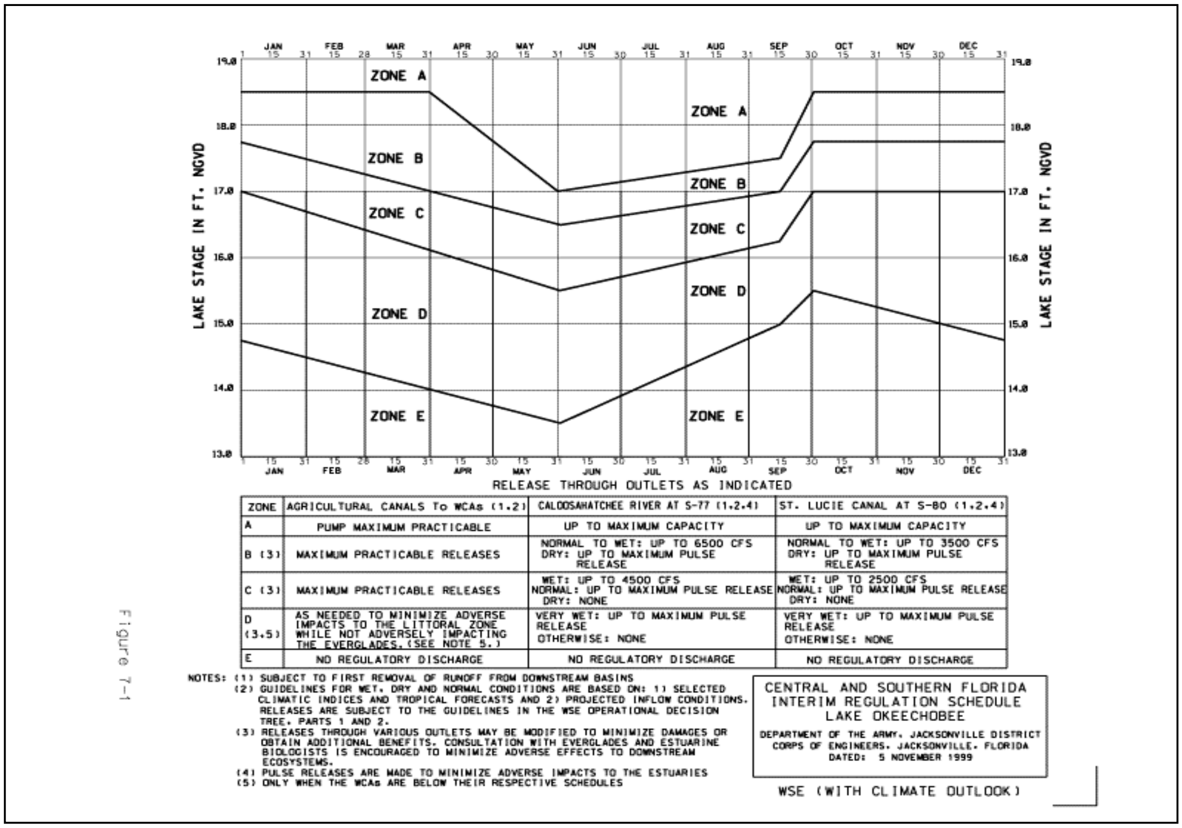

Figure 8. WSE Schedule Part I

CONCLUSIONS

The complex water management system in South Florida consisting of many large lakes and impoundments, numerous canals and water control structures require a multi-objective approach for its operation. The management of Lake Okeechobee in particular can significantly benefit from seasonal and multi-seasonal hydrologic forecasts for balancing the needs of water supply, environment, flood control, and water quality enhancement. Recent advances in long-range forecasting and the improved understanding of such global phenomena as El Nino-Southern Oscillation (ENSO) have allowed the South Florida Water Management District (SFWMD) to develop innovative water management approaches that make use of climate outlook forecasts.

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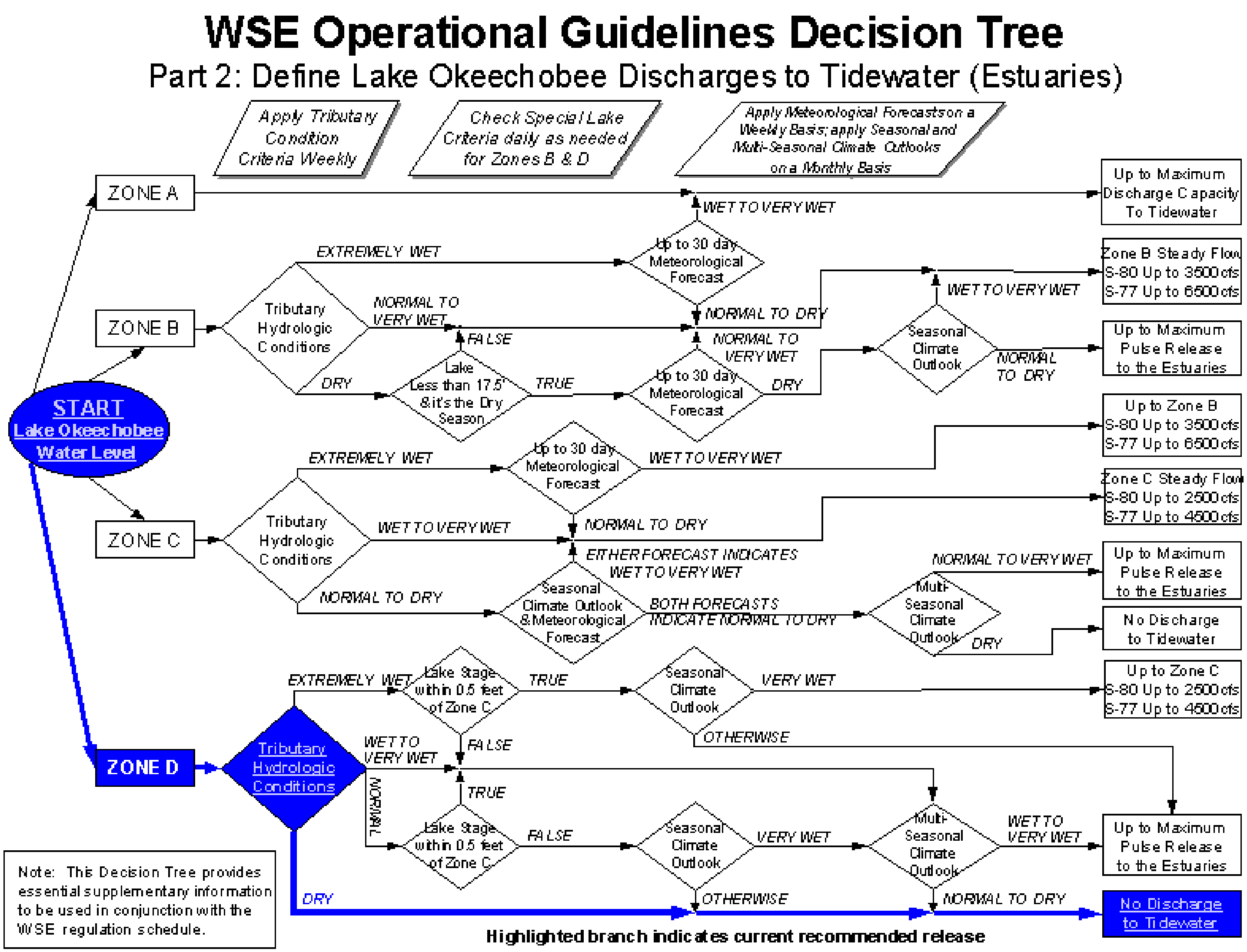

Figure 9. WSE Schedule Part 2

Multi-Objective Trade-Off Analysis

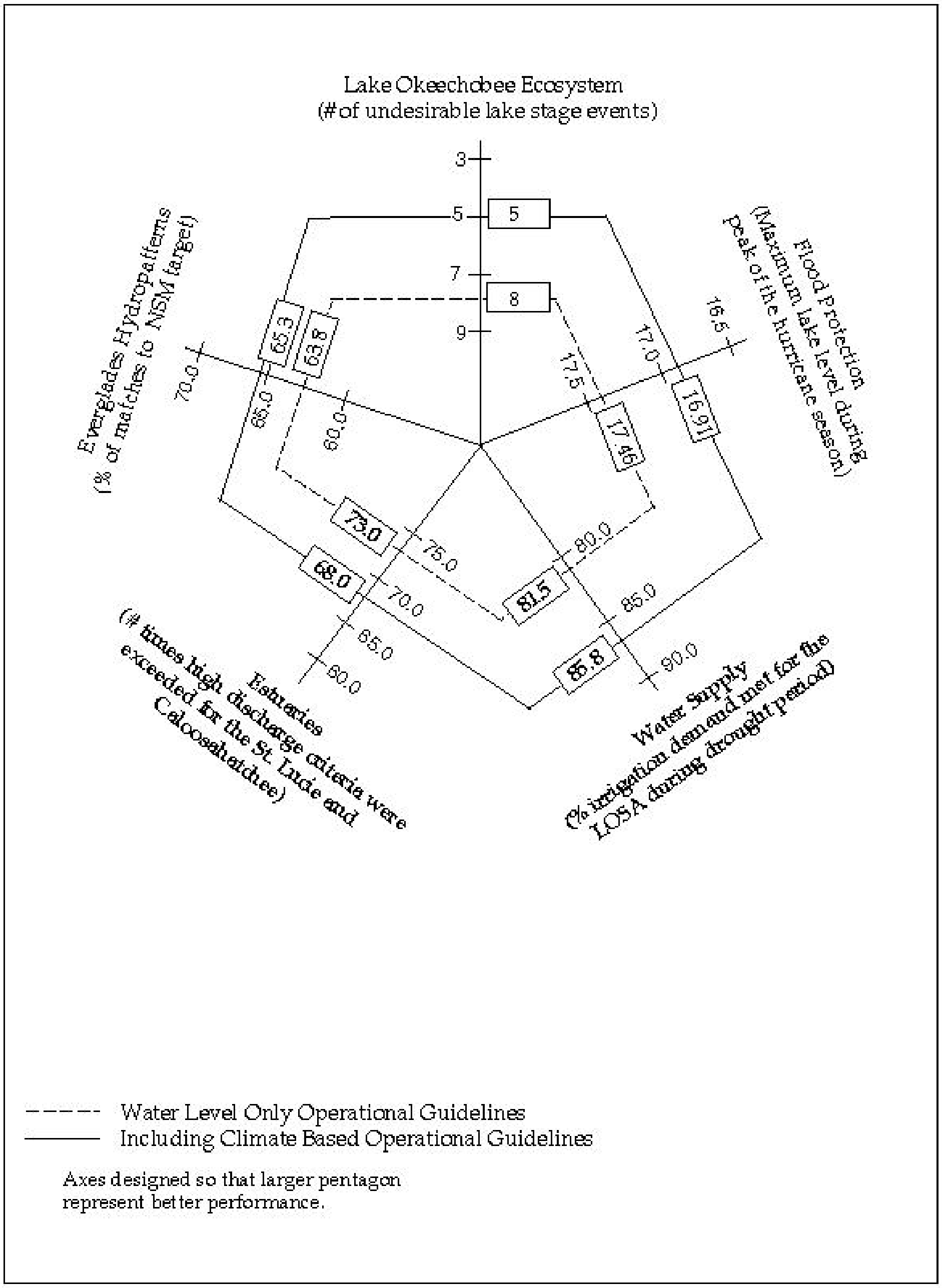

Figure 10. Multi-objective trade-off analysis for Climate Based operation of Lake Okeechobee