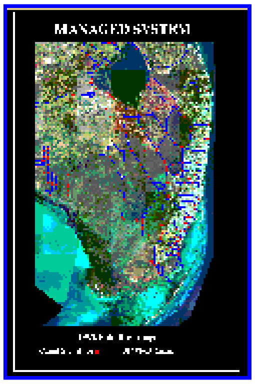
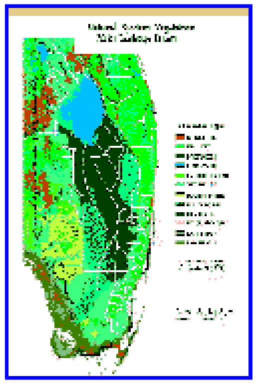
Natural System Model Version 4.2





Contents...

Figures...

Tables...

INTRODUCTION

Pre-Drainage Everglades

Prior to the major drainage activities that began early this century, the Everglades consisted of 3 million acres of subtropical wetlands that covered much of South Florida (Figure 1). The Everglades region was characterized by an extremely low gradient, heterogeneous landscape mosaic that evolved over 5000 years (Science Sub Group Report, 1993). This immense wetland system south of Lake Okeechobee was what Marjorie Stoneman Douglas called the "river of grass" that sprawled from the south shore of Lake Okeechobee to the mangrove estuaries of Florida Bay and the Gulf of Mexico. The Immokalee Ridge and the Atlantic Coastal Ridge generally marked the western and eastern hydrologic boundaries of the Everglades, although numerous flow connections across the coastal ridge overflowed water from the Everglades to the Atlantic Ocean. The primary characteristics of the pre-drainage wetland ecosystem in the Everglades were the hydrologic regime that featured slow sheetflow and natural recession due to storage, large spatial scale, and heterogeneity in habitat.

The Natural System Model

The Natural System Model (NSM) attempts to simulate the hydrologic response of the pre-drainage Everglades using recent (1965-1990) records of rainfall and other climatic inputs (Figure 2). The NSM does not simulate the hydrologic response of the natural system prior to influence by man but rather its hydrologic response due to the most recent climatic inputs. Although one may wish to recreate hydrologic conditions of the late 1800's or early 1900's, climatic and other data necessary to perform such a simulation do not exist. The use of recent historical records of rainfall and other inputs allow modelers to make meaningful comparisons between the response of the current managed system to that of the natural system under conditions of identical climatic inputs. In this sense, the NSM can be a useful planning tool for restoring hydrologic conditions of the natural Everglades.

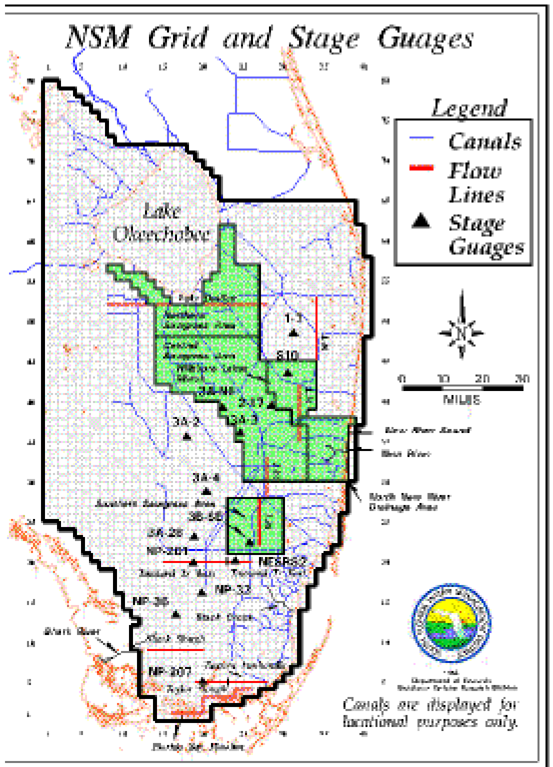
The landscape of present day south Florida has been greatly affected by land reclamation, flood control and water management activities which have occurred since the early 1900's. The NSM, in its current form, attempts to simulate the hydrologic system as it would function today without the existence of man's influence. The complex network of canals, structures and levees are replaced with the rivers, creeks and transverse glades which were present prior to the construction of drainage canals. Vegetation and topography used by the NSM are based on pre-drainage conditions. Landcover simulated by the NSM is static, i.e. the model does not attempt to simulate vegetation succession, a primary feature in other landscape models currently under development (Everglades Landscape Model, 1994).

History

The Natural System Model was first created around 1989 using algorithms of the South Florida Water Management Model (SFWMM) which has been the primary tool for simulating regional hydrology for nearly 15 years (Figure 3). The model was first presented at the Everglades Symposium and was later documented and released as Version 3.4 (Perkins and MacVicar, 1991). Immediately following its initial release, the South Florida Water Management District (SFWMD) and the Everglades National Park reviewed this version, and recommended changes which led to the development and release of Version 3.6. In 1993, the SFWMD embarked on a major effort to improve the NSM for its use in the alternative evaluation phase of the Lower East Coast Regional Water Supply Plan. This effort led to the development of Version 4.1, which was adopted, by a Scientific

Working Group associated with the regional water supply plan, as the best available tool for simulating hydrologic response of the natural Everglades. Further input from the scientists associated with this group resulted in the release of Version 4.2. Improvements made over the years are summarized in Table 1.

Model Boundaries



The NSM encompasses an area from Lake Istokpoga to Florida Bay (Figure 1). The western boundary extends southward from Lake Istokpoga to near the Gulf of Mexico, and continues along the coastal marsh fringe, turning southward to Florida Bay near Shark River Slough. The eastern boundary extends across the northern Indian Prairie Region to the Kissimmee River, and continues around the northern rim of Lake Okeechobee to the eastern most point on the lake, turning eastward to the Atlantic Ocean. The eastern boundary then follows the coastline southward to Biscayne Bay and Florida Bay.

Link to SFWMM

Use of the NSM is closely linked to the SFWMM. The SFWMM is a regional scale hydrologic model that simulates the hydrology and highly managed water system in south Florida. The region simulated by the model includes Lake Okeechobee, Everglades Agricultural Area, Lower East Coast Developed Areas, and the Everglades Protection Area (Water Conservation Areas, Everglades National Park, and parts of Big Cypress Basin). The design of the SFWMM takes into consideration south Florida's unique hydrologic processes and geologic features, such as evapotranspiration (a major component for the hydrologic cycle), integrated surface and ground water hydrology, operation of the Central and South Florida (C&SF) Project, and strong canal and aquifer interaction in the highly permeable Biscayne Aquifer.

The hydrology of south Florida is primarily rainfall driven, and highly influenced by other processes, e.g. evapotranspiration, overland and ground water flow (SFWMD, 1993). The input data, parameters and algorithms used to simulate the movement of water in the NSM are nearly identical to those used in the SFWMM. The model domain for each model is divided into 4 square mile grid cells. General hydrologic processes simulated within each cell are depicted in Figure 4.

INPUT DATA

Input data to the NSM can be classified as static or time variant. Static data describes physical features within a cell, including vegetation, land surface elevation, aquifer properties, and river location. The NSM responds to time variant hydrologic stimuli, including rainfall, potential evapotranspiration and inflow at the model boundary.

Vegetation

The NSM uses vegetation based parameters to compute evapotranspiration and overland flow. Since the NSM cannot be calibrated, these parameters are supplied by the calibrated and verified SFWMM. Use of SFWMM parameters implies: the vegetation classes identified in the NSM can be sufficiently isolated for calibration in the SFWMM, the evapotranspiration and hydraulic characteristics of current vegetation are comparable to pre-drainage vegetation, the parameters are transportable, e.g. parameters calibrated in the Everglades National Park can be applied to areas outside of park boundaries.

Vegetation coverage for the NSM is based on Constanza's (1979) landscape map of south Florida for the early 1900's (Figure 1) . The eleven primary landuse classes described by Constanza have been consolidated into six vegetation and three lake classes for the NSM (Table 2). In general, the vegetation designation for a cell is based on the predominate vegetation class within that cell.

Table 2, NSM and SFWMM vegetation classes.

Code	NSM 4.2	Constanza	NWI
1	mangrove	mangrove saltmarsh	esturine
2	forested	pinelands hardwoods cypress strands scrub cypress	palustrine-forested
3	fresh marsh	fresh marsh	palustrine-emergent (semipermanent)
4	sawgrass	sawgrass	palustrine-emergent (seasonal)
5	wet prairie	wet prairie	palustrine-emegent (temporary)
6	scrub/schrub	scrub/shrub	palustrine-scrub/shrub
7	Lake Okeechobee	open water	deep water habitat
8	Lake Hicpochee	open water	deep water habitat
9	Lake Istokpoga	open water	deep water habitat

The SFWMM uses five landuse classes to designate developed areas (urban, agriculture, agriculture-truck crop, agriculture-sugar cane, agriculture-irrigated pasture) and six NSM vegetation classes. Outside of the Everglades Protection Area (EPA), landuse and vegetation designations are based on level three landuse coverage which is maintained in the SFWMD GIS database. The vegetation coverage in the EPA is based on the National Wetlands Inventory (NWI). The NWI utilizes a hierarchical classification scheme to inventory wetlands and deepwater habitats in the United States (Cowardin et al, 1979). The wetland system forms the highest level in the hierarchy, followed by subsystems, classes and subclasses. In addition, modifying terms may be applied to further describe the wetland. Within the EPA, both estuarine and palustrine wetland systems were identified. Palustrine wetlands are further classified as emergent, scrub/shrub, or forested. Cells with predominately estuarine, palustrine-forest, and palustrine-scrub/scrub wetlands are designated as mangrove, forested, and scrub/shrub, respectively. The water regime modifier is used to distinguish between the various types of emergent wetlands. Emergent wetland areas with semi-permanent, seasonal, and temporary modifiers are designated as fresh marsh, sawgrass and wet prairie, respectively. A comparison of landcover classifications for the NSM and SFWMM is shown in the following figures.

 NSM  1953  1973  Current

Topography

The surface elevations in the NSM approximate pre-drainage topography in south Florida. In general, NSM surface elevations are consistent with elevations in the SFWMM, except in areas affected by soil subsidence (Figures 6) and (Figure 7). The most severe soil subsidence occurred in agricultural areas south of Lake Okeechobee. The 1915 Everglades Drainage District (EDD) map reports point elevations exceeding 19.5 ft NGVD, with muck depths of 10 ft south of the Lake. Comparisons with the 1935 EDD contour map indicate up to 2.0 ft of soil loss occurred during the intervening 20 years. Pre-drainage surface elevations in the area bounded by the Miami and West Palm Beach canals are estimated by using the 1935 EDD contour map and applying a 0.5 to 2.0 offset to maintain consistency with 1915 EDD point elevations. Surface elevations between the coastal ridge and Water Conservation Areas 2B, 3A, and 3B are based on pre-drainage profiles of the North New River, South New River and Miami Canal presented in the Florida Everglades Report (Senate Document No. 379, 1913).

Soil subsidence appears to be less severe in regions designated as fresh marsh in both NSM and SFWMM. Surface elevations in Water Conservation Areas 1 and 2A, and Shark River Slough are consistent between both models. Surface elevations in non-organic soils are based on the most recent survey data (Table 3).

Table 3, Sources of topographic data.

Title	Format	Source	Date
Miami, North New River, Hillsboro, and West Palm Beach Canal Profiles	Profiles	Senate Doc 379, 63rd, 2nd Session	1913
Everglades Drainage District	Spot Elevations	EDD	1915
Caloosahatchee River and Lake Okeechobee Drainage Area	Contour Map	COE	1929
Everglade Drainage District	Contour Map	EDD	1935 1948
Lake Okechobee Topography	Contour Map	COE	1951
USGS Quads	Contour Map	USGS	1950's
C40, C41, and C41A Drainage Areas	Contour Map	COE	1955
Pre-Drainage profile of the Coastal Ridge	Profiles	COE	1960
Loxahatchee NWR	Contour Map	Richardson, et al	1990
Lake Okeechobee Contour Map	Contour Map	Univ. Florida	1990

Aquifer Parameters

Aquifer parameters (depth, permeability and soil storage coefficient) are consistent with the SFWMM. Outside the SFWMM boundaries, aquifer depth and permeability are based on published well log data (Kohout and Meyer, 1959; Klein et al, 1964; Meyer, 1971; Shaw and Trost, 1984; Smith and Adams, 1988; Adams, 1992) and the soil storage coefficient is uniformly set to 0.20 in/in. Depth and permeability are combined in the model to determine the transmissivity shown in Figure 8 .

Channels

The location of channels (rivers, creeks and transverse glades) is described through a series of x-y coordinates. The NSM locates the impacted cells, and computes the channel length within each cell. The location of the pre-drainage channels (Table 4) is based on government survey plots completed between 1855 and 1870 and the SFWMD Primary Hydrography Coverage.

Table 4, Pre-drainage rivers, creeks and transverse glades.

Location	Name	Length (mi)	Width (ft)	Control Elev (NGVD)	Head Drop (ft)
Okeechobee Basin	Kissimmee River	9.6	250	18.0	2.0
	Fisheating Creek	14.0	500	18.0	1.0
	Caloosahatchee River	5.2	100	12.0	1.0
Northern Coastal Ridge	Lake Worth Creek	5.3	100	6.0	1.0
	North Fork Jupiter River	5.0	100	6.0	2.0
	Jupiter Narrows	5.5	100	6.0	2.0
	Jupiter River	10.5	800	5.0	2.0
Central Coastal Ridge	Hillsboro River	12.5	100	2.0	2.0
	Boca Raton Lagoon	9.2	100	5.0	0.0
	Boca Boat Pass	1.4	50	5.0	0.0
	Cypress Creek	5.1	50	3.0	2.0
	Bonnet Slough	5.7	100	3.0	0.0
	Middle River	9.5	100	3.0	1.0
	New River Sound	6.5	500	2.0	0.0
	New River	7.7	250	3.0	1.0
	Big Snake	6.2	100	2.5	1.0
	Arch Creek	3.5	100	2.0	2.0
	Little River	1.7	100	2.0	0.0
	Miami River	3.8	100	2.0	2.0
Southern Coastal Ridge	Snapper Creek	8.5	100	2.0	3.0
	Black Creek	11.9	100	2.0	3.0
	Glade "A"	6.2	100	4.95	0.0
	Glade "B"	7.3	100	5.27	0.0
	Glade "C"	8.7	100	7.62	0.0
	Glade "D"	5.4	100	5.6	0.0
	Glade "E"	8.9	100	5.0	0.0
	Glade "F"	9.9	100	5.0	0.0
Southwest ENP	Broad River	3.1	100	0.5	0.0
	Shark River	10.1	100	0.5	0.0

Rainfall and Potential Evapotranspiration

Time variant inputs of rainfall and potential evapotranspiration are consistent between the NSM and the SFWMM, thereby permitting a valid comparison between model results. Unfortunately, spatial and temporal representation of rainfall in the past 26 years may be different from pre-drainage rainfall distribution. Since little

data is available for pre-drainage years, little is known about climate changes which may have occurred during the past 150 years. Alterations in timing and distribution of rainfall would undoubtedly influence behavior of the model (Fennema et al, 1994).

Spatial variability of rainfall is high in south Florida, particularly during summer months when rainfall occurrences vary significantly over short distances. The NSM and SFWMM utilize a database containing daily rainfall data for each cell in the model domain. Rainfall for a cell is based on data collected at the station nearest to cell center. Rainfall data from 485 stations in ten counties (Figure 9) were used to develop the database.

Daily potential evapotranspiration (PET) is computed for eleven stations (Table 5) using a modified Penman - Monteith Method (Giddings and Restrepo, 1994). A Thiessen polygon approach is used to partition the model domain into eleven corresponding PET zones (Figure 10) . An additional zone is required for cells designated as lakes (Okeechobee, Hicpochee and Istokpoga). PET in this zone is based on pan evaporation. This maintains consistency with the SFWMM, which computes a water budget for Lake Okeechobee using daily pan evaporation.

Table 5, Annual average potential evapotranspiration (1965-1990).

Zone No.	Station	Average Annual PET (in/yr)
1	Royal Palm Ranger Station	59.6
2	Tamiami Trail	51.2
3	Miami Beach	57.1
4	Miami	51.9
5	Hialeah	59.6
6	Ft. Lauderdale	58.3
7	Pompano Beach	60.4
8	West Palm Beach	57.5
9	Belle Glade	56.5
10	Canal Point	57.7
11	Moore Haven	54.9

Boundary Inflow

Inflows at the northern boundary are defined by a series of inflows into Lake Istokpoga and Lake Okeechobee. These flows represent "natural" inflows which would have occurred under pre-drainage conditions. The Lake Istokpoga and Fisheating Creek basins have not been greatly altered by water management projects such as, lake regulation schedules, channelization, and impondments. By assuming the present rainfall-runoff relationship is comparable to pre-drainage, natural inflows from these basins can be defined by the observed structure flow at Arbuckle Creek, Josephine Creek, ungaged local inflow at Lake Istokpoga, and Fisheating Creek.

The Kissimmee River Basin has been affected by a number of water management projects, connection and regulation of lakes in the upper basin, and channelization of the Kissimmee River. Natural inflow from the Kissimmee basin is estimated by calibrating a hydrologic model to the earliest available flow data (1934-1942), and generating a synthetic set of flows using 1965-1990 rainfall and PET data. Inflow from peripheral basins north of Lake Okeechobee (Nubbins Slough, Taylor Creek and S154), are assumed to be proportional to Kissimmee River inflow, based on area.

BOUNDARY CONDITIONS

Boundary conditions for surface water flow are classified as no-flow, fixed head, and fixed gradient. No-flow boundaries are established for non-ocean cells along the northern, eastern, and most of the western limits of the

model domain. Surface water levels in these cells are allowed to fluctuate in response to governing processes within the model domain. A fixed head boundary, based on the long term tidal fluctuation is applied to ocean cells along the eastern and southern limits of the model domain. A fixed gradient boundary is imposed on cells along the southwest boundary. Surface water levels in these cells are set such that the surface water gradient formed with the upstream cells is parallel to the associated land surface gradient. The fixed gradient concept is also applied internally to cells identified as lakes. Lake Okeechobee, Lake Istokpoga and Lake Hicpochee are treated as level pools by using an "equalizing" function to compute the average stage for each lake and applying this stage uniformly across respective lakes.

A fixed gradient boundary condition is established at all ground water flow boundaries. An "imaginary" cell is established outside of the model domain, adjacent to each boundary cell. These external cells have the same transmissivity and head values as their model domain counterparts. Head values in ocean cells coincide with stages established by the tidal boundary.

GOVERNING PROCESSES

Rainfall is added to a model by increasing the surface water depth in each cell at the beginning of the time step. Inflows into Lake Istokpoga and Lake Okeechobee are added in a similar manner by increasing the surface water depth in the respective lake cells by the equivalent depth. Water is distributed within the model domain by a set of governing hydrologic processes. The governing processes are modeled independently within each time step, with the more transient phenomena computed before the less transient phenomena (Figure 11) . Channel flow is computed first, followed by overland flow, infiltration, evapotranspiration and ground water flow.

Channel Flow

Channels are treated as a series of one or more continuous reaches with a downstream control weir. The model subdivides a channel reach into segments defined by the grid cells, and computes the channel to cell interaction for each segment. An iteration scheme is used to determine water level in the channel. Water depth at the downstream weir is adjusted until the change in channel storage from the previous time step is nearly equivalent to the summation of: rainfall and ET over the channel area, channel to cell interactions (overland flow and ground water seepage), and weir discharge. After the convergence criteria is met, channel level, surface water ponding depths and recharge to ground water are adjusted to reflect the transfer of water.

The overland flow interaction is based on Manning's equation:

$$SF_{seg} = \frac{1.49\ L_{seg}}{n}\ d_{pond}^{\frac{5}{3}}\ S^{\frac{1}{2}}\ 86400\ \Delta t$$

where SF_{seg} is the flow surface from a channel segment to its respective cell (ft^3 / day), n is the roughness coefficient for the cell, L_{seg} is the length of channel segment, (ft), d_{pond} is the depth of ponding (ft), S is the slope, and delta t is the time step increment (days). The slope is determined by:

$$S = \frac{h_{cell} - h_{seg}}{0.25\ L_{cell}}$$

where h_{cell} and h_{seg} are the cell and channel segment stages (ft, NGVD), respectively, and the distance between the cell center and channel segment is assumed to be 0.25 * L where L is the cell length (ft).

The ground water seepage interaction is based Darcy's equation:

$$SP_{seg} = (h_{seg} - h_{cell})\ A_{seg}\ C_{cond}\ \Delta t$$

where SP_{seg} is the seepage from a channel segment to its respective cell (ft^3/day), *A* is the surface area of the aquifer-channel interface (ft^2), and C_{cond} is the channel-aquifer hydraulic conductivity coefficient.

Discharge from the downstream end of the channel reach is computed using a simple weir equation:

$$Q_{weir} = C_{weir} W_{crest} (h_{chan} - h_{weir})\ (64.34\ (h_{chan} - h_{weir}))^{\frac{1}{2}}$$

where Q_{weir} is the discharge from the downstream weir (ft^3/day), C_{weir} is the weir coefficient (uniformly set to 3.0), W_{crest} is the weir crest length (ft), h_{chan} and h_{weir} are the channel stage and weir crest (control) elevation (ft, NGVD), respectively.

Overland Flow

The model simulates the movement of surface water by computing overland flow from each cell to its adjacent cells. Overland flow is computed twice within a time step, once for east-west flow followed by north-south flow, using the Mannings equation:

$$SF_{cell} = \frac{1.49\ W}{n}\ h_m^{\frac{5}{3}} \left[\frac{h_u - h_d}{L}\right]^{\frac{1}{2}}\ 86400\ \Delta\frac{t}{2}$$

where SF_{cell} is the outflow from a cell (ft^3 per half day), *n* is the roughness coefficient, *W* is grid cell width (ft), h_m is the average ponding depth (ft) between adjacent cells, h_u and h_d are the upstream and downstream stages (ft, NGVD), respectively, *L* is the grid cell length (ft) and \Delta * t is the time step increment (days).

Starting with the upper leftmost cell, the model computes overland flow to adjacent cells and updates corresponding surface ponding depths. Cells are processed from left to right, one row at a time. The volume of overland flow from a cell can not exceed the volume required to equilibrate the upstream and downstream stages, i.e. reversing gradients within a time step are not allowed.

The roughness coefficient is computed for each cell, based on its vegetation and ponding depth:

$$n = a\ h_m^{\ b}$$

where *a* and *b* are determined through calibration of the SFWMM. The range of roughness coefficients for a relevant range of average ponding depths is shown in Figure 12 . The increase in roughness coefficient with lower ponding depths is an attempt to account for high resistance to flow through dense undergrowth near the land surface. A surface water detention depth (d_{detent}) is defined for each vegetation class (Table 6), below which no flow can occur.

Table 6, Soil infiltration rates.

Predominant Soil(s)	General Location	Infiltration Rate (ft/day)

Torry Muck	Southeast rim of Lake Okechobee	9
sandy soils	Caloosahatchee Fish Eating Creek	26
Perrine marl	Southeast Dade Co.	12
Pahokee Muck	Everglades Agricultural Area	26
Hallandale & Margate fine sand	between WCA's & coastal ridge, Hendry & Glades Co.	26
Lauderhill Muck	eastern WCA3A, WCA3B	26
Myakka, Basinger Imokalee	Hendry & Glades Co. & eastern Palm Beach Co.	26
Shallow perrine marls	Southwest Dade Co. & area west of ENP & WCA3A	12
Rockdale fine sandy loam	eastern Dade Co.	12
sandy soils	coastal ridge	26
Okeechobee & Okeelanta Muck	WCA1, western WCA3A & Shark River Slough	26
Pennsuca Marl, Terra Ceia	southern Dade Co.	26
Rockland, cypress, marsh	central Dade & Collier Co.	12

Infiltration

Channel and overland flow processes are followed by the infiltration process, which simulates the vertical exchange of water from surface to ground water. Soil above the water table is considered completely dry at all times, i.e. there is no provision for unsaturated zone storage. Infiltration is added directly to ground water as recharge. The volume of infiltration in each cell is controlled by the cell's infiltration rate and available soil storage. Infiltration rates are based on Soil Conservation Service Survey data and the Generalized Land Conditions map for the Everglades Region (1947). Infiltration rates for the predominate soils found in the model domain are extremely high (Table 6) , ranging from ?.? to ?.? ft/day. Available soil storage is computed by multiplying "dry" soil storage volume by the soil storage coefficient.

Evapotranspiration

The evapotranspiration (ET) process simulates the return of water to the atmosphere by evaporation from surface and ground water, and by the transpiration of vegetation. ET is removed from surface water by decreasing ponding depth. If ET is greater than ponding depth, ponding is set to zero, and the deficit is added to ground water recharge.

The ET rate is estimated for each cell using the following equation:

$$ET = K\ PET$$

where *K* is a crop coefficient which reflects type and seasonal variation of vegetation, and position of the water table, and *PET* is the potential evapotranspiration rate (in/day) within the respective *PET* zone. The relationship between crop coefficient and water table position is illustrated in Figure 13 , and defined by the following set of equations:

$$K = K_{max} \qquad d_{pond} \geq d_{openwater}$$

$$K = K_{veg} + (K_{max} - K_{veg}) \frac{d_{pond}}{d_{openwater}} \qquad d_{pond} < d_{openwater}$$

$$K = K_{veg} \qquad d_{gw} > d_{shallow}$$

$$K = K_{veg} \frac{d_{deep} - d_{gw}}{d_{deep} - d_{shallow}} \qquad d_{deep} > d_{gw} > d_{shallow}$$

$$K = 0 \qquad d_{gw} \geq d_{deep}$$

where K_{veg} is the vegetation coefficient, K_{max} is the open water evaporation coefficient, d_{pond} is the surface water ponding depth, d_{gw} is the depth to ground water, and $d_{openwater}$, $d_{shallowzone}$, and d_{deep} are the defined depths for deep root zone, shallow root zone and open water ponding, respectively. K_{veg} is computed for each day of the year, based on linear interpolation of monthly midpoint values for each vegetation class (Table 7).

Table 7, Vegetation parameters for overland flow and ET.

Parameter	Mangrove	Forest	Fresh Marsh	Sawgrass	Wet Prairie	Scrub/ Shrub	Lakes
a	0.40	0.50	1.05	0.285	0.150	0.295	0.040
b	-0.77	0.00	-0.77	-0.77	-0.77	-0.77	-0.77
d_{detect}	0.10	0.08	0.08	0.08	0.07	0.08	0.05
K_{veg}(Jan)	0.721	0.643	0.725	0.695	0.813	0.815	1.038
K_{veg}(Feb)	0.940	0.722	0.922	0.875	0.942	1.042	1.038
K_{veg}(Mar)	1.010	0.721	0.940	0.895	0.941	1.050	1.038
K_{veg}(Apr)	0.950	0.713	0.911	0.860	0.923	1.011	1.038
K_{veg}(May)	0.772	0.703	0.755	0.712	0.893	0.835	1.038
K_{veg}(Jun)	0.682	0.634	0.685	0.628	0.871	0.761	1.038
K_{veg}(Jul)	0.782	0.735	0.801	0.712	0.977	0.891	1.038
K_{veg}(Aug)	0.894	0.790	0.835	0.724	1.005	0.971	1.038
K_{veg}(Sep)	0.910	0.800	0.841	0.750	1.010	0.991	1.038
K_{veg}(Oct)	0.844	0.800	0.832	0.724	0.990	0.912	1.038
K_{veg}(Nov)	0.713	0.741	0.734	0.697	0.911	0.834	1.038
K_{veg}(Dec)	0.733	0.684	0.741	0.703	0.794	0.821	1.038
K_{max}	1.0	1.4	1.0	1.0	1.0	1.0	0.865
d_{owpond}	3.0	3.0	3.0	3.0	3.0	3.0	3.0
$d_{shallow}$	0.0	0.0	0.0	0.0	0.0	0.0	0.0
d_{deep}	0.3	6.0	1.5	3.0	4.0	4.0	1.5

Ground Water Flow

The determination of ground water levels involves solving the finite difference approximation of the linearized, two-dimensional, transient, subsurface flow equation for unconfined aquifers:

$$T_x \frac{\partial^2 h}{\partial x^2} + T_y \frac{\partial^2 h}{\partial y^2} = S \frac{\partial h}{\partial t} + R$$

where T_x and T_y are the aquifer transmissivity values in east-west and north-south directions, respectively, h is the ground water stage, S is the aquifer storage coefficient and R is the recharge term which includes seepage interaction with channels, infiltration, and evapotranspiration.

The Saul'yev technique is used to solve finite difference equations. This explicit procedure is unconditionally stable and eliminates the need for iterations within a single time step. Using an alternating direction technique, the finite difference equation is solved from four different directions in four succeeding time steps. Imposed boundary conditions and recharge term provide the primary stimuli in this portion of the model.
