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The Tides and Inflows in the Mangroves of the Everglades (TIME) Project

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The Surface-Water System

Data describing the surface-water system that are required to simulate flow in and between the freshwater wetlands of the Everglades and its adjacent coastal-marine ecosystems include:

- spatial data describing physical properties of the surface-water domain (land surface elevations, vegetation characteristics, embayment bathymetry, etc.)
- time-series data depicting internal and boundary flows, water depths, and salinities
- physical parameters defining hydrologic processes and rates (evapotranspiration, rainfall, wind stress, etc.)
- vegetation classifications contributing to hydraulic property definitions

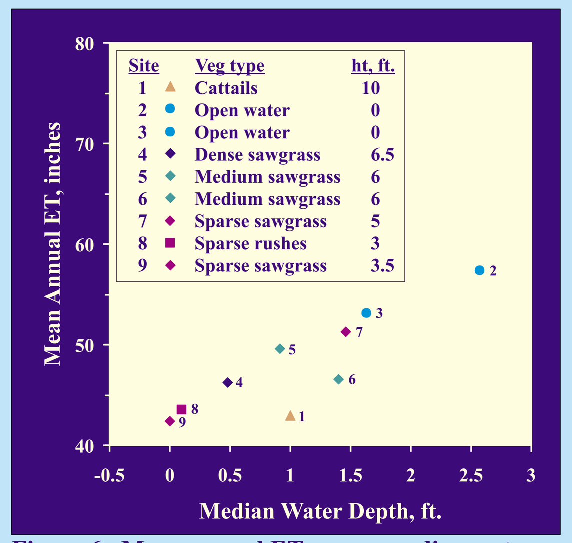


Figure 6. Mean annual ET versus median water depth determined from data collected in 1996 and 1997.

Evapotranspiration (ET) is a major component of the hydrologic cycle of the Everglades. The water level is at or above land surface most of the year in most of the Everglades, and actual ET approaches potential ET (as established by available energy). Nine sites of differing vegetative characteristics and flow hydroperiods were instrumented to collect the data needed to determine ET rates. The variation in annual ET among the nine sites appears to relate, at least partially, to water depth, as shown in Figure 6. Parameters critical to evaluating ET will be input to the TIME model.

Hydraulic measurements were conducted concurrently with vegetation sampling surveys in an indoor flume and in the Everglades wetlands to provide the data needed to determine the correlation between frictional resistance and vegetative characteristics. It was observed that the hydraulic and vegetation data collected in the flume fell into three groups according to the dimensionless stem-spacing parameter, s/h (s = stem spacing, h = water depth), as follows: $0.05 < s/h < 0.08$; $0.09 < s/h < 0.12$; and $0.17 < s/h < 0.19$. Within each group a linear relationship exists between the square of the stem-spacing Reynolds number, R_s (Us/ , U = depth averaged velocity, and = kinematic viscosity), and a dimensionless resistance force, F^*, as shown in Figure 7. Analyses of the wetland data sets are proceeding along similar lines and the resultant correlations will be incorporated into the TIME model governing equations.

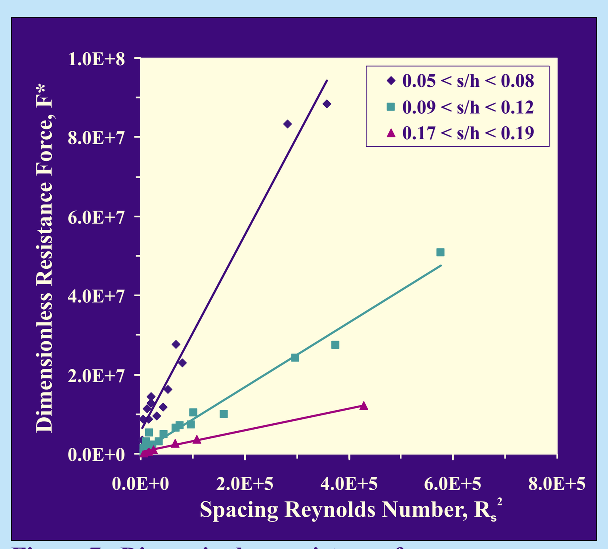


Figure 7. Dimensionless resistance force versus spacing Reynolds number determined from data collected in the flume.

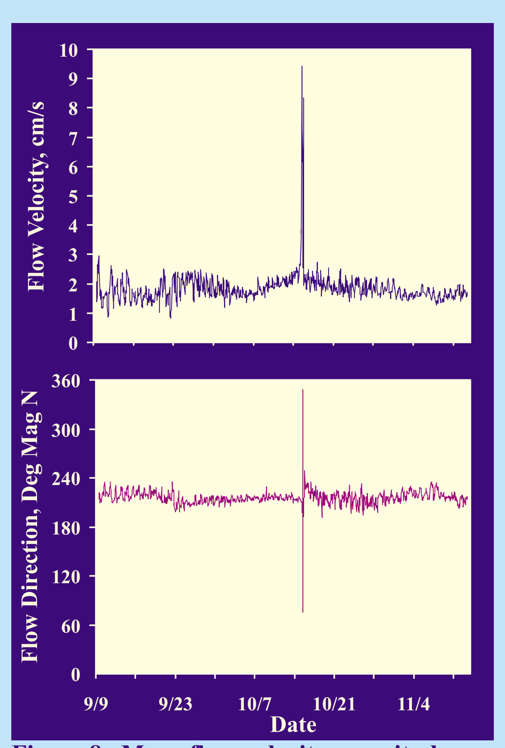
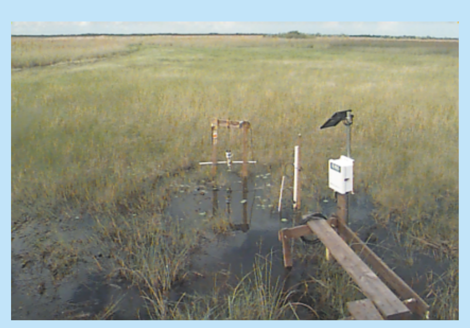


Figure 8. Mean flow-velocity magnitudes and directions recorded in Shark River Slough in 1999.

The shallow slow-moving flow of the Everglades is highly susceptible to internal and external forcing mechanisms. Continuous autonomous monitoring of flow velocities is being conducted to quantify the effects of these forces. Flow velocity magnitudes and directions measured during one deployment of an acoustic Doppler point-velocity (ADV) meter at a site on the edge of a sawgrass stand, (as shown in the photograph), are illustrated in Figure 8. Increased flow velocities and directional changes can be noted in the plotted data during the passage of tropical storm Harvey on September 21 and hurricane Irene on October 15. Data such as these are crucial to TIME model development and calibration.



The TIME Project

In the TIME project the two-dimensional, vertically integrated, hydrodynamic Surface Water Integrated Flow and Transport (SWIFT2D) model is being coupled with the three-dimensional, variable-density ground-water flow model SEAWAT, a coupled version of the Modular Ground-water Flow (MODFLOW) model and the modular solute transport model MT3D. The coupled TIME model will be able to simulate flow exchanges and dissolved salt fluxes between the surface- and ground-water systems comprising the land-margin interface of the Everglades with Florida Bay and the Gulf of Mexico.

The TIME model domain (Figure 1) encompasses the entire freshwater-saltwater interface zone along the southwest Gulf coast and Florida Bay boundaries of Everglades National Park (ENP). The model boundaries extend from Tamiami Trail south to Florida Bay and from L-31N, L-31W, and C-111 canals west to the Gulf coast and Everglades City. Figures in the panels to the left and right illustrate important aspects of the surface-water and ground-water systems under investigation in support of the model development. Figures in the panel below illustrate important components of the model development.

The TIME project and model will help address several key questions pertaining to restoration actions and management decisions:

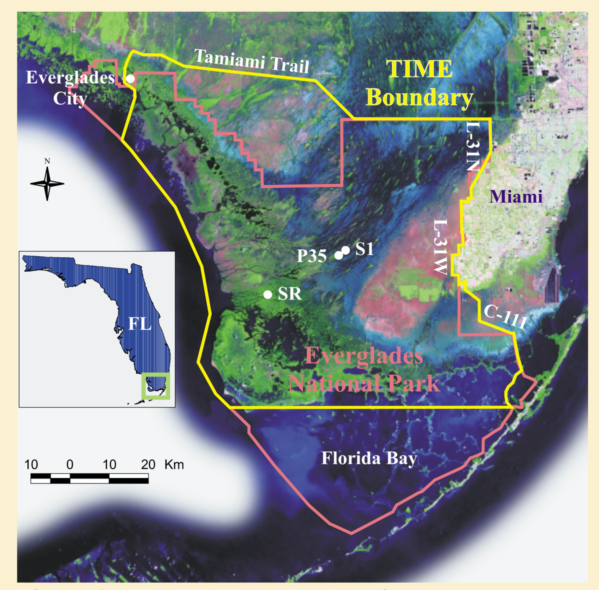


Figure 1. The TIME model domain.

- How do the Everglades freshwater-wetland and coastal-marine ecosystems respond concurrently, both hydrologically and ecologically, to regulation of inflow?
- Will upland restoration actions affect the transformation of freshwater wetlands to brackish and marine marshes and subsequently to mangrove marsh ecotones?
- How will changes in inflows act in concert with predicted increases in sea level to affect migration of the freshwater-saltwater interface within the surface and sub-surface flow systems?
- What key factors influence salt concentrations in the coastal mixing zone and how do these factors interact to affect wildlife habitat areas?
- How will external dynamic forcing factors, such as sea level rise or meteorological effects, impact upland regulatory plans?
- What concurrent changes in wetland hydroperiods and coastal salinities are likely to occur in response to various proposed restoration actions and management plans?

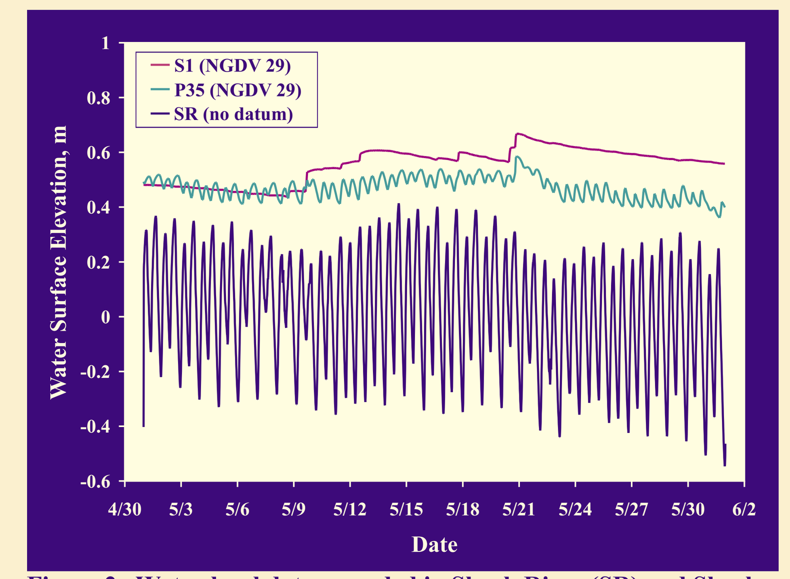


Figure 2. Water-level data recorded in Shark River (SR) and Shark River Slough (P35 and S1) in 1999.

Time-series data quantifying surface-water levels, ground-water heads, flow velocities, structure discharges, tidal fluctuations, salt concentrations, rainfall events, and meteorological conditions are being collected and/or compiled to support the model development. An example of these data is shown in Figure 2 as a plot of water-level data from three hydrologic monitoring stations (sites SR, P35, and S1 identified in Figure 1). These data illustrate the diminishing effect of tide through the mangrove marsh ecotone of lower Shark River Slough and the dynamic characteristic of the ecosystem under investigation in the TIME project. Data collected by the USGS, NPS, USACE, NOAA, and the SFWMD are being used to develop the model.

The TIME Model

Comprehensive tools are required to compile, manage, analyze, and visualize the voluminous amount of input data required by the model and computed results generated during the numerical simulations. Illustrated below are visualization and data management tools developed to aid this effort.

A web-based data-management system has been developed to facilitate the preparation of time-series data for conducting numerical simulations. Data from more than 150 gaging stations spanning 1995 to present have been compiled and are available for use in the model. Scientists can view or download these data easily from the "TIME Data" page (Figure 3) of the TIME website, http://time.er.usgs.gov.

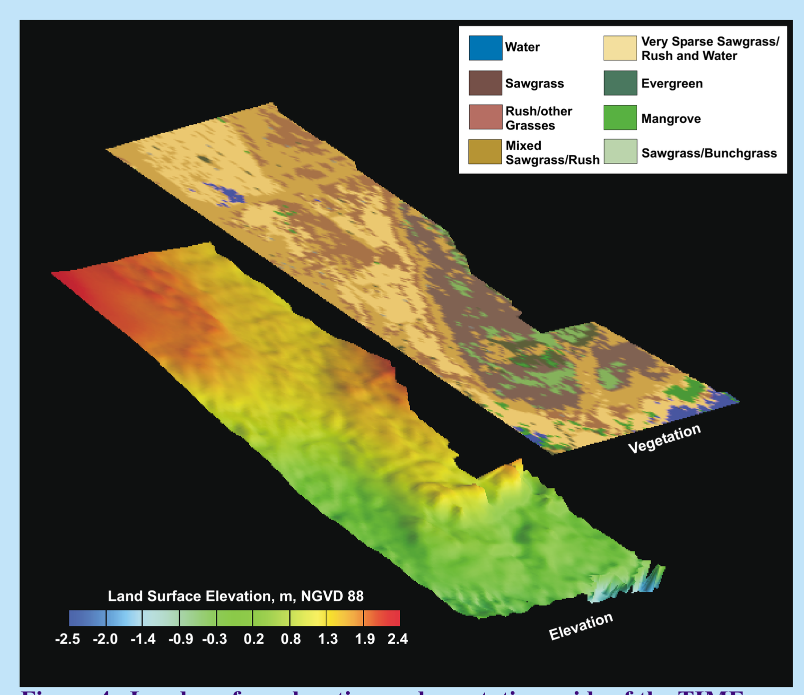


Figure 4. Land-surface elevation and vegetation grids of the TIME model domain within Dade County.

A variety of tools is being developed to analyze and demonstrate model results. These include both two- and three-dimensional imaging capabilities as shown in Figures 4 and 5. Animation tools also are being developed to facilitate the visualization of model results in order to gain insight into the dynamic flow behavior of the ecosystem.

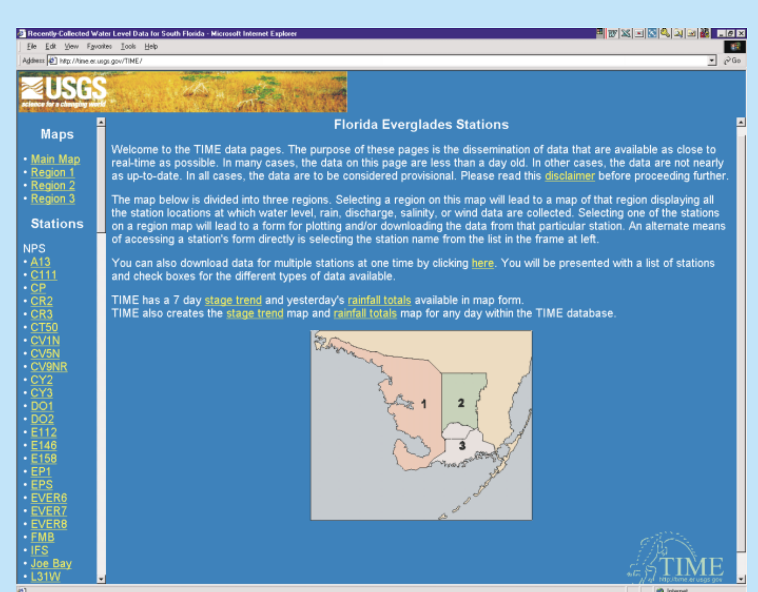


Figure 3. The TIME website's main data page.

The slope of the land surface and the variation in vegetation must be determined in order to accurately simulate surface-water flow. A 500-m square grid representation of the land-surface elevation in the TIME domain is being produced from 400-m spaced elevation data collected by the National Mapping Division. By combining information extracted from the literature and knowledge gained through field experience with unique satellite imagery, a nine-class map of vegetation types is being created to coincide with the elevation grid. The vegetation grid, shown superimposed on the completed part of the elevation grid in Figure 4, will be used to parameterize the role that vegetation plays in affecting the flow through shear resistance and altering the water budget through ET.

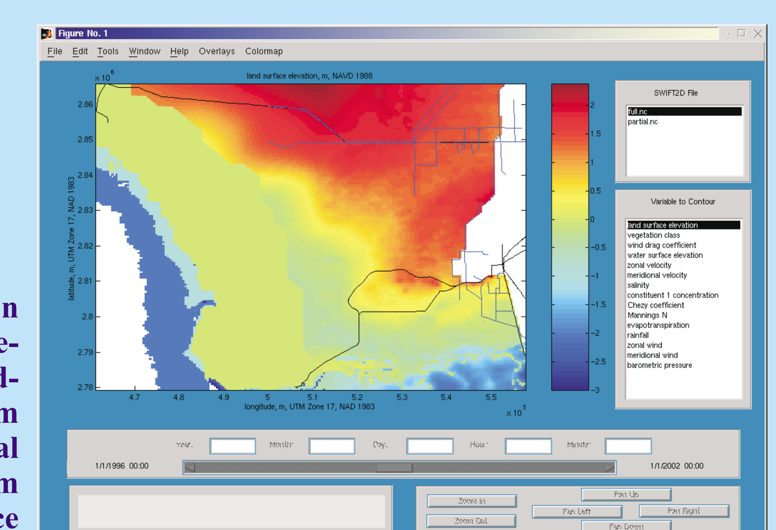


Figure 5. Imaging software for analyzing model results.

Acknowledgements

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The Ground-Water System

Data describing the ground-water system that are required to simulate flow and salinity fluxes within the aquifer and to quantify exchanges with the surface-water system include:

- spatial data describing properties of the ground-water domain (boundaries, transmissivity, storage capacity, dispersivity)
- time-series data depicting ground-water heads and salinities
- spatial and time-series data defining seepage rates
- physical parameters determining peat properties (thickness, hydraulic conductivity)

The ground-water system is composed of the highly permeable coastal Biscayne aquifer, which is separated from a deep Grey Limestone aquifer by a layer of Pinecrest Sand, as illustrated in Figure 9. Previous modeling and field studies suggest that surface-water/ground-water interactions play an important role in the water budget of the Everglades. In particular, they suggest that surface-water/ground-water interactions along the coastal margin affect the spatial and temporal distributions of salinity, but this relation has yet to be quantified and documented.

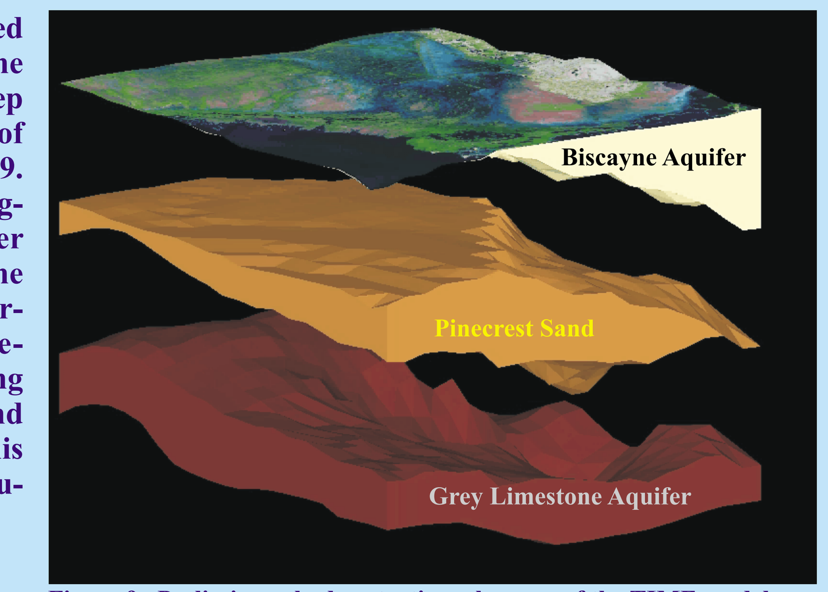

Figure 9. Preliminary hydro-stratigraphy map of the TIME model domain.

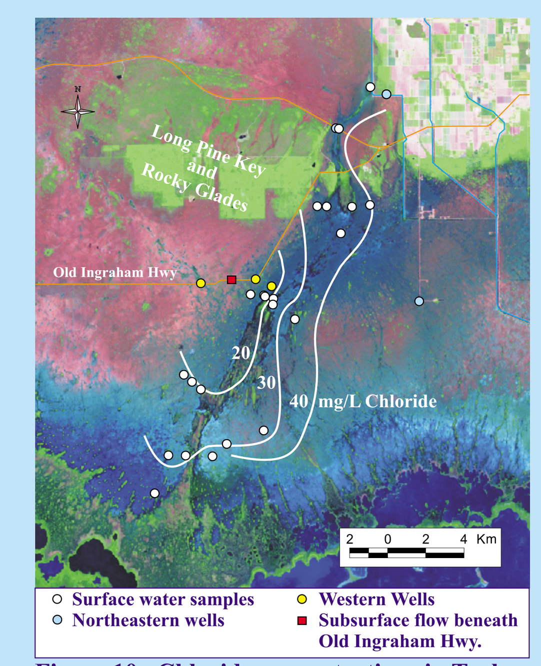

Figure 10. Chloride concentrations in Taylor Slough overlaid on satellite image.

The extent to which hydrologic interactions between the wetland surface water and ground water contribute to freshwater flow to the coast is uncertain. One approach to investigating surface-water/ground-water exchanges involves computing ground-water discharge using environmental tracers such as chloride or isotopes such as radium. The example in Figure 10 shows how measurements of chloride in Taylor Slough are being used to quantify ungaged freshwater flow entering Taylor Slough from its western boundary. Radium and radon measurements are being tested as a means to further separate components of shallow versus deeper ground-water discharge. Similar techniques are being used to investigate surface-water/ground-water exchanges in Shark River Slough.

Airborne geophysical techniques are being used to map the location of the freshwater-saltwater interface within the TIME domain. Helicopter electromagnetic (HEM) surveys and transient electromagnetic (TEM) soundings are being used to estimate formation resistivity along the coastal boundary. Geophysical data have provided information on three factors critical to ground-water model development in the TIME ecosystem: 1) the extent of saltwater intrusion in the surficial aquifer, 2) the depth to the base of the Biscayne aquifer, and 3) evidence regarding fresh ground-water flows to Florida Bay. The location of the freshwater-saltwater interface is identifiable in color-coded resistivity contour maps (red indicates freshwater, blue saltwater). An interpreted resistivity map for a depth of 10 meters is shown in Figure 11. HEM and TEM measurements are being extended to cover the region of Shark River Slough, Lostmans Slough, and north to Tamiami Trail as identified in Figure 11.

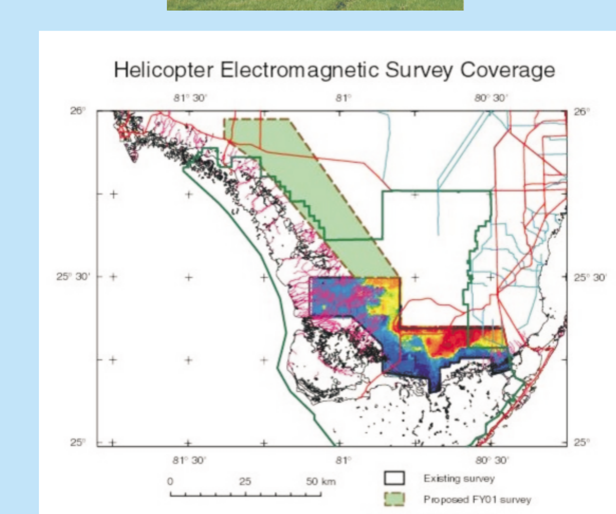

Figure 11. Existing and proposed helicopter electromagnetic survey coverages in the TIME model domain.