Big Cypress Basin Conceptual Ecological Model

1. Model Lead

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2. Introduction

The Big Cypress region covered by this conceptual model includes the freshwater portions of the area extending from the southern edge of the Caloosahatchee River watershed boundary in Lee, Hendry, and northern Collier Counties, and west of the Everglades, as delimited approximately by L-2, L-3 and L-28 in the north and a diagonal line running from Forty-Mile Bend on Tamiami Trail southwest to the coast. In this region, historic water flows were primarily south to the Gulf of Mexico, with minor flows in small creeks that pass through the west coast ridge to the Gulf and somewhat more significant flows east into the Everglades in the northeast corner of the area (Klein et al. 1970). The water table throughout the Big Cypress can be defined as being at the top of the surficial aquifer, which would be above ground over much of the area during the wet season and below ground over most of these same areas during the dry season.

There are three distinct subregions within the Big Cypress Basin, based on the kind and degree of development present in each (Lehman 1976). The least disturbed area, because the hydrology is largely rainfall-driven, is located within the Big Cypress National Preserve in the southeastern portion of the region (Duever et al. 1986). The Preserve, along with a portion of the adjacent Seminole Indian Reservation to the north, is the Big Cypress subregion that was included in the C&SF Project Comprehensive Review Study (Restudy) Alternatives analyses, although only the eastern portion of this area was affected by components included in the various restoration alternatives. The most developed portion of the area, including both urban and agricultural development, is located on and just east of the coastal ridge from Naples north to Ft. Myers. The rest of the area is a mixture of agricultural lands, suburban and rural communities, and small-to-large natural areas that have been altered to varying degrees by upstream and/or adjacent development. Despite the very different degrees of development in the three subregions, the kinds of stressors and their effects on ecosystem attributes are similar throughout the Big Cypress Basin and they differ only in the severity of their impacts. Except for the stands preserved at Corkscrew Swamp Sanctuary and Fakahatchee Strand State Preserve, all the large cypress trees have been logged. In the Golden Gate Estates area, canals have greatly disrupted the hydrological patterns, causing abnormally severe fires.

The Big Cypress region is comparable to the freshwater Everglades in terms of natural community diversity, although the Big Cypress communities are primarily forested and tend to form more of a mosaic as opposed to vast expanses of a number of primarily herbaceous community types. The most extensive natural communities in the Big Cypress are distributed throughout the region along very gentle topographic gradients from short-hydroperiod pinelands on the uplands through marshes to long-hydroperiod cypress forests on lower elevations (Craighead 1971, Davis 1943, Duever 1984, Klein et al. 1970). Small open-water ponds are found in scattered deeper depressions, and small islands of hardwood forest or “hammocks” occur on elevated sites among or along the edges of deeper herbaceous and forested wetlands.

While the Big Cypress is dominated by temperate species, there is a tropical component that is most prevalent in forested upland and swamp communities (Duever et al. 1986). This component is most abundant and diverse close to the Gulf coast, but occurs further inland in association with larger and deeper wetlands, where it is protected from cold winter weather by the temperate forest canopy and/or the moderating effects of standing water. Under natural conditions, the range of annual fluctuation in water levels above and below ground and the duration of inundation are the primary factors influencing the distribution of these communities, although frequent fires exert a secondary influence by controlling the kinds and structure of their dominant plant species (Craighead 1971, Duever 1984, Harper 1927, Klein et al. 1970). Cypress and marsh communities tend to be more common towards the south as elevations approach sea level, while pinelands are more common on the higher and deeper-sand substrates to the north and on the west coast ridge along the Gulf of Mexico.

3. External Drivers and Ecological Stressors

The ultimate source of all ecological stressors in the Big Cypress ecosystem is development for agricultural and residential use. The area's seasonally high water table required the construction of an extensive system of small ditches connected to larger and larger canals to assure that water levels remain below ground throughout the year, in order to make the land suitable for crops and housing (Lehman 1976). The drainage systems produce lowered water tables and shortened hydroperiods for considerable distances in otherwise unaltered lands around and downstream of them (Carter et al. 1973, Klein et al. 1970, Swayze and McPherson 1977). These drier conditions can facilitate major shifts in the composition of affected wetland plant communities to a composition more similar to that found in more upslope communities. These shifts can include colonization by native woody species, such as slash pine, cabbage palms, and a variety of hardwoods, such as red maple (*Acer rubrum*) and laurel oak (*Quercus laurifolia*), or by exotic species, such as melaleuca (*Melaleuca quinquenervia*). Changes in community composition would be further accelerated by the more frequent and severe fires that typically occur under these drier conditions (Robertson 1953, Wade et al. 1980). In addition, the water in canals draining these lands normally has a different chemistry than that found in natural Big Cypress waters. This is of particular concern in terms of undesirably higher concentrations of nutrients and dissolved minerals (Duever et al. 1986), which can encourage the spread and potential dominance of sites by invasive native and exotic vegetation. The human response to South Florida's dry season produces an additional hydrologic stress on natural systems in the Big Cypress in terms of lowered water tables and shortened hydroperiods. When weather conditions are dry for extended periods, water use for crops, lawns, etc. goes up substantially, which results in lower than normal water levels in and for considerable distances around the wells that provide this water (Lehman 1976, Rochow 1985). Excessive draw downs associated with canals and well fields can produce very significant impacts on native amphibian, fish, and crayfish populations that depend on the presence of at least some inundated wetlands or moist wetland substrate for their survival through the dry season. These draw downs can also eliminate the standing water that normally helps to protect tropical vegetation from winter freezes (Duever et al. 1978).

Changes in land use associated with agricultural and residential development not only cause habitat loss on the affected lands, but fragmentation of the habitat mosaic. Habitat loss directly

impacts the availability of resources required by organisms that utilize these areas. However, the distribution of these habitats across the landscape is even more important because few organisms utilize only one habitat type, particularly in a landscape that can fluctuate seasonally from mostly inundated to completely dry and that may be affected by widespread and sometimes severe fires. Thus, when wetland connections to adjacent uplands are severed, innumerable biologically important flows are interrupted and ecosystem diversity and viability are severely compromised (Forman and Godron 1986, Harris 1984). Fragmentation and habitat loss also affects populations by reducing the spatial extent of their resource base to the point where it is no longer able to support viable populations. Exposure of wildlife to hazards associated with development, such as roads, increases dramatically as habitats become smaller and are more and more fragmented, and the resulting extensive edges also facilitate the movement of exotic plants and animals into the native landscape.

As development increases in an area, the seasonality and frequency of fire in natural communities becomes increasingly unnatural (Wade et al. 1980). Natural fires were normally most common during the summer wet season as a result of the high frequency of lightning (Duever 1984). However, they were most widespread at the beginning of the wet season, when the region was at its driest and lightning storms were just beginning to occur. Early in this century, cattlemen greatly increased the frequency of winter fires to provide more forage for their cattle during the nongrowing season (Ackerman 1976, Alvarez no date, Kennard 1915). More recently, fire has been suppressed over much of the more developed portions of the area, which has caused unusually severe fires when they finally occur, as they always do eventually (Hofstetter 1984). The lack of fire has allowed succession to proceed in many areas, so that herbaceous communities are being invaded by dense shrub thickets and pine and cypress forests are being invaded by shrubs and hardwoods (Hofstetter 1984).

Exotic plants and animals produce drastic alterations in the composition and structure of natural communities, although many of these changes are poorly documented, such as the impacts resulting from the spread of feral hogs and exotic fish (Crowder 1974, Dineen 1984, Duever et al. 1986, Layne 1984). Some that are well documented include the spread of melaleuca and other exotic plants (Duever et al. 1986, Myers 1975). Some species, such as melaleuca and feral hogs, can readily utilize undisturbed natural communities. However, development has facilitated the invasion of exotics by creating an abundance of disturbed sites that normally would have been recolonized by native species, but these species are now being outcompeted by more rapidly invading exotics (Elton 1958, Odum 1971). In addition, farms and residential areas create new habitats that are more suitable to new species, which then invade adjacent natural areas and impact native populations either directly by predation or indirectly through competition for resources.

The increasing amounts of pesticides, mercury and other contaminants that are being used over much of South Florida pose a variety of types of threats to fauna at all trophic levels in all South Florida ecosystems, including the Big Cypress Basin area. To increase agricultural productivity levels and due to multiple planting seasons, as well as the climate, Florida agriculture requires usage of a wide variety of pesticides, i.e., insecticides, herbicides, and fungicides. Residues of some of these pesticides have been detected in surface water at South Florida Water Management District structures at various times (Miles and Pfeuffer 1997, Pfeuffer and Matson

2002). Contrary to public perception, USGS reports that insecticides occur more frequently in urban streams than in most agricultural streams (USGS 1999). Urban runoff has been found to contain a wide variety of other toxicants that can result in significant impacts to aquatic biota in receiving waters (Pitt 1995).

Widespread elevated concentrations of mercury were first discovered in freshwater fish from the Florida Everglades in 1989 and, as a result, fish consumption advisories were issued for select species and locations. Elevated concentrations of mercury have subsequently been found in predators like raccoons, alligators, wading birds, and Florida panthers.

Water Quality – Baseline Conditions

The Big Cypress Swamp is primarily part of the Everglades West Coast Basin reporting unit. A recent regional assessment was conducted by the Florida Department of Environmental Protection in fulfillment of the requirements of the Impaired Surface Waters Rule (IWR), Chapter 62-303 F.A.C. This report indicates that three water bodies influencing water quality within the Big Cypress Swamp are potentially impaired for dissolved oxygen, fish consumption (for mercury), cadmium, and copper in the Tamiami Trail; DO and nutrients in the L28 Interceptor, and DO in the L28 Gap. The south Florida ecoregion has one of the highest atmospheric mercury deposition rates in the United States and this source of mercury sustains methylation and food web biomagnification (Kbabbenhoft et. al, 1999). Bodies of water quality impairment were also identified in the July 2000 Environmental Impact Statement on improving the regulatory process in Southwest Florida prepared by the Army Corps of Engineers.

Water Quality of Site Specific Areas Within the Big Cypress Basin

L28 Drainage: The L-28I drainage system is located in or near the northeastern part of BICY. The system was constructed in the mid-1960's to provide flood protection to the Seminole Reservation, and consists of three main canals---L-28I, North Feeder canal, and the West Feeder canal. These canals convey water south and southeast through the S-190 pump station and ultimately discharge into Water Conservation Area 3A (WCA 3A). Currently, water is confined to the canals until it discharges into WCA 3A, but restoration plans being considered include releasing some water from the West Feeder canal into the northern BICY to reestablish historic hydrologic flows to several cypress strands. Waters in the L-28I and the north Feeder canal are enriched in nutrients from agricultural lands to the north, whereas water in the West Feeder canal contains relatively low nutrient concentrations. For example, the average concentration of total phosphorus in the North Feeder canal was 0.25 mg/L during 1996-97 compared with 0.06 mg/L in the West Feeder canal (Germain, 1998). Nutrient concentrations tend to increase in the West Feeder canal during the dry season when S-190 is closed and some water from the North Feeder canal mixes into the West Feeder canal (Sobczak, 2001).

Barron River Canal: The Barron River canal is located along the western boundary of BICY. The canal and the adjacent highway 29 with its roadbed act as a major hydrologic barrier to the wetlands of the BICY. The canal drains predominately agricultural lands north of the Preserve and discharges into Chokoloskee Bay and Everglades National Park. Waters and bed sediment in the canal contain a number of pesticides and other contaminants that are a potential source of contaminants to the bay and the extreme northwest part of Everglades National Park (Miller and

McPherson, 2001; Shahane, 1994). Low concentrations of pesticides or pesticide degradation products were detected in bottom sediments (DDD and DDE) and water, primarily in the northern reach of Barron River Canal where agricultural contamination is the likely source (Miller and McPherson, 2001). The current direction of flow in the canal is south into Chokoloskee Bay or west into the Fakahatchee Strand and Panther refuge, with a less amount of flow entering Big Cypress National Preserve to the east.

Lake Trafford: Lake Trafford is located southeast of Immokalee in the interior of the Big Cypress Swamp. Under natural conditions the lake was a shallow and clear water body with a sandy bottom. Its location, just southeast of Immokalee, places it at the headwaters of both Corkscrew Swamp and Camp Keis Strand, and the lake probably played a role with respect to downstream flow in these systems during predevelopment conditions. Water quality in the lake has gradually worsened over time starting in the 1930s with the introduction of hydrilla. Today, the bottom of the lake is no longer sandy as a result of accumulation of dead plant material over the past several decades. Intensification of agriculture in the surrounding watershed has contributed to eutrophication of the lake in two ways. Nutrients from fertilizers have increased productivity of algae and other quick growing aquatics and wet season "pumping off" and dry season irrigation of surrounding agricultural fields have altered stage levels in the lake. Seepage into the lake from adjacent farm fields during the dry season would not only carry nutrients, but also artificially sustain higher ponding levels in the lake during the dry season, thereby preventing oxidation of organic sediments.

Southern Golden Gate Estates: Southern Golden Gate Estates is located fifteen miles east of Naples, upstream from the western half of the 10,000 Islands coastal feature. The timing, volume, distribution, and quality of water entering into the western stretch of the 10,000 Islands has been significantly impacted by a real estate venture that began in the 1950s, but later failed due to the unsuitability of the area for development. The land has more or less sat dormant for the ensuing decades. The primary water quality effect has been the disruption of freshwater flow to the coastal estuary. Instead of spreading the water across the landscape, allowing for a slow and spatially distributed discharge to the mangrove coast, the majority of water bypassed through the swamp via a parallel network of canals that discharged as a point source into the Faka Union Canal, thereby resulting in freshwater pollution at this locale. More recently, efforts have been put forth to return the affected land to a more natural state. One anticipated result of this restoration project would be to restore the integrity of freshwater delivery to the western half of the 10,000 Islands.

4. Ecological Attributes

Attributes are the biological indicators or components of natural systems, which are representative of the overall ecological conditions of the system. Attributes typically are populations, species, guilds, communities or processes. Attributes (also known as indicators or endpoints) are selected to represent the known or hypothesized effects of the stressors (e.g., numbers of nesting wading birds), and the elements of the systems that have important human values (e.g., endangered species, sports fishing).

Vegetation Community Gradients and Habitat Mosaic

This attribute is affected by all of the stressors except mercury and other contaminants, which tend to be more obviously impacting on animal populations than on plant communities. Hydrologic and fire regimes control the character and distribution of the major types of Big Cypress plant communities (Craighead 1971, Davis 1943). The most frequent and widespread hydrologic alterations typically result in reduced depth and duration of inundation, which tends to shift affected wetland plant communities towards shallower wetland types, or with sufficient drainage to upland types (Alexander and Crook 1973, Duever 1984). Fires are more frequent and severe in these drier environments, in some areas resulting in dense stands of fire-tolerant cabbage palms and fast-growing woody exotics, such as melaleuca (Gunderson and Loope 1982, Tabb et al. 1976). Drainage can also impact tropical components of the communities by eliminating the moderating effect of standing water on cold winter temperatures (Duever et al. 1978). Less frequent alterations involve increasing depths and/or duration of inundation, which can convert uplands to wetlands and wetlands to aquatic habitats. In some situations, such as retention areas associated with on-site canal drainage systems, altered hydrology can produce unnatural permanently disturbed habitats that are at times too deeply flooded to support upland vegetation, but for too short a period to produce wetland communities. However, where sites have been previously drained, incorporation into detention areas with subsequently increased flooding can result in improved conditions for some wetlands (J. Volin and W. Dunson, personal communication). Natural communities in South Florida are adapted to surface waters with a chemical composition that contains low concentrations of dissolved minerals and nutrients. Changes in surface water quality typically involve increased nutrient and mineral concentrations coming from ditch and canal outflows into natural wetlands (Drew and Schomer 1984). These increased concentrations can produce dramatic shifts from diverse herbaceous communities to communities dominated by a few invasive exotic and native species, such as primrose willow and cattail respectively, which are adapted to high nutrient and dissolved mineral concentrations.

Dormant season fires and reduced fire frequencies can result in successional shifts from herbaceous to shrubby communities and from open pinelands, herbaceous wetlands, and cypress forests to shrub and hardwood dominated forests (Alexander and Crook 1971, Duever 1984). As fuels build up in these sites, the inevitable severe wildfire will eventually occur (Hofstetter 1984), and the sites will most likely be converted to early successional communities dominated by weedy herbaceous, vine and shrub species, a large proportion of which are much less abundant, if even present, in natural communities.

Land use changes reduce the area of affected communities and often eliminate the transitions from one to another, particularly along upland to aquatic hydrologic gradients. Since wetlands have more legal protection and are more difficult to develop than uplands, habitat loss is greatest in historical uplands, although this may not be obvious because new upland habitat is being created by the drainage occurring throughout much of the area. Upland development is also resulting in wetlands becoming more and more isolated from each other as well as from other natural parts of the system, which is in turn affecting their faunal populations and fire regimes. Roads represent a particularly insidious form of habitat fragmentation. They often begin as dirt tracks through the countryside, which gradually attract more use and are thus improved to accommodate the increased use, which in turn attracts residential or commercial development.

Initially, the dirt tracts are only threats in terms of mortality of individual organisms. However, as development occurs along the road, adjacent habitats are destroyed, and the surrounding landscape is increasingly fragmented.

All of the ecosystem alterations associated with development are facilitating the increasingly rapid spread of nuisance and exotic species throughout the Big Cypress Region landscape (Drew and Schomer 1984, Duever et al. 1986). In many areas, exotic woody vegetation such as melaleuca, Brazilian pepper, or downy rose myrtle completely dominates what were previously herbaceous communities or open pinelands. Cattails and primrose willow have replaced marsh communities that once supported diverse herbaceous species assemblages. Feral hogs annually "plow" thousands of acres, with unknown impacts on what they are foraging on, but quite visible soil disturbance effects that further exacerbate the spread of exotic plants (Duever et al. 1986, Layne 1984). Measurements of changes in the vegetation mosaic in terms of community cover, density, composition, structure and distribution would provide a basis for assessing gains and losses in the spatial distribution as well as the health of these communities in the Big Cypress Region. The types of measures used to make these evaluations would depend upon the plant community involved, but would primarily be associated with restoring and/or maintaining natural hydrologic (quantity and quality) and fire regimes, and controlling at least the more aggressive exotic and nuisance plant species. The measures would be designed to evaluate dominant structural and compositional characteristics described below for each of the major community types (Duever 1984). In addition, the current official Federal and Florida state lists that indicate the wetland status of each plant species could be used to document changes in the wetland status of sites following restoration. Hardwood hammocks exist in the long-term absence of fire, which is in turn dependent upon an undisturbed hydrologic regime. The occurrence of very severe droughts would allow fires to enter some examples of this community type, but droughts of this severity would not likely occur more often than once in about 500 years, and probably even less frequently at the majority of sites. A hammock community unaffected by recent fire would be expected to have a tall, closed canopy with a variably open-to-dense shrub and ground cover. The presence of viable populations of tree snails (*Liguus fasciatus*) and tropical plant species in appropriate settings, such as near the Gulf coast and in association with major wetlands would indicate the presence of a hydrology adequate to protect these organisms from freezes. Even undisturbed hammocks are susceptible to invasion by a variety of exotic plant species, such as Old World climbing fern (*Lygodium microphyllum*) and Java plum (*Syzygium cumini*).

Pine flatwoods are savanna communities with an open canopy of slash pine (*Pinus elliotti* var. *densa*) and a diverse ground cover of grasses, sedges, and broad-leaved forbs. Shrubs, particularly palmetto, *Serenoa repens*, are typically maintained by a natural fire regime as a scattered and low growing component of this community. A fire frequency of approximately once every three to five years maintains this community structure by controlling colonization by shrubs and hardwoods, while allowing adequate survival of young pines. There is a moisture gradient over which pine flatwoods exist. Wetter sites have a diverse herbaceous ground cover, while drier sites have a more extensive cover of palmetto and mixed shrubs. These two types tend to co-exist as a mosaic, with the wetter type becoming more dominant within the mosaic as one moves down slope and the drier type becoming more dominant as one moves upslope. Even

undisturbed pine flatwoods are susceptible to invasion by a variety of exotic plant species, such as melaleuca and downy rose myrtle (*Rhodomyrtus tomentosa*).

Herbaceous wetlands are dominated by grasses and sedges, along with a variety of broad-leaved forbs. The dominant species are often arranged in a pattern of concentric rings or zones of vegetation oriented perpendicular to the hydrologic gradient. The driest sites are short hydroperiod wet prairies that typically occur on a mineral substrate. Wet prairies support a diverse plant community that can vary in structure from open to dense, and is generally dominated by short vegetation less than about 4 ft tall. This structure allows substantial amounts of sunlight to reach the water surface, which facilitates development of productive submerged algal communities. The wettest sites are long hydroperiod marshes that typically occur on a deep organic substrate. They have a lower diversity than wet prairies, and a relatively tall, dense structure that allows little sunlight to reach the water surface. Drainage can convert the drier sites to upland communities, and the wetter sites to something more similar to the drier sites. Loss of organic soils can be particularly damaging, because of their rapid disappearance following drainage and their very slow rate of recovery even when the hydrologic regime is restored. In the absence of a fire frequency of about every three to ten years, shrubs and trees gradually colonize these wetlands, and can eventually convert them to forested sites. As with all South Florida communities, herbaceous wetlands are low-nutrient systems. Significant increases in nutrients can drastically alter their composition. The best documented example of this alteration is the conversion of sawgrass marshes to cattail marshes in areas where there have been substantial inputs of phosphorus (Davis 1994). However, as with the upland communities, even undisturbed herbaceous wetlands are susceptible to invasion by a variety of exotic plant species, such as melaleuca on drier sites and West Indian marsh grass (*Hymenachne amplexicaulis*) on wetter sites.

Forested wetlands occupy sites that are typically wetter than those occupied by herbaceous communities. As a result, they burn less frequently, and woody vegetation is able to colonize and dominate these sites. As with the other major community types, the character of forested wetlands changes substantially along a moisture gradient that, in concert with organic soil depths, controls the frequency and severity of fires. Virtually mono-specific stands of young, densely-spaced cypress (*Taxodium distichum)*, growing on a mineral soil dominate the canopy of sites at the drier end of this gradient, where severe fires probably occur every 15 to 50 years. A diverse grass and sedge ground cover with few shrubs is usually found on these sites. At the wet end of the gradient are forests still dominated by a dense cypress canopy, but here they are large and more widely spaced and are growing on a deep organic soil. There is typically a well-developed subcanopy of hardwoods, and a variably dense cover of shrubs and herbaceous vegetation, with scattered ponds that may have an open water surface or a cover of floating plants. Fire still occurs in these latter sites, but because of their very wet setting, severe fires are not likely at a frequency greater than about once every 1000 years. However, the more varied topography of these sites, which contributes to their high diversity, partially results from patchy and variable consumption of the underlying peat during these rare fire events. Diversity associated with topographic variation is also increased when a large cypress dies, and the fallen log and stump are colonized by vegetation that could not become established on the forest floor because of the depth and duration of inundation in this community. Drainage of these sites can result in the conversion of the shallower forested wetlands to herbaceous wetlands or upland

communities through a more frequent and severe fire regime, and conversion of the deeper wetland plant communities to something more similar to the shallower forested wetlands. There are again the same problems associated with rapid organic soil loss following drainage, and its very slow recovery following reestablishment of the hydrologic regime. Hydrologic restoration of drained sites would be evidenced by the redevelopment of a closed cypress canopy through expansion of existing canopies and seedling establishment, and the presence of stressed and dying species less tolerant of extended inundation than cypress, such as slash pine, laurel oak, and grape vines (*Vitis* sp.) that invaded the site following drainage. Reestablishment of an appropriate fire regime would still allow fire to regularly enter the shorter hydroperiod cypress forests so that hardwoods would not be present on these sites. The longer hydroperiod mixed cypress forests would not experience fires for periods on the order of centuries, and hardwoods, such as dahoon holly (*Ilex cassine*), sweet bay (*Magnolia virginiana*), and red maple, would be a major subcanopy component of these diverse systems. As for the hardwood hammocks, the presence of tropical plant species in appropriate settings, such as near the Gulf coast and in association with major wetlands would indicate the presence of a hydrology adequate to protect these organisms from freezes.

The above discussion is not meant to be exhaustive, but provides examples of the kinds of community characteristics and site changes that would be useful to monitor, particularly in areas that are established as major restoration sites or are set aside for preservation. Rates of change in these communities in response to increased or decreased levels of stressors will vary from three to twenty or more years depending on community type and the management required to accomplish restoration. Early successional communities, such as the herbaceous wetlands and pine flatwoods, tend to respond more rapidly to changes than do later successional communities, such as the hammocks and forested wetlands. Management actions that directly affect vegetation, such as application of herbicides or prescribed fire, will produce more rapid responses than will management actions that indirectly affect it, such as changes in hydrology or a reduction in fire frequency.

Breeding Birds (including Red-cockaded Woodpecker)

Logging of old growth pines, which occurred in the Big Cypress through the 1950s, has removed many of the prime red-cockaded woodpecker (*Picoides borealis*) nesting trees throughout its range (Ligon 1971, Patterson and Robertson 1981). In addition, conversion to agriculture and housing is eliminating their habitat. The current altered fire regime is resulting in colonization by native and exotic woody vegetation of the remaining pinelands, which is eliminating the open character of these pinelands that is needed to support this species (Patterson and Robertson 1981, Jackson 1971). Successful reproduction in this species is one possible measure of pineland condition, since it is dependent upon mature, open pinelands. Suitable habitat should be extensive enough so that it would burn regularly, while having a hydrology that would prevent excessively severe fires. Sites should not support nuisance exotics that would tend to grow up and both eliminate the site's open character and produce fuel loads that would result in excessively severe fires. Response to restoration that increases the suitability of habitat would likely be expected within five to ten years, where reestablishing the open character of a pineland is involved, but could be thirty or more years, where young pine stands need to reach large enough sizes to provide suitable nest sites.

Aquatic Fauna

These species are affected primarily by altered hydrology and land use changes, both of which have resulted in habitat loss and fragmentation over large areas of the Big Cypress. Of particular concern is the loss of dry season refugia, which have been replaced by deep canals and excavations with quite different physical and biological characteristics. Abundance of marsh fishes has been correlated with duration of flooding in the Everglades (Loftus and Eklund 1994), suggesting a decline in fish populations in remaining Big Cypress wetlands where water tables have been lowered and hydroperiods shortened. Habitat fragmentation is particularly damaging to these species, which in more natural settings take advantage of the wet season expansion of surface waters into the surrounding uplands by increasing their numbers and biomass, which then becomes available to wading birds and other predators during the surface water's subsequent retreat during the dry season (Carlson and Duever 1979, Kolopinski and Higer 1969, Kushlan et al. 1975). A poorly known influence on them are exotic fish and amphibian species that have invaded the area, which are both preying on native species and competing with them for resources (Dineen 1984, Duever et al. 1986). Documenting the abundance, distribution, and diversity of these taxa will provide useful measures of how the stressors affecting them are being minimized in protected areas and are being ameliorated in areas being restored. Since these populations show a dramatic annual cycle in their numbers and biomass, responses to increasing or decreasing levels of stressors should be detectable within three to five years.

Potential inputs of pesticides, mercury and other contaminants in agricultural and urban runoff water, which may be needed for hydropattern restoration in the Big Cypress, could result in reduced health, behavioral and physical abnormalities, and loss of reproductive vigor unless measures are taken to restrict loads of these toxins in waters flowing into natural areas. Measures of aquatic faunal health that reflect responses to the mercury and pesticide inputs include body burdens of mercury and other toxins in representative top predators, especially long-lived predators/scavengers such as fish and alligators.

Wood Stork & Wading Birds

The Big Cypress region supported the two largest nesting colonies of wood storks (*Mycteria americana*) in North America between 1900 and 1965 (Ogden personal communication). During that period, 6,000-10,000 pairs nested annually in the Corkscrew colony, the Sadie Cypress colony of Okaloacoochee Slough, and smaller subsidiary colonies. Since 1965, wood stork nesting in Big Cypress has declined and has ranged from less than 500 to 1500 pairs since 1990 (Ogden personal communication). The subsidiary colonies have been largely lost. Accompanying the decline in numbers of nesting pairs has been a reduction in nesting success in the remaining colonies. The decline in success is attributed to a change in the timing of the initiation of nesting from November to February (Kushlan et al. 1975, Ogden et al. 1987, Ogden 1994). Delay in nesting until February puts nesting out of synchrony with seasonal rainfall patterns. With the onset of the wet season, rising water levels decrease food availability before the young storks fledge, causing nestling mortality due to starvation. The reduction in numbers of nesting pairs and nesting success is attributed to the loss of early dry season foraging habitat of the higher elevation wetlands of the Big Cypress region that have been drained and developed. Recovery of fish production in the higher elevation wetlands by raising water tables in preserved

areas in the western and northern portions of the Big Cypress basin is expected to halt the decline in wood stork nesting in Big Cypress. A trend of increasing numbers of nesting pairs, nesting success and reestablishment of subsidiary colonies should be evident over a decade-long time scale after water table recovery.

Florida Panther and Prey

The endangered Florida panther (*Puma concolor coryi*) is the only representative of the species *P. concolor* surviving in the eastern United States. Over the past 100 years, bounty hunting, land clearing, urbanization, and increased human activity throughout the landscape have contributed to the rangewide decline of the panther and have resulted in a population threatened with extinction. The panther's current distribution occupies approximately 890,000 ha, which is greatly reduced from the subspecies' historical range. The current verified population (2002) totals 80 panthers, which represents the number of adult and subadult panthers documented during field investigations (McBride 2002). The only known reproducing Florida panther population is located in the Big Cypress/Everglades physiographic region of south Florida. Seventeen years of monitoring indicate a stable but saturated panther population in the northern portion of its current range, which encompasses public lands north of Interstate 75 and adjacent private lands (Jansen, Big Cypress National Preserve, personal communication). Habitat vacancies in southern Big Cypress National Preserve and Everglades National Park have not been filled due to the difficulty of population increase when there are few individuals, at times only a single sex, and infrequent ingress of new individuals. The initial results of genetic restoration have been promising, with an increasing population, signs of increased genetic health, current recolonization of areas in Big Cypress National Preserve and Everglades National Park recently unoccupied, and increased dispersal (McBride 2000, 2001, 2002; Maehr *et al.* 2002).

The habitat of the Florida panther is an extensive landscape comprised of a mixture of natural, semi-natural, and agricultural land uses. Within this landscape, panthers maintain functional home ranges, have access to mates, find suitable denning sites, rear young, and disperse upon reaching adulthood. The maintenance and enhancement of appropriate cover types, existing agricultural land uses, and landscape configurations is necessary to conserve the existing panther population in south Florida. Panther require dry areas for daytime resting but readily travel through inundated habitats (Jansen 1987). Deer, a preferred prey species, benefit from a hydroperiod that promotes nutritious wetland vegetation (Loveless 1959), and prescribed fire improves the nutritional quality of food used by panther prey species. Food habit studies of Florida panthers indicate that feral hog (*Sus scrofa*) was the most commonly taken prey followed by white-tailed deer, raccoon (*Procyon lotor*), and nine-banded armadillo (*Dasypus novemcinctus*) (FWS 1999).

Stressors for the panther include loss and fragmentation of habitat due to urbanization and agricultural development, genetic erosion, mortality associated with road hazards, and mercury toxicosis. The sources of methyl mercury, reported as the cause of death of at least one panther and known to compromise normal biological functions, have yet to be confirmed and remedied (Roelke et al. 1991). Habitat protection, including land acquisition, land management (exotic control, prescribed fire), and restoration of natural hydroperiods with clean water would benefit the panther by providing suitable land for population expansion, as well as an uncontaminated and abundant prey base (Jansen, Big Cypress National Preserve, personal communication).

5. Ecological Effects

Ecological effects are the biological responses caused by the stressors. They are critical linkages between stressors and attributes.

Vegetation Community Gradients and Habitat Mosaic

Relationship of Vegetation to Reduced Hydrologic Regime

The occurrence and distribution of all native and some exotic plant communities in the Big Cypress region are a function of hydrology. A reduction in hydroperiod and depth results in dominance by more terrestrial communities, while an increase in hydroperiod and depth results in dominance by plant communities more tolerant of extended inundation. Severe reduction or alteration of hydrologic regimes result in further changes in vegetation due to invasion of exotic plants, increased fire severity, woody plant colonization, and reduction in populations of native tropical plant species due to freezes.

Level of Certainty – High

Relationship of Vegetation to Habitat Loss and Fragmentation

Loss of plant community spatial coverage is proportional to the loss of Big Cypress habitats to drainage and development. In addition, disturbance related to compartmentalization facilitate exotic vegetation invasion, since invading species typically are more prolific, disseminate their propagules more widely, and grow more rapidly than most native species.

Level of Certainty – High

Relationship of Vegetation to Exotic Plant Invasion

A number of the more aggressive exotic plant species can completely alter the species composition and structure of plant communities, as well as the ecological processes operating on a site. Spread of exotic plants is related to fire and disturbance, as noted in other hypotheses.

Level of Certainty – High

Relationship of Vegetation to Exotic Hog Impacts

Hog impacts result from their rooting of soils over extensive areas. Their effects are thought to operate primarily at the plant species composition level, in terms of reducing populations of species upon which they forage, and favoring others that are benefited by soil disturbance.

Level of Certainty – Moderate

Relationship of Vegetation to Fire

The occurrence and distribution of all native and some exotic plant communities in Big Cypress are a function of fire. Certain exotic plant species are very fire adapted, and their structural and chemical characteristics can greatly increase fire frequency and severity as they come to dominate a site. Increased fire frequency results from reduced hydrologic regime. Increased fire severity also results from reduced hydrologic regime, in combination with less frequent fire, which in turn results in fuel build-up. Less frequent fire also results in woody plant colonization.

Level of Certainty – High

Relationship of Vegetation to Nutrient Inputs

Nutrient inputs affect species composition, primarily in wetland plant communities, by favoring populations of aggressive native and exotic species, which reduces other native species populations through competition.

Level of Certainty – High for phosphorus and Low for other water quality parameters

Wetland Aquatic Fauna

Relationship of Aquatic Fauna Populations to Habitat Loss

The conversion of portions of the Big Cypress Basin to agricultural and urban land use represents a proportional loss in the populations of fishes and other aquatic fauna that once inhabited that region. That loss is considered to be irreversible, short of reflooding developed areas and reconnecting them to the remaining natural system.

Level of Certainty – High

Relationship of Marsh Fish Populations to Hydroperiod

The density, size structure and taxonomic composition of fish populations in Big Cypress wetlands are limited by the annual duration of uninterrupted flooding. This is because fish density is directly related to the period of population recovery between marsh dry downs. The relative abundance of fish species also responds to hydroperiod. Centrarchids and other larger fish species are less represented under shorter hydroperiods, which affects size structure of marsh fish populations. The reduction of hydroperiod in overdrained Big Cypress wetlands limits fish density, size structure and representation of long-hydroperiod species to levels below those expected under natural hydrologic conditions. Hydroperiod restoration is expected to result in the recovery of fish density, size structure and relative abundance. Hypothetical relationships of fish populations to hydroperiod are based on those developed in the Everglades, and comparatively little information is available for Big Cypress, which differs considerably from the Everglades in topography and hydrology.

Level of Certainty – Low

Relationship of Marsh Fish Populations to Exotic Fishes

Canals and areas close to canals support exotic fish species, which can dominate the fish populations in those areas. So far, the distribution of high densities of exotic fishes appears to be limited to canals and wetlands hydrologically-connected to these canals.

Level of Certainty – Moderate

Macroinvertebrate and Herpetofauna Populations: Controlling Variables and Functional Importance

Hypotheses that have been proposed for population responses of marsh fishes to hydroperiod and exotics are assumed to also apply to mollusks, crayfish and amphibians. However, little is known about the life histories, population dynamics and ecosystem roles of species such as apple snails, grass shrimp, crayfish, and frogs in the Big Cypress Basin. Although they would also be expected to decline in abundance with the overdrainage of Big Cypress wetlands, in response to the same factors affecting the fishes, quantitative relationships are mostly lacking. Crayfish constitute an important prey item in the diets of many vertebrates inhabiting Big Cypress, including pig frogs, otters, alligators and white and glossy ibis. The lack of information regarding the population dynamics functional roles of macroinvertebrates and herpetofauna in Big Cypress, despite the potential importance of these groups, represents an important gap in our information regarding the degradation and restoration of wetland systems.

Level of Certainty – Low

Relationship of the Health of Aquatic Fauna to Environmental Contaminants

Environmental contaminants, such as pesticides and heavy metals, can be concentrated in organisms through food webs. These bioaccumulated toxins can have significant effects on the health of populations of aquatic fauna, and ultimately on the survival of at least some species. Contaminants can also significantly affect aquatic fauna without being bioaccumulated, particularly for those species with gills or permeable surfaces exposed to water.

Level of Certainty – High

Wood Stork & Wading Birds

Relationship of Wood Stork Nesting to Density, Size Structure and Seasonal Concentration of Marsh Fish Populations

The density and seasonal concentration of fishes above ~10cm in length is the primary factor limiting the wood stork's ability to reproduce in their traditional large nesting colonies in the Big Cypress Region. The conversion and drainage of wetlands, including larger wetlands as well as shallow depressions in hydric pinewoods, has resulted in a reduction in the distribution, density and seasonal concentration of marsh fish populations, which is the primary cause of nesting failure and colony abandonment by wood storks in the Big Cypress region.

Level of Certainty – Moderate

Florida Panther

Relationship of Florida Panther Population to Habitat Loss and Fragmentation

It is well established that habitat loss and fragmentation are among the most important threats to persistence of Florida panthers (Maehr 1990; Maehr et al. 2002)

Level of Certainty – High

Relationship of Florida Panther Health to Bioaccumulation of Environmental Contaminants

There are a number of reasons for concern about contaminants and their potential effects on the persistence of the Florida panther, not the least of which is the small population. Furthermore, part of the Florida panther population lives near the lower end of the Everglades hydrologic system, which is subject to pollution from urban, suburban, industrial, and agricultural land uses. Finally, as a top predator, the panther may be subject to bioaccumulation of toxins.

Level of Certainty – Moderate

6. Research Questions

Relationship of Wetland Aquatic Fauna Populations to Hydroperiod and Water Depth

How do hydroperiod and water depth affect the density, biomass, and taxonomic composition of fish, crayfish, grass shrimp, and frog populations, as intermediate trophic levels in food webs of Big Cypress wetlands? What are the hydroperiod and depth requirements to produce wetland fishes >10 cm in length as a forage base for wood storks? Develop quantitative relationships and models of fish, crayfish, grass shrimp, apple snail, and frog populations in relation to hydroperiod and depth in the major wetland habitats of the Big Cypress region.

Plant Community Alterations Associated With Inflows of Drainage Water With High Mineral Content

How are the composition and structure of native plant communities altered when water with a higher than normal mineral content for surface waters enters wetland systems from canals, aquifer storage and recovery, and in-ground reservoirs?

Feral Hog Impacts on Plant Communities

How does hog rooting affect the composition of native plant communities, particularly in enhancing the spread of exotic or invasive species?

Relationship of Florida Panther Health to Bioaccumulation of Environmental Contaminants

Does existing tissue samples and data now available show a correlation between tissue levels of toxins and the fitness of individual panthers? If this analysis suggests that mercury (or any other toxin) may still be a problem, research should identify the ultimate source of the mercury (toxins), and follow it through the food chain by sampling aquatic plants, invertebrates, and the vertebrate prey consumed by panthers (Beier et al. 2003).

7. Hydrologic Performance Measures

Successful protection of undisturbed areas and restoration of disturbed areas require the establishment of hydrologic targets that define the desired characteristics of a site's hydrologic regime, and then the development of hydrologic performance measures to evaluate the current status of the site relative to the targets. Hydrologic targets will be based on conditions predicted by the Natural System Model (NSM) being developed by the Southwest Florida Feasibility Study (SWFFS). Development of the NSM will be based on the distribution of pre-development southwest Florida plant communities, whose classification is directly related to the hydrologic regime of the sites where each community is located.

The SWFFS has developed a set of seven hydrologic performance measures to evaluate regional effects predicted during the detailed design of individual SWFFS components and to provide targets for field monitoring following implementation of the components. Of the seven hydrologic performance measures, six are applicable to the Big Cypress Basin region and include the following:

1. Duration of Uninterrupted Inundation.

This performance measure is the mean duration (in terms of the number of five-day periods) of all inundation events during the 36-year period of record in each Indicator Region in southwest Florida. This performance measure will be automated so that an inundation event is defined as the number of weeks from when water >0.0 ft until water < 0.0 ft. The target would be to have the duration of uninterrupted inundation be within 10 percent (plus or minus) of NSM conditions, unless other than NSM targets were specified for individual indicator regions.

2. Number of Dry Events.

Dry events are defined as times when the water level drops either to or below the ground surface (0.00 ft). This performance measure is the number of dry events during the 36-year period of record in each Indicator Region in southwest Florida. The target would be to have the number of dry events be within 10 percent (plus or minus) of NSM conditions, unless other than NSM targets were specified for individual indicator regions.

3. Hydroperiods.

Hydroperiods are defined as the average number of five-day periods per year when the water level is above (>0.01 ft) the ground surface during the 36-year period of record. They will be calculated in each Indicator Region in southwest Florida. The target would be to have the hydroperiod be within 10 percent (plus or minus) of NSM conditions, unless other than NSM targets were specified for individual indicator regions.

4. Duration of Water Level Deviation.

Two levels of deviation will be calculated in each Indicator Region in southwest Florida . The first would be a count of the number of five-day periods when the NSM water table is at or below ground (<0.00 ft) and the scenario being evaluated is <0.5 ft higher or lower than the NSM water level. The count would be divided by the number of weeks the NSM water table is below ground to determine the percentage of time the count did not exceed the threshold. The second would be a count of the number of weeks when the NSM water table is above ground (>0.01 ft) and the scenario being evaluated is <0.25 ft higher or lower than the NSM water level. The count would be divided by the number of weeks the NSM water table is above ground to determine the percentage of time the count did not exceed the threshold. The target would be to have the duration of water level deviation beyond these thresholds be no more than 10 percent of the number of five-day periods in the period of record used in the model, unless other than NSM targets were specified for individual indicator regions.

5. Seasonal Amplitude and Interannual Variability of Water Levels.

This performance measure uses water depths above and below ground for five-day periods to calculate the average annual maximum and minimum water levels, the average range of annual fluctuation, and year-to-year variation in these values in each Indicator Region in southwest Florida. The target would be to have the average annual maximum and minimum water levels, the average range of annual fluctuation, and the interannual variability be within 10 percent (plus or minus) of NSM conditions, unless other than NSM targets were specified for individual indicator regions.

6. Water Levels and Timing.

This performance measure evaluates water levels relative to the ground surface and timing in each Indicator Region in southwest Florida. The model output is presented as five-day periods summarized into wet season, dry season, and annual average water levels. The target would be to have the water levels be within 10 percent (plus or minus) of NSM conditions for each time interval, unless other than NSM targets were specified for individual indicator regions.

It is important to be aware that the above performance measures are based on long-term averages, and there is a great deal of natural year-to-year variability in these values. In addition, the same types of plant communities vary substantially from one place to another, because of

differences in their setting and site history. Even though extreme environmental events can have major affects in shaping plant communities, they don't normally produce shifts from one community type to another because the overall ecosystem has evolved in the context of these events. These concepts will be important to take into consideration when evaluating project alternatives.

8. Ecological Performance Measures

Ecological performance measures were developed based primarily on attributes identified in the Big Cypress Conceptual Ecological Model. However, a number of the attributes identified in the model have not been included in the current set of performance measures and others have been modified or added to provide greater consistency among the SWFFS ecological conceptual models. Some attributes were not included because we could not see a clear relationship to restoration actions. Examples are *black bear presence, distribution, and relative abundance, red cockaded woodpecker nesting success,* or *panther habitat*. In addition, some such as *panther numbers* were not included because we felt it would be difficult to document change in response to restoration actions. However, while we felt that it would be difficult to document change in *panther numbers* in response to restoration actions, the primary prey of panthers is the white-tailed deer, which is present in sufficient numbers that should make it possible to detect changes in *deer number and distribution* in response to restoration. In some cases the Big Cypress performance measure was generalized to provide for greater consistency with similar performance measures in other greater Everglades regional conceptual models. Examples include wood storks being combined under *wading bird nesting,* and native fish, crayfish, and amphibians being combined under *wetland aquatic fauna*. *Alligator abundance, distribution, and size classes, alligator condition,* and *wetland soil accretion* were three performance measures that were added to provide for consistency with the other greater Everglades regional conceptual models. Five performance measures were developed to provide a basis for monitoring Big Cypress plant communities. These included *composition and structure of major plant communities*, *plant community mosaic*, *plant community gradients, wetland restoration,* and *forested wetland hydrology indicators*.

9. Water Quality Performance Measures

The SWFFS Water Quality Sub-team has developed two sets of performance measures: 1) evaluation measures (Table 1) and 2) assessment measures (Table 2). Evaluation performance measures are used to predict the performance of a given alternative. Assessment performance measures are used to measure real responses as a basis for tracking how well the plan is meeting its goals. Targets for these performance measures are currently being developed along with tools for their assessment (for details, see SWFFS Water Quality strategy paper).

In addition to the water quality performance measures developed for the SWFFS, water quality performance measures are being developed for those portions of the Big Cypress that will be affected by CERP restoration actions. These include sites along the eastern portion of the Big Cypress adjacent to the Everglades and the Big Cypress Critical Projects, such as South Golden Gate Estates hydrologic restoration, Lake Trafford demucking, southern Corkscrew Regional Ecosystem watershed (CREW) restoration, Tamiami Trail canal plugs and bridges, and Belle Meade and Henderson Creek restoration. Phosphorus loads and concentrations are the water

quality performance measures that have the strongest scientific basis and the most widespread and long-term database in South Florida. They have been proposed for monitoring throughout the area. Other performance measures proposed for widespread monitoring throughout the greater Everglades include organics (pesticides) and trace metals (mercury). However, there is only a very limited database on their occurrence in the South Florida environment, and even less information on their effects on the ecosystem, particularly as it relates to CERP restoration actions. A few other performance measures have been proposed for individual Critical Projects in the Big Cypress region. One is hardness in South Golden Gate Estates, where most of the nonprecipitation water inputs will be from canal flows. The other is dissolved oxygen in Lake Trafford where a large accumulation of muck sediments will be removed.

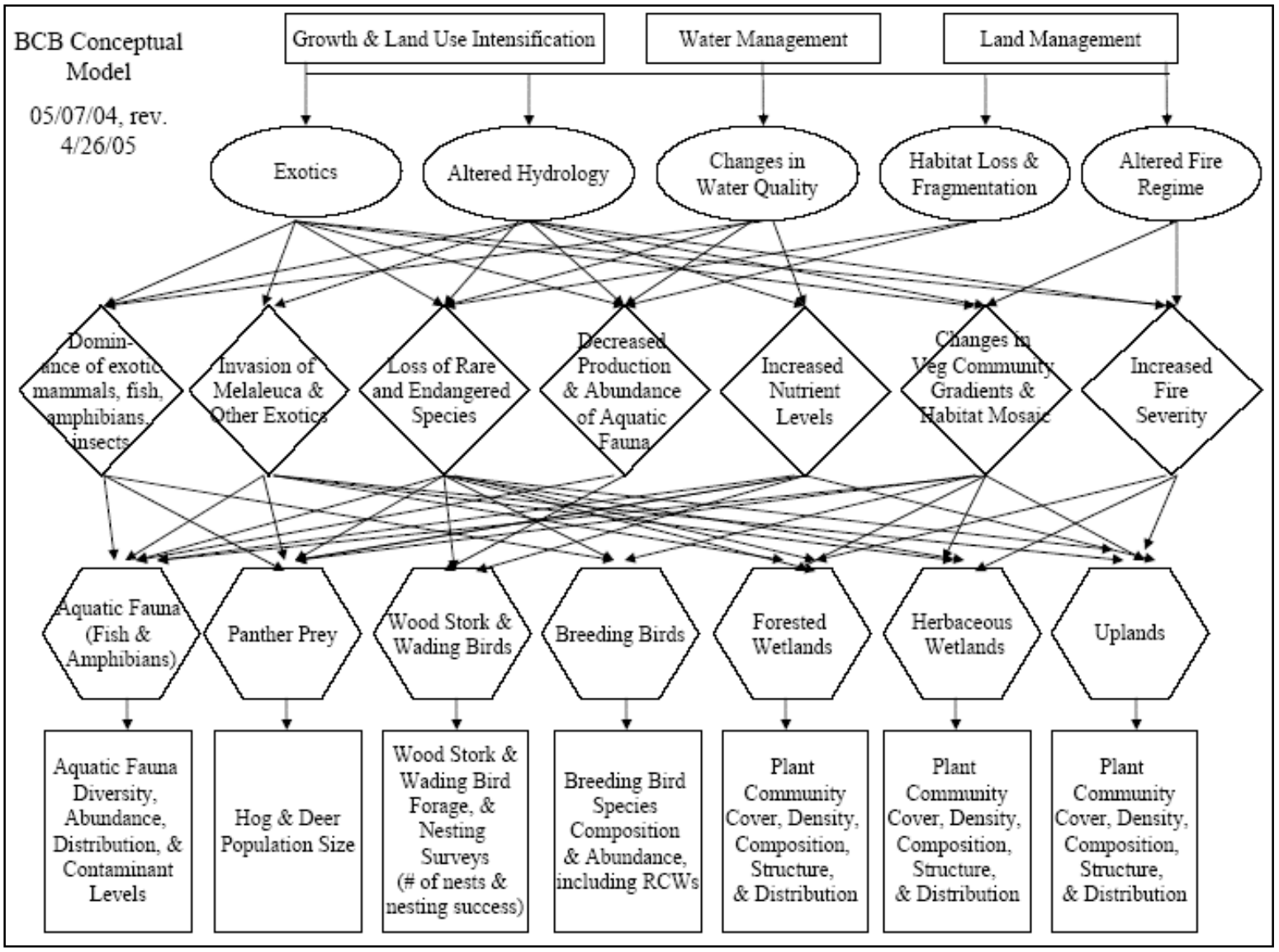
Table 1. SWFFS Water Quality Sub-Team Evaluation Performance Measures.

Evaluation Performance Measures
Dissolved Oxygen (DO)
Salinity (PSU)
Turbidity/TSS
Photosynthically Active Radiation (PAR) / Color
Chlorophyll a (Chl-*a*)
Total Nitrogen (TN)
Dissolved inorganic nitrogen (DIN)
Soluble Reactive Phosphorus (SRP)
Total Phosphorus (TP)

Table 2. Assessment Water Quality Performance Measures for SWFFS

Assessment Performance Measure	**Target**
Dissolved Oxygen (DO)	*Project/indicator region specific*
Specific Conductance	Project/indicator region specific
Salinity	Project/indicator region specific
Turbidity/ TSS / Color	Maintain or reduce to levels that support healthy flora and fauna.
Photosynthetically Active radiation (PAR) / secchi disc depth	Maintain or increase to levels that support healthy flora and fauna.
Chlorophyll a (Chl *a*)	Maintain or reduce to levels that support healthy flora and fauna.
Total Nitrogen / Ammonia Nitrogen / Total Kjeldahl Nitrogen / Nitrate / Nitrite / Dissolved inorganic nitrogen	Maintain or reduce loads and concentrations to support healthy flora and fauna.
Total Phosphorus/ Orthophosphate/soluble reactive phosphorus	Maintain or reduce loads and concentrations to support healthy flora and fauna.
Chloride	Project/indicator region specific
Sulfate	Project/indicator region specific
Silica	Project/indicator region specific
Pesticides	Project/indicator region specific
Trace Metals	Project/indicator region specific

10. Model Diagram



11. Literature Cited

Ackerman, J. A., Jr. 1976. Florida cowman, a history of Florida cattle raising. Florida Cattleman's Association, Kissimmee. 287 pp.

Alexander, T. R. and A. G. Crook. 1973. Recent and long term vegetation changes and patterns in South Florida. Appendix G, Part I. South Florida ecological study. University of Miami, Coral Gables, Florida. 215 pp.

Alvarez, K. C. no date. A brief history of Florida cattle ranching (1521-1900). Unpublished report. 68 pp.

Beier, P., M.R. Vaughan, M.J. Conroy, and H. Quigley. 2003. An analysis of scientific literature related to the Florida panther. Final Report. Florida Fish and Wildlife Conservation Commission, Tallahassee, Florida, USA.

Carlson, J. E. and M. J. Duever. 1979. Seasonal fish population fluctuations in south Florida swamp. Proceedings of Annual Conference of Southeastern Association of Fish and Wildlife Agencies 31: 603-611.

Carter, M. R. , L. A. Burns, T. R. Cavinder, K. R. Dugger, P. L. Fore, D. B. Hicks, H. L. Revells, and T. W. Schmidt. 1973. Ecosystem analysis of the Big Cypress Swamp and estuaries. United States Environmental Protection Agency. EPA 904/9-74-002. 375 pp.

Coultas, C. L. and M. J. Duever. 1984. Soils of cypress swamps. Pages 51-59 in H. T. Odum and K. C. Ewel, eds. Cypress swamps. University of Florida Press, Gainesville.

Craighead, F. C., Sr. 1971. The trees of South Florida. Volume 1. The natural environments and their succession. University of Miami Press, Miami, Florida. 212 pp.

Crowder, J. P. 1974. The exotic vertebrates of South Florida. United States Department of the Interior, Bureau of Sport Fisheries and Wildlife, Ecological Report DI-SFEP-74-30. 43 pp.

Davis, J. H., Jr. 1943. The natural features of Southern Florida. Florida Geological Survey Bulletin 25. 311 pp.

Davis, S. M. 1994. Phosphorus inputs and vegetation sensitivity in the Everglades. Pages 357-378 in S. M. Davis and J. C. Ogden, eds. Everglades: the ecosystem and its restoration. St. Lucie Press, Delray Beach, Florida.

Dineen, J. W. 1984. The fishes of the Everglades. Pages 258-268 in P. J. Gleason, ed. Environments of South Florida: past and present II. Miami Geological Society, Miami, Florida.

Drew, R. D. and N. S. Schomer. 1984. An ecological characterization of the Caloosahatchee River/Big Cypress watershed. United States Department of the Interior Minerals Management Service and Fish and Wildlife Service. FWS/OBS-82/58.2. 225 pp.

Duever, M. J., J. E. Carlson, L. A. Riopelle, and L. C. Duever. 1978. Ecosystem analyses at Corkscrew Swamp. Pages 534-570 in H. T. Odum and K. C. Ewel, eds. Cypress wetlands for water management, recycling, and conservation. Fourth annual report to National Science Foundation and Rockefeller Foundation. Center for Wetlands, University of Florida, Gainesville.

Duever, M. J. 1984. Environmental factors controlling plant communities of the Big Cypress Swamp. Pages 127-137 in P. J. Gleason, ed. Environments of South Florida: past and present II. Miami Geological Society, Miami, Florida.

Duever, M. J., J. E. Carlson, J. F. Meeder, L. C. Duever, L. H. Gunderson, L. A. Riopelle, T. R. Alexander, R. L. Myers, and D. P. Spangler. 1986. The Big Cypress National Preserve. National Audubon Society Research Report No. 8, New York. 455 pp.

Elton, C. S. 1958. The ecology of invasions by animals and plants. John Wiley, New York. 199 pp.

Forman, R. T. T. and M. Godron. 1986. Landscape Ecology. John Wiley and Sons, New York. 619 pp.

Germain, G.T. 1998. Surface water quality monitoring network south Florida Water Management District. Technical memorandum: WRE # 356, 261p.

Gunderson, L. H. and L. L. Loope. 1982. A survey and inventory of the plant communities in the Raccoon Point area, Big Cypress National Preserve. South Florida Research Center, National Park Service, Everglades National Park, Homestead, Florida. Report T-665. 36 pp.

Harper, R. M. 1927. Natural resources of southern Florida.18th Annual Report of Florida Geological Survey, Tallahassee. 25-206.

Harris, L. D. 1984. The fragmented forest: island biogeography theory and the preservation of biotic diversity. University of Chicago Press, Chicago, Illinois. 211 pp.
Hofstetter, R. H. 1984. The effect of fire on the pineland and sawgrass communities of southern Florida. Pages 465-476 in P. J. Gleason, ed. Environments of South Florida: past and present II. Miami Geological Society, Miami, Florida.

Jackson, J. A. 1971. The evolution, taxonomy, distribution, past populations and current status of the red-cockaded woodpecker. Pages 4-29 in R. L. Thompson, ed. Proceedings of a Symposium on the Red- cockaded Woodpecker, Okefenokee National Wildlife Refuge, Folkston, Georgia.

Jansen, D. K. 1987. Big Cypress use study. Florida Game and Freshwater Fish Commission, Tallahassee. 240 pp.

Krabbenhoft, D.P. and Fink, L.E. 2000. The effect of dry down and natural fires on mercury methylation in the Florida Everglades. Extended abstract,. 11th International Conference on heavy Metals in the Environment.

Kennard, F. H. 1915. The Okaloacoochee Slough. Auk 32: 154-166.

Klein, H., W. J. Schneider, B. F. McPherson, and T. J. Buchanan. 1970. Some hydrologic and biologic aspects of the Big Cypress Swamp drainage area. United States Geological Survey Open File Report 70003. 94 pp.

Kolopinski, M. C. and A. L. Higer. 1969. Some aspects of the effects of the quantity and quality of water on biological communities in the Everglades National Park. United States Geological Survey, Open File Report 69007. 97 pp.

Kushlan, J. A., J. C. Ogden, and A. L. Higer. 1975. Relation of water level and fish availability to wood stork reproduction in the southern Everglades, Florida. United States Department of the Interior, Geological Survey, Open File Report 75-434. 56 pp.

Layne, J. N. 1984. The land mammals of South Florida. Pages 269-296 in P. J. Gleason, ed. Environments of South Florida: past and present II. Miami Geological Society, Miami, Florida.

Lehman, M. E. 1976. Collier County: growth pressure in a wetlands wilderness. Florida Bureau of Comprehensive Planning. Tallahassee. 59 pp.

Ligon, J. D. 1971. Some factors influencing numbers of the red-cockaded woodpecker. Pages 30-43 in R. L. Thompson, ed. Proceedings of a Symposium on the Red- cockaded Woodpecker, Okefenokee National Wildlife Refuge, Folkston, Georgia.

Loftus, W. F. and A. Eklund. 1994. Long-term dynamics of an Everglades small-fish assemblage. Pages 461-483 in S. M. Davis and J. C. Ogden, eds. Everglades: the ecosystem and its restoration. St. Lucie Press, Delray Beach, Florida.

Logan, T., A. C. Eller, Jr., R. Morrell, D. Ruffner, and J. Sewell. 1993. Florida panther habitat preservation plan: south Florida population. Florida Panther Interagency Committee. 105 pp.

Loveless, C. M. 1959. The Everglades deer herd, life history and management. Florida Game and Freshwater Fish Commission Technical Bulletin 6. 104 pp.

Maehr, D.S. 1990. Florida panther movements, social organization, and habitat utilization. Final Performance Report. Florida Game and Fresh Water Fish Commission, Tallahassee, Florida, USA. 165pp.

Maehr, D.S., E.D. Land, D.B. Shindle, O.L. Bass, and T.S. Hoctor. 2002. Florida panther dispersal and conservation. Biological Conservation 106:187-197.

McBride, R.T. 2000. Current panther distribution and habitat use: a review of field notes, fall 1999-winter 2000. Report to Florida Panther Subteam of MERIT, U.S. Fish and Wildlife Service, South Florida Ecosystem Office, Vero Beach, Florida.

McBride, R. T. 2001. Current panther distribution, population trends, and habitat use: report of field work: fall 2000-winter 2001. Report to Florida Panther Subteam of MERIT, U.S. Fish and Wildlife Service, South Florida Ecosystem Office, Vero Beach, Florida.

McBride, R. T. 2002. Current panther distribution and conservation implications -- highlights of field work: fall 2001 -- winter 2002. Report to Florida Panther SubTeam of MERIT, U.S. Fish and Wildlife Service, South Florida Ecosystem Office, Vero Beach, Florida.

Miller, R. L., R. V. Sobczak, C. J. Clark, and B. F. McPherson. 2002. Water Quality In Big Cypress National Preserve And Everglades National Park --Trends And Spatial Characteristics Of Selected Constituents. U.S. Geologic Survey Circular (publication pending).

Myers, R. L. 1975. The relationship of site conditions to the invading capability of Melaleuca quinquenervia in southwest Florida. Master's Thesis, University of Florida, Gainesville. 151 pp.

Odum, H. T. 1971. Environment, power, and society. John Wiley, New York. 331 pp.

Ogden, J. C. , D. A. McCrimmon, Jr. , G. T. Bancroft, and B. W. Patty. 1987. Breeding populations of the wood stork in the southeastern United States. The Condor 89: 752-759.

Ogden, J. C. 1994. A comparison of wading bird nesting colony dynamics (1931-1946 and 1974-1989) as an indication of ecosystem conditions in the southern Everglades. Pages 533-570 in S. M. Davis and J. C. Ogden, eds. Everglades: the ecosystem and its restoration. St. Lucie Press, Delray Beach, Florida.

Patterson, G. A., and W. B. Robertson, Jr. 1981. Distribution and habitat of the red-cockaded woodpecker in the Big Cypress National Preserve. South Florida Research Center, National Park Service, Homestead, Florida. 137 pp.

Robertson, W. B., Jr. 1953. A survey of the effects of fire in Everglades National Park. Unpublished Report. United States Department of the Interior, National Park Service, Homestead, Florida. 169 pp.

Rochow, T. F. 1985. Hydrologic and vegetational changes resulting from underground pumping at the Cypress Creek well field, Pasco County, Florida. Florida Scientist 48: 65-80.

Roelke, M. E. , D. P. Schultz, C. F. Facemire, S. F. Sundlof, and H. E Royals. 1991. Mercury contamination in Florida panthers. Florida Panther Technical Subcommittee. 55 pp.

Shahane, A. N. 1994. Pesticide detections in surface waters of Florida. IN Dutton, A.R. (ed) Toxic substances in the hydrologic sciences. American Institute of Hydrology, Minneapolis, MN.

Sobczak, R.V. 2001. Hydrology of the Addition Lands, Big Cypress National Preserve. National Park Service publication.

Swayze, L. J. and B. F. McPherson. 1977. The effect of the Faka Union canal system on water levels in the Fakahatchee Strand, Collier County, Florida. United States Geological Survey Water Resources Investigation. 77-61.

Tabb, D. C., E. J. Heald, T. R. Alexander, M. A. Roessler, and G. L. Beardsley. 1976. An ecological and hydrological assessment of the Golden Gate Estates drainage basin, with recommendations for future land use and water management strategies. Tropical Bioindustries Development Company. Miami, Florida. 178 pp.

United States Army Corps of Engineers and South Florida Water Management District. 1999. Central and southern Florida project comprehensive review study, final integrated feasibility report and programmatic environmental impact statement. Jacksonville, Florida.

U.S. Fish and Wildlife Service (FWS). 1999. South Florida Multi-species Recovery Plan. Atlanta, Georgia. 2172 pp.

Wade, D., J. Ewel, R. Hofstetter. 1980. Fire in south Florida ecosystems. United States Department of Agriculture, Forest Service General Technical Report SE-17. 125 pp.