11.0 Greater Everglades CERP-Specific Conceptual Ecological Models and Performance Measures

The Greater Everglades region includes J.W. Corbett Water Management Area/Pal Mar, the water conservation areas (WCAs), Everglades National Park, mangrove estuaries along the southern coast, part of Big Cypress National Preserve, and Lake Okeechobee littoral zones (**Figure 11-1**). Lake Okeechobee littoral zones are included because wading birds and alligators utilize these areas.

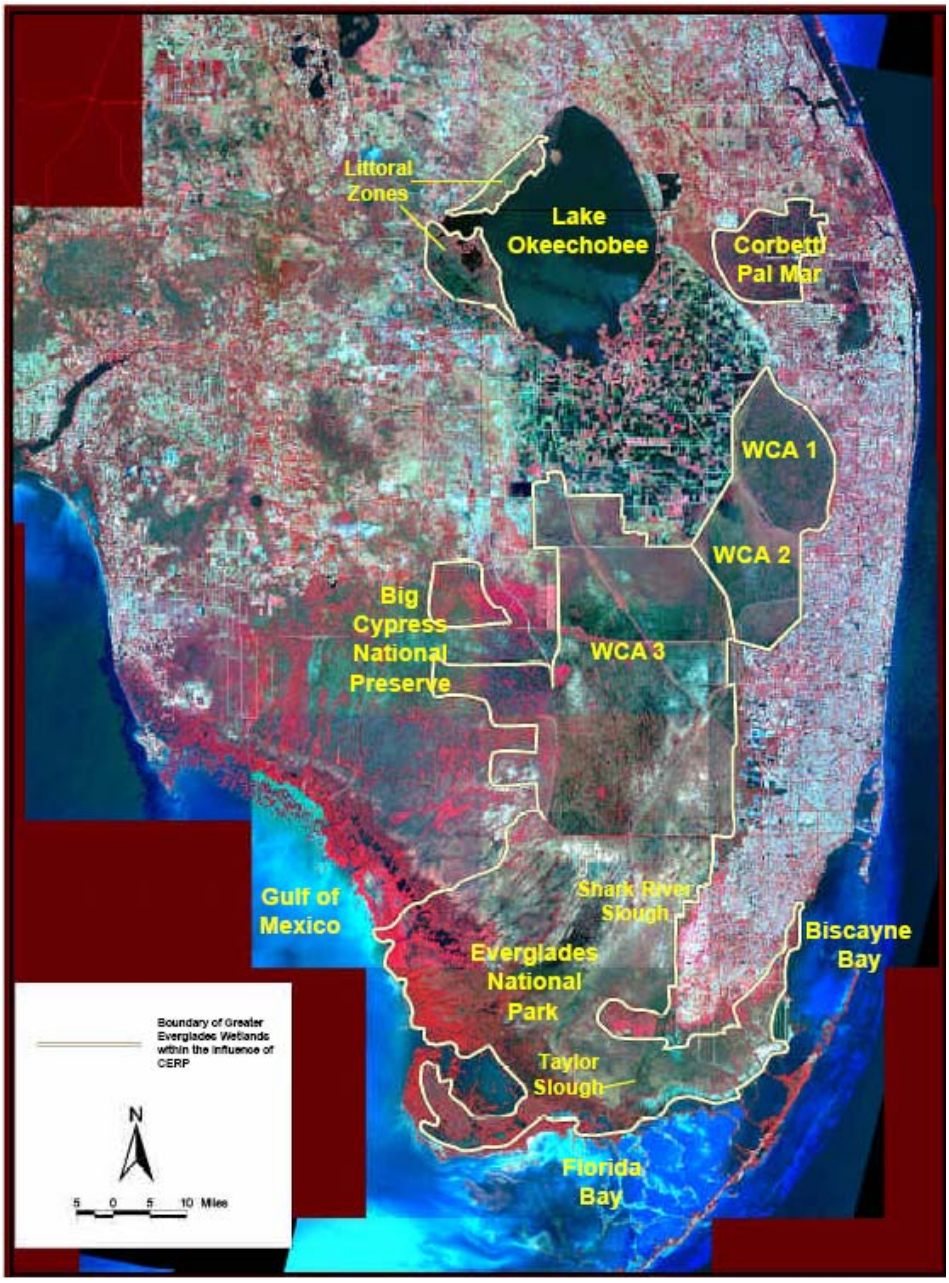

Figure 11-1. Boundary of Greater Everglades within CERP influence CERP

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, includes the clusters of interrelated hypotheses for the Greater Everglades. CERP-specific conceptual ecological models were developed to depict pathways described in hypotheses clusters:

- Integrated Hydrology and Water Quality
- Coastal Transgression
- Tidal Channel Characteristics
- Coastal Salinity Gradients
- Mangrove Forest Production, Organic Soil Accumulation and Resilience
- Ridge and Slough Landscape Dynamics
- Plant Communities/Elevation Gradients
- Predator-Prey Interactions of Wading Birds and Aquatic Fauna Forage Base
- Linkage of Periphyton to Higher Trophic Levels
- Everglades Crocodilian Populations

The following sections summarize descriptive text for hypotheses and present conceptual ecological models along with how performance measures relate to them. Application of performance measures during evaluation (planning) and assessment process, including the hypothesis-based approach, are discussed in more detail in Section 2. Full discussion of hypotheses clusters from the draft Assessment Strategy can be accessed from the CERP System-wide Performance Measures web page: http://www.evergladesplan.org/pm/recover/recover_docs/et/060507_pm_report/hypothesis_clusters_ge.pdf.

11.1 Integrated Hydrology and Water Quality

Direct rainfall onto a vast wetland landscape of low topographic relief resulted in sheet flow and low levels of phosphorus and other chemical constituents in the predrainage Everglades. Restoration of the Everglades ecosystem depends on restoration of volume, timing and distribution of sheet flow and on restriction of inputs of phosphorus and other chemical constituents to levels approximating those in direct rainfall.

Sheet flow, in combination with direct rainfall, produced fundamental hydrologic and landscape characteristics of the predrainage Everglades (**Figure 11-2**). Compartmentalization has altered or eliminated sheet flow and related natural system hydrologic and landscape characteristics throughout the Everglades. Decompartmentalization combined with resumption of natural volume, distribution, and timing of freshwater delivery is expected to restore sheet flow and predrainage hydrologic and landscape characteristics to an undivided ecosystem encompassing much of WCA 3A and 3B, eastern Big Cypress and Everglades National Park. A sheet flow performance measure has recently been developed and is under review.

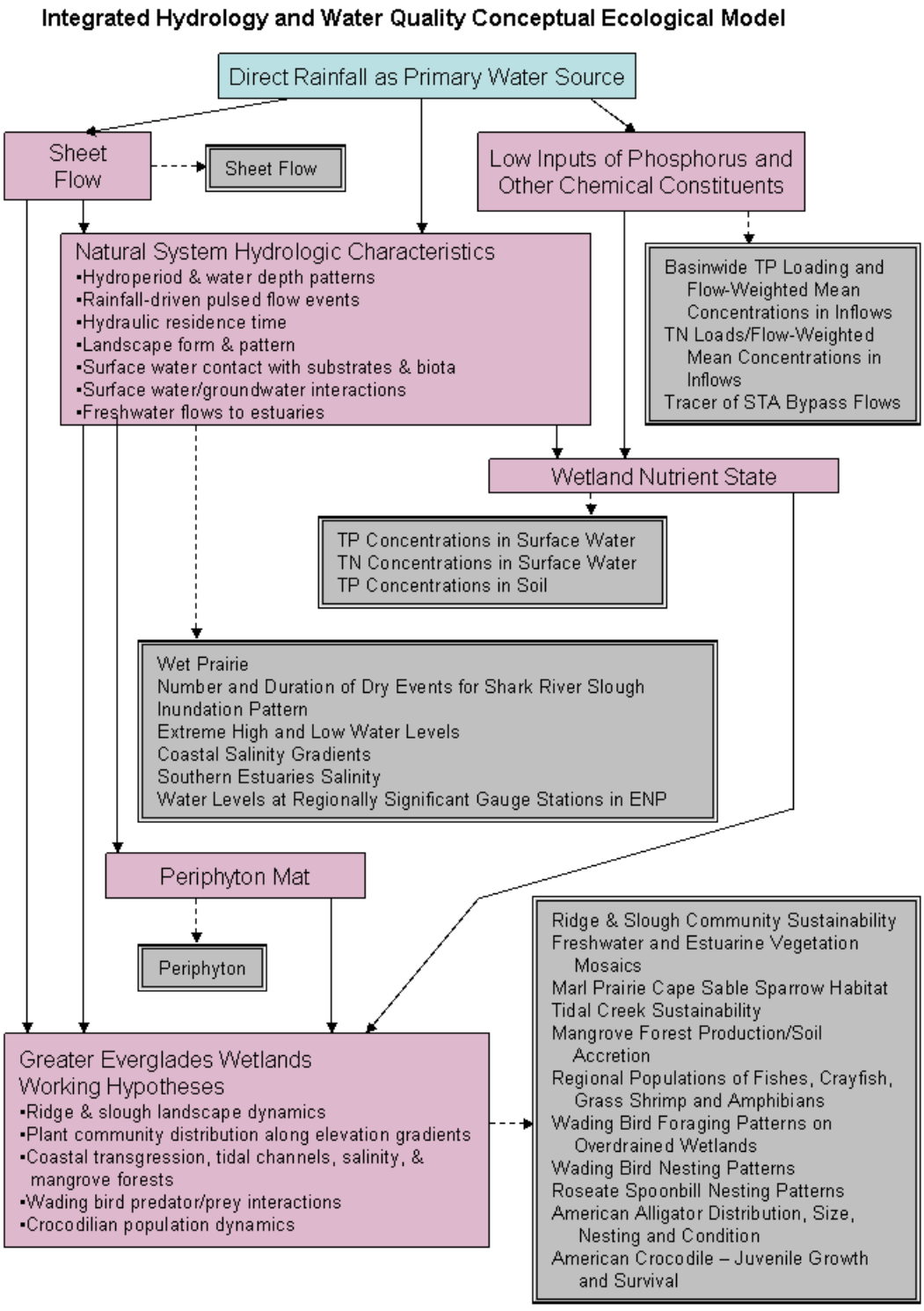

Figure 11-2. Integrated Hydrology and Water Quality Conceptual Ecological Model with associated performance measures

Performance measures have been developed to measure hydrologic responses of Greater Everglades freshwater wetlands to CERP implementation: 1) Wet Prairie, 2) Number and Duration of Dry Events for Shark River Slough, 3) Inundation Pattern in Greater Everglades Wetlands, and 4) Extreme High and Low Water Levels in Greater Everglades Wetlands. The Wet Prairie performance measure has recently been developed and is under review. Performance measures have also been developed to measure hydrologic response of mangrove estuaries to altered freshwater flows resulting from CERP implementation: 1) Coastal Salinity Gradients and 2) Southern Estuaries Salinity. The second measure is a Southern Estuaries performance measure, but it also pertains to Everglades mangrove estuaries within the Greater Everglades module boundary.

Increased phosphorus concentrations and loads in agricultural runoff water, and replacement of sheet flow with canal flows and point-source discharges, have produced phosphorus concentration gradients downstream of canal discharge structures, shifting wetlands from oligotrophic to eutrophic states. Nitrogen dynamics are dominated by local cycling and processing under natural conditions in the Everglades. Performance measures have been developed to address the state of phosphorus and nitrogen in the Greater Everglades Wetlands.

Pathways in this conceptual ecological model represent major stressors on the system, while the remaining models represent attributes. Pathways presented in this model affect attributes of all other Greater Everglades models.

11.2 Coastal Transgression

Southern Everglades' shoreline and coastal wetland stability is determined by dynamic interaction of freshwater outflows, sea level rise, saline water inflow, sediment import/export rate, and response of sedimentary environment to water level changes (**Figure 11-3**). Sustained substrate buildup in coastal marl and mangrove environments are not capable of keeping up with sea level rise, resulting in encroachment of marine conditions inland. Also, organic peat substrates beneath living red mangroves and sawgrass tend to collapse and rapidly subside in response to community stress initiated by hurricanes, freeze, fire or salinity change.

Performance measures have been developed for hydrologic stressors: 1) Sheet Flow in the Everglades Ridge and Slough Landscape, 2) Water Levels at Regionally Significant Gauge Stations in Everglades National Park, and 3) Southern Estuaries Salinity (**Figure 11-3**). The sheet flow performance measure has recently been developed and is under review. Salinity gradients resulting from interactions between freshwater flow and sea level rise are tracked using Coastal Salinity Gradients and Southern Estuaries Salinity performance measures. Coastal substrate accretion is tracked by the Mangrove Forest Production/Soil Accretion performance measure. Freshwater and Estuarine Vegetation Mosaics, and Southern Estuaries Submerged Aquatic Vegetation performance measures relate to conversion of coastal wetlands to sub-aqueous environments. Some of these performance measures mentioned are Southern Estuaries performance measures, but they also pertain to Everglades mangrove estuaries.

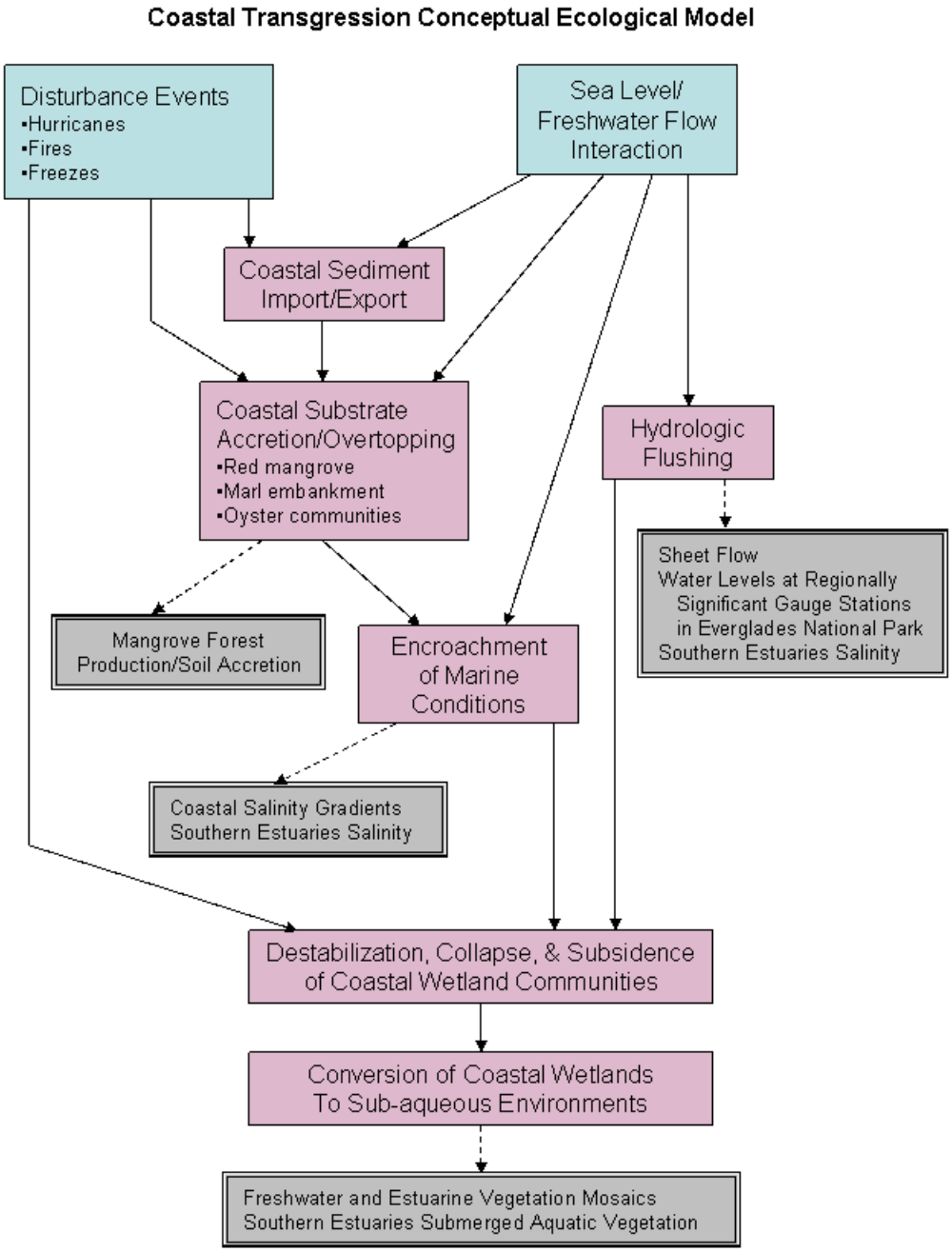

Figure 11-3. Coastal Transgression Conceptual Ecological Model with associated performance measures

11.3 Tidal Channel Characteristics

Dendritic pattern, channel width and depth, flow volume, and material transport of tidal watercourses through coastal mangrove estuaries are controlled by sea level interacting with volume, timing and distribution of sheet flow and channel flow from the southern Everglades (**Figure 11-4)**. Many tidal creeks have disappeared entirely during the past century because they have been filled in with sediments and vegetation of surrounding landscapes. Reduced freshwater flow volume and rising sea level are probable contributing factors. Restored freshwater inflow from the Everglades is expected to help sustain open watercourses through the estuary that will more closely resemble historic patterns, yet sea level rise is expected to modify patterns of connectivity through coastal wetlands and create increased sediment loads. With rising sea level, offshore marine waters become connected to interior lakes and freshwater marshes, increasing tidal water area and volume. This process is expected to result in stronger tidal currents through channels resulting in increased erosion and widening of those channels. Such conditions are expected to result in an increased import and/or export of particulates, nutrients and dissolved organics.

A performance measure, Tidal Creek Sustainability, has been developed to track effects of restoration and sea level rise on tidal creeks. Several hydrologic performance measures that pertain to Tidal Channel Characteristics Conceptual Ecological Model stressors are 1) Sheet Flow in the Everglades Ridge and Slough Landscape, 2) Water Levels at Regionally Significant Gauge Stations in Everglades National Park, and 3) Southern Estuaries Salinity. These measures will track effects of altered flow, which will, in turn, have an effect on tidal creeks. The sheet flow performance measure has recently been developed and is under review.

11.4 Coastal Salinity Gradients

Sheet flow in southern Everglades prior to drainage produced prolonged pooling of fresh water upstream and prolonged patterns of freshwater flow into mangrove estuaries. Freshwater pooling and inflow supported a wide salinity gradient, including a broad oligohaline zone, in mangrove estuaries. Reduced freshwater flow and increased sea level rise have resulted in higher salinities in formally estuarine mangrove zones and significant saline intrusion into former freshwater marshes of the lower Everglades. **Figure 11-5** depicts these pathways.

CERP is expected to increase seasonal freshwater sheet flow to the lower Everglades. This is expected to provide a broader zone of salinity gradients in the lower Everglades and coastal wetlands and should, in the short term, reestablish an oligohaline zone in coastal wetlands. A sheet flow performance measure has recently been developed and is currently under review. The Water Levels at Regionally Significant Gauge Stations in Everglades National Park is a Southern Estuaries performance measure that pertains to water levels along the southern coast of the Everglades. The Coastal Salinity Gradients performance measure relates to surface water salinity gradients in the southern Everglades.

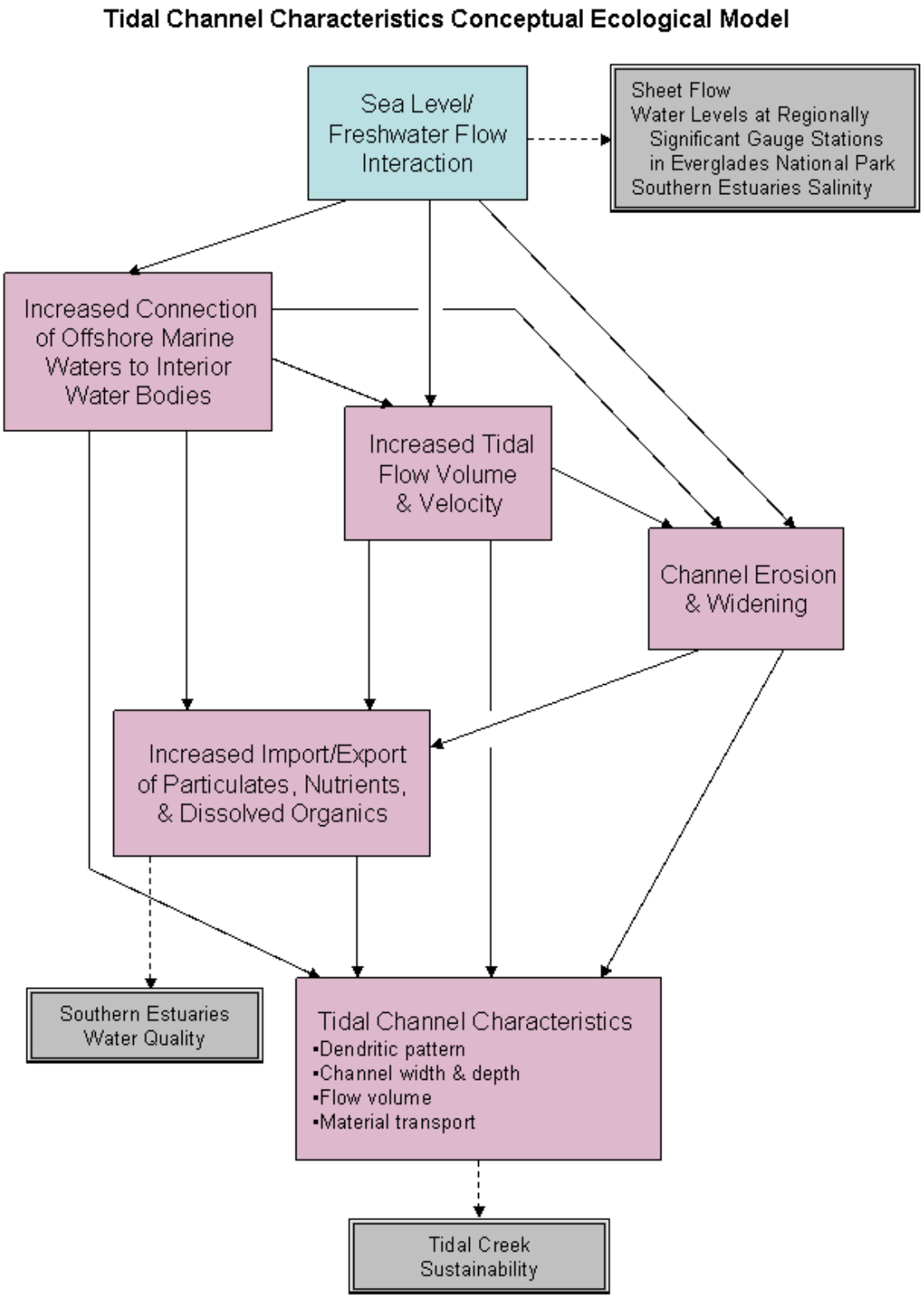

Figure 11-4. Tidal Creek Channel Conceptual Ecological Model with associated performance measures

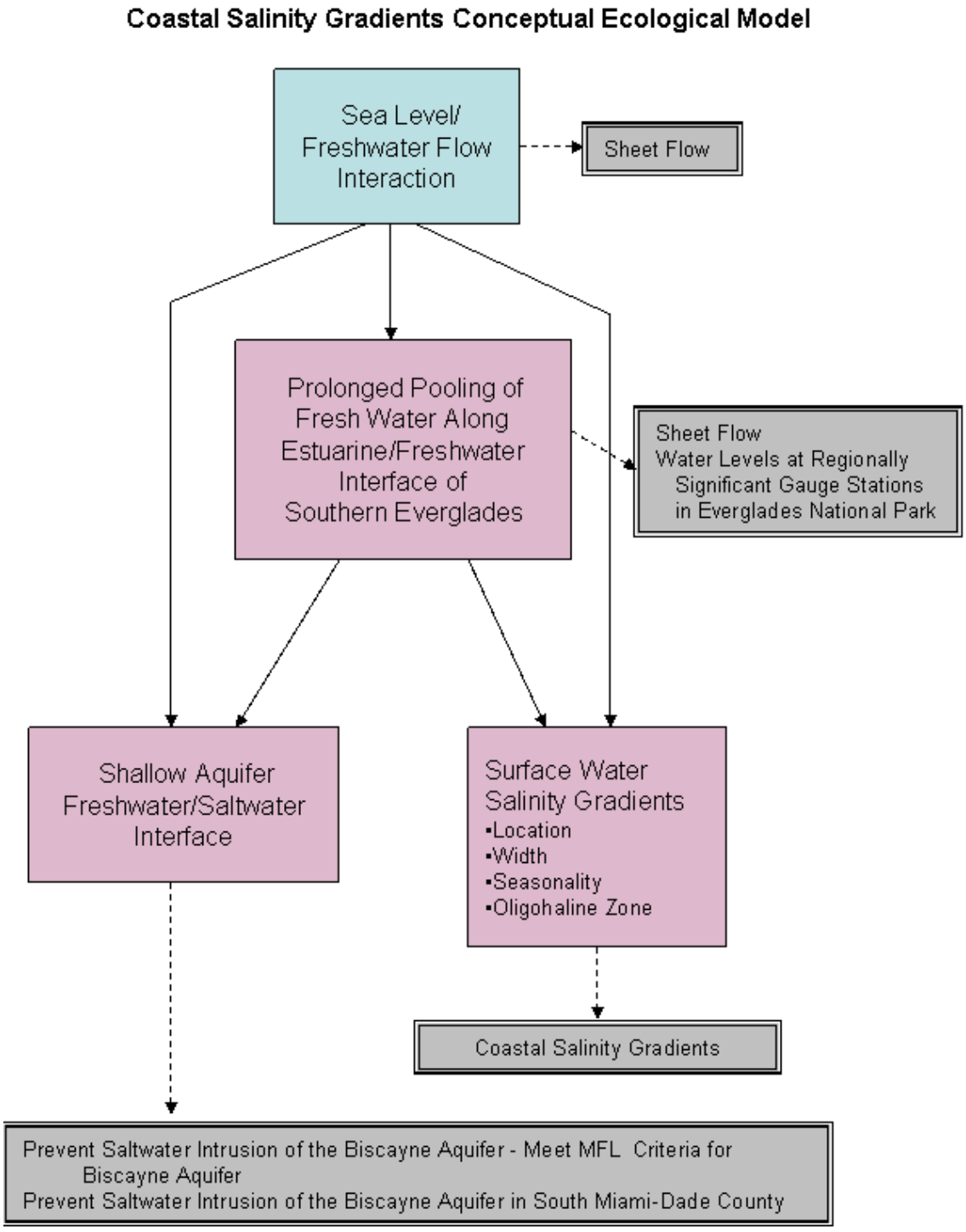

Figure 11-5. Coastal Salinity Gradients Conceptual Ecological Model with associated performance measures

Movement of the freshwater/saltwater interface in the shallow aquifer depends on intensity and duration of freshwater flows to the lower Everglades during the dry season. As freshwater flow has decreased, saltwater has intruded into the aquifer. Currently, two water supply performance measures have been developed to track saltwater intrusion into the aquifer: 1) Prevent Saltwater Intrusion of Biscayne Aquifer - Meet Minimum Flows and Levels Criteria for Biscayne Aquifer and 2) Prevent Saltwater Intrusion of Biscayne Aquifer in South Miami-Dade County. While the measures do not deal with the ecological implications of saltwater intrusion, they are currently the only saltwater intrusion performance measures that have been developed.

11.5 Mangrove Forest, Organic Soil Accumulation and Resilience

Phosphorus availability, mangrove production and soil elevation are driven by opposing influences of sea level and sheet flow (**Figure 11-6**). Production and organic soil accretion in coastal Everglades mangrove forests are controlled by phosphorus availability. Increased freshwater sheet flow caused by CERP implementation is expected to maintain low nutrient conditions in the Everglades mangrove estuaries, and is being tracked by two performance measures: 1) Greater Everglades Wetlands Total Phosphorus (TP) Concentrations in Surface Water and 2) Greater Everglades Wetlands Nutrient Total Nitrogen (TN) Concentrations in Surface Water. These low nutrient conditions are expected to enhance belowground productivity by mangroves, which will maintain peat production and soil elevation increases, ultimately enhancing the ability of these low salinity forests to maintain themselves against sea level rise. The 1) TP Concentrations in Soil and 2) Mangrove Forest Production/Soil Accretion performance measures relate to peat production and soil elevation increases.

Resilience of the mangrove forests of the coastal Everglades after disturbance by hurricanes, fires, freezes or salinity changes, is dependent on hydrologic flushing by either fresh or saline water, which is driven by sea level and sheet flow from the Everglades. A sheet flow performance measure has recently been developed and is currently under review. In addition to the sheet flow performance measure, two performance measures pertain to hydrologic flushing: 1) Water Levels at Regionally Significant Gauges Stations in Everglades National Park and 2) Southern Estuaries Salinity. Both are Southern Estuaries performance measures, but they pertain to the mangrove forest along the edge of the Greater Everglades module boundaries. If flow and flushing diminish, then wetland communities collapse. Improved freshwater flow and flushing through the lower Everglades and coastal wetlands are expected to aid in recovery of wetlands from catastrophic setbacks. The Wetland Landscape Patterns – Freshwater and Estuarine Vegetation Mosaics performance measure includes these wetland communities.

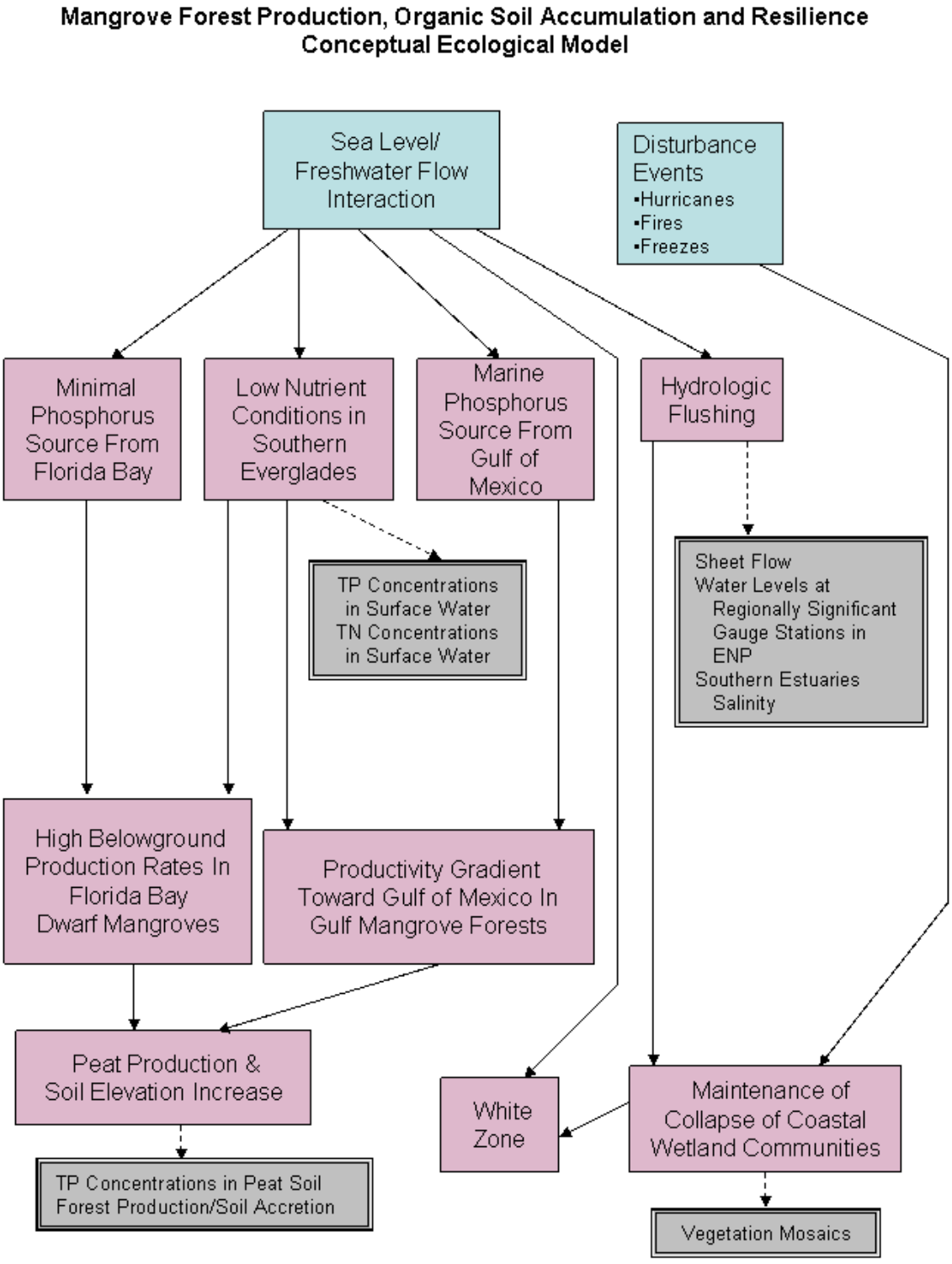

Figure 11-6. Mangrove Forest Production, Organic Soil Accumulation, and Resilience Conceptual Ecological Model with associated performance measures

11.6 Ridge and Slough Landscape Dynamics Conceptual Ecological Model

Ridge and slough landscape dynamics are maintained by sheet flow interacting with hydroperiod, water depth, nutrient dynamics and fire to maintain organic soil accretion and loss in a state of dynamic equilibrium (**Figure 11-7**). Dynamic equilibrium involves a balance of particulate organic matter transport, and accumulation, oxidation and combustion of organic soil. Altered sheet flow magnitude, duration and direction causes disequilibrium of accretion and loss processes. Disequilibrium is exacerbated by eutrophication. Disequilibrium of accretion and loss processes causes micro-topography degradation. Degradation of micro-topography interacts with hydroperiod, water depth, eutrophication, fire and cattail expansion to reduce natural habitat diversity and stability.

Decompartmentalization, in combination with sheet flow resumption, will restore natural features of the Everglades ridge and slough landscape. A sheet flow performance measure has recently been developed and is under review. Hydroperiod and water depth in the ridge and slough landscape are being addressed by three performance measures: 1) Number and Duration of Dry Events for Shark River Slough, 2) Inundation Pattern in Greater Everglades Wetlands, and 3) Extreme High and Low Water Levels in Greater Everglades Wetlands. The sheet flow performance measure has recently been developed and is currently under review. Nutrient dynamics are being addressed with performance measures for TP and TN concentrations in surface water and TP concentrations in peat soil. Two wetland landscape pattern performance measures, Ridge and Slough Community Sustainability, and Freshwater and Estuarine Vegetation Mosaics, address habitat diversity and stability.

11.7 Plant Communities/Elevation Gradients Conceptual Ecological Model

Composition and distribution of plant communities along elevation gradients are determined by patterns of hydroperiod, water depth, nutrient dynamics and fire patterns (**Figure 11-8**). Dynamic equilibrium of the vegetation mosaic is maintained if biogeochemical processes in soil support physiological requirements of vegetation. It is altered if water depths or hydroperiods decrease or increase. Anthropogenic disturbances of hydroperiods, water depths, eutrophication, fire patterns, land use change, and spread of exotic plants have shifted the vegetation mosaic away from historic dynamic equilibrium. More natural hydroperiods, water depths and flow regimes will reestablish and sustain ridge and slough landscape patterns without significant infringement on adjacent marl prairies.

Performance measures have been developed to address plant communities and elevation gradients. A sheet flow performance measure has recently been developed and is under review. Hydroperiod and water depth patterns are being addressed by 1) Wet Prairie, 2) Number and Duration of Dry Events for Shark River Slough, 3) Inundation Pattern in Greater Everglades Wetlands, and 4) Extreme High and Low Water Levels in Greater Everglades Wetlands. The Wet Prairie performance measure has recently been developed and is under review. Nutrient dynamics are being addressed with performance measures for TP and TN. Two performance measures, 1) Freshwater and Estuarine Vegetation Mosaics and 2) Ridge and Slough Community Sustainability, address plant communities.

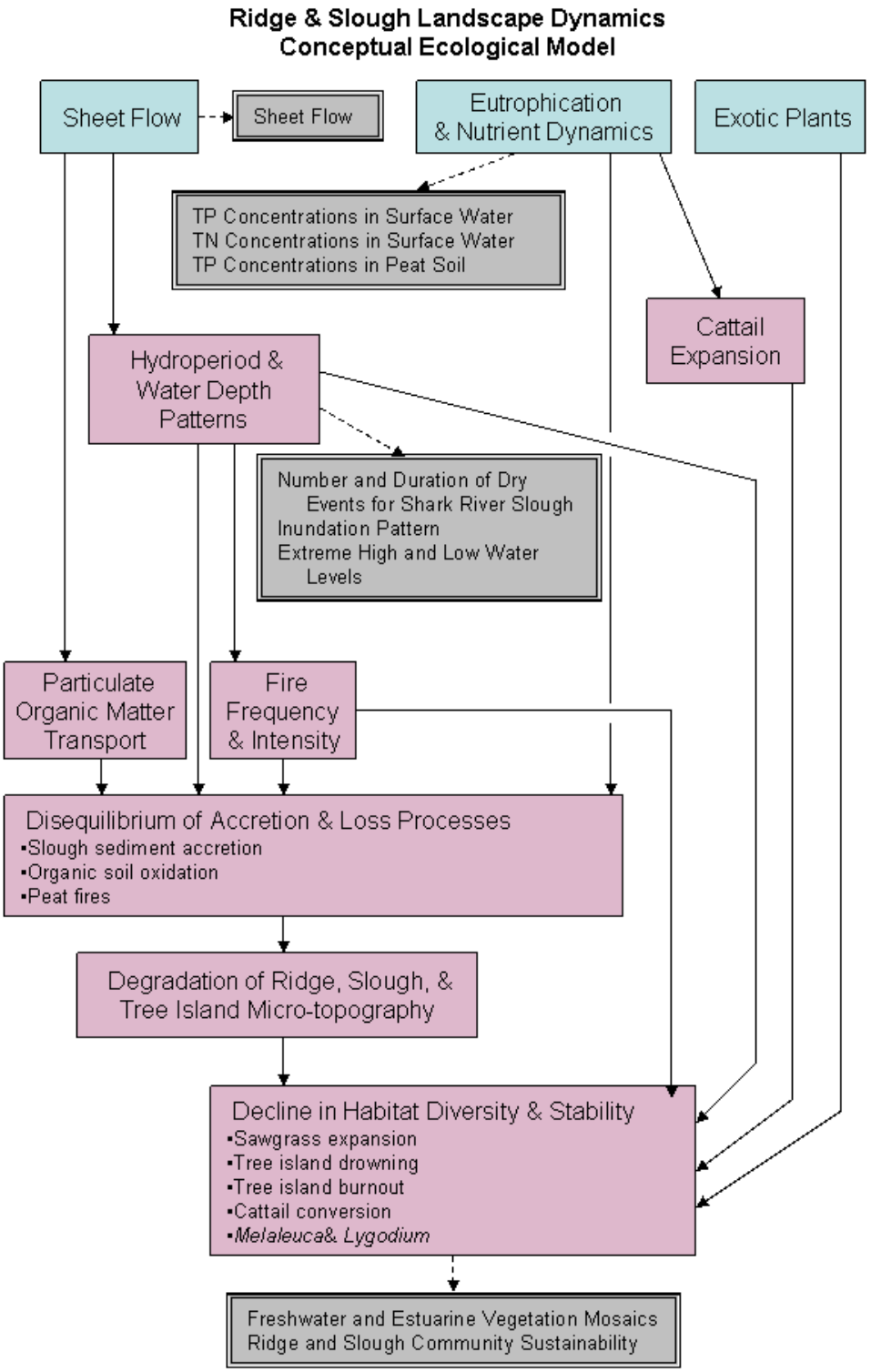

Figure 11-7. Ridge and Slough Landscape Dynamics Conceptual Ecological Model with associated performance measures

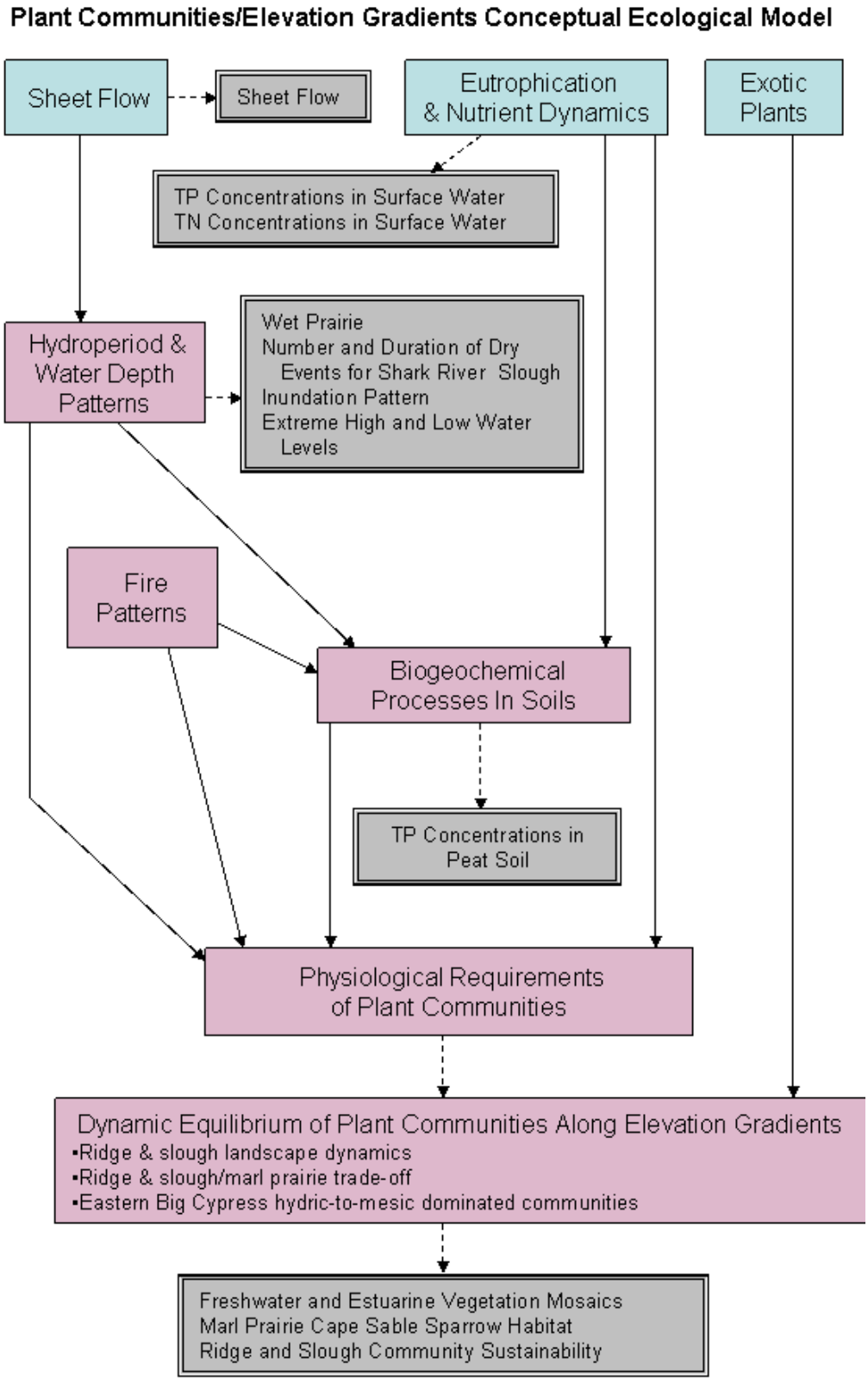

Figure 11-8. Plant Communities/Elevation Gradients Conceptual Ecological Model with associated performance measures

11.8 Predator-Prey Interactions of Wading Birds and Aquatic Fauna Forage Base Conceptual Ecological Model

Wading bird nesting colony collapse in the southern Everglades is attributed to declines in population densities and seasonal concentrations of marsh fishes and other aquatic prey organisms, a shift in location and timing of these seasonal concentrations, and reduced shallow water foraging options for wading birds along elevation gradients (**Figure 11-9**). Wading bird forage base has been disrupted by disruption of dry season water level recession patterns, multi-year wet and dry cycles, and possibly, nutrient dynamics.

Population densities of aquatic fauna are low in much of the southern Everglades, while densities have increased in the artificial pools of the WCAs, which now favor larger, longer-lived species. While increased prey densities in these artificial pools have attracted wading bird nesting colonies to those areas after coastal colony collapse, drying pattern interruptions in the WCAs often disrupt prey concentrations that are required for successful foraging by wading birds, resulting in failure of nesting colonies.

Restoration of natural hydrologic conditions by implementing CERP is expected to restore historical patterns of water level recession and drying edges. This will reestablish distributions of prey densities and concentrations across the landscape. It will also concentrate wading bird prey into a succession of high-density patches throughout the dry season in the remaining ridge and slough, marl prairie and coastal landscapes. Prey base restoration is expected to reestablish wading bird nesting colonies in coastal and tributary regions of the southern Everglades and roseate spoonbill nesting colonies in northeastern Florida Bay. It is also expected to increase numbers and success of nesting wading birds, wood storks and roseate spoonbills and to allow wood storks to initiate nesting no later than January in most years.

Unusually large aggregations of nesting wading birds, referred to as super colonies, consisting of mostly white ibis, formed in the predrainage system in response to extreme, natural patterns of drought prior to colony formation. Super colonies periodically formed along the freshwater-estuarine transition zone at lower reaches of Everglades and Big Cypress basins. A substantial reduction in frequency of super colonies is attributed to disrupted multi-year wet and dry cycles. Reduction in super colony size may be related to reductions in wading bird prey. Population dynamics of crayfish may play an important role, since super colonies form when marsh fish populations would be expected to be minimal, and because white ibis feed primarily on crayfish, which are affected by both hydroperiod and nutrient dynamics.

Multi-year wet and dry cycles will also be restored by the restoration of natural hydrologic conditions. This is expected to stimulate pulses of secondary productivity that will likely involve crayfish populations. Pulses in secondary production are expected to result in an increase in return frequency and size of ibis-dominated super colonies in tributary headwaters of Shark River and other Gulf of Mexico mangrove estuaries at a frequency of two or more events per decade.

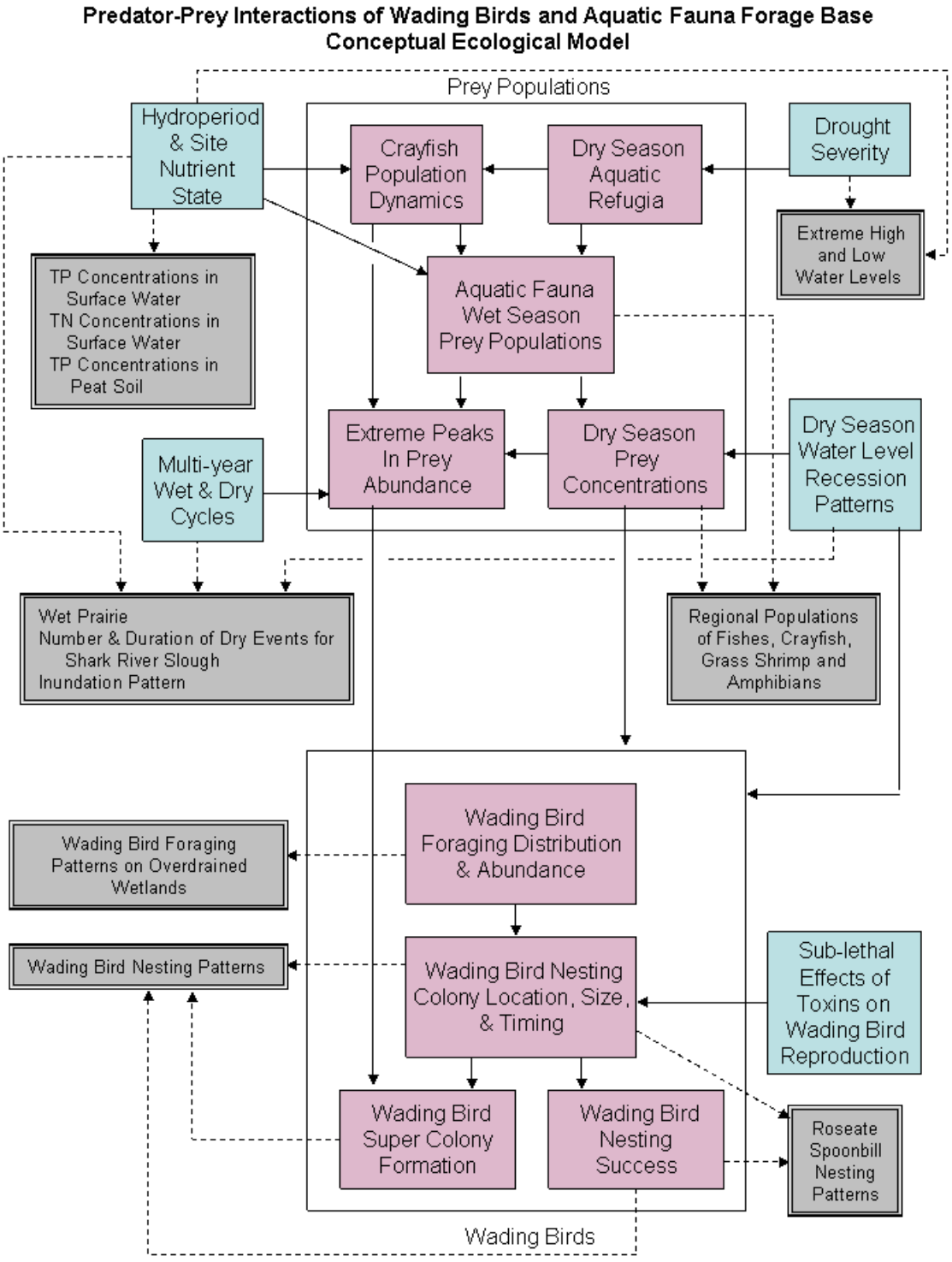

Figure 11-9. Predator-Prey Interactions of Wading Birds and Aquatic Fauna Forage Base Conceptual Ecological Model with associated performance measures

Several hydrologic performance measures pertain to this model: 1) Wet Prairie, 2) Number and Duration of Dry Events for Shark River Slough, 3) Inundation Pattern in Greater Everglades Wetlands, and 4) Extreme High and Low Water Levels in Greater Everglades Wetlands. The Wet Prairie performance measure has recently been developed and is under review. Site nutrient state is being addressed by TP and TN concentration measures for surface water, and TP in soils. Prey base response to restoration efforts will be tracked by the Regional Populations of Fishes, Crayfish, Grass Shrimp and Amphibians performance measure. A performance measure has been developed to address wading bird foraging patterns and two performance measures have been developed to address nesting patterns.

11.9 Linkage of Periphyton to Higher Trophic Levels Conceptual Ecological Model

Floating mats of periphyton and bladderworts, which require long hydroperiods and low TP levels to survive and expand, provide critical support to the Everglades' food web, both as a food source and a refuge for aquatic macroinvertebrates (**Figure 11-10**). These macroinvertebrates are consumed by small fish, crayfish and grass shrimp, which in turn, are consumed by higher trophic levels such as wading birds, alligators and crocodiles. Increased freshwater delivery due to CERP implementation may broaden the zone of high periphyton productivity.

Several performance measures pertain to this model. Response of hydroperiod to CERP restoration is being tracked by three performance measures: 1) Number and Duration of Dry Events for Shark River Slough, 2) Inundation Pattern in Greater Everglades Wetlands, and 3) Extreme High and Low Water Levels in Greater Everglades Wetlands. The Greater Everglades Wetlands TP Concentrations in Surface Water performance measure addresses site nutrient state, which affects periphyton mats. Several performance measures have been developed to address trophic levels affected by periphyton: 1) Regional Populations of Fishes, Crayfish, Grass Shrimp and Amphibians, 2) Wading Bird Foraging Patterns on Overdrained Wetlands, 3) American Alligator Distribution, Size, Nesting and Condition, and 4) American Crocodile-Juvenile Growth and Survival.

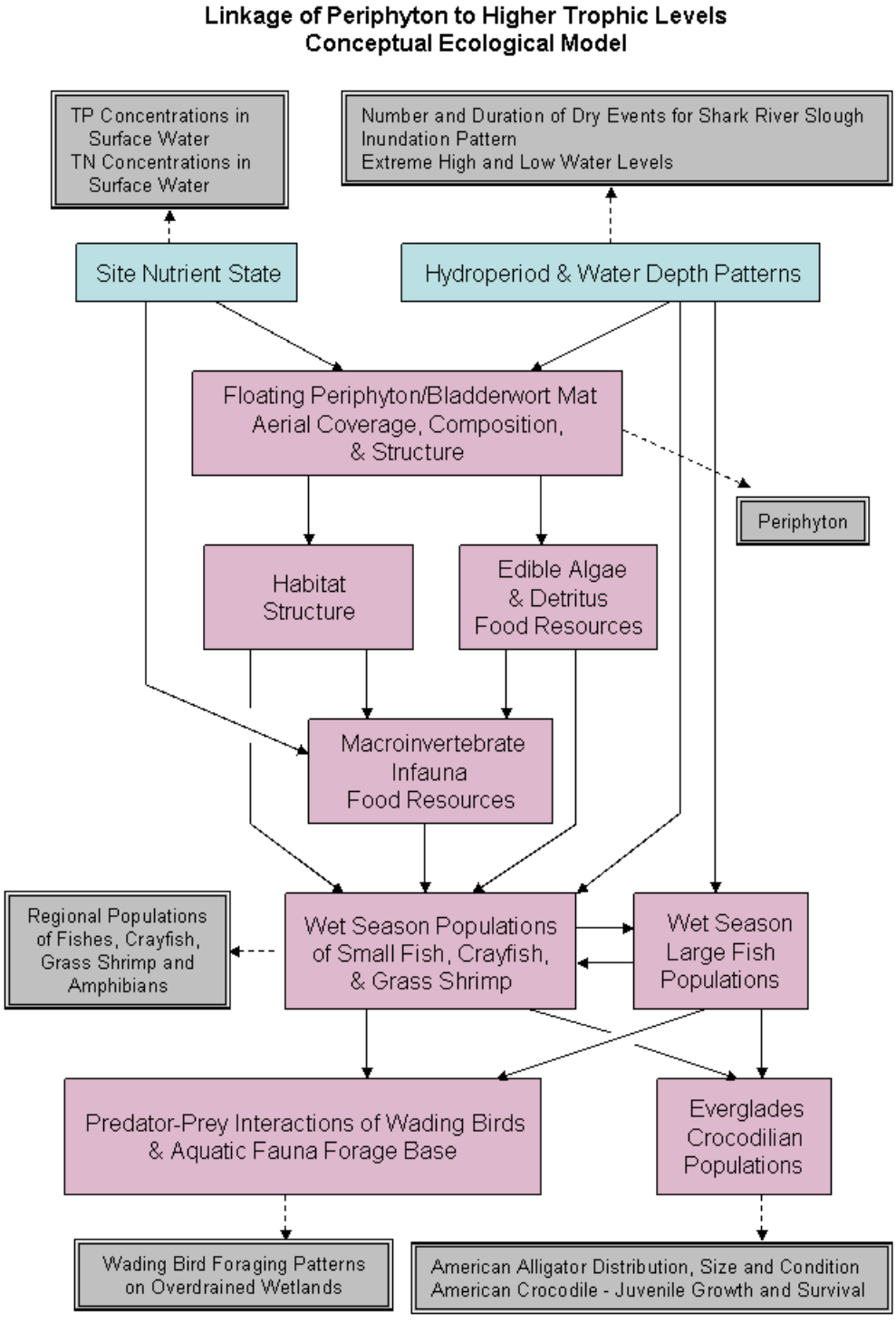

Figure 11-10. Linkage of Periphyton to Higher Tropic Levels Conceptual Ecological Model with associated performance measures

11.10 Everglades Crocodilian Populations Conceptual Ecological Model

American Alligator

American alligator distribution, abundance, reproduction and body condition in the Everglades are controlled by hydroperiod and water table in rocky glades, salinity in mangrove estuaries, and water depth patterns in ridge and slough landscapes, all of which were driven by direct rainfall and sheet flow prior to drainage (**Figure 11-11**). Shortened hydroperiod and lowered water table in rocky glades have reduced alligator abundance and reproduction because of aquatic habitat loss and reduced aquatic prey base. A positive feedback loop of increased alligator populations and alligator holes (aquatic refugia) leading to increased aquatic fauna density (alligator prey) has been disrupted. Reduced freshwater flow into mangrove estuaries has resulted in succession of former freshwater mangrove areas to saltwater systems, reducing alligator populations in tidal rivers and tributaries. Compartmentalization, disrupted sheet flow, and regulatory water releases restrict alligator populations in the ridge and slough landscape by causing nest flooding, unsuitable overdrained and pooled habitats in WCAs, and low hatchling and juvenile survival in canals during low water periods.

With resumption of natural flow patterns to the Everglades as CERP is implemented, the American alligator is expected to repopulate and resume nesting in rocky glades and freshwater reaches of tidal rivers in mangrove estuaries and will increase in population size and improve in body condition. Three performance measures will track response of hydroperiod and water depth patterns to CERP implementation: : 1) Number and Duration of Dry Events for Shark River Slough, 2) Inundation Pattern in Greater Everglades Wetlands, and 3) Extreme High and Low Water Levels in Greater Everglades Wetlands. Response of salinity in tidal rivers and tributaries are addressed by the Coastal Salinity Gradients performance measure. Response of aquatic prey base is addressed by the Regional Populations of Fishes, Crayfish, Grass Shrimp and Amphibians performance measure. A performance measure has also been developed to track American alligator distribution, size and condition.

American Crocodile

In estuaries, crocodiles orient towards areas of low salinity and freshwater sources. Alteration of location and quantity of freshwater flow to Southern Estuaries has lowered relative density of crocodiles in estuarine areas from which fresh water has been diverted and decreased growth and survival of juvenile crocodiles throughout the estuary in areas of higher salinities (**Figure 11-11**). Restoration of freshwater flow will result in an increase in relative density of crocodiles in areas of restored flow, such as Taylor Slough/Taylor River drainage. Reestablishing salinity gradients will increase growth and survival of juvenile crocodiles.

Two performance measures address salinity in areas inhabited by crocodiles: 1) Coastal Salinity Gradients and 2) Frequency of Low Salinities and High Salinities in Florida Bay (a Southern Estuaries performance measure). A performance measure has also been developed for American crocodile juvenile growth and survival.

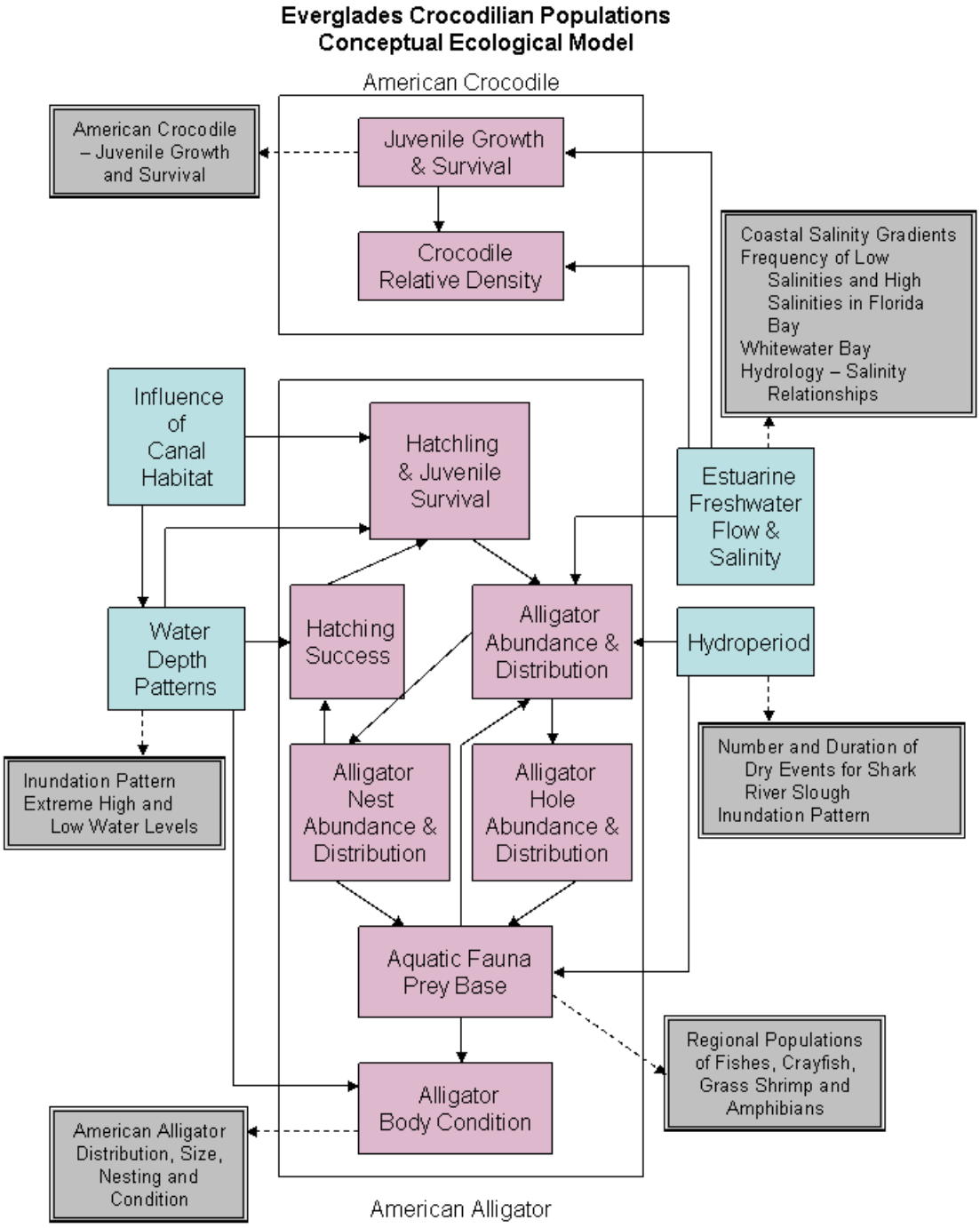

Figure 11-11. Everglades Crocodilian Population Conceptual Ecological Model with associated performance measures

11.11 Greater Everglades Wetlands Performance Measures

Greater Everglades Wetlands performance measures are as follows:

- Sheet flow in the Everglades Ridge and Slough Landscape (under review)
- Wet Prairie (under review)
- Number and Duration of Dry Events for Shark River Slough
- Inundation Pattern in Greater Everglades Wetlands
- Extreme High and Low Water Levels in Greater Everglades Wetlands
- Greater Everglades Wetlands TP Concentrations in Surface Water
- Greater Everglades Wetlands Basinwide TP Loading and Flow-Weighted Mean Concentration in Inflows
- Greater Everglades Wetlands Nutrient TN Concentrations in Surface Water
- TN Loads/Flow-Weighted Mean Concentration in Inflows to Greater Everglades Wetlands
- TP Concentrations in Soil
- Greater Everglades Tracer of Stormwater Treatment Area Bypass Flows
- Greater Everglades Wetlands Sulfate Concentrations in Surface Water
- Greater Everglades Wetlands Conductivity in Surface Water
- Greater Everglades Wetlands Coastal Salinity Gradients
- Wetland Landscape Patterns - Freshwater and Estuarine Vegetation Mosaics
- Wetland Landscape Patterns - Marl Prairie Cape Sable Sparrow Habitat
- Wetland Landscape Patterns - Ridge and Slough Community Sustainability
- Wetland Landscape Patterns - Tidal Creek Sustainability
- Wetland Trophic Relationships - Periphyton
- Wetland Trophic Relationships - Mangrove Forest Production/Soil Accretion
- Wetland Trophic Relationships - Regional Populations of Fishes, Crayfish, Grass Shrimp and Amphibians
- Wetland Trophic Relationships - Wading Bird Foraging Patterns on Overdrained Wetlands
- Wetland Trophic Relationships - Wading Bird Nesting Patterns
- Roseate Spoonbill Nesting Patterns
- Wetland Trophic Relationships - American Alligator Distribution, Size, Nesting and Condition
- American Crocodile – Juvenile Growth and Survival

Documentation sheets can be accessed from the Greater Everglades Performance Measures web page: http://www.evergladesplan.org/pm/recover/perf_ge.aspx.

11.12 References

RECOVER. 2006. Monitoring and Assessment Plan (MAP), Part 2, 2006 Assessment Strategy for the MAP, Final Draft. Restoration Coordination and Verification Program, c/o United States Army Corps of Engineers, Jacksonville District, Jacksonville, FL, and South Florida Water Management District, West Palm Beach, FL. December 2006. http://www.evergladesplan.org/pm/recover/recover_map.aspx