Coupling Models for Canal and Wetland Interactions in the South Florida Ecosystem

U.S. Department of the Interior—U.S. Geological Survey

Introduction

The U.S. Geological Survey is one of several agencies participating in the scientific effort to provide knowledge that can help protect and preserve the ecosystem of south Florida. One project of the intergovernmental South Florida Ecosystem Program (SFEP) is focused on developing a computer model to simulate the flow of water and analyze the transport of waterborne chemical constituents between canals and wetlands. Quantification of dynamic flows within the south Florida ecosystem is vital to understanding the implications of the residence time of water, potentially nutrient-enriched (with nitrates or phosphates) or contaminant-laden (with metals or pesticides), that can alter plant life and affect biological communities. Nutrients carried in the water conveyed by canals draining agricultural areas and dispersed into wetlands by canal discharges, by levee overflows, or by seepage are considered to be a major contributor to changes in the types of vegetation found in the Everglades. Freshwater inflows, typically of varying magnitudes and durations, not only influence the salinity of Florida Bay but also potentially carry toxic substances that can affect and alter the Bay's aquatic biota. The simulation capability being developed within the SFEP can be useful for identifying approaches to alleviate adverse impacts of excessive or deficient flows and transported constituents. Through strategic use of a simulation model, cause-and-effect relations between discharge sources, flow magnitudes, transport processes, and changes in vegetation and biota can be investigated. The effects of driving forces on nutrient cycling and contaminant transport can then be quantified, evaluated, and considered in the development of remedial management plans.

Ecosystem Flow/Transport Characteristics

Flow behavior and transport properties in low-relief environments such as south Florida are complex. Flows from canals to neighboring wetlands and reciprocal runoff flows are the combined result of hydraulic, inertial, and meteorologic forces. Because velocities are extremely low, water movement is highly susceptible to winds that potentially can reverse the flow direction and even cause a wetland area to drain or flood. Wetlands adjacent to Florida Bay also are subject to tidal effects that further complicate flow analyses. Moreover, flow and transport are integrally linked meaning that precise quantification of the fluid dynamics is required to accurately evaluate the transport of waterborne constituents. In other words, in order to investigate the movement of constituents, it is essential to understand the forces governing the flow of water that is the transporting media.

Additional complications are introduced in the south Florida ecosystem by a diversity of natural and man-made flow controls. A complex canal and levee system, designed to control flooding and provide a continuous supply of fresh water for household and agricultural use, has altered naturally occurring flow patterns through the Everglades and into Florida Bay. Flow in the straight, uniform canals is predominately confined to one direction and can be readily characterized in terms of mean cross-sectional properties. Flows in the wetlands, however, can be highly irregular in direction in response to varied topographical patterns and vegetative features. Improved numerical techniques are needed not only to accurately evaluate discrete forces governing flow in the canals and wetlands but also to analyze their complex interaction in order to facilitate coupled representation of transport processes.

Canal C-111 Drainage Basin

One area of particular interest in terms of flow-distribution analyses is the drainage basin of the canal identified as C-111 in southern Dade County (fig. 1). A dam and water-control structure, S-197, which regulates freshwater flows and prevents saltwater intrusion from Florida Bay, is located near the bend in the canal at the middle right in the aerial photograph. Gaps have been cut in the spoil mound along the southwest bank of the canal in an attempt to reestablish shallow surface-water flow,

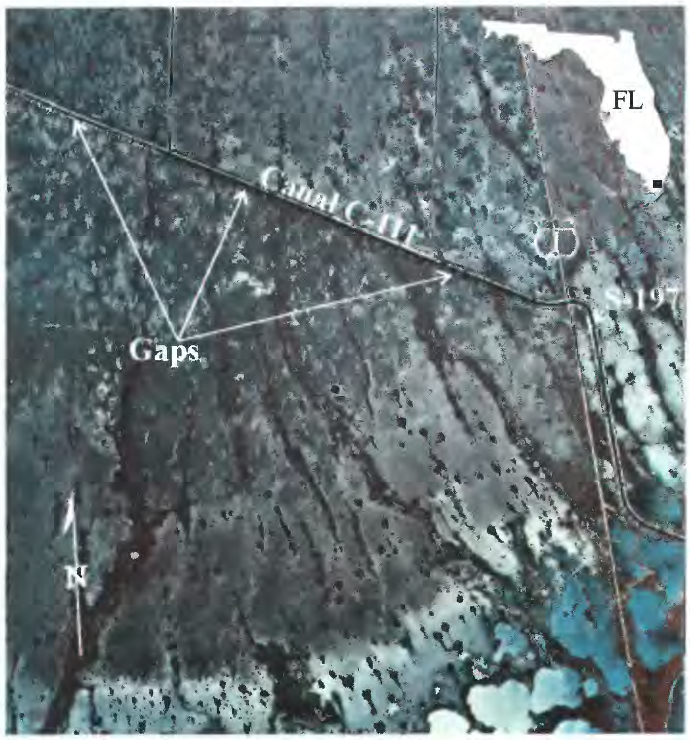

Figure 1. Aerial photograph, approximately 1:88,000 scale, of portion of canal C-111 drainage basin taken on January 15, 1994, showing gaps cut in spoil mound along southwest bank.

referred to as sheet flow, to the south into Florida Bay. Tree islands (dark red, teardrop-shaped, forested areas) and elongated patterns of vegetation along channel banks identify the historical direction of sheet flow to the Bay. These indicate that impediments to the natural surface runoff and drainage patterns have been created by the construction of roads, canals, levees, and hydraulic control structures. Major water-management issues having to do with flow-control measures for the C-111 drainage basin are:

- What are the cause-and-effect relations between tides, winds, and altered freshwater flows on neighboring wetlands, mangrove ecosystems, and coastal water bodies?
- What are the effects of outflows from C-111 on salinity dynamics of Florida Bay?
- What processes control the fate of nutrients or contaminants and govern their dispersal into neighboring wetlands and adjacent ecosystems?
- What are the consequences of various C-111 redesign alternatives on inflows to Manatee Bay, Barnes Sound, and other coastal water bodies?
- How do the dynamics of outflows from C-111 affect sheet flow through wetlands in the adjacent Everglades National Park?
- How does canal C-111 interact with other hydrologic and hydrodynamic systems?

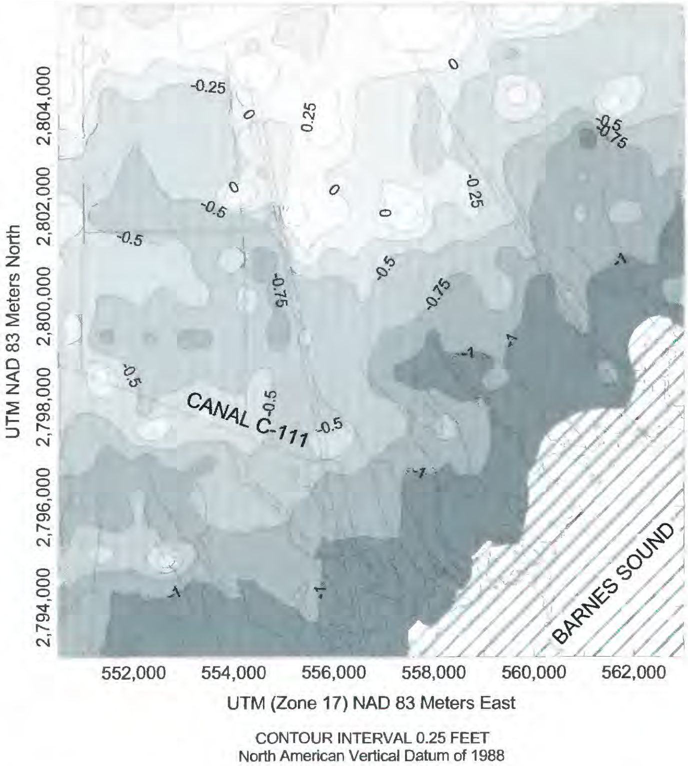

Figure 2. Ground contours in the Glades topographic quadrangle of south Florida.

Model-Implementation Requirements

From precisely measured land-surface elevations, computational grids that depict flow systems can be developed for implementing a mathematical model. Special projects of the SFEP, such as the Elevation Data project, are employing advanced mapping techniques to collect data defining topographic patterns and land-surface features at the high resolutions required for model implementation. Roads, canals, levees, and wetlands need to be accurately described in the model grid and features such as culverts, pumps, levees, and other hydraulic-control structures must be properly represented. Ground contours of one preliminary model grid encompassing the Glades topographic quadrangle of the C-111 drainage basin are illustrated in figure 2. Ground contours in figure 2 are derived from one-hectare (100-m square) grid cells interpolated from land-surface elevations collected using the satellite-based NAVSTAR Global Positioning System (GPS). The preliminary model grid of 125 by 130 one-hectare cells is illustrated in figure 3. Roadways, canals, and levees have yet to be integrated in this preliminary computational grid. Land-surface elevations in Barnes Sound and bordering mangroves (cross-hatched area in figure 2) are also presently undefined due to the lack of data. A slight northwest to southeast gradient is evident in the land-surface elevations. Precise resolution of this gradient and definition of other topographic features are required to accurately simulate sheet flow through wetlands of the south Florida ecosystem. Mangroves and other types of dense vegetation present unique mapping difficulties and new techniques are being explored within the SFEP to survey these areas of limited accessibility.

In addition to required topographic data, flow levels and rates, needed for model calibration and for the conduct of numerical simulations, are being determined by other SFEP projects, such as the Freshwater Discharge to East Coast and Florida Bay projects, using conventional and advanced acoustic measurement techniques.

Model Development

The capability of a mathematical model to simulate flow and transport in a complex environment such as the south Florida ecosystem is highly dependent on its representation of important forces and processes. Of particular concern in the development of models for the south Florida ecosystem is representation of precipitation gains from rainfall, frictional effects due to vegetation, driving forces of winds, and losses by evapotranspiration and ground-water infiltration. New techniques for expressing these processes in numerical simulation models are being investigated and data-collection efforts by complementary projects of the SFEP, such as the Vegetative Resistance to Flow and Evapotranspiration Measurements projects, are seeking improved equation representations founded on field-defined parameters. As new expressions for these processes are defined, numerical

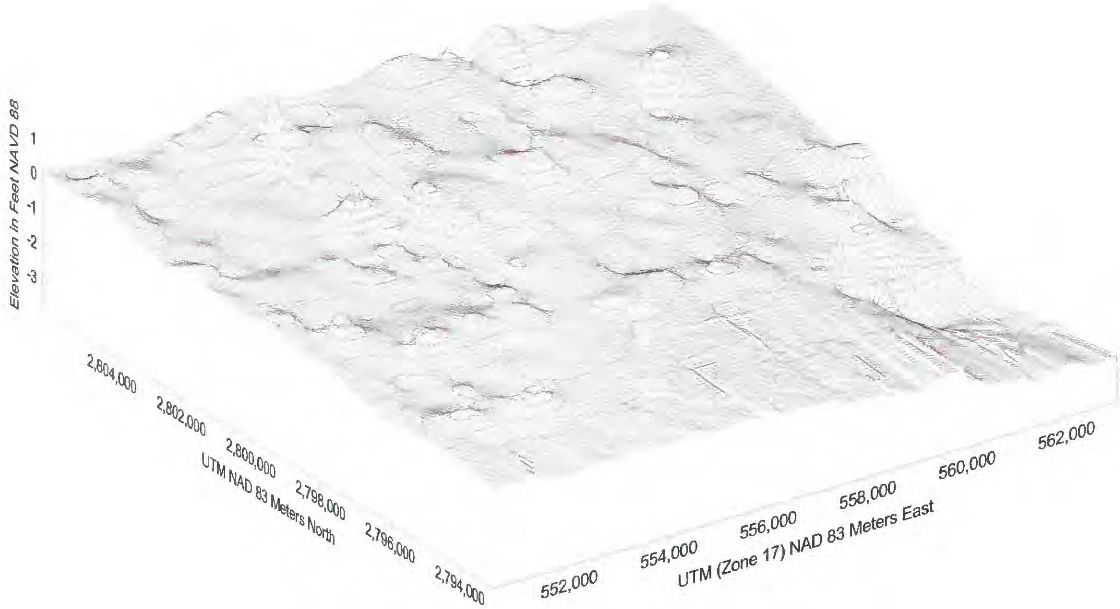

Figure 3. Grid of 125 by 130 one-hectare cells of land-surface elevations.

approximations are developed and tests are conducted using the model. Tests are typically made using known theoretical solutions and, eventually, using fine-scale grids of limited canal and wetland areas for which detailed data can be collected.

Very often the nature of flow and transport conditions also dictate the need for much finer grid resolution than the one-hectare cell size illustrated in figure 3. Geometric conditions that typically require fine-scale resolution are transition areas between deep canals and shallow wetlands. Such a transition area from the C-111 drainage basin is depicted in figure 4.

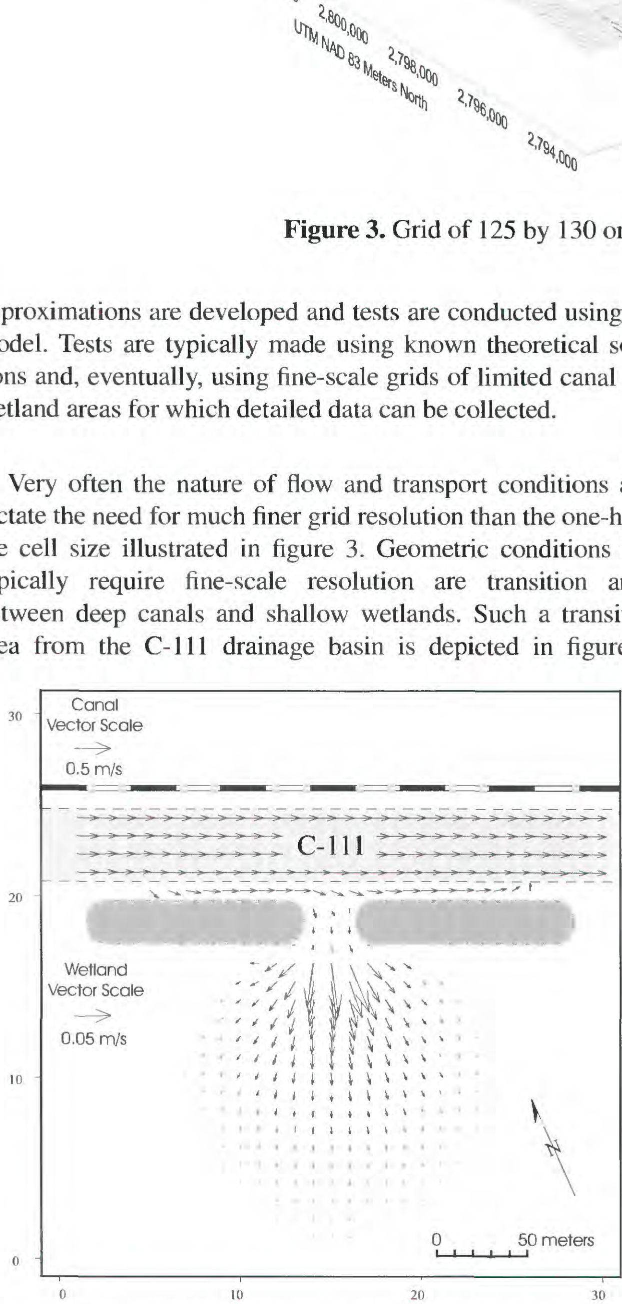

Figure 4. Grid of 29 by 29 model-simulated velocity vectors illustrating flow pattern through one gap in spoil mound along southwest bank of canal C-111.

Velocity vectors, simulated by the model over a 290-m square area, illustrate a flow pattern through one of the 54 gaps in the C-111 southwest spoil mound. In this grid, each arrow indicates the direction of flow and average speed in a 100 m^2 area. The approximate in-bank flow condition of the C-111 canal is identified by the parallel dashed lines in figure 4. For visualization purposes, lengths of vectors representing flow velocities in the wetland have been increased by a factor of ten over those in the canal. This was necessary because of the large disparity in flow velocities, which are a maximum of 0.32 m/s in the canal and 0.07 m/s in the wetland for this particular simulation. Note the uniformity of flow velocities in the canal and the non-symmetrical, residual effect of the left-to-right flow direction through the gap and into the wetland. Such subtle but important flow features can easily be lost in coarse-scale model grids or in models that do not appropriately treat all relevant forces affecting the flow through such transitions.

Summary

The interconnected canals, wetlands, and underlying shallow aquifer of south Florida represent a geometrically complex, physically diverse, and dynamically changing hydrologic environment. Mathematical models of this interconnected hydrologic system must include terms in their governing equations that represent all relevant hydraulic forces and transport processes. Moreover, high-quality data that accurately depict the topographic properties are required for proper implementation and use of resultant models. In this regard, several hydrologic investigations and efforts, directly related to flow and transport model development for the south Florida ecosystem, are underway. Model-related activities being conducted within this project and(or) by other complementary projects of the SFEP are intended to:

- Improve fundamental concepts and numerical expressions by which to represent the variable effects of precipitation, constituent sources, winds, resistance caused by vegetation, and losses due to evapotranspiration and ground-water infiltration.
- Evaluate existing techniques and formulate new approaches for coupled treatment of flow and transport conditions between canals, wetlands, and the underlying aquifer system.
- Develop and appraise new techniques and approaches, using state-of-the-art instrumentation and systems such as acoustic Doppler velocimeters and Differential Global Positioning System (DGPS) technology, to collect basic data required to implement and calibrate numerical models.
- Design and develop computer tools, using the latest Geographic Information System (GIS) and scientific visualization products, to facilitate integration of model input data and scientific interpretation of simulation results.
- Provide techniques to identify and quantify flow losses and canal/wetland exchanges due to leakage through and(or) beneath spoil mounds and levees.
- Collect data and develop ratings to quantify freshwater flows through primary channels into Florida Bay.
- Test and evaluate enhanced and new advanced mapping techniques with which to collect high-quality elevation data needed to identify topographic features at spatial-resolution scales required for model implementation and numerical simulation.

It is anticipated that this model-development effort will provide improved tools for water managers to use in their analysis and evaluation of alternative management plans and strategies for the south Florida ecosystem.

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For more information on the South Florida Ecosystem Program refer to Fact Sheet FS-134-95 entitled South Florida Ecosystem Program of the U.S. Geological Survey. Additional information on the program can also be found on the World Wide Web at "http://fl-h2o.usgs.gov/sfei.html."