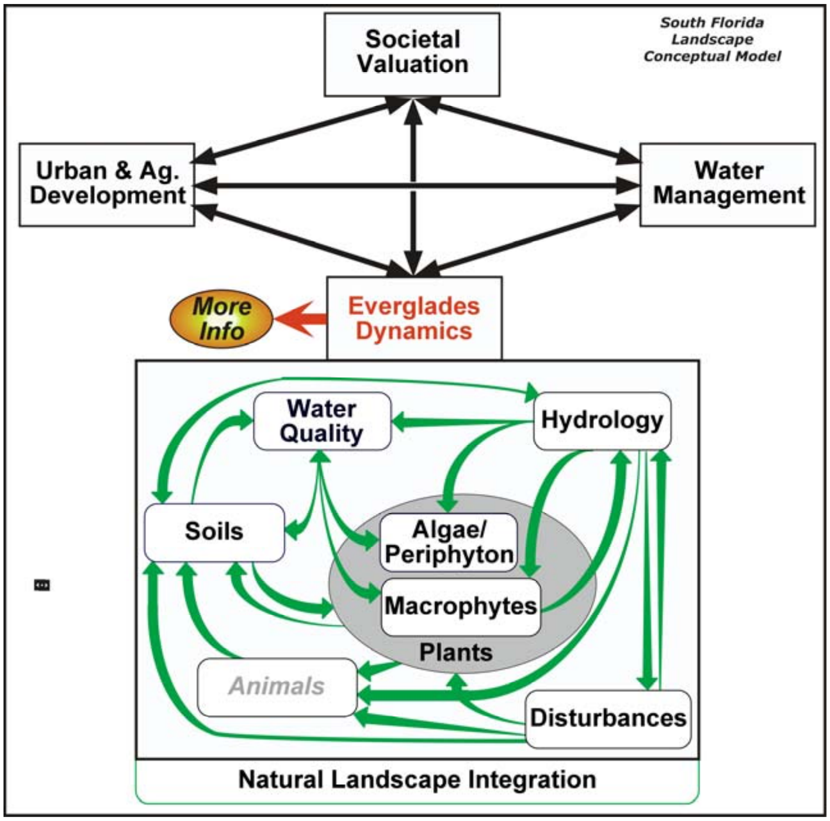
Documentation of the Everglades Landscape Model: ELM v2.5

Chapter 3: Conceptual Model



http://my.sfwmd.gov/elm

July 10, 2006

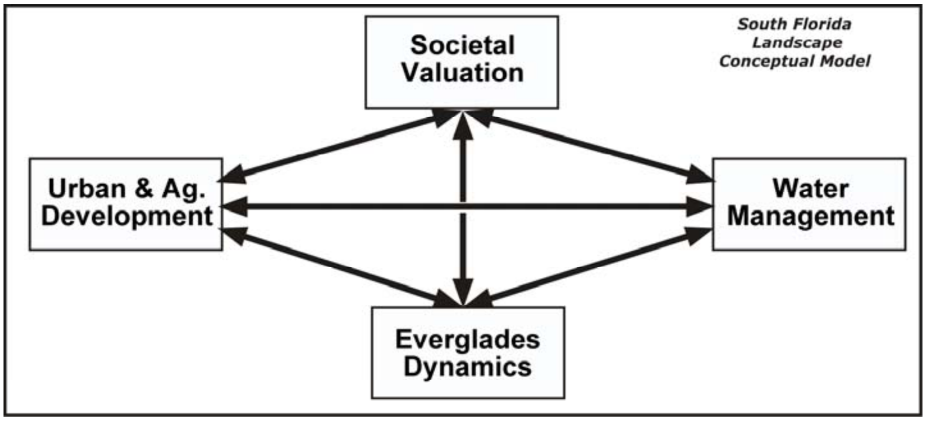
Chapter 3: Conceptual Model

3.1 Overview

The fundamental linkages among the natural and human-based environments are described in this chapter, using the South Florida Conceptual Model. This establishes the context of the “natural” Everglades landscape as it is integrated into the issues of the south Florida region. The General Ecosystem Conceptual Model for the “natural” area is then described, summarizing the ecological interactions among the primary physical, chemical, and biological processes that drive the ecosystem(s). Natural systems integrate these processes in a dynamic landscape. This is the basis of the concepts that were used in designing the Everglades Landscape Model, which is summarized in a subsequent Chapter on the Model Structure.

We recommend viewing this Conceptual Model via the hyper-linked version on the ELM web site (Home: Landscape tab at http://my.sfwmd.gov/elm).

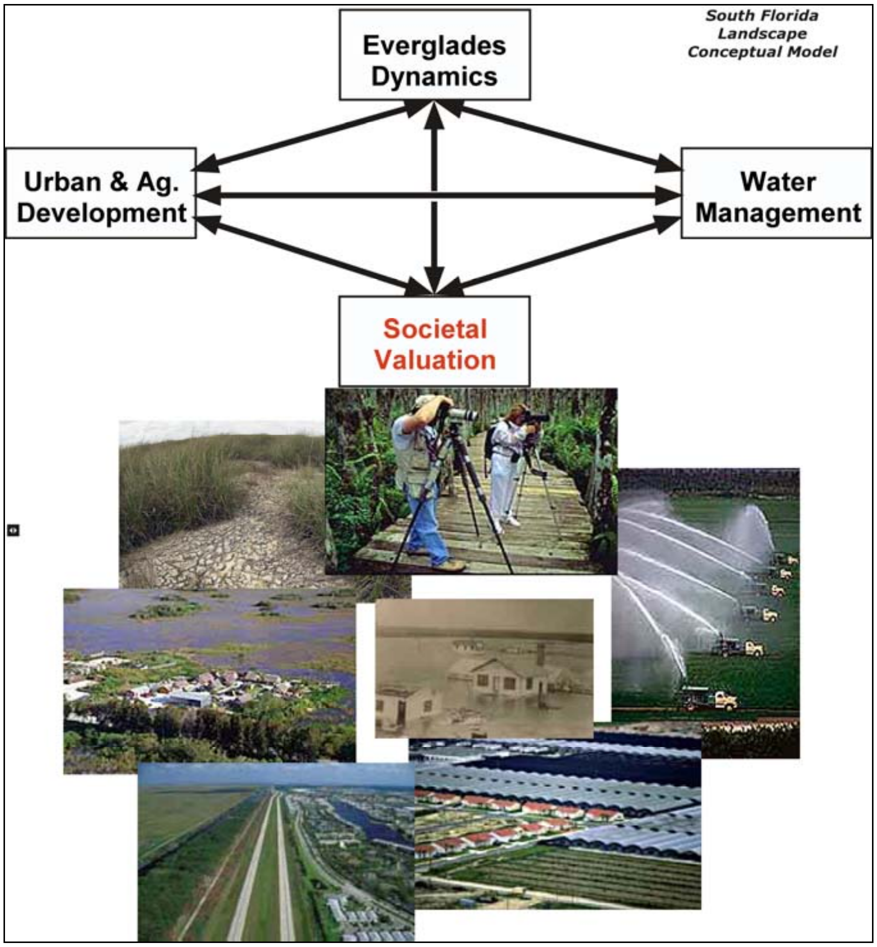
3.2 South Florida Conceptual Model



The ecology of the Everglades should be considered in the broader context of the South Florida landscape. A simple conceptual model of the relationships among the natural system and the different components of south Florida is briefly demonstrated in our South Florida Landscape Conceptual Model.

Water managers in south Florida are responsible for balancing the various demands placed on our public water resources in order to achieve a sustainable and productive environment for humans and the natural system on which we all depend. Field/lab research and modeling can aid in understanding the dynamics of the Everglades system in response to current and future water management practices. The interactions among the four Conceptual Model components shown here drives the ecological and economic system of south Florida. Water management attempts to integrate our societal values with the resource demands of urban, agricultural, and natural components of the regional landscape.

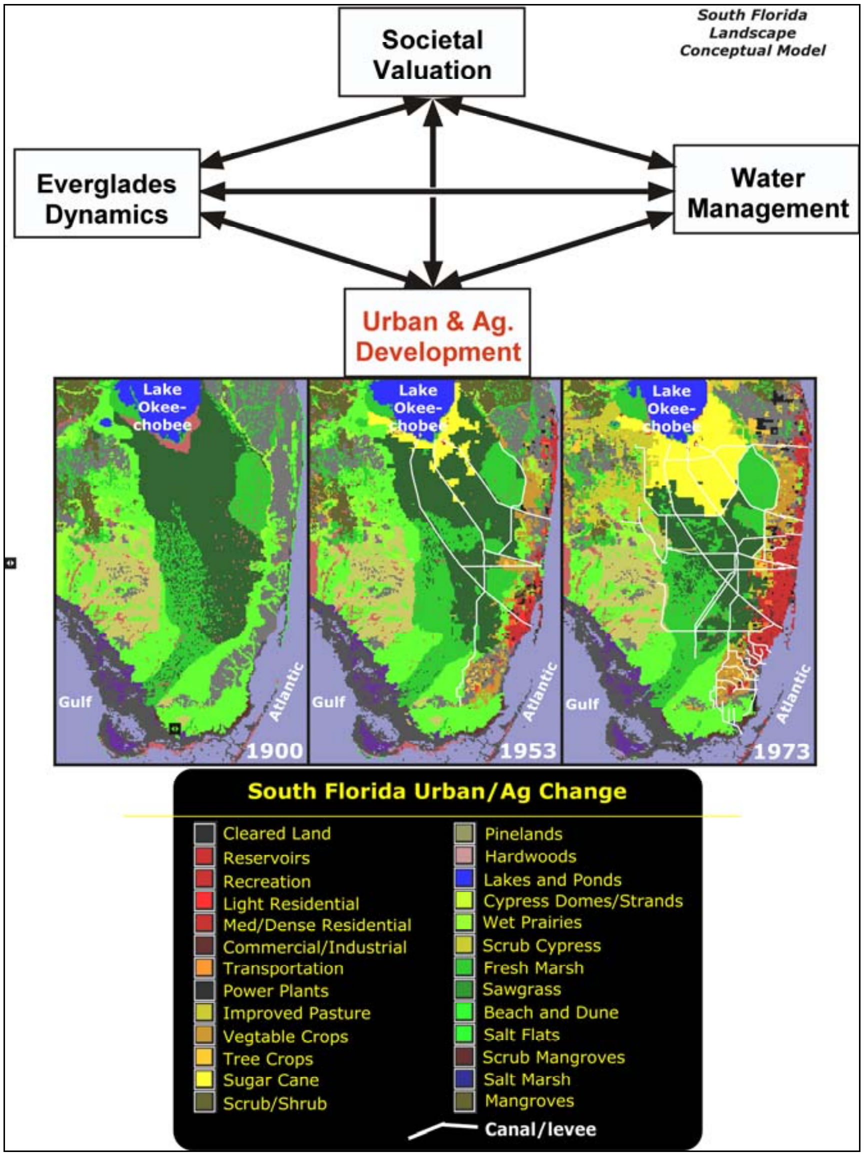
3.2.1 Societal valuation



Water Managers are responsible for balancing the various demands placed on our water resources in order to achieve a sustainable and productive environment for humans and the natural system on which we depend.

The economy of south Florida depends not only on tourism: agriculture contributes significantly to its productivity. The water resource needs of this sector are a significant consideration in water management planning. Water supply for residential demands is another important component of the regional water budget, while flood control for land used for agriculture and housing poses a different type of demand on water management. With human populations increasing dramatically since the mid 20th century in south Florida, water management has disrupted the natural timing and distribution of water in the Everglades, with concomitant deterioration in water quality. These changes have led to significant deterioration of this internationally recognized wetland. Demands for restoration of this unique landscape have come from the national and local levels, with citizens demanding that the natural system have a much greater consideration than in the past. Thus, a variety of publicly funded projects, including the ca. $9 billion Comprehensive Everglades Restoration Plan (CERP), have been initiated to restore this valued natural system. In this process, management alternatives are being tested to optimize the balance between the natural and human demands on water resources - with the primary objective involving the restoration the Everglades.

3.2.2 Urban and agricultural development

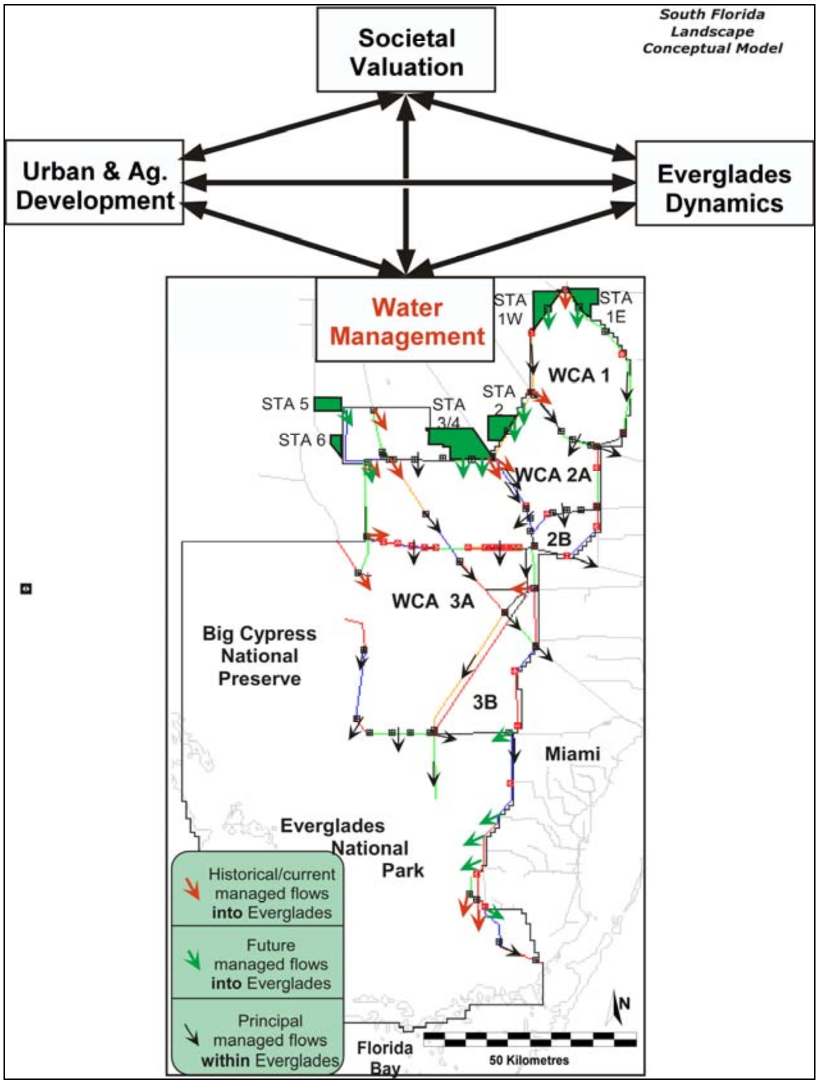


As canals and levees were built during the 19th and 20th centuries, agriculture and urban land uses dramatically increased, significantly reducing the spatial extent of the "natural" Everglades system by the mid 1970's.

Starting in the late 1800's and the early 1900's, long stretches of canals were dug in attempts to drain the relatively pristine Everglades for agriculture. Problems such as devastating floods led to Federal authorization (1948) of the Central and South Florida (C&SF) Project, creating an elaborate network of canals, levees, and water control structures to improve regional flood control and water supply. It was ultimately very effective in managing water for those purposes, accelerating the development of urban and agricultural sectors of the region. Agricultural and urban development has generally continued through the present day, particularly along the corridors east and north of the Everglades. The C&SF Project led to a reduction in spatial extent of the Everglades, and also fragmented the once-continuous Everglades wetlands into a series of large impoundments.

In the current-day Everglades, the existing management infrastructure bisects the area into a series of impoundments, or Water Conservation Areas (WCAs). Everglades National Park is south of these WCAs, while Big Cypress National Preserve is to the west. Agricultural land uses dominate the area just north of the Everglades, while extensive (primarily) urban land uses predominate along the eastern boundary of the Everglades. Lake Okeechobee, historically bounding the northern Everglades marshes, is now connected to those marshes via canals.

3.2.3 Water Management



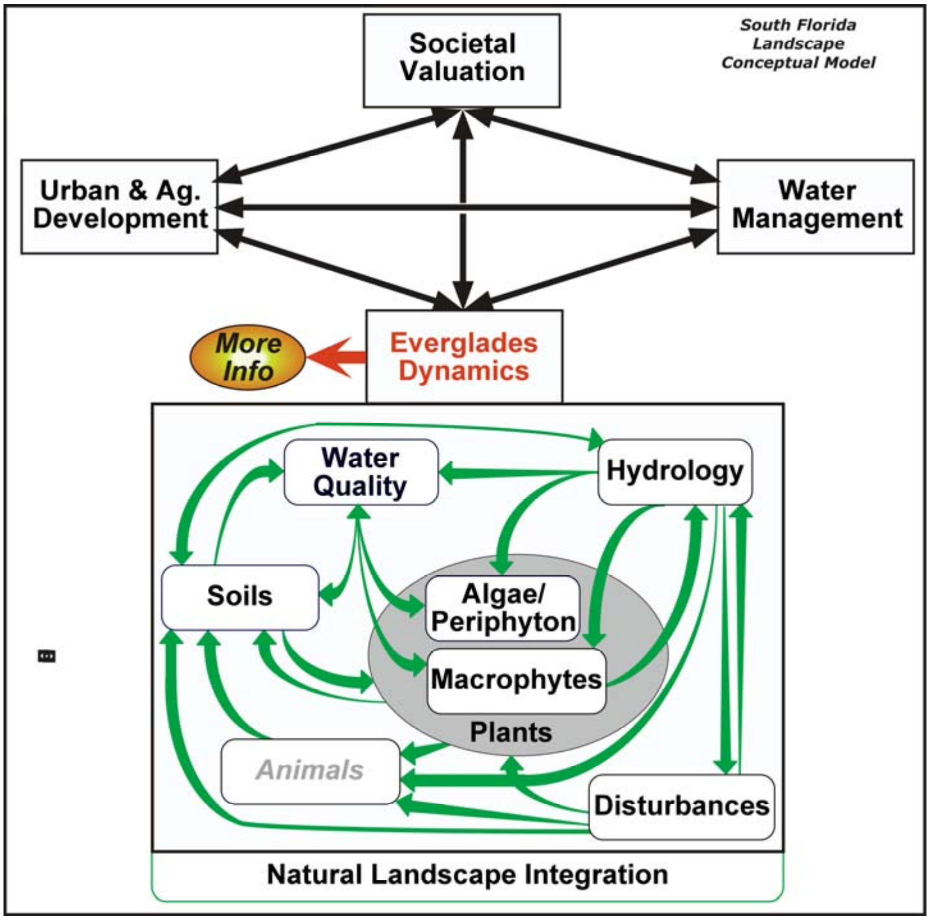
The managed flows of water into, and within, the Everglades are being evaluated by scientists and engineers in attempts to optimize the management network for the needs of this dynamic landscape.

The south Florida region, and much of the greater Everglades region, is driven by a complex engineering infrastructure that is operated to distribute water for environmental, water supply, and flood control needs. This network of canals, levees, and water control structures was designed many decades ago with the primary goal of improving water supply and flood control for the urban and agricultural sectors of the regional economy.

While successful in those respects, this hydrologic management - in conjunction with deteriorating water quality - had significant negative impacts on the Everglades ecology. The Everglades had been fragmented into separate, impounded basins (Water Conservation Areas) with dramatically altered flows and hydropatterns. Water historically flowed from the northern parts of the region into and through the Everglades largely as overland sheet flow. This flow regime changed to point releases at the pumps and weirs of water control structures. Operational criteria for these managed flows dictated the timing and magnitude of water distribution into and within the Everglades, further modifying its hydrology. With agricultural and urban runoff, many of these inflows also carried higher loads of nutrients into the historically oligotrophic (low-nutrient) Everglades. The altered distribution and timing of flows in a fragmented watershed, combined with increased nutrient loads, changed the mosaic of Everglades habitats - for the worse.

Details on the location, magnitude, and timing of these managed flows are vital components of understanding the Everglades dynamic response, from the scale of an individual tree island to that of the broader landscape of a Water Conservation Area or Everglades National Park. A variety of projects are underway to restore the Everglades by optimizing management of hydrology and water quality, two fundamental "drivers" of Everglades ecology. Multiple research groups are providing critical scientific insights into the benefits and risks associated with these endeavors, integrating quantitative ecological science into decisions on modifying Everglades water management.

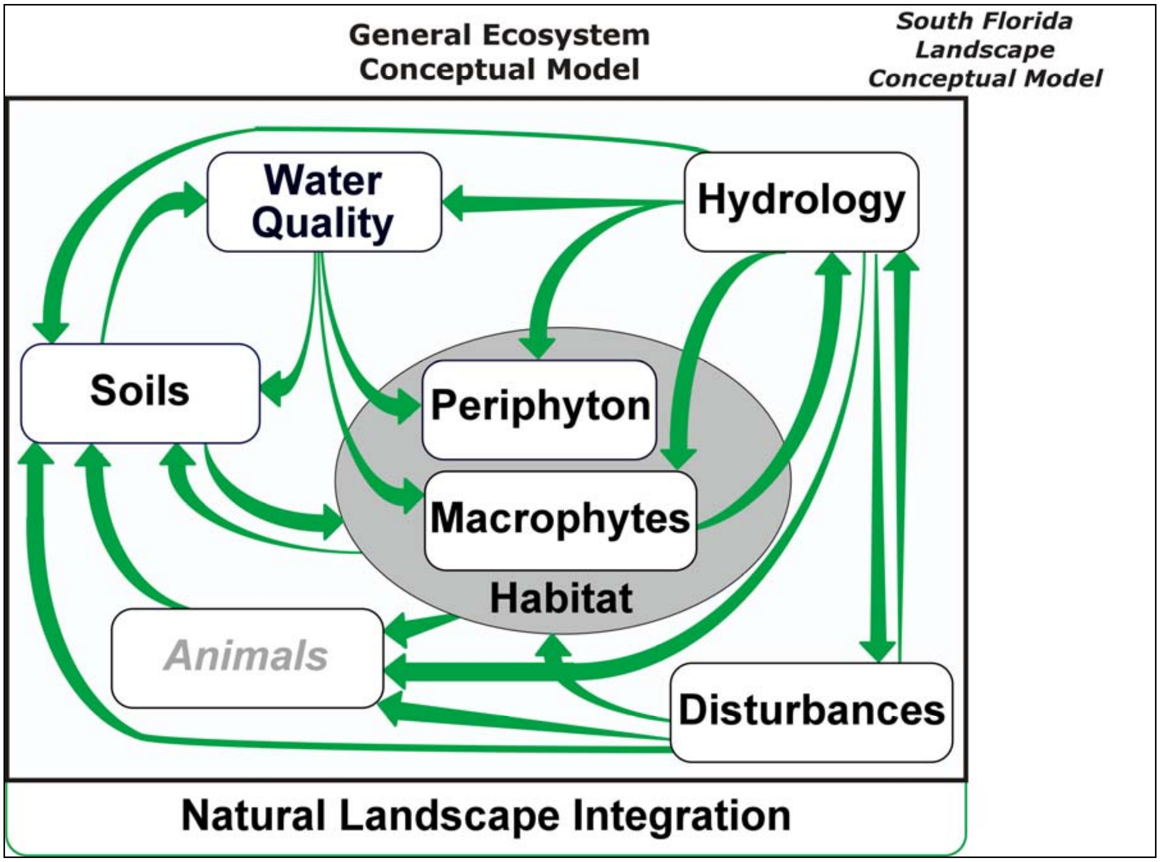
3.2.4 Everglades dynamics



As E.P. Odum (one of the "fathers" of ecology) put it, an ecosystem is more than the sum of its parts. The ecosystem feedbacks, or interactions, among the physical, chemical, and biological components of the Everglades landscape are fundamental to the dynamics of this complex system. Using a simple framework, we believe that insights into the basic interactive processes aid in better understanding the system behavior as a whole.

The Everglades landscape is a mosaic of different habitats that have evolved under a highly dynamic set of environmental conditions. As with any complex system, interactions among its different components are a fundamental aspect of its operation, and play an important role in sustaining the Everglades. [The human body is a complex system that is highly dependent on the proper interactions amongst it's physics (e.g., skeleton, blood flow), chemistry (e.g., nutrients, oxygen), and biology (e.g., organs, growth)]. The physical hydrology, biogeochemical nutrient cycling, and biology of plant & animal communities are determinants of the emergent ecosystem properties that comprise the landscape. Field/lab research and models involve methods to help understand these different "processes" that "drive" the system, providing us with insight into how to best attempt to restore and maintain this dynamic landscape.

3.3 General Ecosystem Conceptual Model

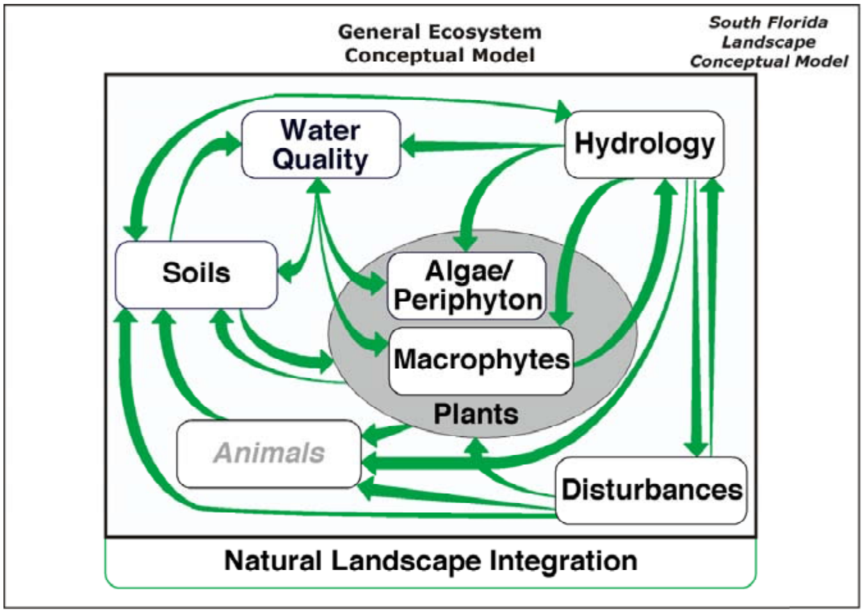


To assess the status of the natural system, it is critical to understand the interactions among the physical, chemical, and biological components of the Everglades landscape. ***The key is to simplify these interactions down to their most fundamental components, especially where supporting data are sparse.***

This **General Ecosystem Conceptual Model** summarizes the basics of these interactions among multiple variables in the landscape. *This conceptual model is at the heart of the dynamic equations that comprise the Everglades Landscape Model*, and has been part of a framework of research hypotheses. We have devoted a very large part of ELM efforts on developing the simplest set of fundamental, interacting equations that we believe effectively capture the essence of the important ecosystem dynamics.

Note: because the Everglades is such a tightly integrated functional system (as seen in the relationships in this Conceptual Model), it can be somewhat misleading to attempt to "measure" the performance of the system through one or two attributes such as water depth or water column nutrient concentration. The multiple Performance Measures that are being used for CERP and other restoration projects can best be understood and interpreted from a well-integrated, systems ecology perspective.

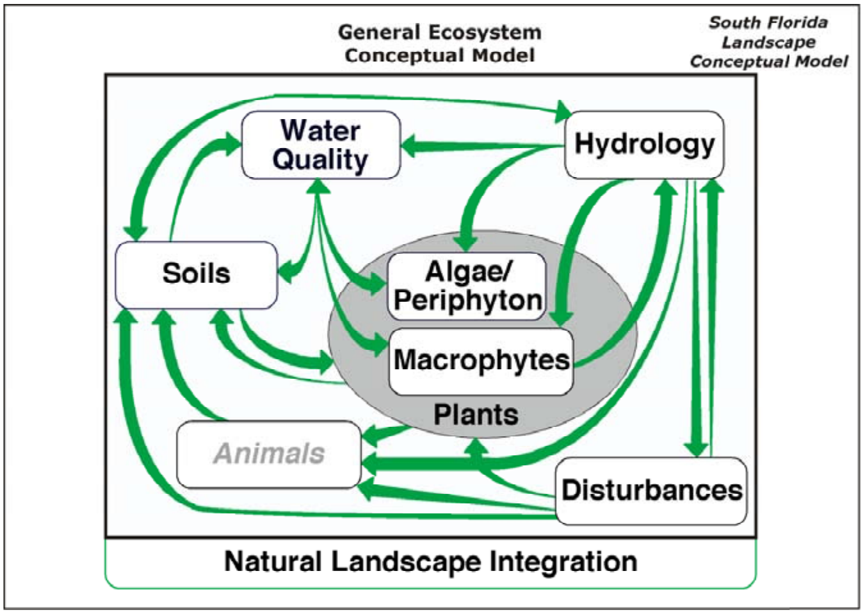
3.3.1 Hydrology



***Hydrology** is a critical "driver" of the landscape, in that we need to understand and get the water "right" in order to sustain a healthy Everglades.*

Hydrology is one of the "fast" processes that can change significantly on time scales on the order of hours, but climate change can produce decadal shifts in dynamics of the regional hydrologic cycle. While rainfall in south Florida is seasonal, it is variable both within seasons and among years. Intense rainfall events are often heterogeneously distributed at local scales; tropical disturbances can deluge the entire region. The pattern of water distribution (hydropattern) across the landscape is driven not only by rainfall inputs and (atmospheric- and macrophyte- mediated) evapotranspiration losses, but is intensively managed via the operations of the water management infrastructure (canals, levees, water control structures). Changes to water depths and flows can alter the habitat because different macrophyte species and algal/periphyton assemblages have distinct hydrologic adaptations. Likewise, changing water depths can alter the soils through increased accretion rates when wet for prolonged periods (i.e., long hydroperiods). On the other hand, soil losses increase with the oxidation (and fires) occurring under short hydroperiods. This increased soil oxidation increases the nutrient availability surface/soil waters. Soil nutrient chemistry is also affected by water exchanges between surface and soil/sediment water storages, a vertical advective process driven by groundwater losses due to plant transpiration and/or horizontal groundwater flows. Surface water flows are an important transport mechanism for nutrients and suspended organic matter in the landscape, while canal fluxes are faster across long distances. Surface water flows also play a role in suspension and deposition of soils & sediments, potentially altering the physical pattern of creeks and sloughs. While most of the horizontal flows in the Everglades are induced by head (elevation) gradients, wind and tide-driven circulation is predominant in Florida Bay. These surface flows are highly dependent upon the resistance to flow by macrophytes, and groundwater flows and seepage through levees vary significantly across the region depending on aquifer (or levee) transmissivity.

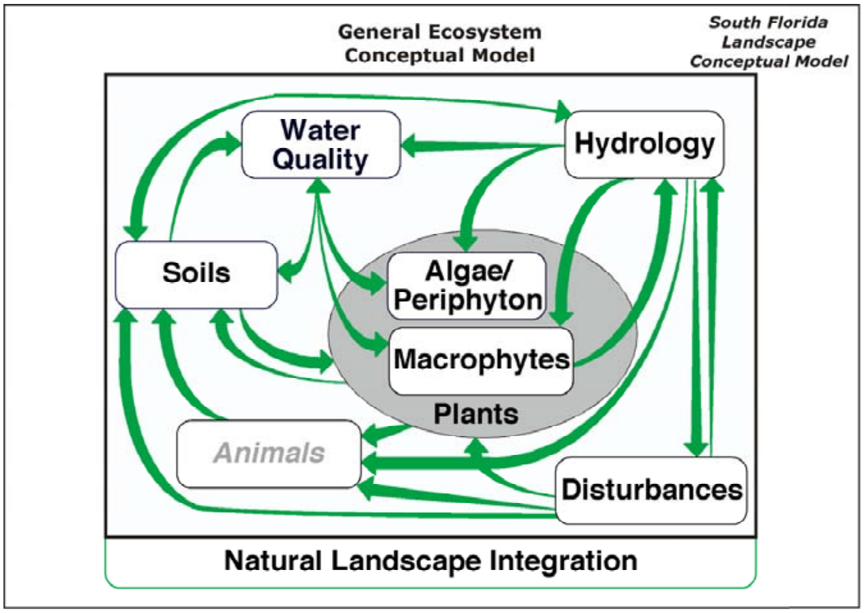
3.3.2 Water Quality



Water quality *has been responsible for shifts in primary productivity and species composition of macrophyte and periphyton communities, and is another primary "driver" of the landscape at fast (weekly to annual) time scales.*

Because the predominant "native" Everglades macrophyte and periphyton communities have adapted to oligotrophic (low nutrient) waters, increases in phosphorus and nitrogen (i.e., eutrophication) can be detrimental to the structure and the function of those communities. Phosphorus is generally the more limiting nutrient in the freshwater Everglades, while nitrogen tends to govern plant productivity rates in the southern Everglades/Florida bay where estuarine gradients occur. Typically, anthropogenic (man-made) loading of otherwise-limiting nutrients causes ecological imbalance, shifting the structure and function of the ecosystem. Management of flows through water control structures and canals has significantly modified the distribution of these nutrient loads and concentrations across the landscape. Different macrophyte and periphyton communities can uptake phosphorus and nitrogen at varying rates, changing the ambient water quality (and changing the plant tissues and growth). As water exchanges among surface and soil/sediment pore waters, the associated nutrient fluxes can alter the microbially-mediated rates of soil/sediment decomposition, releasing nutrients in inorganic forms that are more available for biotic uptake. Along with nutrient availability, salinity gradients in the southern Everglades/Florida Bay have the potential to modify communities that have adapted to particular environmental conditions.

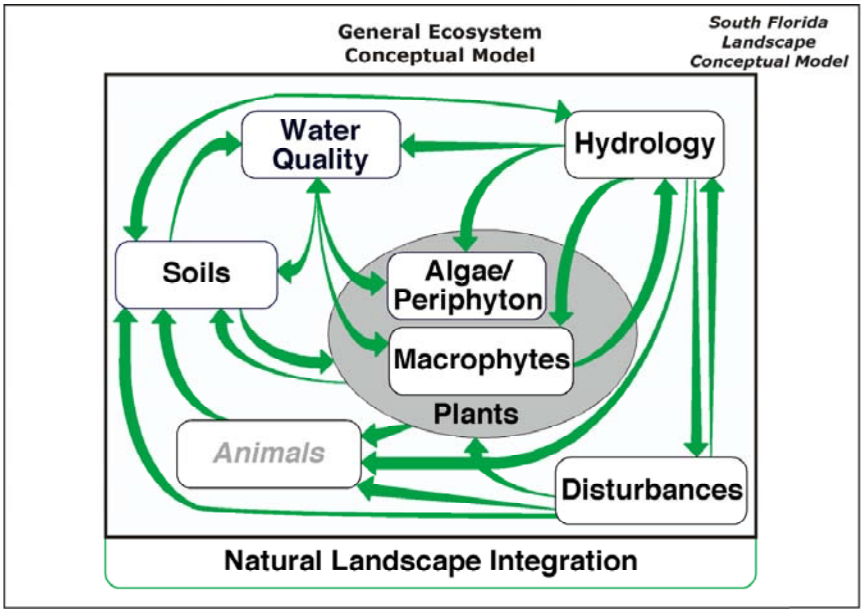
3.3.3 Algae/periphyton



__Periphyton__ (assemblages of __algae__ and microbes) are sentinel indicators of the quality of many habitats of the Everglades.

Periphyton are found attached to macrophyte stems, floating as mats in the water column, and as a benthic layer on top of the soil . Long considered an integral part of the animal food web, periphyton respond rapidly to changes in water quality and hydroperiod. Like macrophytes, "native" periphyton are adapted to oligotrophic (low nutrient) conditions, while a variety of other periphyton are common in eutrophic (high nutrient) waters. Another important control on periphyton and algae is light availability: at intermediate and high plant densities (such as in high nutrient areas), emergent marsh macrophytes shade periphyton, and (to some extent) prevent healthy communities from developing. Capable of senescing during dry periods and coming back to high growth levels upon rehydration, there are a variety of different types of periphyton species & communities, depending on the subregion of the Everglades and its local environmental conditions.

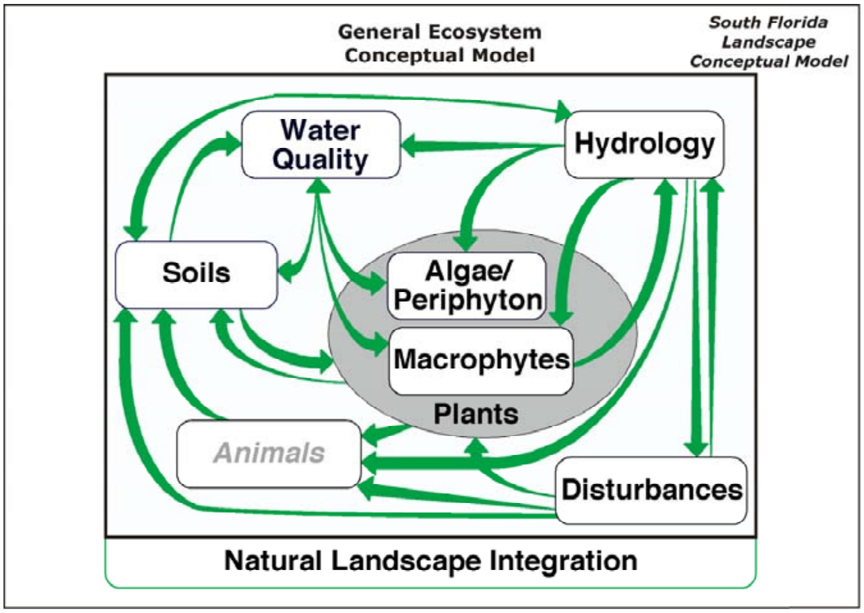
3.3.4 Macrophytes



***Macrophytes** are a primary determinant of the habitat quality in the Everglades landscape, which is largely defined by its heterogeneous mosaic of macrophytic vegetation that is dynamic over both annual and decadal time scales.*

There is a high diversity of plants in this region, ranging from emergent marsh plants such as the ubiquitous sawgrass, to hardwood trees of tree islands and mangrove forests. These, and many other common species, form a wide variety of plant communities with very different nutrient requirements, distinct hydrologic needs, and dynamic effects on the hydrologic cycle itself. Different adaptations by these plants create the habitat mosaic in response to a changing environment. For example, cattail is a "nuisance" species that grows rapidly in response to elevated nutrient availability, has morphological characteristics that allow it to thrive in flooded conditions, and easily colonizes areas that have been disturbed by man-made or natural events. Sawgrass, on the other hand, is a very dominant species in much of the Everglades where there are oligotrophic (low nutrient) conditions and "natural" fluctuations of water levels and disturbances. With mortality or dieback of leaves and roots of these plants comes the accumulation of organic matter in the form of peat soils. Tree islands have "died" in recent years due not only to excessive water depths covering tree roots for prolonged periods, but also due to fires in regions that have been overdrained and made more susceptible to catastrophic disturbance. Where regions of the Everglades have undergone successional shifts in plant communities, animal communities invariably are affected. Many animals are adapted to, and rely upon, high quality habitats that are often characterized by the heterogeneous, alternating distributions of dense and sparse vegetation of different species.

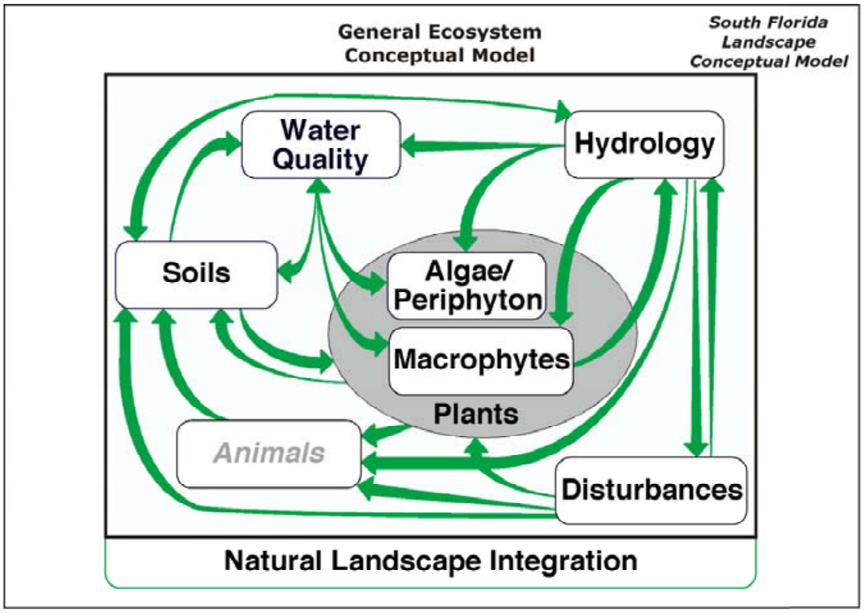
3.3.5 Soils



Soils (and sediments) *are in a long term, ca. decadal, balance between processes of accumulation and oxidation (and sometimes erosion), and are closely integrated with the development of different habitats.*

In regions of long hydroperiods where water ponds for much of the year, peat soils tend to accrete organic material that come from plant mortality and litterfall. Under shorter hydroperiods when those soils are exposed more frequently to the air (and thus more aerobic conditions), oxidation of the organic matter tends to reduce the depth of peat. This process is governed by microbial dynamics, and can be accelerated with higher nutrient availability. The oxidation of soil releases nutrients from tightly bound organic forms into inorganic chemical forms that are more readily available to plants and microbes. Disturbances such as droughts and "muck" fires can have significant impacts on peat soils, rapidly oxidizing the organic carbon, but leaving behind much of the nutrients to which the ecosystem may respond. Throughout much of the Everglades is a upper-soil layer of flocculent (fluffy) organic material that is partly live periphyton, but is principally the organic material from dead periphyton and macrophytes. This "floc" appears to play a critical role in nutrient cycling and transport of organic material among habitats - and potentially forms part of a detrital food web for animals. Thus, soils are closely integrated with water quality and plant or periphyton growth, and respond strongly to changes in hydrology. Inorganic constituents of soils vary in importance through the Everglades system, with calcitic periphyton sequestering calcium and phosphorus into an inorganic component that forms marl soils.

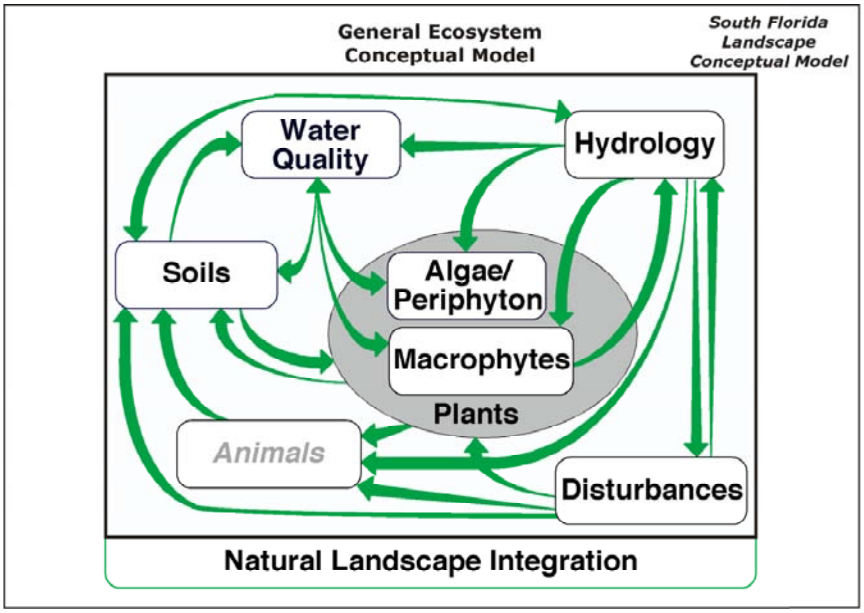
3.3.6 Disturbances



Disturbances *such as fires, hurricanes, and severe drought or flooding can alter the ecological characteristics of the landscape over short and long time scales. There exists an important interaction between response to disturbances and the pre-existing structure and function of these dynamic ecosystems.*

The primary disturbances considered in the current version of the Everglades Landscape Model are drought and flood conditions. The Everglades landscape has adapted to "expect" natural variability in climate and related disturbances. While droughts and fire may appear to decimate the landscape, most of the vegetation and animal communities of the region can respond in positive ways: fire occurring in relatively local "patches" at infrequent intervals can enhance the system by opening up new space or clearing away brush species amongst cypress or hardwood communities; hurricanes may flush accumulated organic debris from the shallows of Florida Bay. However, there is potential danger in management regimes that exacerbate the natural response to disturbances. If the seasonality and frequency of disturbances are significantly altered, areas that remain overly dry during unusual periods can experience severe "muck" fires that burn deeply into the peat and eliminate more soil and vegetation than "surface" fires. Such fires can burn away the carbon in the soil, leaving elevated levels of phosphorus. Some macrophyte species such as nuisance cattail rapidly colonize and thrive in such a highly disturbed environment. Regions that have accumulated stresses such as long term nutrient loading can be "primed" for dramatic, potentially catastrophic shifts in the ecological balance.

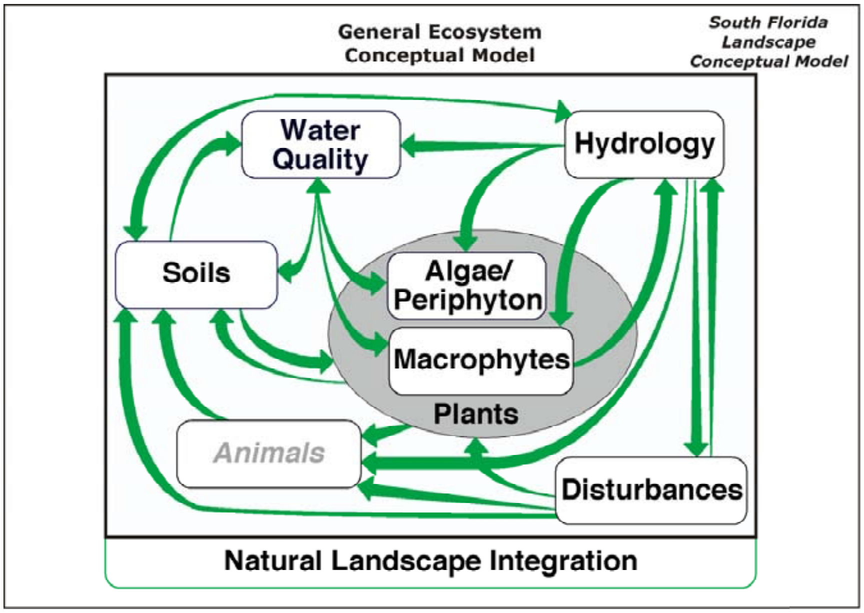
3.3.7 Animals



***Animal** communities tend to integrate and respond to many of the factors that change the habitat mosaic of the landscape. Different populations of animal species have distinct reproductive and migratory habits that result in complex seasonal, annual, and decadal shifts in their population viability as the landscape evolves.*

The current Everglades Landscape Model does not consider animal dynamics, simulating only their habitat landscape. The ELM assumes that the higher trophic levels respond to changes in habitat, without the animal communities affecting the regional landscape changes over long time periods. Although most animals do not appear to significantly affect ecosystem processes or landscape patterns, some modify local habitats at small spatial scales, such as the development of ponds excavated by alligators for nesting, or local nutrient enrichment from colonies of birds. Wading birds are one of the conspicuous animals that thrive in the various hydrologic and habitat gradients of the Everglades. They respond to changing water levels and availability of (fish and other) prey, and can select for subregions throughout south Florida as conditions change among seasons and years. While fish are capable of migrating within regions of suitable hydrology and habitat, they obviously become limited in range, (and potentially more available as prey), as a region dries out. Many Everglades fish are omnivorous, feeding on a variety of detrital and invertebrate food sources. The nature of the interactions among animal populations, and among animals and their habitats, is one (very dynamic) indicator of the "health" of the landscape.

3.3.8 Integrated landscape



*An **integrated landscape** perspective allows us to synthesize the principal aspects of this dynamic system. The interactions among the ecological processes modifies the landscape pattern, while there is a critical effect of this pattern on the nature of these ecosystem processes themselves.*

Many research projects are conducted at relatively small scales in the laboratory or the "field". By formally aggregating and extrapolating some of these data, simulation modeling and other landscape-level analyses (such as those associated with the Everglades Landscape Model project) facilitate our understanding of the spatial and temporal interactions of this complex system. As part of this procedure, mapping the vegetation and soils gives a spatial perspective on the landscape pattern. To understand temporal interactions, many research projects provide insights on the mechanisms underlying the rates of change in soils, habitats, animals, and landscape drivers such disturbances, hydrology, and water quality. Simulation models allow us to further develop hypotheses on the landscape dynamics over long time scales, and can be used to make relative predictions of landscape responses at the appropriate temporal and spatial scales of interest.