

Freshwater and Nutrient Fluxes to Coastal Waters of Everglades National Park—A Synthesis

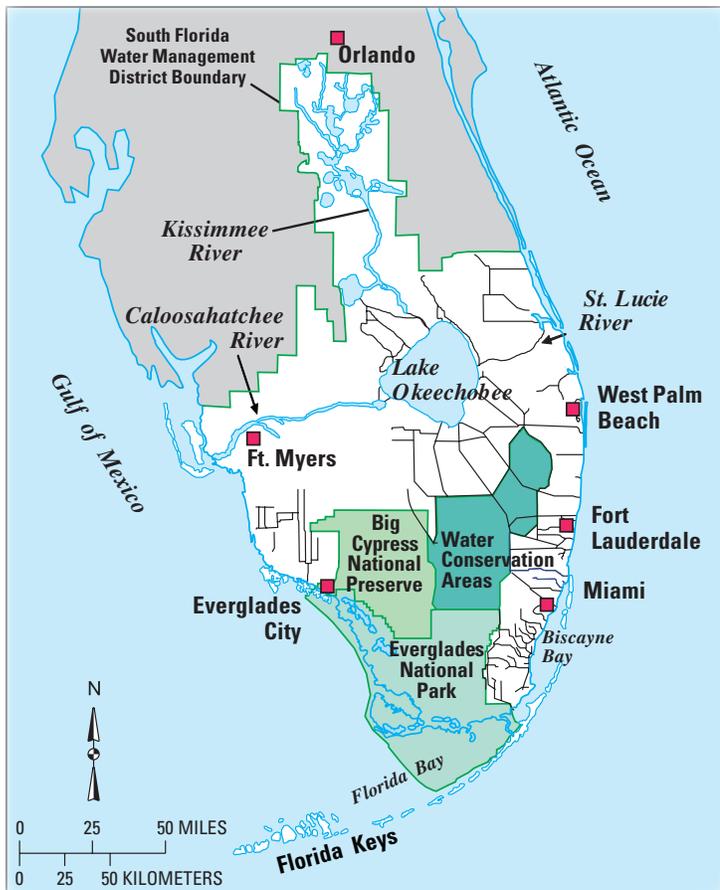
Introduction

The coastal ecosystem of south Florida formed during the last several thousand years after worldwide climate changes and sea-level rise. The ecosystem is characterized by subtropical estuaries, bays, tidal rivers, lagoons, coastal mangrove swamps, and marshes (figs. 1 and 2).

Freshwater in the Everglades and the Big Cypress Swamp drains south and southwest into coastal regions where it mixes with seawater to create the salinity gradients characteristic of productive estuarine and marine systems. Salinities in the coastal region range from hypersaline to nearly fresh, depending on location, season, and climatic changes.



Figure 1. (left) Lostmans Creek in Everglades National Park, looking north. **(below)** Turner River, at mouth, near Everglades City.



Studies in Florida Bay have shown that over the last 100 to 200 years, salinity and seagrass distributions have fluctuated substantially in response to natural climatic cycles. For example, seagrass and macrobenthic algae were much less abundant in the 1800s and early 1900s, than in the last half of the 20th century when fluctuations in salinity and seagrass distributions in Florida Bay were much greater. The timing of this change in salinity and seagrass coincides at least in part with the canal construction and landscape alterations in the Everglades (Lynn Brewster-Wingard, accessed online, 2006) that have altered the quantity, timing, distribution, and quality of surface water that flows south into the coastal waters.

Everglades National Park (ENP, established in 1947) and Big Cypress National Preserve (BCNP, established in 1974) were created by Congress to preserve and protect

Figure 2. Overall features of south Florida, which includes Everglades National Park, Big Cypress National Preserve, Florida Bay, and Water Conservation Areas.

Federal and State agencies have undertaken a massive Everglades Restoration project that will require changes in water-management procedures throughout the Everglades and will affect water flows to the coastal region. One of the major concerns involving changes in water flow is how this will affect salinity and nutrient availability in coastal waters.

Watershed inflows into ENP

The average annual freshwater inflow from the Big Cypress watershed to ENP is a little more than half the total inflow (Klein and others, 1970), as shown in figure 4. The average annual freshwater inflow from the Everglades watershed (1980-89) to ENP was 813,000 acre-feet, of which 559,000 acre-feet flowed under Tamiami Trail into Shark River Slough and 254,000 acre-feet flowed to Taylor Slough (86,300 acre-feet) and the C-111 basin (167,700 acre-feet) (Light and Dineen, 1994).

large areas of the south Florida ecosystem that had remained relatively intact and free of development, including much of the coastal region (fig. 3). Both ENP and BCNP are subject to the effects of upstream development and water management because of their location downgradient from the altered landscape. The effects of upstream development in recent decades are believed to be partly responsible for undesirable changes in water quality and biology in coastal waters of ENP. These alterations include increases in turbidity, hypoxia, algal blooms, changes in seagrass species, and large die-off of seagrasses and other marine organisms (Fourqurean and Robblee, 1999; Brand, 2002; Durako and others, 2002).

Federal and State agencies have undertaken a massive Everglades restoration project that will require changes in water management throughout the Everglades, and this will affect water flows to the coastal region. A major concern involves how changes in water flow could affect salinity and nutrient availability in coastal waters.

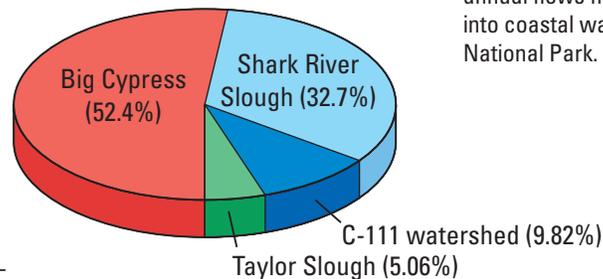


Figure 4. Percentages of average annual flows from different sources into coastal waters of Everglades National Park.

What are the major sources of nutrient loads?

The percentages of nutrient loading into Florida Bay from the Gulf of Mexico, atmospheric sources, basins and their tributaries, and the Florida Keys, are illustrated in the following diagrams (fig. 5). The Gulf is the major source of nitrogen and phosphorus loads, contributing more than 85 percent to the total loads. Other contributing sources could include submarine ground-water discharge (probably very small, at least into Florida Bay), and the mangrove system. Although basin tributaries contribute relatively small amounts of nutrient loads compared to the Gulf or from rainfall, they remain an important factor, because tributaries are the sources most subject to human control and activities.

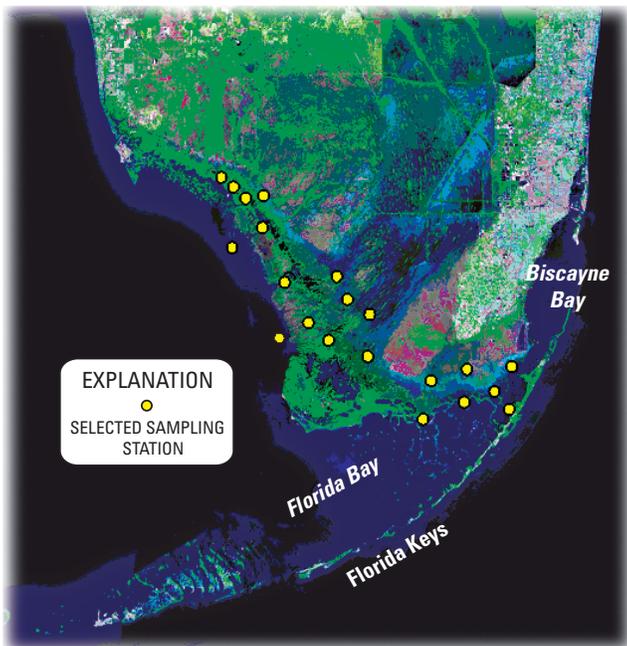


Figure 3. South Florida, showing selected USGS sampling stations in the tributaries and coastal waters of Everglades National Park.

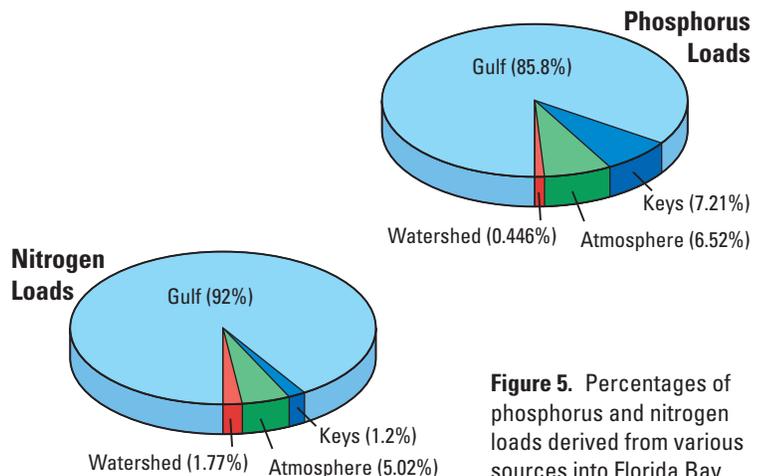


Figure 5. Percentages of phosphorus and nitrogen loads derived from various sources into Florida Bay (Rudnick and others, 1999).

Of the freshwater and nutrient sources that enter the coastal waters of Everglades National Park, watershed contributions were the most affected by human activities in the past and will be the most affected in the future.

Current and historical work on freshwater and nutrient watershed inputs

In 1995, the U.S. Geological Survey (USGS) began a series of studies to monitor the tributaries that discharge freshwater into northeastern Florida Bay and the southwestern estuaries of ENP. These studies provide: (1) flow, salinity, water temperature, and water-level data for research applications, including model development and calibration; and (2) base-line information for other physical, biological, and chemical studies being conducted in these areas. As part of these studies, a network of 35 estuarine and wetland hydrologic monitoring stations was constructed (Hittle and others 2004). These data enable USGS and other agencies to develop mathematical models to study the interaction of overland sheetflow and dynamic tidal forces (including flow exchanges and salinity fluxes between the surface- and ground-water systems) in the mangrove-dominated transition zone between the Everglades wetlands and adjacent coastal-marine ecosystems.

Investigators have measured relatively low concentrations of phosphorus and nitrogen in wetlands of ENP. Median values (in milligrams per liter) in wetlands were mostly less than 0.01 total phosphorus (TP) and 1.5 total nitrogen (TN) (Miller and others, 2004). When TP and inorganic nitrogen (N) flowed into Everglades wetlands, concentrations rapidly diminished, but TN did not (Rudnick and others, 1999). Loading from the southern Everglades watershed—which includes Taylor Slough and areas south of the C-111 canal—annually exported the following nutrients (in grams per metered squared): carbon (7.1), nitrogen (0.46), and phosphorus (0.007). Some data indicate a decreasing long-term trend in concentrations in recent years at West Highway Creek (W.B. Shoemaker, U.S. Geological Survey, written commun., 2005).

Concentrations of TP are higher in the mangrove zone than in upstream freshwater wetlands, indicating a marine source for this limiting nutrient. Childers and others (2005) report a 150-percent TP increase (from 0 to 30 parts per thousand) in TP along a transect of the Shark River, indicating the Gulf of Mexico as a major source. They attribute the higher values in the Florida Bay mangroves to a combination of the influx of phosphorus-rich carbonate particles from Florida Bay and to internal biogeochemical processing during longer periods.

There are a few direct measurements of nutrient fluxes in the tidal tributaries of ENP. Levesque (2004) reported that total monthly mean nutrient flux for five southwest coastal tributaries (Shark, North, Broad, and Harney Rivers, and Lostmans Creek) for August 1999 to January 2000 ranged from 0 to 390 short tons TN and 0 to 6 short tons TP. These measurements were made within the mangrove zone and reflect the higher concentrations found there compared to upstream marshes. Shoemaker (U.S. Geological Survey, oral commun., 2005) reported that annual (2004) TP loads at West Highway Creek and North River

were about +40 and +90 kg (kilograms), respectively, and that total kjeldahl nitrogen loads were about +3,100 and +6,300 kg, respectively.

Everglades TP fluxes were 3 to 4 orders of magnitude lower than published flux estimates from wetlands influenced by terrigenous sedimentary inputs. This reflects the inherently low TP concentrations of Everglades waters and the efficiency of Everglades carbonate sediments and biota in conserving and recycling this limiting nutrient (Sutula and others, 2003). The seasonal variations of freshwater input to the watershed were responsible for major temporal variations in nutrient export to Florida Bay; about 99 percent of the export occurred during the rainy season (Sutula and others, 2003).

Childers and others (2005) discuss the relation between nutrients and salinity in Shark River Slough and estuary and Taylor Slough and Florida Bay.

Total phosphorus (TP) increased along an increasing salinity gradient through the Shark River estuary and from freshwater sites in Taylor Slough to a saline mangrove site. TP concentrations were less variable and often lower at sites in Florida Bay than at the mangrove site. Concentrations of TP at the Taylor Slough mangrove sites tended to be higher during the dry season when salinities were highest.

Median concentrations of total nitrogen (TN) decreased down-estuary in Shark River, whereas concentrations tended to be lower at the Taylor Slough freshwater site than at the more saline mangrove site (which also showed typically higher values for TN than those at the offshore Florida Bay sites).

Hurricanes, tropical storms, and periods of high rainfall usually result in large increases in runoff and tributary nutrient loading (McPherson and Sonntag, 1984). The result of Hurricane Andrew's passage across south Florida in 1992 resulted in a large increase in concentrations of ammonia, dissolved phosphate, turbidity, and dissolved organic carbon and a decrease in dissolved oxygen and an increase in phytoplankton in coastal waters of ENP (Davis and others, 1994; Lovelace and McPherson, 1996).

Tropical storm activity across south Florida has resulted in decade-long trends of alternating sediment/organic carbon buildup and reduction that correspond, respectively, with periods of infrequent and more frequent hurricane activity. The frequency of hurricanes is probably the controlling mechanism for carbon storage and removal in Florida Bay (Nelson and others, 2002).

Water-quality (nutrient) models for restoration

Hydrologic flow models for the Everglades and Florida Bay have been developed for many years, for various purposes, and by different County, State, and Federal agencies. The Comprehensive Everglades Restoration Plan (CERP), approved by Congress in December 2000, initiated several individually and collectively funded water-flow model studies. With the completion of most of these studies, a need exists to develop and add water-quality components, including nutrients, into the models so predictions can be made on how the Everglades restoration project will affect water quality.

For many years, the South Florida Water Management District has used the South Florida Water Management Model (SFWMM) and the Natural Systems Model (NSM) to simulate hydrologic processes in south Florida. Both of these models, however, have inherent limitations for accurately simulating responses of the natural ecosystem to proposed restoration activities. Using recent advances in computer technology, computational methods, and information-technology related developments, this agency is currently developing the South Florida Regional Simulation Model (SFRSM). This new generation model will better simulate surface-water and ground-water interactions at regional/subregional scales and will be capable of better integrating ecosystem responses to hydrologic changes that are expected to occur during the implementation of various restoration events. Because of the recent emphasis on water quality in the restoration process, water-quality components are being added into the SFRSM. The model will be used to evaluate restoration alternatives being considered under CERP.

Likewise, the U.S. Army Corps of Engineers has developed and is expanding the Regional Engineering Model for Ecosystem Restoration (REMER). This model is an application of the WaterShed systems model, which includes 1-D stream-river networks, 2-D overland flow regimes, and 3-D flow and transport regimes (WASH123D). The WASH123D model also will be used in the CERP project area for simulations of variable-density water flow and contaminant and sediment transport.

The USGS has developed two models: the Southern Inland and Coastal System (SICS) model and the Tides and Inflows in the Mangroves of the Everglades (TIME) model (Raymond Schaffranek, http://sflwww.er.usgs.gov/projects/coupling_mdls/ and <http://sflwww.er.usgs.gov/projects/time/>). Both models currently are being used to bridge the gap between the SFWMM inland freshwater hydrodynamic model and the Across Trophic Level System Simulation (ATLSS) ecological models.

The SICS model will extend the capability of the SFWMM model to predict coastal flows to Florida Bay under future restoration conditions. The TIME model will extend this capability into southwestern coastal waters. The USGS is committed to the development of a water-quality module for SICS and TIME that can be used to predict nutrient loads into Florida Bay and the southwest coastal region. The water-quality modeling will build on the USGS flow and water-quality data being collected by USGS.

The ATLSS models were developed primarily by the University of Tennessee under the contract and guidance of the USGS (Donald DeAngelis; <http://sflwww.er.usgs.gov/projects/atlss/>). These models require water levels and salinity to simulate habitat suitability indices. In the past, the SFWMM model has been used to provide the hydrologic input for ATLSS,

despite two limitations—an inadequate scale resolution and the inability to simulate hydrologic conditions within the coastal zone. The SICS and TIME models currently provide the best hydrologic simulations for the coastal zone region, including those needed by ATLSS. When fully developed, the SFRSM and WASH123 models will replace the older SFWMM for many Everglades restoration modeling needs.

References

- Brewster-Wingard, Lynn, undated, Accomplishments, section in Ecosystem history: Florida Bay and the southwest coast: U.S. Geological Survey online project report accessed on 2006 at http://sflwww.er.usgs.gov/projects/eh_fbswcfwinaccomplish.html.
- Brand, L.E., 2002, The transport of terrestrial nutrients of south Florida coastal waters, in Porter, J.W., and Porter, K.G., eds., *The Everglades, Florida Bay, and coral reefs of the Florida Keys*: Boca Raton, Fla., CRC Press, p. 361-414.
- Childers, D.L., Boyer, J.N., Davis, S.E., and others, 2005, Relating precipitation and water management to nutrient concentrations in the oligotrophic "upside-down" estuaries of the Florida Everglades: *Limnology and Oceanography*, v. 50, no. 3.
- Davis, G.E., Loope, L.L., Roman, C.T., and others, compilers, 1994, Assessment of Hurricane Andrew impacts on natural and archeological resources of Big Cypress National Preserve, Biscayne National Park, and Everglades National Park, 15-24, September 1992: National Park Service, 158 p.
- Durako, M.J., Hall, M.O., and Merello, M., 2002, Patterns of change in the seagrass-dominated Florida Bay hydroscape, in Porter, J.W., and Porter, K.G., eds., *The Everglades, Florida Bay, and coral reefs of the Florida Keys*: Boca Raton, Fla., CRC Press, p. 523-538.
- Fourqurean, J.W., and Robblee, M., 1999, Florida Bay: A history of recent ecological changes: *Estuaries*, v. 22, no. 2B, p. 345-357.
- Hittle, C., Patino, E., and Zucker, M., 2004, Hydrologic characteristics of estuarine river systems within Everglades National Park: U.S. Geological Survey Fact Sheet 2004-3129, 4 p.
- Klein, Howard, 1970, Preliminary evaluation of availability of potable water on Elliott Key, Dade County, Florida: U.S. Geological Survey Open-File Report FL-70010, 15 p.
- Levesque, V.A., 2004, Water flow and nutrient flux from five estuarine rivers along the southwest coast of the Everglades National Park, Florida, 1997-2001: U.S. Geological Survey Scientific Investigations Report 2004-5142, 24 p.
- Light, S.L., and Dineen, J.W., 1994, Water control in the Everglades: A historical perspective, in *Everglades the ecosystem and its restoration*: Delray Beach, Fla., St. Lucie Press, p. 47-84.
- Lovelace, J.K., and McPherson, B.F., 1996, Effects of Hurricane Andrew (1992) on wetlands in southern Florida and Louisiana, in *National Water Summary*: U.S. Geological Survey Water-Supply Paper 2425, p. 93-96.
- McPherson, B.F., and Sonntag, W.H., 1984, Transport and distribution of nutrients in the Loxahatchee River estuary, southeastern Florida, 1979-81: *Water Resources Bulletin*, v. 20, no. 1, p. 27-34.
- Miller, R.L., McPherson, B.F., Sobczak, R., and Clark, C., 2004, Water quality in Big Cypress National Preserve and Everglades National Park—Trends and spatial characteristics of selected constituents: U.S. Geological Survey Water-Resources Investigations Report 03-4249, 34 p.
- Nelson, T.A., Garte, Ginger, Featherstone, Charles, Wanless, H.R., and others, 2002, Linkages between the south Florida peninsula and coastal zone: A sediment-based history of natural and anthropogenic influences, in Porter, J.W., and Porter, K.G., eds., *Boca Raton, Fla., CRC Press*, p. 415-449.
- Rudnick, D.T., Chen, Z., Childers, and others, 1999, Phosphorus and nitrogen inputs to Florida Bay: The importance of the Everglades watershed: *Estuaries*, v. 22, no. 2B, p. 398-416.
- Sutula, M.A., Perez, B.C., Reyes, and others, 2003, Factors affecting spatial and temporal variability in material exchange between the southern Everglades wetlands and Florida Bay (USA): *Estuarine Coastal and Shelf Science*, v. 57, p. 757-781.

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