14.0 Total System CERP-Specific Conceptual Ecological Models and Performance Measures

The total South Florida ecosystem encompasses all natural areas that were once interconnected and embedded within the vast Everglades basin, which once extended from coast to coast and from the upper Kissimmee basin headwaters south to the Gulf or Mexico and Florida and Biscayne Bays (**Figure 14-1**). This area includes all areas already covered by regional modules (Lake Okeechobee, Northern Estuaries, Greater Everglades and Southern Estuaries).

A conceptual ecological model has been developed for the total South Florida system, referred to as the Total System (Ogden et al. 2005). This model is based on defining characteristics of the South Florida ecosystem: 1) abundant large vertebrates and aquatic prey bases, 2) animals with large spatial requirements, 3) healthy, dynamically sustainable estuaries, 4) oligotrophic freshwater wetlands, and 5) complex landscape mosaics and interactions. Restoration of this system will be successful once defining characteristics of the pre-altered system are recovered to the extent possible given reduction of spatial extent.

Neither the *CERP Monitoring and Assessment Plan: Part 1, Monitoring and Supporting Research* (RECOVER 2004) nor the final draft of the *Monitoring and Assessment Plan (MAP), Part 2, 2006 Assessment Strategy for the MAP* (RECOVER 2006), referred to as the Assessment Strategy, contains a Total System module. Therefore, CERP-specific models for the Total System are presented here for the first time and the section is much longer than preceding regional sections. Like regional conceptual ecological models presented in proceeding sections, these models contain only those stressors and attributes expected to be affected by CERP.

Boundaries of the Total System (**Figure 14-1**) used by RECOVER to consider CERP's system-wide effects are the same as those used in the overarching conceptual ecological model (Ogden et al. 2005). For the most part, regional modules have smaller boundaries to limit the area considered to that affected by CERP. The purpose of the Total System module is to look at CERP's effects system-wide, whether effects were expected in an area or not.

Only a few total system performance measures have been developed to date, but many indicators in regional performance measures will provide information related to defining characteristics. These measures have been added to the CERP-specific Total System Conceptual Ecological Model diagrams along with the total system measures. Additional total system performance measures are currently being developed and existing measures are being refined.

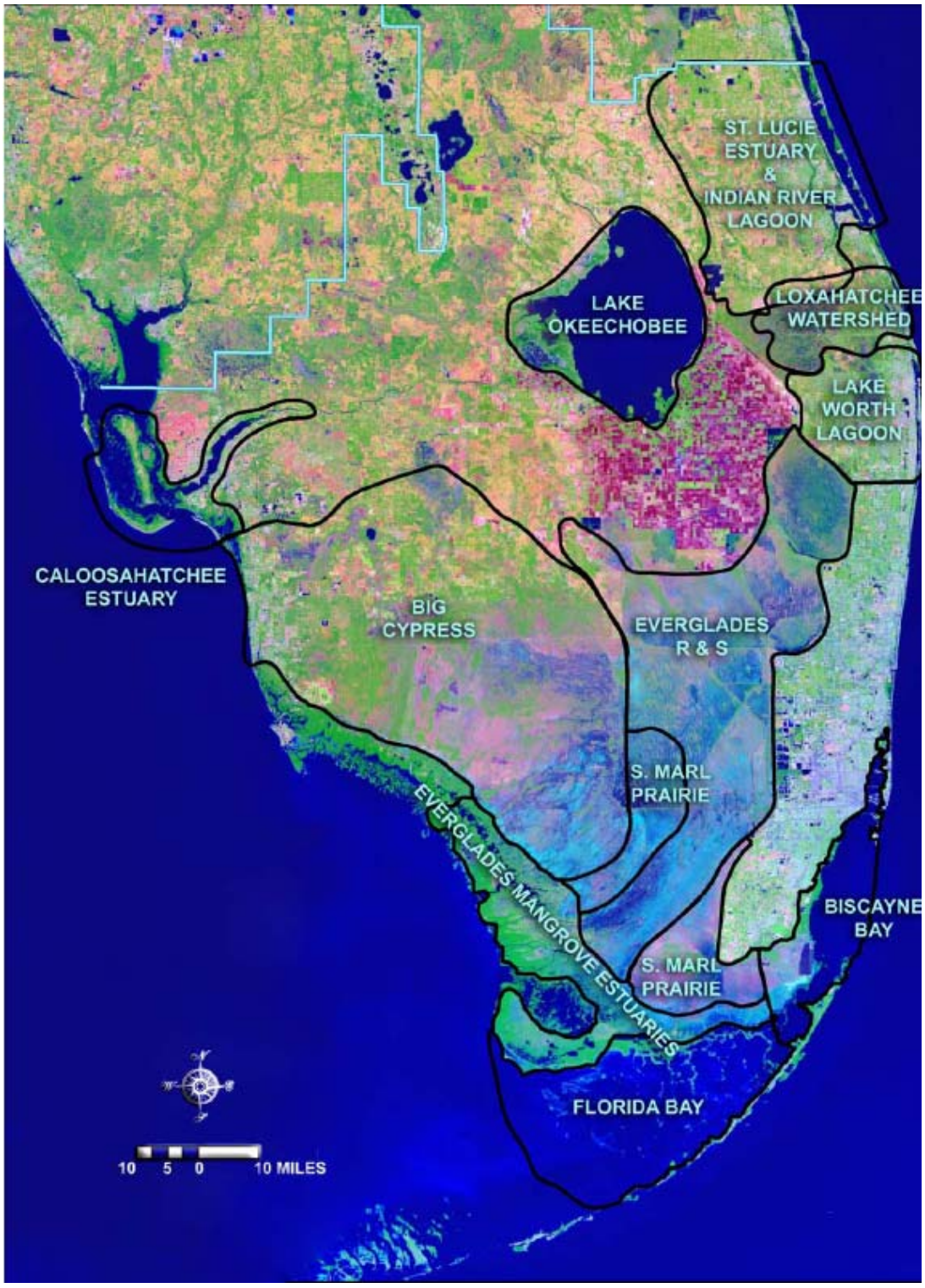

Figure 14-1. Total System Conceptual Ecological Model boundary

14.1 Abundant Large Vertebrates and Aquatic Prey Bases

Large vertebrates that were abundant in the pre-drainage Everglades include white ibis, wood stork and American alligator. These species, and populations of major prey organisms upon which they feed, including marsh fishes and crayfish, represent defining characteristics of the Everglades. These attributes are all affected by marsh aquatic fauna prey base, hydroperiod and depth patterns, and habitat availability and fragmentation (**Figure 14-2**). Water management and land use practices have resulted in increased inputs of nutrients; loss of connectivity, sheet flow and spatial extent; introduction and spread of exotic plants and animals; and altered volume and timing of flow, distribution of regional hydropatterns, salinity gradients, geomorphology and topography. The relationship between large vertebrates and aquatic prey base has also been addressed in the Predator-Prey Interactions of Wading Birds and Aquatic Fauna Forage Base Conceptual Ecological Model (**Figure 11-9**) in the Greater Everglades section of this document.

Performance measures developed for Greater Everglades and Southern Estuaries regions relate to stressors, effects and attributes within the Abundant Large Vertebrates and Aquatic Prey Bases pathway (**Figure 14-3**). Measures have been developed for phosphorus and nitrogen input into and surface water concentrations within Greater Everglades wetlands. Hydrology performance measures have been developed for sheet flow, water levels, flows, dry events and inundation pattern for Greater Everglades and Southern Estuaries. Salinity performance measures have been developed for the southern edge of the Everglades. Greater Everglades performance measures pertaining to attributes of this model include those for wading bird foraging patterns; wading bird nesting patterns; fish, crayfish, grass shrimp and amphibian populations; and alligators. These attributes are discussed in more detail in the following sub-sections.

White Ibis

White ibis was, and remains, the numerically dominant species of wading bird in South Florida wetlands. As many as 50,000 to 100,000 pairs nested in some years during the 1930s to early 1940s in large “super colonies” located in inland headwaters of tidal streams at the lower end of the Everglades system (Ogden 1994). Ibis forage to a large extent in very shallow water on freshwater crayfish, as well as on high concentrations of smaller size-classes of fishes. White ibis are much more nomadic than traditional in selecting nesting colony sites, with large numbers of birds moving quickly to form nesting colonies wherever foraging conditions are locally favorable (Frederick and Ogden 1997). This reproductive strategy works well when ibis can forage over extensive areas of wetlands.

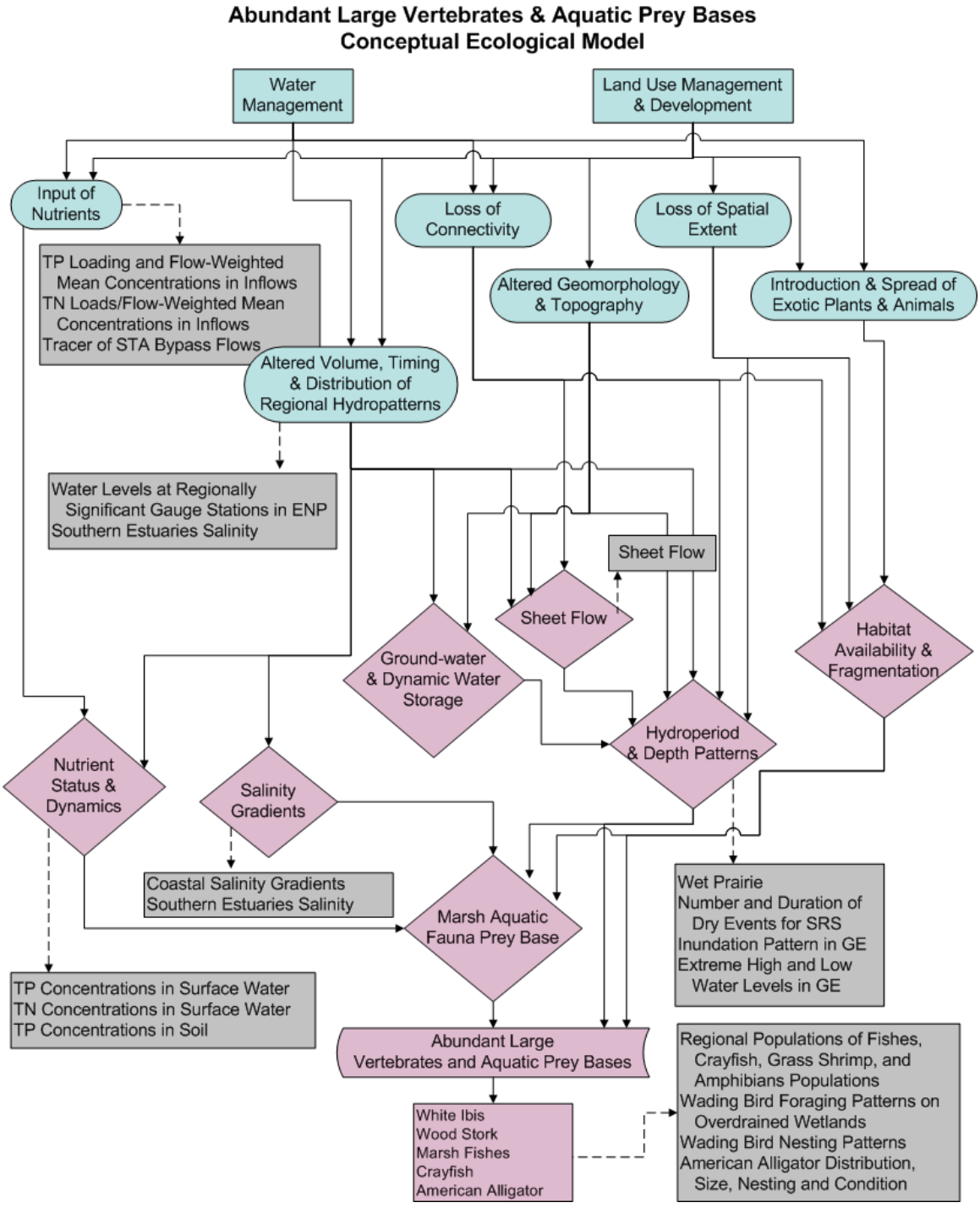

Figure 14-2. Abundant Large Vertebrates and Aquatic Prey Bases Conceptual Ecological Model and associated performance measures

Wood Stork

Historically, well over one-half of the total U.S. population of wood storks nested in 3-5 large colonies in South Florida (Ogden 1978). Total number of nesting storks in South Florida prior to about 1960 may have ranged annually between 7,000 and 10,000 pairs (Ogden 1994). Storks nest primarily in locations where drying of wetlands produces high concentrations of right size classes of fishes (Kushlan et al. 1975, Ogden et al. 1978). Stork's foraging strategy is to soar for long distances out of nesting colonies to locate places where water depths and fish concentrations are appropriate. These long foraging flights were an important factor that made it possible for storks to return annually to traditional colony sites in an environment that under natural conditions had highly variable water depth and distribution patterns. The great expanse of pre-drainage wetlands provided an overall abundance of prey as well as many options for long-flying adults to exploit a succession of drying wetlands over about a four-month nesting cycle for storks. Overall, wood stork epitomized pre-drainage wetlands, in that it is a species that developed a large local population by exploiting extensive space and variable habitat conditions that characterized the South Florida system.

Marsh Fishes

Population density, size structure and relative abundance of fishes in South Florida wetlands are regulated by annual duration of uninterrupted flooding. Relative abundance of fish species also responds to hydroperiod. Relative abundance affects size structure. Marsh fishes and associated aquatic fauna concentrate in high-density patches where birds can feed effectively as water levels recede during the dry season.

Crayfish

Crayfish are an abundant and important prey resource for many faunal species of South Florida, including several species of wading birds, reptiles, amphibians and mammals (Kushlan and Kushlan 1979, Ashton and Ashton 1988, Conant and Collins 1991, Choate et al. 1994, Fredrick and Spalding 1994, Tenant 1997). As prey, they provide important links between energy stored in detrital and herbaceous matter and higher order vertebrate predators (Momot et al. 1978).

American Alligator

American alligator was an abundant and ubiquitous animal in pre-drainage wetlands. Alligators are dependent on hydrologic conditions for growth and survival (Hines et al. 1968, Fogarty 1974, Wilkinson 1983). Open water is required for breeding (McIlhenny 1935, Garrick and Lang 1975, Garrick and Lang 1977, Vliet 1987). Nesting success is also dependent on egg survival during an extended incubation period, when they can be exposed to flooding or desiccating conditions (Joanen 1969, Kushlan and Jacobsen 1990, Fleming 1991). Alligator are an important keystone species in South Florida, where its activities have shaped the landscape by creating ponds and trails that provide important survival, foraging and movement functions for many species.

14.2 Animals with Large Spatial Requirements

Animals within the South Florida system that require large spatial requirements include white ibis, wood stork, Florida panther and snail kite. These are affected by habitat availability and fragmentation (**Figure 14-3**). Habitat is affected by three stressors, which are driven by water management and land use: loss of connectivity, loss of spatial extent, and introduction and spread of exotic plants and animals.

White Ibis and Wood Stork

The pre-drainage Everglades system was dominated by large populations of two species of wading birds, white ibis and wood stork, with different foraging habitats and nesting strategies (Ogden 1994, Frederick and Ogden 1997). Ibis forage in very shallow water in wetlands that dried annually in most years. Ibis tend to forage for prey close to colony locations and, therefore, relocate their colony sites and alter timing of nesting from year to year in responses to shifting locations of high prey densities. Storks forage on larger marsh fish, often in deeper pools that did not dry annually. As mentioned above, storks routinely soar to forage great distances from colony sites. Historically, ibis initiated nesting in most years in mid- to late dry seasons when regional water levels were generally low, while storks initiated nesting early in dry seasons when water levels were generally higher. With a comparatively short nesting cycle for ibis and a much longer cycle for storks, both species fledged young birds into regional marshes at about the same time in the late dry season when prey concentrations in late-drying parts of the system were high. The Everglades system could support contrasting behavioral patterns of these two species because of the large spatial extent of the system and temporal and spatial complexity of landscape mosaics and water depths. Greater Everglades Performance measures have been developed for wading bird foraging and nesting patterns (**Figure 14-3**).

Snail Kite

Prior to the 1920s, kites in Florida were commonly observed at many shallow, freshwater, long-hydroperiod wetland sites throughout much of the peninsula. Population size in pre-drainage Florida is unknown but must have numbered in the thousands. The Florida subspecies, commonly known as the snail kite, was federally listed as endangered in 1967. Kites are highly nomadic, roost and nest colonially or in loose aggregations, and are specialized predators of freshwater apple snails. Long-term survival of healthy populations of kites depends on availability of numerous habitat options where kites can relocate in response to spatially and temporally complex wet and dry climate patterns. A Total System performance measure has been developed for snail kite foraging conditions (**Figure 14-3**).

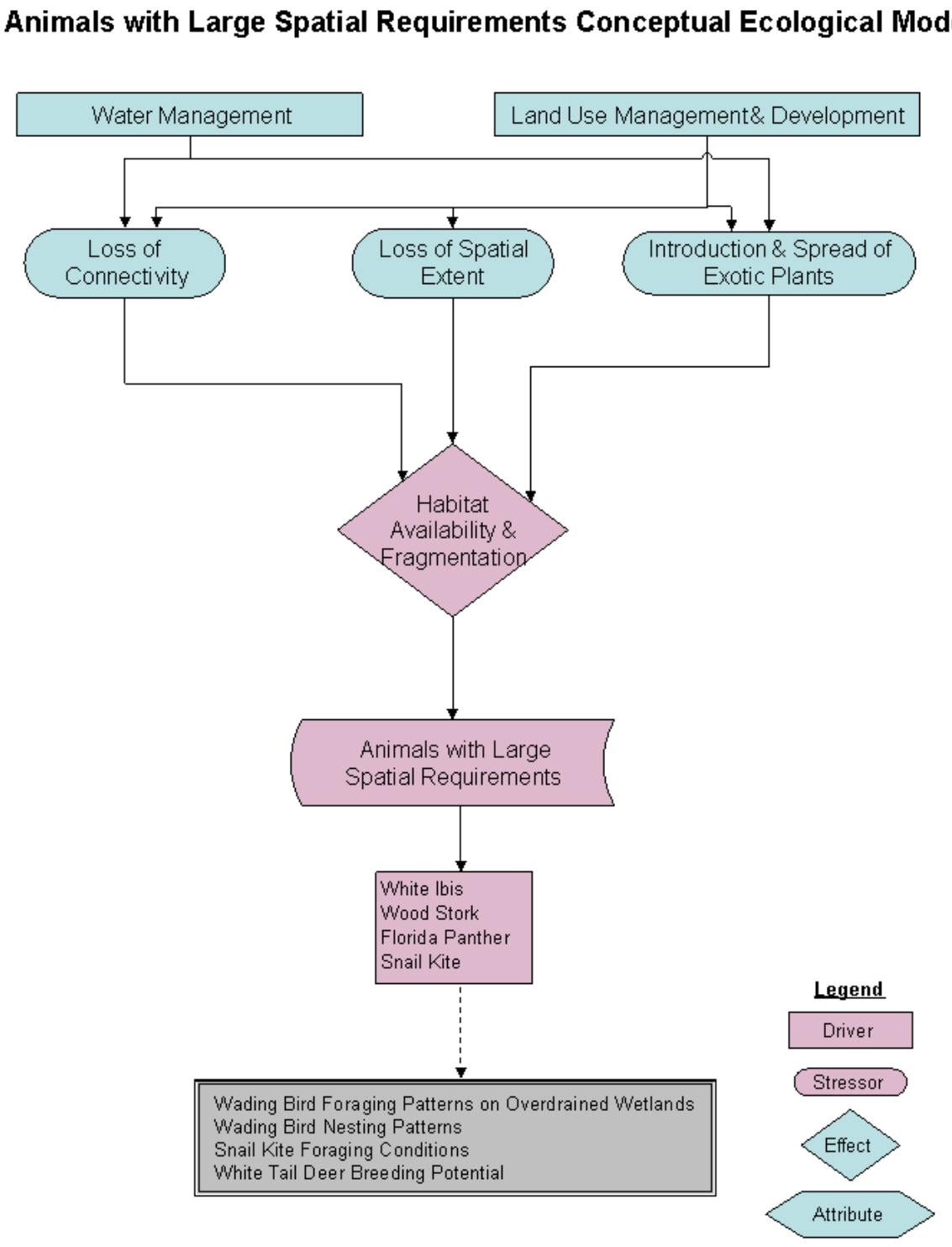

Figure 14-3. Animals with Large Spatial Requirements Conceptual Ecological Model and associated performance measures

Florida Panther

Prior to drainage, Florida panthers occurred throughout uplands and short hydroperiod wetlands of Florida. Panthers require large home ranges. Numerous factors influence actual home range size and reproductive success, including habitat quality, prey density and landscape configuration. Panther dispersal tends to be interrupted by natural barriers (e.g., large water bodies) and anthropogenic barriers (e.g., highways, urban areas, large expanses of row crops and improved pasture) (Maehr et al. 2002, Beier et al. 2003). White-tailed deer and wild hogs are dominant prey for panthers, while rabbits, raccoon and armadillos were of secondary importance (Beier et al. 2003). As Florida panthers are scarce and hard to track, white deer are used as a surrogate indicator (**Figure 14-3**).

14.3 Healthy, Dynamically Sustainable Estuaries

Water management and land use changes, along with sea level rise, have altered volume, timing and distribution of fresh water to South Florida's estuaries (**Figure 14-4**). These alterations have altered natural salinity gradients. Restoration of more natural salinity gradients and nutrient dynamics is necessary for healthy, dynamically sustainable estuaries. CERP goals include reestablishing more natural salinity gradients by restoring freshwater flow to estuaries. Several performance measures have been developed for freshwater flow and salinity gradients/patterns (**Figure 14-4**). A sheet flow performance measure has been developed for the ridge and slough landscape and is currently under review. The Southern Estuaries Salinity performance measure has targets for surface water flow and salinity envelopes. Another Southern Estuaries performance measure has targets for water levels at gauges in Everglades National Park from which water flows into Florida Bay. Salinity gradient performance measures have also been developed for Northern Estuaries and Everglades mangrove estuaries.

Nutrient inputs to the Everglades and Lake Okeechobee have increased as a result of water management and land use changes. Increased inputs have the potential to affect nutrient dynamics within estuaries, especially with reestablishment of freshwater flow to Southern Estuaries via the Everglades. Nutrient input increases to Lake Okeechobee have already affected Northern Estuaries. Winds from three recent hurricanes, Francis and Jeanne in 2004 and Wilma in 2005, have caused resuspension of phosphorus-rich sediments within Lake Okeechobee's water column. Heavy rains have required large-scale releases of these phosphorus-laden waters to tide via St. Lucie and Caloosahatchee Estuaries resulting in extensive algal blooms. As these events have occurred after the Total System Conceptual Ecological Model (Ogden et al. 2005) was written, they are not currently reflected in the following discussions. Performance measures have been developed for nutrients in estuaries (**Figure 14-4**).

Four indicators have been chosen to best represent estuary conditions: 1) functional submerged aquatic vegetation (SAV)-phytoplankton balance, 2) nitrogen-phosphorus balance, 3) American oyster, and 4) nursery ground function. Reasons these indicators were chosen are discussed below.

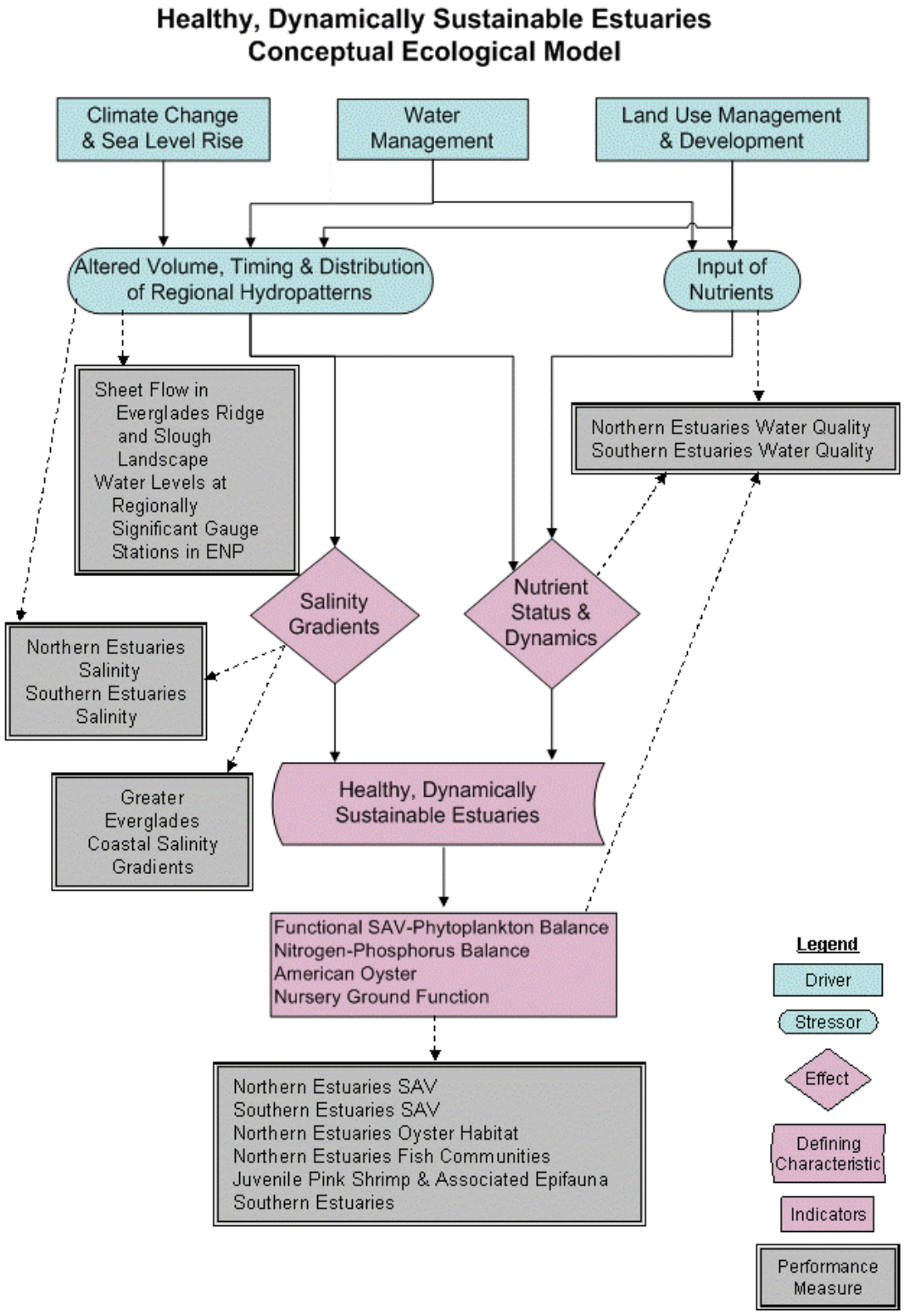

Figure 14-4. Healthy, Dynamically Sustainable Estuaries Conceptual Ecological Model and associated performance measures

Functional SAV-Phytoplankton Balance

Within estuaries and coastal lakes of the South Florida ecosystem, SAV provides habitat and nursery grounds for many fish and invertebrate communities (Gilmore 1977, Ogden and Zeiman 1977, Gilmore et al. 1981, Furse and Fox 1994). Changes in SAV distribution, composition and density due to changes in quantity, quality, timing and distribution of freshwater flows into coastal water bodies (**Figure 14-4**) can be detected and remotely mapped at a system-wide scale. SAV is sensitive to water clarity, nutrient levels and salinity (Hurley 1991, Dennison et. al. 1993, Morris and Tomasko 1993, Stevenson et al. 1993). SAV communities may not only be directly influenced by nutrient inputs from a watershed; they may influence effects of these nutrients by competing with phytoplankton for them and altering nutrient cycles. Performance measures for SAV and algal blooms have been developed for Northern and Southern Estuaries (**Figure 14-4**).

Nitrogen-Phosphorus Balance

With strong phosphorus retention, the pre-development Everglades watershed probably released low phosphorus concentrations to downstream estuaries. Even with land development and phosphorus enrichment of the Everglades, phosphorus loads to the coast through the Everglades remain low (Rudnick et al. 1999). Hydrologic conditions strongly influence nutrient uptake via changing plant community structure and productivity, nutrient retention and release via changing microbial (including periphyton) activity in and above the soil (**Figure 14-4**), and changing transport. In particular, nitrogen transformations are highly sensitive to molecular oxygen concentration, and thus sensitive to hydrologic conditions. Likewise, within estuaries, nutrient (both nitrogen and phosphorus) processing and availability are strongly influenced by community structure and oxygen concentrations that are in turn influenced by salinity conditions, which will change with restoration (Rudnick et al. 2005). The Southern Estuaries Water Quality performance measure pertains to nutrients.

American Oyster

Oyster reefs constitute a major habitat and their presence is indicative of a functional mesohaline community dependent upon upstream freshwater inflows (**Figure 14-4**). Decreases in oyster harvests are attributed to habitat loss, disease and water quality problems. The primary ecological importance of the American oyster is as a filter-feeding primary consumer, as prey for numerous higher consumers, and as habitat. All of these are important in overall estuarine ecology. The filtration process results in greater light penetration, promoting SAV growth immediately downstream from oyster bars. The American oyster is highly sensitive to salinity and siltation. A performance measure has been developed for Northern Estuaries oyster habitat (**Figure 14-4**).

Nursery Ground Function

South Florida forage fish and invertebrate communities fill a critical role in the estuarine food web by serving as prey for higher trophic level species, such as game fish, water birds and dolphin. Pink shrimp is ecologically important in Florida Bay, Biscayne Bay

and mangrove estuaries of southwest Florida as a major link between food web base and top consumers, including game fish (Rutherford et al. 1982, 1983, Schmidt 1989, Koenig et al. 2001) and wading birds (Palmer 1962). Pink shrimp is also economically important as the basis of the multi-million-dollar Tortugas fishery (Upton et al. 1992) and other fisheries. Pink shrimp spawn on Tortugas grounds; resulting larvae/post-larvae migration to Florida Bay, where they spend their juvenile stage, then return to Tortugas grounds to spawn. The entire cycle occurs in just a few months, enhancing potential for determining influencing factors. A performance measure has been developed for juvenile pink shrimp and associated epifauna (**Figure 14-4**).

SAV communities within estuaries provide nursery habitat for juvenile stages of reef and recreationally important fishes (Virnstein et al. 1983, Lewis 1984). Spotted seatrout is almost entirely dependent on estuaries throughout its life cycle (Iverson and Tabb 1962) because it does not move offshore to spawn (Bryant et al. 1989) and may not move out of the home estuary throughout its entire life (Weinstein and Yerger 1976). For this reason, its status may be indicative of local estuarine conditions. Performance measures have been developed for Northern and Southern Estuaries fish communities (**Figure 14-4**).

14.4 Oligotrophic Freshwater Wetlands

Prior to development and drainage, the Everglades was an oligotrophic wetland system that received external water and nutrient inputs primarily from direct rainfall (Davis 1994). Inputs of nutrients to the pre-drainage Everglades were non-point source rainfall and sheet flow with relatively low concentrations of phosphorus. Construction of the C&SF Project's drainage system of canals, pump stations and levees, and subsequent conversion of sawgrass plain to the Everglades Agricultural Area, changed patterns of nutrient input to point source discharges of agricultural drainage water (Light and Dineen 1994).

Input of nutrients, mainly phosphorus, and alteration of regional hydropatterns, which have resulted from the water management system and land use changes, have affected nutrient status and dynamics of Everglades wetlands (**Figure 14-5**). Increased nutrient concentration in surface water and soil within these wetlands has resulted in changes to the periphyton community (Browder et al. 1994, McCormick et al. 2002) and has caused a dramatic shift from diverse herbaceous communities to communities dominated by a few invasive exotic and native species (Davis 1994). Greater Everglades nutrient loading and hydrological performance measures relate to stressors affecting indicators of this defining characteristic. Hydrologic performance measures include 1) Sheet Flow in Everglades Ridge and Slough Landscape, 2) Wet Prairie, 3) Number and Duration of Dry Events for Shark River Slough, 4) Inundation Pattern in Greater Everglades Wetlands, and 5) Extreme High and Low Water Levels in Greater Everglades Wetlands. The sheet flow and wet prairie performance measures are still under review.

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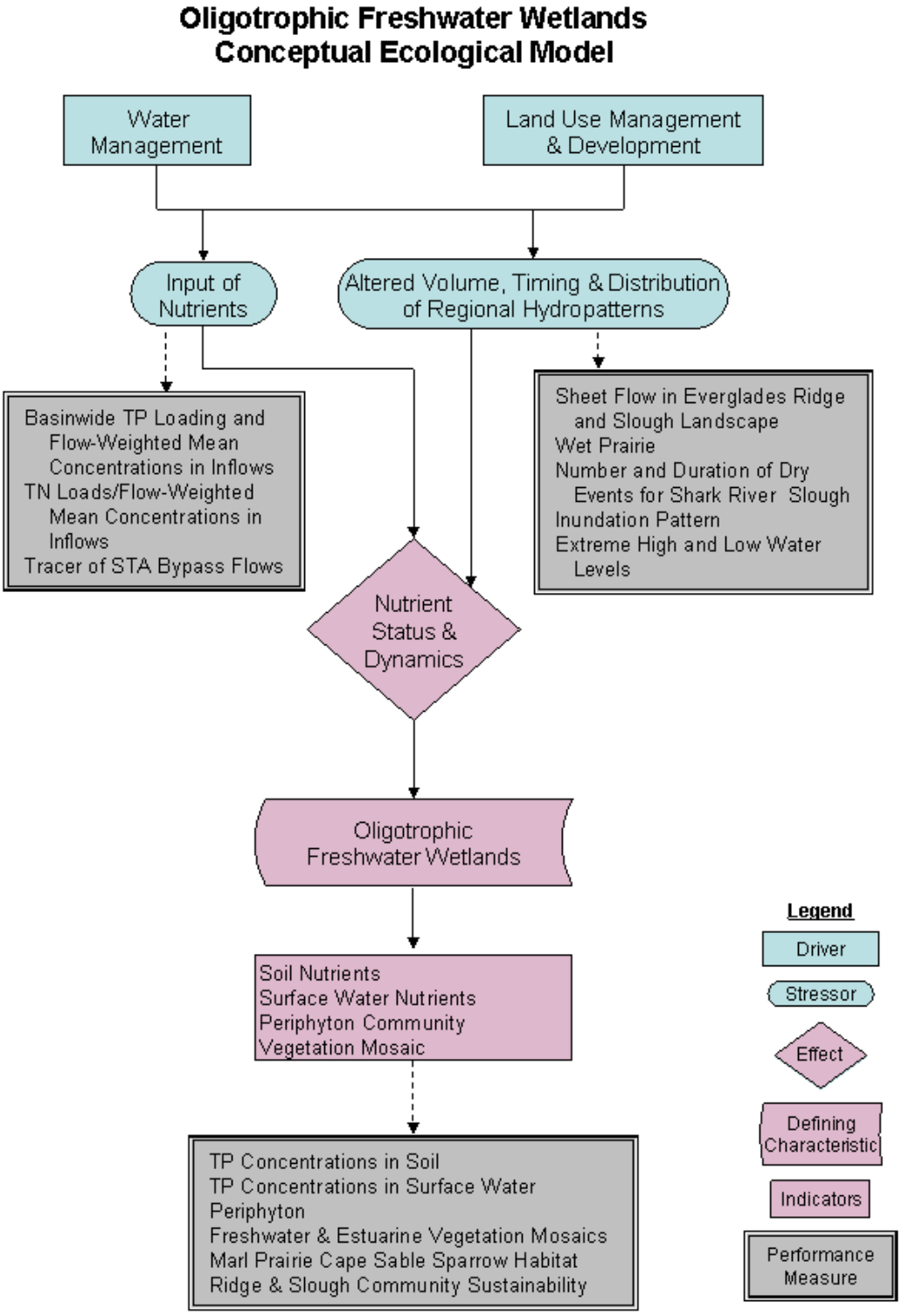

Figure 14-5. Oligotrophic Freshwater Wetlands Conceptual Ecological Model and associated performance measures

Indicators for this defining characteristic are soil nutrients, surface water nutrients, periphyton community and vegetation mosaic (**Figure 14-5**). Performance measures have been developed for the Greater Everglades region that relate to these indicators. Total Phosphorus (TP) Concentrations in Soil relates to soil nutrients. Performance measures have been developed for both TP and TN concentrations in surface water and periphyton. Three Greater Everglades performance measures pertain to vegetation mosaic: 1) Freshwater and Estuarine Vegetation Mosaics, 2) Marl Prairie Cape Sable Sparrow Habitat, and 3) Ridge and Slough Community Sustainability

14.5 Complex Landscape Mosaics and Interactions

Major landscape and topographic features of South Florida form a mosaic and a dynamic continuum from upland to freshwater wetland to estuarine habitats. Scrub forests, rockland hardwood and pine forests, hydric pine flatwoods, sawgrass plains, southern marl prairies, ridge and slough peatlands, cypress and hardwood swamp forests, oligohaline wetlands, mangrove forests, and estuarine lagoons transition along gradients of elevation, substrate, hydropattern, fire and salinity. They are affected by alterations in gradient as well as by loss of spatial extent, inputs of nutrients, and introduction of exotic plants and animals (**Figure 14-6**). Performance measures have been developed for the Greater Everglades for nutrient inputs and altered hydrology. Two broad ecological functions of the Everglades at the total system, biodiversity and foraging options for mobile vertebrates, are indicators for this defining characteristic.

Biodiversity

Spatial extent of many South Florida landscapes is sufficiently large to sustain communities and reproducing populations of indigenous plants and animals, many of which are limited in distribution to specific landscapes or habitats. Examples include the Cape Sable seaside sparrow breeding population (Pimm 1995) that are endemic to southern marl prairies and more than 100 plant species that have been reported from that landscape (Olmstead and Loope 1984). Multiple landscapes of sufficient size thus support a species richness for the total Everglades ecosystem that is high in comparison to that of specific landscapes and to other wetland systems with lesser landscape complexity and spatial extent. Flora comprises approximately 850 species in 20 associations across major South Florida landscapes.

Upland landscapes strongly contribute to plant and vertebrate species richness in South Florida despite their limited spatial extent in comparison to wetlands. Rockland pine forests support 186 species of understory plant species (Loope et al. 1979) and 50-75 species of hardwoods, mostly of West Indian origin (Taylor and Herndon 1981), including 51 species of special concern, most of which are endemic (Gunderson 1994). Rockland tropical hammock forests support the greatest number of rare and threatened plants in South Florida, including 59 taxa (Gunderson 1994). Endemic vertebrates are concentrated in limited upland areas in comparison to more expansive wetlands, and vertebrate species that are represented by relatively small populations are more numerous in upland habitats (Robertson and Frederick 1994).

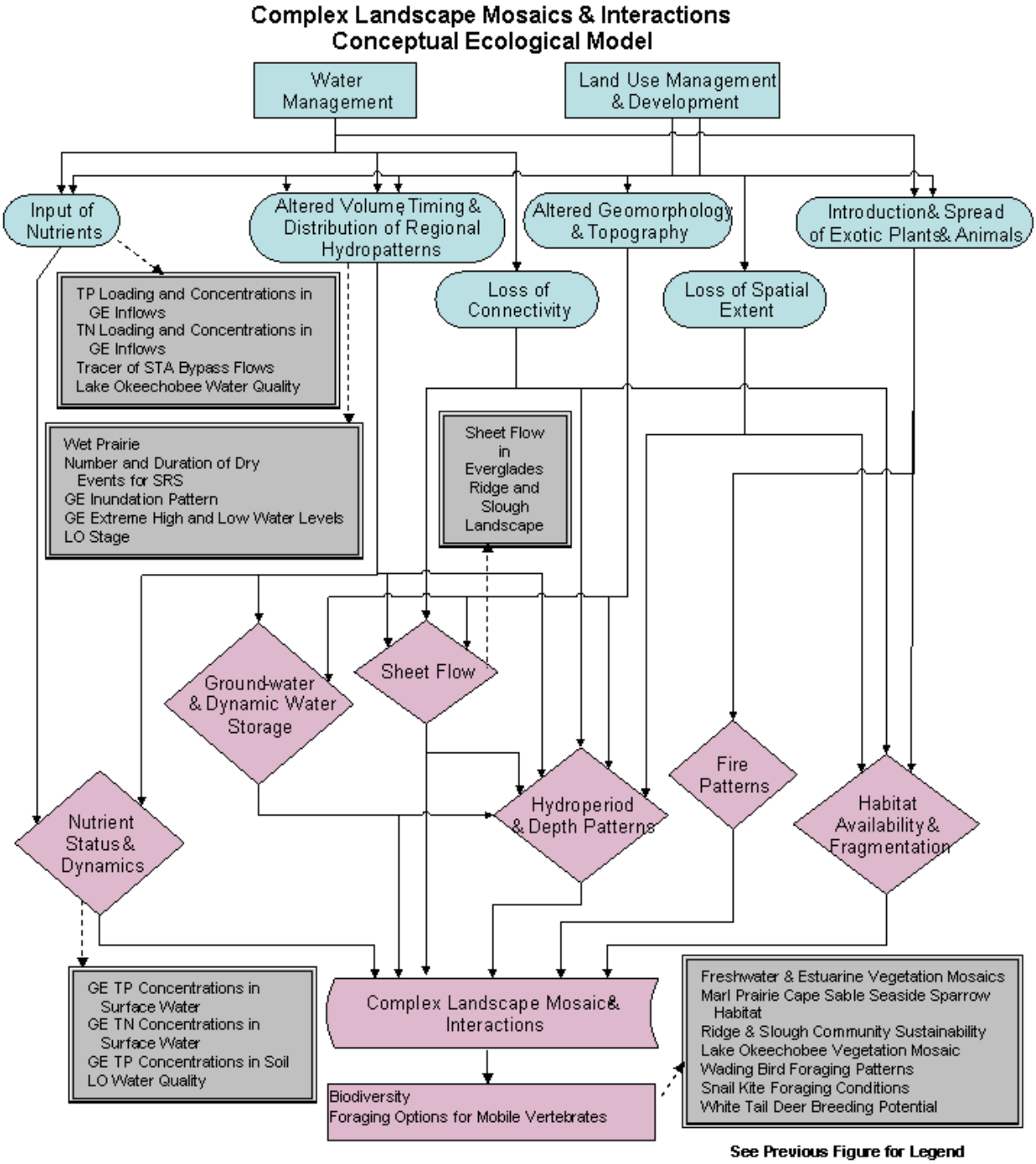

Figure 14-6. Complex Landscape Mosaics and Interactions Conceptual Ecological Model and associated performance measures

Several performance measures have been developed that can be used to track biodiversity during CERP implementation. Within the Greater Everglades region, measures have been developed for the following wetland landscape patterns: freshwater and estuarine vegetation mosaics, marl prairie Cape Sable seaside sparrow habitat, ridge and slough community, and tidal creeks. Measures have been developed for vegetation mosaics within Lake Okeechobee. Northern and Southern Estuaries have SAV measures.

Foraging Options for Mobile Vertebrates

The large spatial extent of the natural system included topographic and physiographic variations that provided a "hierarchy of choices" for vertebrates in the system (Holling et al. 1994). Resulting range of foraging options sustained highly mobile fauna, including water birds, snail kites and Florida panthers during annual and inter-annual fluctuations in climate and hydrology (Ogden et al. 1978, Browder 1984, Hoffman et al. 1994). For this indicator, two Total System performance measures have been developed: Snail Kite Foraging Conditions and, as a surrogate for the Florida panther, White Tail Deer Breeding Potential.

Receding water levels produced water depths and prey concentrations suitable for wading bird foraging early in the dry season in short-hydroperiod wetlands, such as southern marl prairies, to be followed by a succession of favorable foraging conditions in longer-hydroperiod ridge and slough and oligohaline habitats as the dry season progressed (Ogden 1994) (**Figure 14-7**). Progression of water-level succession and prey concentration across short and long-hydroperiod landscapes supported successful wading bird nesting from its early initiation through fledging before advent of summer rains and dispersion of prey. A performance measure has been developed for wading bird foraging patterns in the Greater Everglades region.

14.6 Summary of Total System Performance Measures

As mentioned in the introduction to this section, most indicators within this model are covered by performance measures developed for the regions. Exceptions to this are measures for snail kite and white tail deer, which is a surrogate for the Florida panther. A performance measure has also been developed for system-wide mercury but it is not linked to this or any other conceptual ecological model. The *CERP Monitoring and Assessment Plan: Part 1, Monitoring and Supporting Research* (RECOVER 2004) does contain a South Florida Mercury Bioaccumulation Module. A summary list of Total System performance measures is as follows:

- Snail Kite Foraging Conditions
- White Tail Deer Breeding Potential
- Mercury Bioaccumulation

Documentation sheets for these performance measures can be found on the Total System Performance Measures web page:
http://www.evergladesplan.org/pm/recover/perf_total_system.aspx.

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