

Climate Change and Ecosystem Services of Florida's Largest Water Body: Lake Okeechobee¹

Karl Havens²

Summary

Future climate change could result in higher temperatures and greater evaporative water loss in Florida. If these changes are not compensated for by more rainfall, the state's largest water body, Lake Okeechobee, could experience prolonged periods of very low water levels and catastrophic loss of its ecosystem services, which are the benefits that people receive from ecosystems.

Background

Lake Okeechobee is a large, shallow lake located in the center of the Florida peninsula, about midway between Orlando and Miami. The natural lake is the largest in Florida and in the southeastern US. At over 430,000 acres, it is one of the shallowest large lakes in the world, averaging just 9 feet deep. The lake bottom is uplifted seabed. This seabed remained dry at the end of the last Ice Age, when sea level was low and climate was dry in Florida. Even after the ice age was over, the shallow basin remained dry. Six thousand years ago, during the Holocene period, peat build-up at the south end of the lake created a natural dam that ultimately enabled the lake to form. Up until the early 1900s, the lake received its water from the meandering Kissimmee River, from a broad wetland that connected Lake Istokpoga in the northwest to Lake Okeechobee, and from the wetlands of Fisheating Creek, which flows into the lake from the west. Water levels in the lake were highly variable, and at times water spilled out of the southern end into the Everglades

as sheet flow, directly hydrating pond apple forests and sawgrass prairies.



Figure 1. A photo of Lake Okeechobee, looking out over the western marsh region to the open waters of the large lake. Credits: South Florida Water Management District

Because of flooding in the 1920s, 40s and 50s, and a desire to use land south, east, and west of the lake for agriculture, a massive project was undertaken by the US Army Corps of Engineers called the Central and Southern Florida Flood Control Project. This project involved construction of a large earthen dike around Lake Okeechobee, with locks and gates that release water primarily to the east, into the St. Lucie Estuary, and west, into the Caloosahatchee Estuary. Smaller canals to the south deliver water to a large agricultural area called the Everglades Agricultural Area,

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2. Karl Havens, director, Florida Sea Grant College Program, UF/IFAS Extension, Gainesville FL 32611.

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where sugar cane and vegetables are grown on land that formerly was part of the Everglades. Water from the lake also hydrates large water conservation areas that help prevent saltwater intrusion into the water supply of 8 million people who live along the lower east coast of Florida.



Figure 2. A photo of a fish nest in the shallow water of the Lake Okeechobee marsh.
Credits: Karl Havens

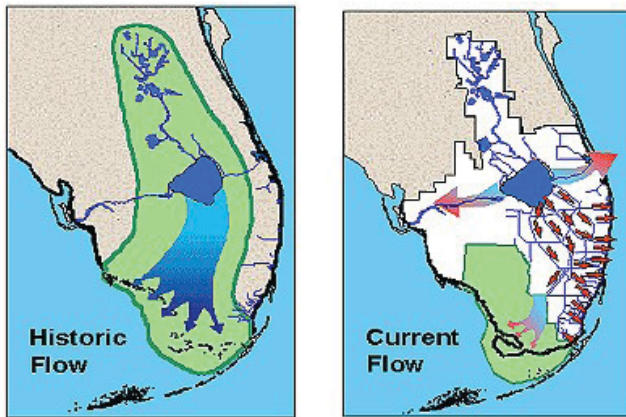


Figure 3. These maps illustrate the historic and current water flow into and out of Lake Okeechobee. Green areas are natural wetlands, which once encircled nearly the entire regional ecosystem; blue arrows are natural water flows; and red arrows are flows in man-made canals.
Credits: South Florida Water Management District

Water levels in the lake now vary much less than they did historically, both for safety reasons (risk of levee failure) and to protect the large marsh that formed inside the levee on the western side of the lake. This marsh area supports a diverse plant community and a multi-million-dollar-a-year sport fishery. Another attribute of the lake that has changed markedly over the last 100 years is nutrient enrichment and consequent development of algal blooms. Algal blooms result from nutrient-rich agricultural runoff north of the lake. Nutrients are delivered to the lake quickly by channelized

tributaries, including the Kissimmee River. The nutrients and associated silt have accumulated on the lake bottom, resulting in a high rate of internal nutrient cycling in the system. For a detailed overview of the history and evolution of the lake and the source of this introductory material, see Aumen and Wetzel (1995) and Havens, Aumen, and Smith (1996).

Ecosystem Services of Lake Okeechobee

Ecosystem services include direct benefits such as drinking water or fish that are caught and sold commercially and indirect benefits such as control of local rainfall or removal of nutrients from water. Lake Okeechobee, even in its modern-day, altered configuration, provides a large number of ecosystem services in south Florida, which include:

- Habitat for several species of recreational sport fish
- Habitat for a commercial catfish fishery
- Habitat for federally endangered Everglades snail kites
- Water supply for downstream agriculture
- Water supply for urban areas
- Cross-state navigation via a canal that runs from the Atlantic Ocean to the St. Lucie River through the lake and then via the Caloosahatchee River to the Gulf of Mexico
- Flood protection for much of southeast Florida
- Freshwater that periodically is needed to protect aquatic plants in the Caloosahatchee River when salt water moves too far up into that system
- Freshwater that periodically is needed to push harmful algae blooms out of the Caloosahatchee River to the Gulf of Mexico

Optimal and Actual Water Levels in Lake Okeechobee

The optimal range of water levels in Lake Okeechobee for providing each of these services differs considerably. Protection of the marsh habitat is optimized by water levels measured at the center of the lake that vary from 12 to 15 feet, as identified by Aumen and Wetzel (1995) and Havens (2002). This range of water level wets the entire marsh habitat in summer and allows it to dry out in winter, permitting natural fires to burn back thatch and exotic plants. Because the marsh is critical habitat for fish and birds, this range

also is optimal for recreational fish, commercial fish, and snail kites.

The optimal variation in lake water levels often does not occur because of the configuration of the lake in relation to the surrounding landscape. The watershed of Lake Okeechobee, which is the land area from which rain water flows into the lake, is many times the size of the lake itself. In years with just average summer rainfall, the lake can receive many times its volume of water as runoff from the Kissimmee River, Fisheating Creek, and other inflows. When this happens, the lake can rise to 17 feet or more and threaten the integrity of the levee. Water then is discharged at high rates via canals to the St. Lucie and Caloosahatchee Estuaries, resulting in poor water quality, high loads of sediment, and adverse impacts to aquatic plants, oysters, and other aquatic life (Steinman, Havens, and Hornung 2002).

Projected Changes in the Climate of South Florida

In 2013, the South Florida Water Management District, Florida Sea Grant (UF/IFAS), the US Geological Survey, and the Florida Center for Environmental Studies at Florida Atlantic University performed a scenario analysis to determine how potential changes in the future climate of south Florida would affect the hydrology of various parts of the greater Florida Everglades, including Lake Okeechobee, the Everglades Water Conservation Areas, and coastal ecosystems of Florida.

The approach that was used to model what climate might be like in the future (2060) is explained in a report by Obeysekera, Barnes, and Nungesser (2015). In short, the projections of 15 different climate models gave average estimates of a 3°F increase in temperature, a rise in evapotranspiration proportional to the temperature increase, and a rise in sea level of 1.5 feet. Evapotranspiration is loss of water to the atmosphere by evaporation and from plants in a process called transpiration. One major factor controlling the rate of evapotranspiration is temperature. The climate models did not agree on what will happen with future rainfall. Some models predicted more rain, some predicted less rain, and others predicted no change. For this exercise, therefore, we used both plus and minus 10 percent rainfall as possible future conditions.

Effects on Water Levels in Lake Okeechobee

Effects of the projected changes in climate on water levels in Lake Okeechobee were determined using a regional hydrologic model that the South Florida Water Management District developed in the 1990s and used to evaluate alternative plans for restoring the Everglades. This model, known as the South Florida Water Management Model (SFWMD 2005), considers water entering the regional system by rainfall, water moving over the surface and in the ground, water taken from the system for consumptive uses (e.g., crop and lawn irrigation and drinking water), water lost to the ocean, and water lost to the atmosphere by evapotranspiration.

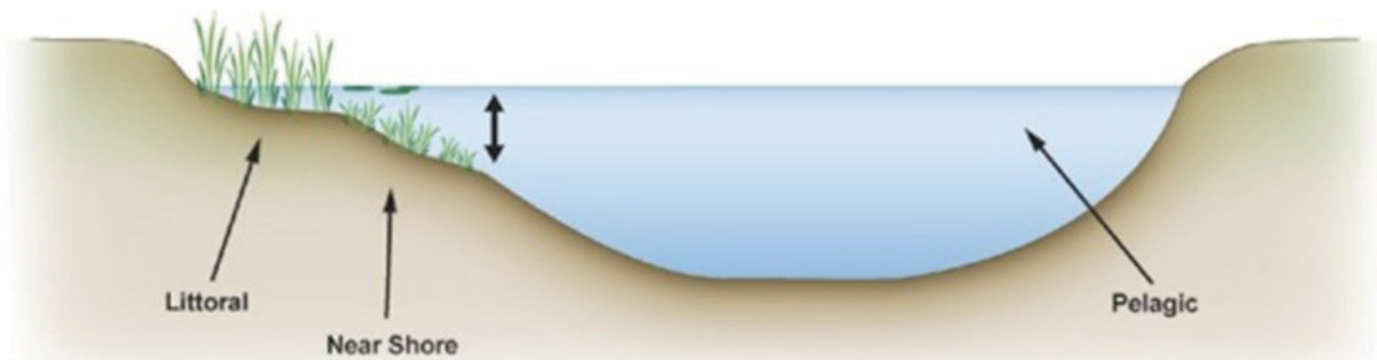


Figure 4. A cross-section through Lake Okeechobee (highly exaggerated in the vertical dimension) showing three major zones of the lake: a deep pelagic or open-water zone, a shallow littoral or marsh zone, and a zone in between, lying on a shelf of intermediate depth called the near-shore zone. The marsh supports emergent plants like cattail, willow, and sawgrass. The near-shore zone supports submerged (underwater) and floating-leaved plants like tapegrass, pondweed, and water lily. The pelagic zone is too deep to support any plants. The two-ended arrow illustrates an optimal situation of rising and falling water levels between summer and winter that wets and dries the marsh zone, i.e. 12- to 15-foot range of depth, measured at mid-lake.

Credits: Karl Havens

The model simulates inputs and outputs of water to and from Lake Okeechobee, respectively, and generates a time series of projected water levels based on a historic time series of rainfall. In this case, the time series was 1965 to 2005. Model runs were done for different possible futures. These were compared to a future condition with no change in any of the climate variables. From here on the following abbreviations will be used: ET (evapotranspiration) and RF (rainfall). This model asks “if climate conditions were altered in this manner what would the water depths in Lake Okeechobee have looked like over the period 1965 to 2005, compared to what actually occurred?”

This was done with these climate conditions:

- A future with increased temperature and ET with no change in rainfall [+ET]
- A future with increased temperature and ET and 10 percent more rainfall [+RF+ET]
- A future with increased temperature and ET and 10 percent less rainfall [-RF+ET]

For coastal ecosystems in south Florida, such as coastal estuaries, sea-level rise is directly important, but for Lake Okeechobee, located at the center of the state and surrounded by a levee, effects of sea-level rise had no influence on future conditions in the model runs.

In Lake Okeechobee, the future model condition with 10 percent more rainfall balanced the effects of higher temperature, and a 40-year time series of water levels showed no noticeable change (Havens and Steinman 2015). In the future model condition with no change in rainfall and only

increased temperature and evapotranspiration, water levels in the lake dropped markedly. Instead of having lake levels in the optimal depth zone of 12 to 15 feet about 60 percent of the time (future with no climate change), optimal depth conditions were projected to prevail just 40 percent of the time. In the future model condition with higher temperature and evapotranspiration and a 10 percent decline in rainfall, severe low lake levels occurred, at times reaching just 5 feet, a point at which a person could nearly walk across the lake. There were periods lasting several years when the lake was below 8 feet and the entire marsh region and near-shore region of submerged plants would be dry. In that hot/dry future, the lake is in its optimal depth zone of 12 to 15 feet only 15 percent of the time.

Differences between scenarios in the year 2060 are most evident if we look at water levels in the lake using visual aids (color-coded maps of water depths). At 15 feet, the lake has standing water right up to the edge of the levee, including shallow water over the entire western marsh region. At 12 feet, the marsh is dry, but water still covers a zone between the marsh and open water of the lake, an area that is important for submerged plants and fish nurseries. As noted, the range between these two extremes is optimal for health of the lake (Aumen and Wetzel 1995, Havens 2002). In contrast, in the hot/dry 2060 scenario, the lake is reduced to a small area of very shallow water, and all of the critical habitat areas are bone dry. There were no future scenarios with more water in the lake; only status quo if it rains more in 2060, or lower lake levels if rainfall stays the same or declines.

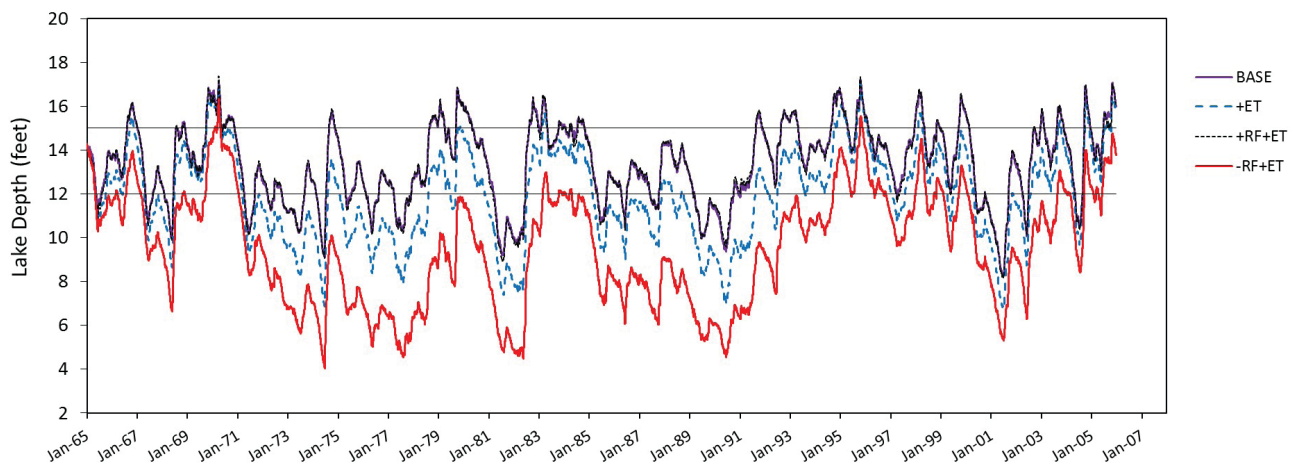


Figure 5. Water levels in Lake Okeechobee from 1965 to 2005, simulated by the South Florida Water Management Model under different future climate conditions. Depth is on the vertical axis and year on the horizontal axis. The two horizontal lines (at 12 and 15 feet) bound the optimal zone of lake levels for a healthy marsh, submerged plants, and fisheries.

BASE = future with no changes in climate; +ET = future with no change in rainfall (RF) and higher temperature and evapotranspiration (ET); +RF+ET = future with more rainfall and higher temperature and ET, which counter-balance one another and so the line lies right on the line for the BASE; -RF+ET = hot/dry future situation with less RF and greater temperatures and ET.

Credits: Havens and Steinman, 2015

Effects on Ecosystem Services

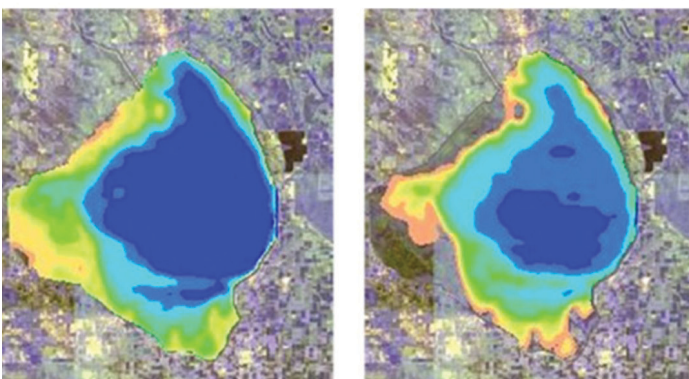
To assess how these changes in future water levels might affect ecosystem services, consider again that the lake has distinct zones, each of which provides different services to society. The western marsh zone, the shallowest part of the lake, provides important feeding and nesting areas for migratory birds, fish, and the Everglades snail kite. When lake stage is high, near the 15-foot level, the marsh is also a prime area for bass fishing and bird watching. In future scenarios with the same or less rainfall, the marsh would be dry for long periods of time, woody plants would likely replace aquatic plants, and these services would largely be lost. It is uncertain if such services could recover in short intervals when lake level is higher because it might take years for aquatic plants to become re-established after woody plants are flooded and die.

The near-shore area of the lake, which occurs between the marsh and the open-water central area, supports submerged plants and is a prime habitat for fish, fishing, boating, and bird watching. This area, too, is dry for long periods of time in the scenarios with the same or less rain in the future. In fact, the periods during which this area is completely dry may be so frequent and long-lasting (especially in the future with less rainfall and increased temperature) that the lake no longer can support any of these services. It is unclear whether the plants and the habitat they provide could shift to deeper water—probably not. The area where there is water in the right two panels of Figure 6 coincides almost exactly with the area of the lake that has soft, unconsolidated mud on the bottom, and plants cannot take root in such loose, constantly shifting sediment.

In a future with a very shallow lake, wind would likely suspend the mud continually, resulting in highly turbid water with little or no light penetrating to the lake bottom—and, therefore, no plants. That low-water future would see a lake with extremely high concentrations of the nutrient phosphorus in the water because suspended bottom sediments are rich in phosphorus (Havens 2007). High levels of phosphorus might stimulate blooms of toxic blue-green algae if there were sufficient light to allow them to grow. Such blooms might be most dense around the edge of the area covered with water, another reason that it is unlikely that plants could grow on the bottom—because of intense shading by algae.

Direct human services, including navigation and water supply, would be severely impacted by a very low Lake Okeechobee. There are two US Army Corps of Engineers navigation routes across the lake: (1) a channel that crosses the lake just south of its center, and (2) another that goes around the southern end of the lake in a “rim canal.” Havens and Steinman (2015) calculated that in a future with just higher temperature and evapotranspiration, navigation might not be affected. They concluded, however, that in a hot/dry future with less rain, higher temperature and more evapotranspiration, the cross-lake route could be navigated by a small boat (1.5-foot draft) just 72 percent of the time and the rim canal route just 50percent of the time.

15 and 12 feet—the optimal range



7 and 5 feet—in a hot/dry future

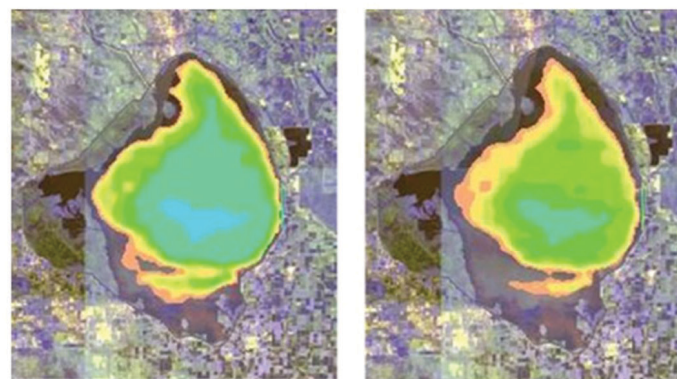


Figure 6. Depth contour maps showing the extent of water in Lake Okeechobee in its optimal range (left two panels) and under extreme drought conditions, as might occur in a hot/dry future (right two panels). Colors correspond generally to water depths, with dark blue about 15 ft and orange less than a foot (Source: South Florida Water Management District).

Credits: South Florida Water Management District

In the hot/dry 2060 model scenario, there were reductions in water supply to agricultural areas downstream of the lake, where there are vast farms of sugar cane, vegetables and citrus. Although it is not possible to project exact impacts, we know that in 2000-01, when the lake dropped below 9 feet in just one year, cutbacks in water delivery led to large-scale crop losses and severe restrictions on water use in the major metropolitan areas of southeast Florida. The tree and ornamental plant industry lost 2,000 jobs and the negative direct-value-added impact of the drought on agriculture was estimated to have been \$40 million dollars (Hodges and Haydu 2003).

In that drought, water was high enough to remain in the rim canal at the south end of the lake, where it was pumped out of the lake for human uses. At the lower lake levels in the right two panels of Figure 6, water could be miles away from the lake's edge, and it might be impossible to pump for human uses.

Lake Okeechobee is an important water supply to downstream ecosystems. Regional-level planning to restore the Everglades assumes a large amount of water will flow from the lake to that wetland ecosystem. This could not happen in the hot/dry future scenario. Nor could there be deliveries of water to the Caloosahatchee Estuary, which are needed periodically to reduce salinity that impacts submerged plants and water intakes for coastal cities. This water is also needed to push blue-green algae blooms from the Caloosahatchee River to the sea.

Remedies

On a global scale, a large reduction in carbon emissions or development of technologies that sequester carbon from the atmosphere might slow or stop climate change. These options are, however, beyond the scope of this fact sheet.

Assuming that the future is hotter, it is reasonable to expect lower water levels in Lake Okeechobee and loss of services. The most recent report of the Intergovernmental Panel on Climate Change (IPCC 2014) indicates that in the future, droughts might last longer, and when rainfall does occur, it might be delivered in shorter, more intense events. If that happens, the outcomes for Lake Okeechobee would be much worse than projected here because the model assumed that the temporal pattern of rainfall in the future will mimic that of the past.

One option for establishing a secure water supply might be to construct a large reservoir. It could be used to store water when it rains, and make that water available when it

is dry. The problem with that approach is the tremendous volume needed. To compensate for the difference in water storage between the hot/dry future and the base condition, Havens and Steinman (2015) calculated it would require a 7-foot-deep reservoir with an area of 220,000 acres to accommodate just a single year's storage, because each year such a reservoir in south Florida would lose about 60 percent of its water to evaporation.

Such a solution would not be helpful in a drought that lasts 3, 5, or 7 years. At this time it is not clear if the ecosystem services provided by Lake Okeechobee can be protected if climate change in future decades includes both increased temperature and less rainfall. The worst-case scenario underscores the fact that some changes caused by climate change are so extreme as to preclude adaptation. The larger goal of reducing the rate of climate change by cutting greenhouse gas emissions may in some cases be the only solution to avoid catastrophic outcomes.

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