

Modeling the biophysical and social dynamics of a 'River of Grass': a challenge for hydroinformatics

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ABSTRACT

A number of major water resource ecosystem restoration projects are currently underway in the United States. One is focused on the Everglades, a unique ecosystem in southern Florida. The Everglades restoration project is estimated to cost some \$8 billion over a period of about 50 years. It is not only a challenge to scientists attempting to understand the physical and biological processes affecting the unique hydrology and ecology but also to planners and decision makers dealing with the social dynamics of the people living in the area. People impact the Everglades, and the rate of population growth in southern Florida shows no sign of decreasing. The outcome of this ecosystem restoration effort will largely be determined by the land use decisions and social activities of these people over the next several decades. It may also be influenced by political decisions made far outside the region, such as in Washington with respect to sugar subsidies (i.e., our relations with Cuba). It may be influenced by climate change (e.g., sea level rise) as well. In this complex physical and social environment, scientists from private and public agencies are working together with all concerned stakeholders to plan and manage the restoration project. Models are being developed and used to estimate the various impacts that may result from any plan or management policy. As expected, there exist conflicts among various stakeholders. If there was ever a challenge for those involved in building models and associated decision support systems for impact prediction and for communicating information to multiple stakeholders having quite different interests and concerns—all in an effort to obtain some consensus or shared visions of what should be done, and why—this project provides one.

Key words | ecology, Everglades, hydrology, modeling, restoration, social issues

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INTRODUCTION

'There are no other Everglades in the world.'

'They are, they have always been, one of the unique regions of the earth, remote, never wholly known. Nothing anywhere else is like them: their vast glittering openness, wider than the enormous visible round of the horizon, . . . They are unique also in the simplicity, the diversity, and the related harmony of the forms of life they enclose. The miracle of light pours over the green and brown expanse of saw grass and of water, shining and slow-moving below, the grass and water that is the central fact of the Everglades of Florida. It is a river of grass.'

(Douglas 1947)

Douglas' 'River of Grass' was a vast network of land and water—of sawgrass sloughs, cypress swamps,

freshwater lakes, rivers, marshes, ponds, prairies, forests and coastal lagoons, bays and estuaries. This 60-mile-wide shallow flat river of grass, called the south Florida ecosystem, stretched south from Orlando through the Chain of Lakes, the Kissimmee Valley, Lake Okeechobee (the second largest freshwater lake wholly within the United States and considered the 'heart' of Florida), and on to the waters of Florida Bay and the coral reefs (Figure 1). The Everglades uniqueness was characterized by its topography, how the water flowed, the area's large size, and its variety of habitats. Many of the Everglades' plant and animal species are dependent



Figure 1 | An outline of South Florida, showing the various agricultural and conservation areas and parks and rivers and bays (B. Kranzer, Governor's Commission for the Everglades).

upon clean, free-flowing water and expansive natural areas.

Today the Everglades still exist, but their uniqueness is threatened. People have encroached on what was once the habitat of storks, alligators, panthers and other wildlife. With the arrival of people came the desire to control floods, to drain swamps and wetlands, to farm and build on floodplains, and to control the flow from Lake Okeechobee to the Florida Keys. For half a century they did just that, and very effectively. The result: large segments of the Everglades have been converted to urban and agricultural uses. Half of the original wetlands area has disappeared. Drainage systems involving canals and pumps and flood protection levees have altered the natural flow patterns. The ecosystem as described by Douglas over a half century ago is not only about half its original size, it is also under considerable stress. Today many are concerned over the potential loss of this unique ecosystem. The public's goals and objectives, and the increasing value they place on this ecosystem, is being expressed by their willingness to pay the cost of restoring and preserving what remains (Davis & Ogden 1994; SFWMD 2000).

Today the Everglades provide the fresh water supply, income and recreational opportunities for an estimated 6 million residents, 20 million annual visitors, and a variety of agricultural, municipal and industrial activities. These activities have brought economic benefits, and few wish to give them up. Yet they have also caused fish kills in the estuaries, a significant loss of sea grasses in Florida Bay, a major reduction in the number of tree islands and in fish and wildlife populations. Wading bird flocks have decreased by 90%, and the population of Florida panthers has been reduced to less than 50. Few, if any, wish to see these losses continue.

The US Army Corps of Engineers and the local South Florida Water Management District manage the water in southern Florida. They, together with other Federal, state, and local agencies and organizations, have recently completed a plan for restoring the vitality of the remaining Everglades, while at the same time preserving the economic benefits development has brought to the region. It envisions developing surface and groundwater storage reservoirs, creating water preservation areas, managing Lake Okeechobee as an ecological as well as water resource, developing and managing wetlands for removing pollutants from agricultural and urban runoff, altering the Everglades' hydroperiod (time under water), increasing the sheetflow through the Everglades, reusing wastewater and modifying the quantity and improving the quality of the flows entering the coastal bays and estuaries. Resource managers must find ways of balancing the needs of an imperiled natural ecosystem within a highly sensitive economy and multicultural landscape.

DEVELOPMENT HISTORY

While people from the north began moving to South Florida some 100 years ago, its significant population increase began after World War II (Figure 2). Hurricanes, floods, droughts, fires, and mosquitoes were common (Figure 3). As expected, the then 500,000 people, desiring a less hostile environment, convinced Congress to authorize the Central and Southern Florida Project. This water management project was originally intended to

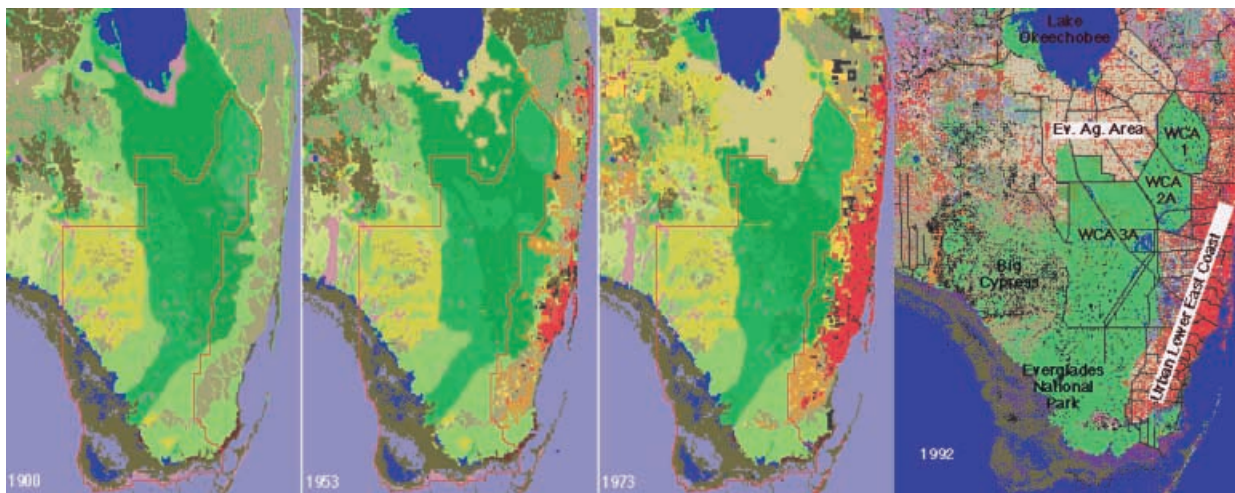


Figure 2 | Natural, agricultural, and urban land use changes in South Florida from 1900, 1953, 1973 and 1992.

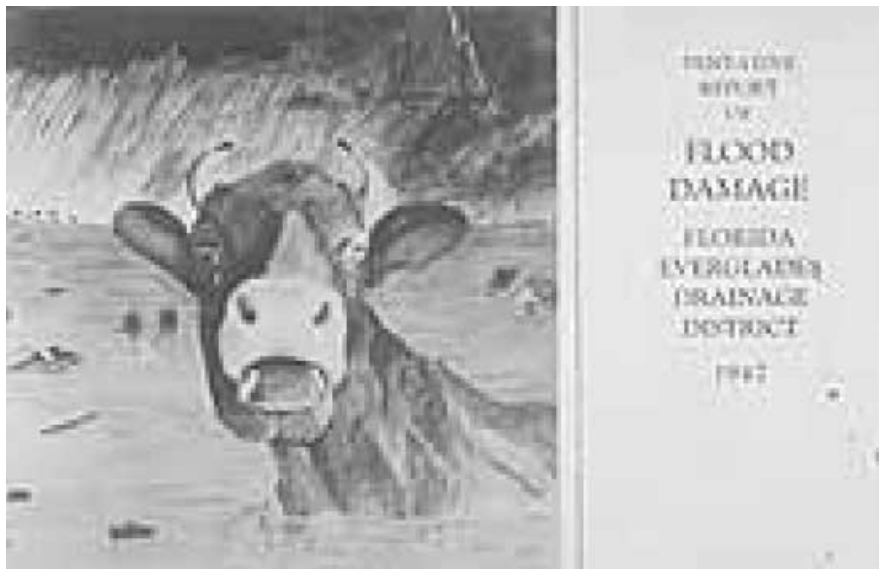


Figure 3 | A 1942 poster depicting a flood in the Everglades, the severity and frequency of which was to be reduced by engineering works undertaken by the Florida Everglades Drainage District.

provide flood protection and water to the people and agricultural lands. Later the project's objectives were expanded to include water supply for municipal and industrial uses and for the Everglades National Park, prevention of saltwater intrusion, and protection of fish and wildlife resources. The Project now encompasses an area of over 18,000 square miles, and includes one

thousand miles of canals, 720 miles of levees and almost 200 gates, pumps and other water control structures

When conceived in the early 1950s, the project's economic analyses assumed there might be two million people benefiting from the improved water management by the year 2000. Today—in the year 2000—the population is closer to 6 million people: three times more than the

project was designed to serve. With current (and admittedly uncertain) population projections of 8 million by the year 2010 and 12–15 million by the year 2050, effective management of the region's land, water, and ecological resources becomes increasingly critical, as well as political.

CURRENT STATE

Water for ecosystems

Over the past half-century of land development, the quantity and quality of water entering the Everglades has decreased. The timing and spatial distribution of that water has changed. The water that currently enters the Everglades cannot move as it used to throughout the entire system. As a result, the health of south Florida ecosystem including Lake Okeechobee (an important habitat for fish and wildlife) and the estuaries and bays (critical nurseries and habitats for many fish and wildlife) has suffered. Approximately a million acres of the ecosystem are contaminated with mercury. Over 1.5 million acres are infested with invasive, exotic plants. Cattails are replacing sawgrass in many areas, a visible sign of excessive nutrients entering the Everglades. Due to reduced, degraded or eliminated habitats, wading bird and other plant and animal populations that live in the Everglades and in the St. Lucie and Caloosahatchee estuaries and in Biscayne and Florida bays are in danger of becoming extinct.

Water for people

There is not enough water for the people in South Florida either. Water shortages and restrictions are becoming increasingly common, as is saltwater intrusion along the lower east coast where approximately two-thirds of the region's people are concentrated. Urban water supply demands could double from approximately one billion gallons of water per day today to two billion gallons of water per day by 2050. Currently approximately 1.7 billion gallons of water per day on average that would otherwise

flow through the Everglades are lost through discharge to the ocean via canals or rivers.

In dry periods of the year, the demand for an inexpensive reliable supply of water for agriculture, industry, and an increasing urban population already exceeds the limits of readily accessible sources. As the water needs of the region's ecosystems receive more attention, as they must if these ecosystems are to survive, conflicts for water among users will become even more severe. Water shortages will likely become more frequent and more severe unless changes to the water management system are made.

RESTORATION PLAN

In recognition of the damage being done to this unique ecosystem, Congress gave the US Army Corps of Engineers the authority to coordinate a review the current Central and Southern Florida Project. In partnership, the Corps and the South Florida Water Management District worked over six years with ecologists, hydrologists, engineers and other professionals from more than 30 Federal, state, tribal, and local agencies to take a system-wide look at water management. The result is the Central and Southern Florida Project Comprehensive Review Study (USACOE 1999). It is a comprehensive plan to restore, preserve and protect the south Florida ecosystem while providing for other water-related needs of the region, including flood control. The restoration project is expected to extend over the next half century. It may well be the most ambitious ecosystem restoration effort ever undertaken in the United States. Its fundamental goal is to capture most of the fresh water that now flows unused to the ocean and gulf and to deliver it when and where it is needed most in the Everglades.

Stated in other words, the Plan is to enhance the region's ecological, economical and social values. No one argues with this overall goal. However, just how that goal is to be accomplished has been, and will continue to be, debated among all the participants and affected stakeholders.

Those involved in drafting the Comprehensive Plan are convinced that the problems in the Everglades and the

entire south Florida ecosystem are primarily the result of water management and related activities. Their solutions to Everglades' restoration involve four interrelated factors: water quantity, quality, timing, and distribution. Restoration will require the reallocation of water quantity and quality over space and time. Water—in the right place, at the right time, in the right quantity and quality—is a primary driver of the Everglades ecosystem restoration plan. Here, the word 'right' means historic, or what would occur if the activities of man did not interfere. The idea is to restore what remains of the Everglades to the ecosystem it used to be, in so far as it is possible.

To do this, much of the water that is now discharged into the sea is to be stored, above and below ground (in more than 217,000 acres of new reservoirs and wetlands-based treatment areas, and in some 300 underground aquifer storage and recovery wells) so as to be available for the ecosystem and urban and agricultural users when and where needed. The Plan includes a number of features to improve the quality of water flowing from the agricultural and urban areas to the Everglades' natural environment. Flood protection will continue to be provided for south Florida. To improve the connectivity of natural areas, and to enhance sheetflow, more than 240 miles of levees and canals within the Everglades will be removed. Most of the Miami Canal in Water Conservation Area 3 (Figure 1) will be removed and 20 miles of the Tamiami Trail (US Route 41) will be rebuilt with bridges and culverts, allowing water to flow more naturally into Everglades National Park. In the Big Cypress National Preserve, the levee that separates the Preserve from the Everglades will be removed to restore more natural overland water flow (USACOE 1999; SFWMD 2000).

The Comprehensive Plan is based on many considerations, one of which is science. The Plan is to be adaptive and responsive to the best available science. Independent scientific review will be an integral part of its development and implementation. Based on what scientists learn and observe, the plan can be changed when change seems appropriate. The Comprehensive Plan's adaptive assessment strategy provides an efficient way to for restoration to begin now and for the agencies to make necessary mid-course corrections.

SCIENTIFIC AND ENGINEERING CHALLENGES

Extent and timing of project tasks

The project involves many separate, yet interdependent structural and non-structural tasks to be carried out over a large area and long period of time. The extent of ecosystem improvement or change resulting from each completed task, and from sets of completed tasks, is not completely certain. There is considerable uncertainty and much of that uncertainty will only be reduced after years of observation before and after the task is completed or implemented. As individual components or groups of components are further planned and designed, analyses and evaluations will be needed to measure the overall contribution to system-wide goals. *A challenge: how to identify, size and schedule the project's tasks so as to provide the maximum contribution to the restoration of the entire south Florida ecosystem per dollar spent?*

Ecosystem performance indicators

How does one determine whether or not any particular water management plan is working? Such a judgment will depend on how well the ecosystem responds to the change in water regime. Ecosystem indicators are used to compare ecosystem responses. Some ecological indicators focus on individual species, such as the endangered Cape Sable seaside sparrow; some focus on community composition and structure, such as the Index of Biotic Integrity; and some focus on ecosystem processes, such as biological productivity or trophic status. In addition, some of the proposed indicators, as now defined, are binary: they are either met or not. This is usually not a true indicator of the quality of life or death of some plant or animal species, but rather an acknowledgement of the lack of information available to determine just what might happen if these binary indicators are only partially met. Depending on how they are chosen, different ecological indicators may respond differently to various environmental factors and to different restoration activities. In such cases, choices need to be made. Thus, understanding the reasons for choosing various ecological indicators is critical to understanding the scientific basis for implementation of the

ensure that each project has the best design to achieve its intended purpose and that the project is shown to be a sound investment. Implementation of the Comprehensive Plan represents a substantial financial investment by all levels of government. Many private contractors will be involved. There will be many who will view this project as a way to benefit economically and who will not be motivated to make sure the money they get will be spent on the right things in the right way. *A challenge: how to ensure that public fiscal resources are spent efficiently and effectively?*

Meeting the demands of all beneficiaries

The entire economy of South Florida depends on water. Water links the natural system with the urban and agricultural sectors in south Florida. To a large extent, the ability to sustain the region's natural resources, economy, and quality of life depends on how well the Plan's measures enhance, protect, and better manage the region's water resources for all water users, not just the Everglades ecosystem. New storage facilities will eventually lessen urban and agricultural user's dependence on the natural system for water supply. As components are completed, more water will become available for the ecosystem. *A challenge: how to achieve increasing environmental/ecosystem benefits while also satisfying growing agricultural and urban demands for both supply and flood protection?*

Improving water quality

The Comprehensive Plan proposes infrastructure, including constructed wetlands, to capture runoff from agricultural and urban areas and improve the quality of water entering natural areas. Phosphorus contained in that runoff is a problem. The Everglades can tolerate only the tiniest dose of phosphorus before its unique prairies of sawgrass become dense clusters of cattail. Cattails do not provide the habitat for species that make the Everglades unique. Over a period of four years, the amount of acreage of cattails in the northern Everglades has quadrupled. Implementation of best management practices can reduce

the phosphorus in agricultural and urban runoff, but not enough. *A challenge: how to reduce phosphorus concentrations in runoff entering the Everglades to the level they can tolerate—10 parts per billion? How tiny is that? It is the equivalent of 10 s in over 31 years. No other ecosystem demands such clean water. A challenge: how to ensure that the water quality improvement components of the Plan are located, designed, and operated consistently with existing and future water quality protection criteria and restoration targets and at acceptable costs?*

Marine ecosystem impacts

Many of the ecological communities along South Florida's coasts and in the coastal ocean are sensitive to the amount, timing, salinity, and other aspects of the chemistry of the water that flows to them. This flow, in part, comes from the Everglades. Some of those ecological communities are in national parks or national marine sanctuaries, and all of them are of biological, recreational, commercial, or aesthetic interest. It is important to understand how changes in the Everglades have affected those marine communities and how various aspects of the restoration plan might affect them. *A challenge: how to couple the hydrologic regional models with the estuarine circulation models in order to better understand the causes of changes in productivity of Biscayne Bay, and the effects of nutrients on coral-reef communities?*

Aquifer storage and recovery

The feasibility and cost-effectiveness of aquifer storage and recovery, ASR (Figure 5), as a major component of the restoration effort is a critical question in the restoration effort as currently conceived. It is important that aspects of this technology, including water quality, and its feasibility at the large scales being planned, be better understood and as soon as possible. Much of the value of adaptive management comes from designing pilot and other projects to maximize opportunities for learning. This is especially true for a large-scale project like ASR, where it is important to design (small-scale) pilot projects that

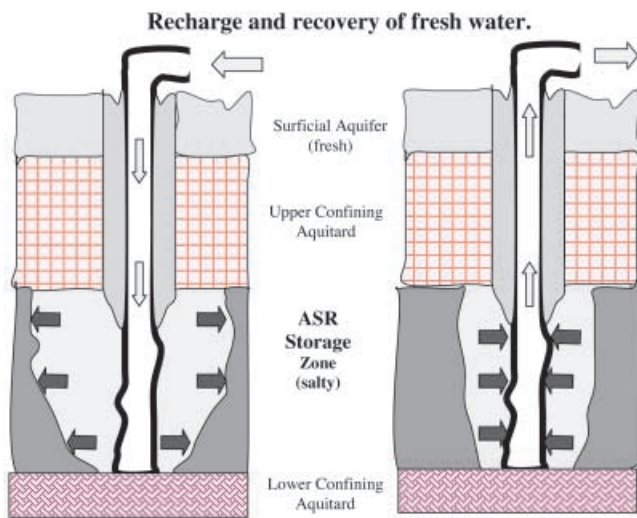


Figure 5 | Aquifer storage recharge and recovery schematic showing recharge to and recovery of fresh water from a confined saline aquifer (SFWMD 1999).

will allow inferences about injection, storage, and recovery aspects and impacts on water quality expected for the full project. *A challenge: how to design an adaptive management project that will best provide information about how big an ASR project, or how many wells, will be needed to meet the needs of the Everglades and other land uses in some cost-effective manner?*

Land development

Planners in South Florida tell me that land developers have never lost a battle over land in Florida. Whether true or not, the resolution or management of growth issues is critical to the success of the ecosystem restoration efforts. Pressures for development can only increase as restoration efforts improve the environment and attractiveness of the region. Efforts to balance growth and resource protection, as well as efforts to enhance the quality of life in urban areas are important to the people living in the region. Land use and water management will determine the future economic, social, and environmental sustainability for most of the region. *A challenge: how to provide a continually updated information base together with analysis tools that will better inform those attempting*

to balance land and water management to meet both economic and environmental needs?

An uncertain future

Florida's population growth is real and well documented. What is uncertain is just how that growth will take place in the future. Sea level rise is also a real possibility, if in fact not already observed. What is uncertain is just how much will occur over the time this project is projected to last—some half a century. These events could substantially alter the Everglades in spite of the best efforts, and the billions of dollars spent, trying to restore and preserve it. *A challenge: how to create plausible scenarios of land use and climate changes over time and evaluate current water and ecosystem management strategies in light of those scenarios and their likelihood's of happening?*

SOCIAL CHALLENGES

Economic benefits

Though notable politicians have stated that the economy of south Florida depends on its environment, a persuasive demonstration of the argument has not been made to the average citizen. It is crucial that economic assessments clearly demonstrate just how dependent the South Florida environment is to the \$18 billion/year recreation and tourism industry and to the commercial, residential and employment sectors. The lack of such environmental economic benefit assessments has hindered a balanced benefit–cost analysis of the pros and cons of ecosystem restoration. *A challenge: how to identify the monetary as well as non-monetary benefits derived from the ecosystem, in various states of restoration, and how to conduct an economic analysis comparing those ecosystem benefits to benefits that could result from spending these restoration project funds on other aspects of human welfare?*

Environmental justice

Not everyone benefits uniformly from restoration investments. Restoration projects need to be designed through

community planning processes in which community goals and needs are among restoration objectives. There is often the likelihood that those living in traditionally low-income areas will bear more of the costs or damages resulting from restoration projects than will those who live in high-income areas. Currently there is disagreement over whether the Everglades restoration project is truly for environmental restoration or whether it is a massive water engineering project solely to benefit the contractors and the growing urban population. The Miccosukee Tribe that lives in the northern Everglades does not want its homeland damaged in the name of restoration. Nor does a group of residents in western Miami-Dade County, who are unwilling to sell their homes so their land can be restored to a floodplain under the project. Thousands of acres of farmland are at stake, along with the jobs of the people who farm them. Restoration project planning must identify and resolve such environmental justice issues. *A challenge: how to identify the linkage between community goals and river restoration activities through community visioning, goal setting and conservation/restoration incentives programs?*

Modeling human behavior

The various models being used to estimate 'what will happen if' scenarios are all dedicated to describing the internal dynamics of the Everglades ecosystem, either original or remnant. They depend on many exogenous variables that define the current state of the Everglades and the likely growth in its human population. However, the big social drivers (population change, urban growth, agriculture, long-term change in economic activity, tourism) are expanding in ways that are unexplained and unpredictable on the time scales of interest to the restoration effort. From agriculture to industry, it is likely no planner would have predicted the Florida of today even 20 years ago, let alone 50 years ago. When considering any region as large as the Everglades, and as long as the Everglades restoration effort will take, it is risky to separate the principal biophysical driving forces from the dynamics of social change. Both

influence the restoration effort. *A challenge: how to integrate or incorporate the natural and social processes in the conceptual modeling and implementation processes?*

Considering a time scale of plus or minus 50 years from the present day (in other words, back to the origin of the Central and South Florida Development Project and forward to 2050, the expected time in which the restoration project will end), it is clearly unreasonable to assume that anyone could have predicted how urban and agricultural conditions have changed these past 50 years, or how it will change in the coming 50. Consider the history of urban fresh water demand, of ocean discharge, of nutrient load in the Everglades and attendant consequences, of flood control, seepage, and even the directionality of E-W flow (which has changed from West-to-East to East-to-West in the southern Everglades (Dade) and from East-to-West to West-to-East in the north), near the Water Conservation Areas around Palm Beach. In a time of considerable social change, vulnerability to prediction errors is present. No case has been made that history provides a good predictor. No case has been made that models provide a good predictor of social change either. *A challenge: how to model the interactions between natural and social systems, systems that are influenced by factors or drivers coming from within as well as outside the region?*

How to identify the critical human forces driving or affecting restoration and the critical political actors/forces that influence political decisions at Federal, state and local levels? To what extent is the restoration itself a function of politics, rather than to science? Clearly the principal actors—the Corps, the water management districts, the state and Federal governments—are acting in response to politics as much as in response to science. *A challenge: how can we who model, we hydroinformaticists, identify and display the important 'political' as well as ecological and hydrological landscapes that might offer a clearer understanding of how best to proceed with the overall restoration effort?* Having a better view of the political as well as scientific impacts of possible restoration efforts, as they become more clearly defined, could substantially aid those responsible for overall project planning and management.

HYDROINFORMATICS CHALLENGES

This restoration project provides a case study in the implementation of computer-based decision support systems, of hydroinformatics, combining mathematical models describing the natural phenomena with the human interface for effective communication among the models and humans. These interactive modeling systems are being used to explore, identify, and evaluate various aspects of multiple restoration alternatives and their impacts. Project-specific hydrologic models simulate the groundwater/canal interaction in the Everglades. Models now under development will simulate groundwater/surface-water interaction. Hydraulic models are used to calculate the water surface profiles. Hydrodynamic models are used to study the circulation characteristics in bays and estuaries and the effects of changes in freshwater flows from coastal canals and groundwater sources. Regional hydrologic models are used to evaluate water management changes and major structural modifications of the Central and South Florida Project and to develop operational guidelines and determine the optimal allocation of water resources over time and space.

Some of the models being used in the Everglades restoration planning include:

ATLSS: Across Trophic Level System Simulation that includes panther, deer, wading bird, sparrow, alligator, fish, hydrology and vegetation submodels (IfEM 1998).

ELM: Everglades Landscape Model is a regional simulation model that predicts landscape ecosystem response to water management scenarios.

EWQM: Everglades Water Quality Model for predicting the fate and transport of pollutants within the Everglades.

LOWQM: Lake Okeechobee Water Quality Model simulates eutrophication processes in water columns and underlying sediments in Lake Okeechobee.

ROGEM: River of Grass Evaluation Methodology is a collection of landscape scale equations that predict relative fish and wildlife habitat quality responses to restoration alternatives.

MANGROVE MODEL: Simulates response of mangroves to changes in water quantity and quality.

NSM: Natural System Model is a 2×2 mile grid regional simulation model for estimating the hydrology that would have happened had the region not been developed. It is based on the SFWMM, without the canals and pumping stations (SFWMD 1998).

SFWMM: South Florida Water Management Model is the current regional water management model, incorporating the current hydraulic infrastructure (SFWMD 1999).

These models range from regional to local scales and together include groundwater, surface-water quality and ecosystem variables and indicators. The models also vary in resolution and applicability to the questions that need to be resolved in order to develop detailed designs and an operation plan for the region. *The challenge: how can these different models be used in a way that achieves a comprehensive understanding and shared vision among all stakeholders of what alternatives are best based on their economic and social costs and their ecosystem and political impacts?*

SUMMARY

The focus of the south Florida ecosystem restoration project is not just on the natural environment; it is also on the built, and human, environments. Successful ecosystem restoration will depend upon an integrated approach that recognizes and understands the interrelationships and interactions between a healthy sustainable natural ecosystem and the social and economic systems that impact it. These systems are dynamic, uncertain and unpredictable. As the natural system restoration activities increase in the near future, its planners and managers must take into account both the biophysical as well as the social and political systems that operate in south Florida. As complex and interdependent as the ecological or hydrological systems are, so are the south Florida communities that are of multiple cultures, beliefs, attitudes, institutions, economies, land uses and histories. A scientific framework that collects, analyzes, disseminates, and integrates

cultural and socio-economic data with ecological and hydrological modeling provides a basis for future research, funding and policy decisions.

The opportunity and challenge for hydroinformatics is there—to broaden our view to include more than just the hydro. Can we as systems analysts trained in hydroinformatics help in

- Providing fundamental socio-economic and cultural information needed to accomplish restoration activities better?
- Improving communications among all stakeholders?
- Building the tools that will allow stakeholder participation in model development and use in such a complex environment?
- Providing stakeholders with a clearer picture of what might be and why?
- Helping stakeholders reach a consensus and participate in the resource planning and management processes?

In the next half-century, as in the previous half-century, significant changes are likely in the major physical, biological, and socioeconomic drivers affecting the dynamic behavior of the Everglades. The future state of the Everglades is highly dependent on these drivers. It seems critical, therefore, that the hydrological and ecological models currently being used need to be expanded to

include the social dynamics if they are to be expected to identify and evaluate the broadest possible set of plausible future actions, conditions and impacts. This is a major challenge for hydroinformatics—to grow in scope and to become a more valuable component of any integrated social-ecosystem restoration project.

REFERENCES

- Davis, S. M. & Ogden, J. C. (eds) 1994 *Everglades: The Ecosystem and Its Restoration*, St. Lucie Press, Boca Raton, FL, 826 pp.
- Douglas, M. S. 1947 *Everglades: River of Grass* (revised edition 1988), Pineapple Press, Sarasota, FL, 448 pp.
- Institute of Environmental Modeling, 1998 *ATLSS: Across Trophic Level System Simulation*, University of Tennessee, Knoxville, TN.
- South Florida Water Management District, 1998 *Natural Systems Model Version 4.5 Documentation*, Hydrologic Systems Modeling Division, Planning Department, SFWMD, West Palm Beach, FL.
- South Florida Water Management District, 1999 *A Primer to the South Florida Water Management Model*, Hydrologic Systems Modeling Division, Planning Department, SFWMD, West Palm Beach, FL.
- South Florida Water Management District, 2000 *Everglades: Consolidated Report*, Hydrologic Systems Modeling Division, Planning Department, SFWMD, West Palm Beach, FL.
- US Army Corps of Engineers, 1999 *Chief of Engineers Report: Central and Southern Florida Project Comprehensive Review Study*, Washington, DC.