# Estuarine Response in Northeastern Florida Bay to Major Hurricanes in 2005

By Jeff Woods and Mark Zucker

*Hurricanes and tropical storms are critical components of the south Florida hydrologic cycle. These storms cause dramatic and often rapid changes in water level of, salinity of, and discharge into northeastern Florida Bay as well as into adjacent marine estuaries. During 2005, two major hurricanes (Katrina and Wilma) crossed the southern estuaries of the Everglades and had substantial impacts on hydrologic conditions.*

## Introduction

The southern coastline of Florida has several small estuarine creeks and estuaries that transport fresh water from the Everglades wetlands into northeastern Florida Bay (fig. 1). These creeks provide habitat to a wide variety of wildlife that depends on the environmental conditions of the estuaries for survival. The productive coastal environment of Florida Bay serves as a nursery for many oceangoing fish and at least 22 commercially important species such as drum (*Umbrina cirrosa*), snapper (*Lutjanus* sp.), tarpon (*Megalops atlanticus*), snook (*Centropomus undecimalis*), and Florida stone crab (*Menippe mercenaria*) (Davis and Ogden, 1997).

A total of 80 percent of all fresh water discharged from the Everglades wetlands into northeastern Florida Bay occurs during the wet season (June–October), particularly during tropical storms and hurricanes (Hittle and others, 2001). These storms can disrupt the biological life cycles of organisms living in the estuaries of the southern Everglades by causing extreme changes in salinity and temperature over short time periods which can contribute to high mortality rates for fish, invertebrates, and seagrasses (Davis and Ogden, 1997).

Data collection during extreme hydrologic events, such as hurricanes, is critical not only for understanding the impacts of storm events on the ecology but also for documenting long-term changes in estuarine conditions. Documenting these changes will help in understanding the impacts related to global climate change and/or upstream hydrological modifications performed to restore the Everglades wetlands as part of the Comprehensive Everglades Restoration Plan (CERP) (U.S. Army Corps of Engineers, 2006).

To provide science support for Everglades restoration, 27 estuarine creeks flowing from the Everglades wetlands into northeastern Florida Bay are monitored in near real time for water level, discharge, salinity, and temperature by the U.S. Geological Survey (USGS). These monitoring stations provide accurate and reliable data to decision makers and the public as support for restoration efforts of the Everglades. During the 2005 hurricane season, Katrina and Wilma passed through the USGS coastal monitoring network (fig. 1), where hydrologic data are incrementally recorded every 15 minutes. Both storms crossed the southern Everglades, Katrina as a category 1 hurricane and Wilma as a category 3 hurricane, although Katrina's strength was arguably just below hurricane status (Grauman and others, 2005; Knabb and others, 2005). Three stations, McCormick Creek, Trout Creek, and a creek known as West Highway Creek (fig. 1), were chosen to illustrate the water-level, salinity, and discharge response caused by Katrina and Wilma.

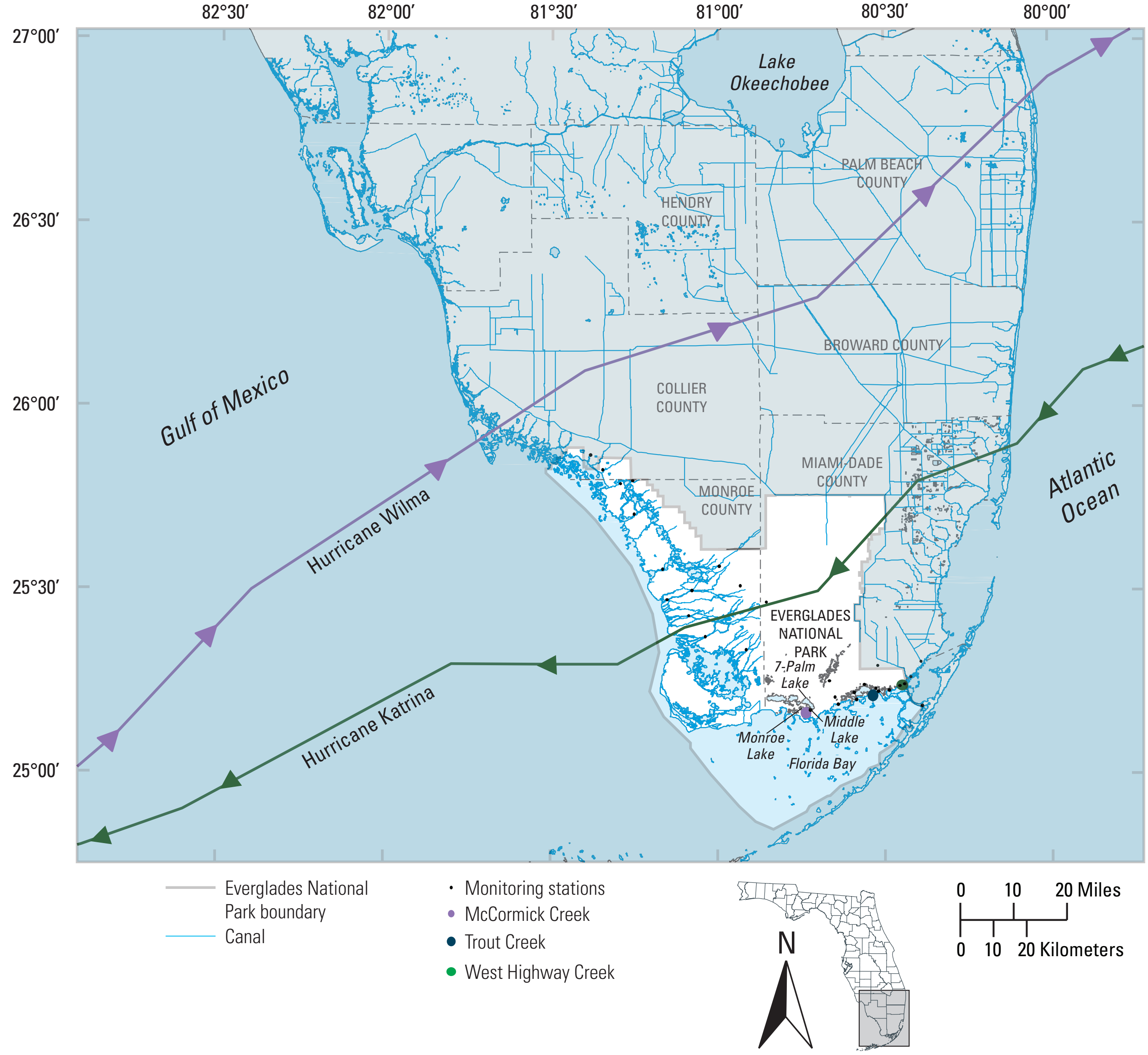


**Figure 1.** Location of selected U.S. Geological Survey coastal monitoring stations in Everglades National Park along with the tracks of Hurricanes Katrina and Wilma over the southern tip of Florida.

## Water-level Response

Katrina and Wilma caused substantial storm surge at West Highway, Trout, and McCormick Creeks. Rainfall caused by Katrina was substantial (7 inches (17.78 cm)), whereas rainfall during Wilma (1 inch (2.54 cm)) did not have as great of an effect in the southern Everglades wetlands (Knabb and others, 2005; Pasch and others, 2005). As Katrina approached the south Florida coastline on August 25, 2005, water levels rapidly increased from about 0.5 ft (0.15 m) below the North American Vertical Datum of 1988 (NAVD 88) to a maximum of 1.82 ft (0.55 m), 1.97 ft (0.6 m), and 3.11 ft (0.94 m) above NAVD 88 at the West Highway, Trout, and McCormick Creek stations, respectively (fig. 2).

The differences in rainfall contributions in conjunction with Katrina's storm track (traveling east to west over the bay) caused water levels in the wetlands to remain above average. This scenario set the conditions for Wilma (traveling west to east), which subsequently increased water levels at record highs for the three stations during the period of study. Maximum recorded water levels were 2.59 ft (0.79 m), 2.87 ft (0.87 m), and 3.53 ft (1.08 m) at West Highway, Trout, and McCormick Creeks, respectively, on October 24, 2005 (fig. 2).

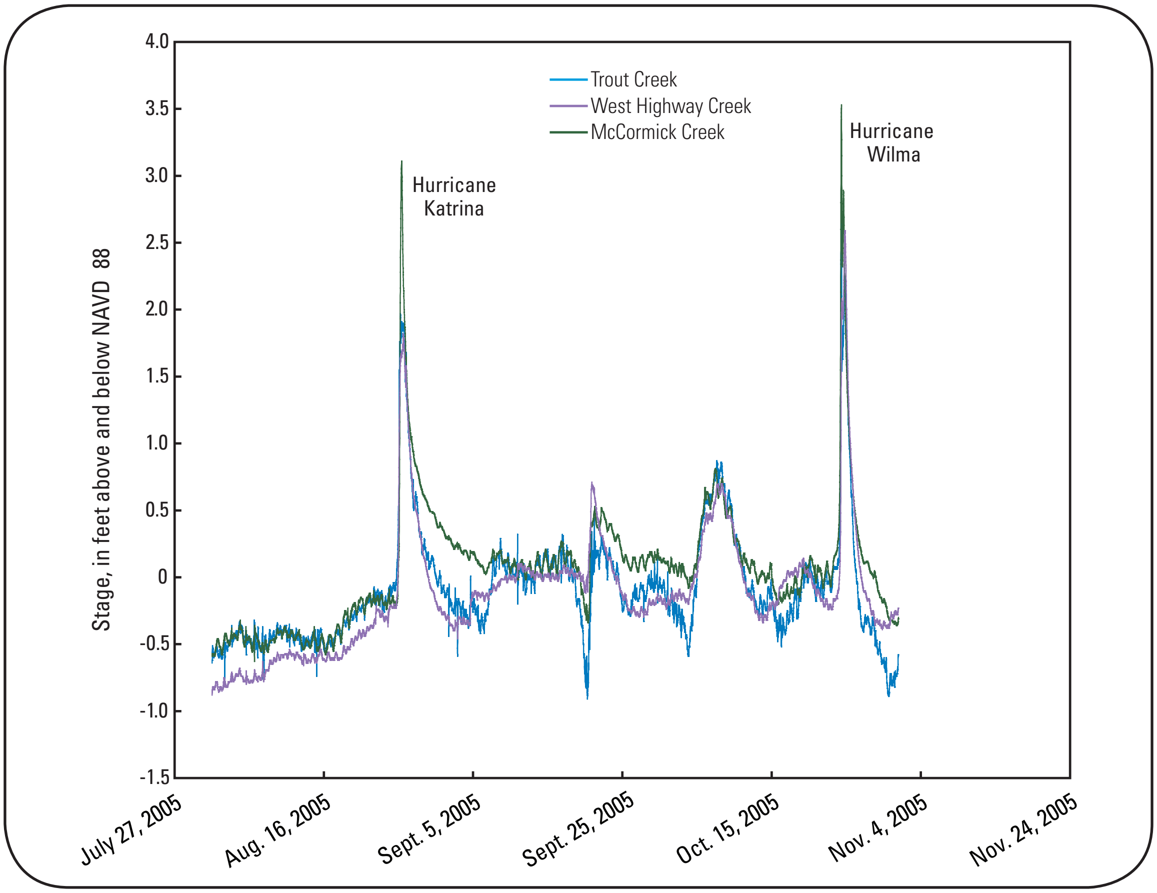


**Figure 2.** Water levels recorded at the McCormick Creek, Trout Creek, and West Highway Creek stations during the peak of hurricane season, 2005.

## Salinity Response

Prior to the arrival of Katrina, salinity conditions at West Highway and Trout Creeks were lower, whereas those at McCormick Creek were notably higher (fig. 3). Salinities at McCormick Creek varied between 32 and 40 parts per thousand (ppt), or nearly oceanic. Prestorm salinities at West Highway and Trout Creeks were about 10 ppt (brackish). During Katrina, salinities rapidly increased to 35 ppt (nearly oceanic) at Trout Creek but reached only 20 ppt at West Highway Creek. Salinity at all three sites decreased only days after the passing of Katrina because of the high rainfall inputs dropped over the southern Everglades, which then began to flow toward Florida Bay (fig. 3). Low salinities were also a result of water-management practices before and after the storm as part of flood control by opening structures which usually impede the natural flow to the wetlands and southern estuaries. The operation of water-control structures during major storms can provide additional overland freshwater flow to wetlands upstream from Trout and West Highway Creeks but not to McCormick Creek, which is more isolated from these structures.

During Wilma, storm surge pushed saline water from central Florida Bay over a naturally occurring embankment bisected only by a few major creeks including McCormick and Trout Creeks. Salinities at McCormick Creek diminished from about 40 to 5 ppt after 37 days (fig. 3). The delayed recession in salinity at McCormick Creek can be explained by storm surge into a system of lakes (Monroe, Middle, and Seven Palm Lakes) that lie to the north and upstream from McCormick Creek. Saltwater storm surge was stored in the upstream lakes with no means of drainage except through McCormick Creek. Consequently, outflow from McCormick Creek was more saline after Wilma because of the saltwater storm surge stored in the upstream lakes. Another potential factor elevating poststorm salinities at McCormick Creek is evapotranspiration, which can occur at a higher rate than rainfall in the dry season. This process can remove freshwater in the upstream lakes, leaving a residual salt concentrate.

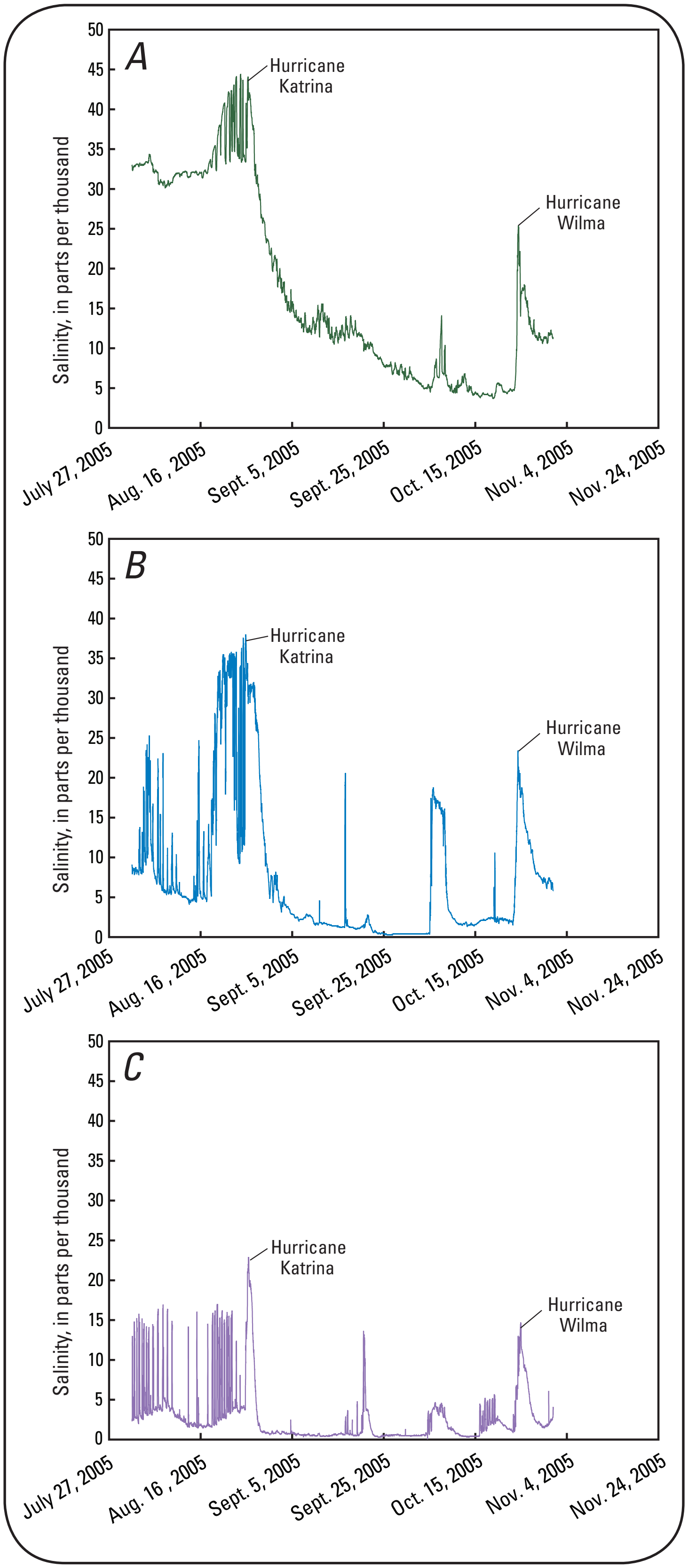


**Figure 3.** Salinity for McCormick Creek (*A*), Trout Creek (*B*), and West Highway Creek (*C*) during the peak of hurricane season, 2005.

## Creek Flow Response

Between 1996 and 2005, total combined annual flow for McCormick, Trout, and West Highway Creeks ranged from 85,480 acre-ft (1.05 by $10^8$ $m^3$) in 2004 to 325,130 acre-ft (4.01 by $10^8$ $m^3$) in 2005 (fig. 4). Katrina and Wilma created record high creek flows at McCormick, Trout, and West Highway Creeks during the 2005 wet season. A drought in 2004 and in early 2005 that preceded these hurricanes contributed to lower water levels, setting

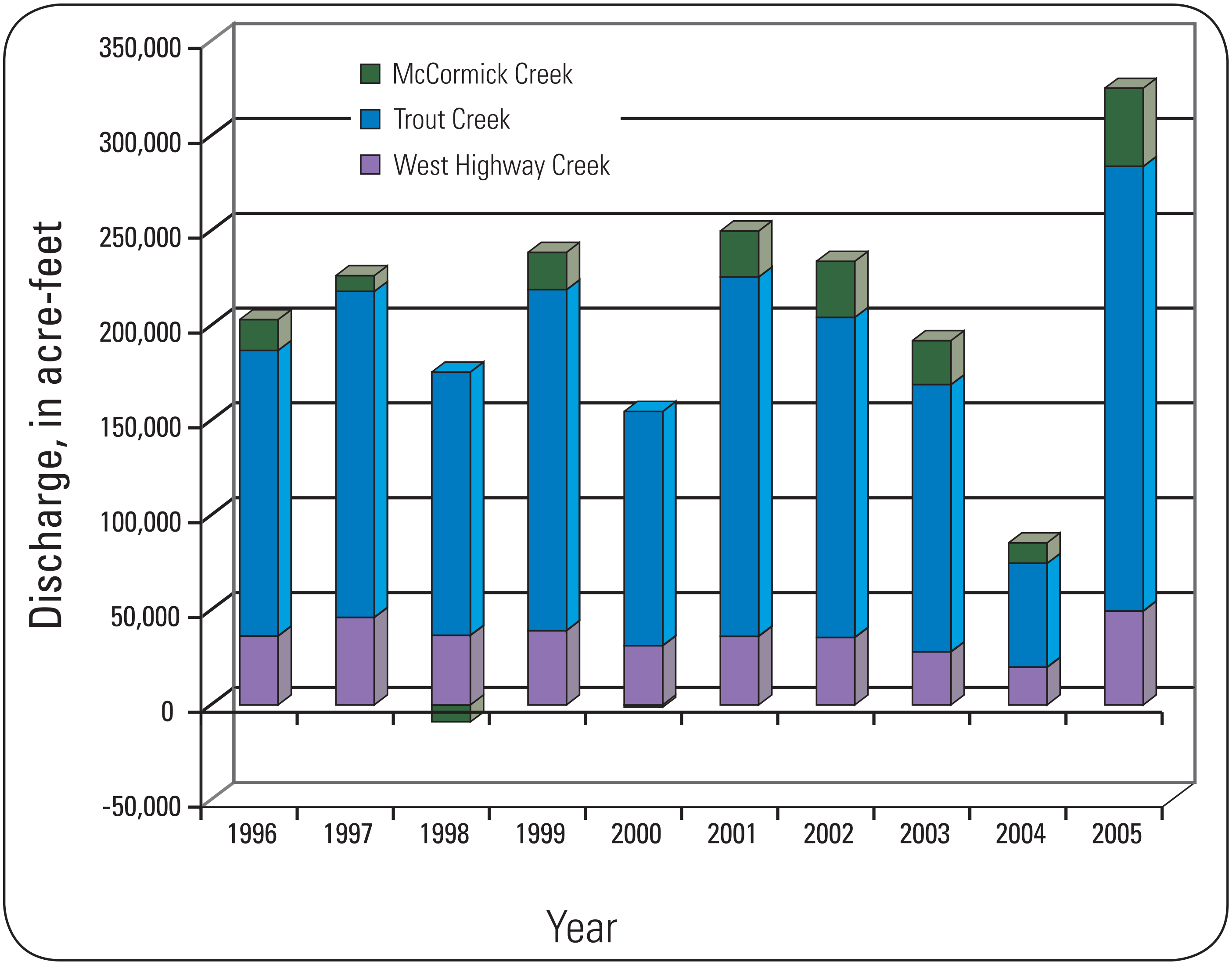


**Figure 4.** Total discharges of fresh water into northeastern Florida Bay for McCormick, Trout, and West Highway Creeks, 1996–2005. In 2004, the lowest flows were recorded because of a dry year partially caused by a lack of hurricane activity in this region. In 2005, the highest flows were recorded primarily because of the occurrences of Hurricanes Katrina and Wilma, which passed directly over the study area.

conditions which were favorable for a record maximum negative discharge recorded by these stations during Katrina at McCormick Creek (-912 $ft^3/s$ (-25.8 $m^3/s$)), Trout Creek (-4,370 $ft^3/s$ (-123.7 $m^3/s$)), and West Highway Creek (-829 $ft^3/s$ (-23.5 $m^3/s$)) (fig. 5). A negative discharge indicates flow from Florida Bay into the Everglades wetlands, whereas a positive creek discharge indicates flow from the Everglades wetlands into Florida Bay. Flow conditions changed dramatically following the passage of Katrina in 2005; specifically, maximum positive discharges were recorded at McCormick Creek (481 $ft^3/s$ (13.6 $m^3/s$)) on August 30, Trout Creek (2,730 $ft^3/s$ (77.3 $m^3/s$)) on September 2, and West Highway Creek (676 $ft^3/s$ (19.1 $m^3/s$)) on September 2 (fig. 5).

During Wilma, creek discharge at McCormick, Trout, and West Highway Creeks again changed rapidly. Specifically, maximum negative discharges were recorded at McCormick Creek (-911 $ft^3/s$ (-25.8 $m^3/s$)), Trout Creek (-5,140 $ft^3/s$ (-145 $m^3/s$)), and West Highway Creek (-1,160 $ft^3/s$ (-32.8 $m^3$)) on October 24, 2005. For all monitoring sites except McCormick Creek, the maximum negative creek discharge during Wilma was greater than the maximum negative creek discharge during Katrina.

Negative creek discharges during Wilma were partly caused by the storm path, which came from the southwest and pushed water into the shallow confines of Florida Bay. Wilma raced across the Florida Peninsula in only 4.5 hours, reemerging into the Atlantic Ocean near West Palm Beach, Fla. After Wilma left Florida, flows reversed at West Highway, Trout, and McCormick Creeks as rainfall drained from the upstream wetlands into Florida Bay, and the momentum from the water pushed upstream from the hurricane reversed. The maximum positive creek discharge following Wilma occurred on October 24, 2005, at Trout Creek and equaled 3,050 $ft^3/s$ (86.4 $m^3/s$). The maximum positive creek discharge following Wilma at McCormick and West Highway Creeks occurred on October 26 and 30, 2005, and equaled 476 $ft^3/s$ (13.5 $m^3/s$) and 585 $ft^3/s$ (16.6 $m^3/s$), respectively.

The rainfall contribution from Katrina was much greater over the southern Everglades wetlands than was the contribution from Wilma. This contrast is primarily due to

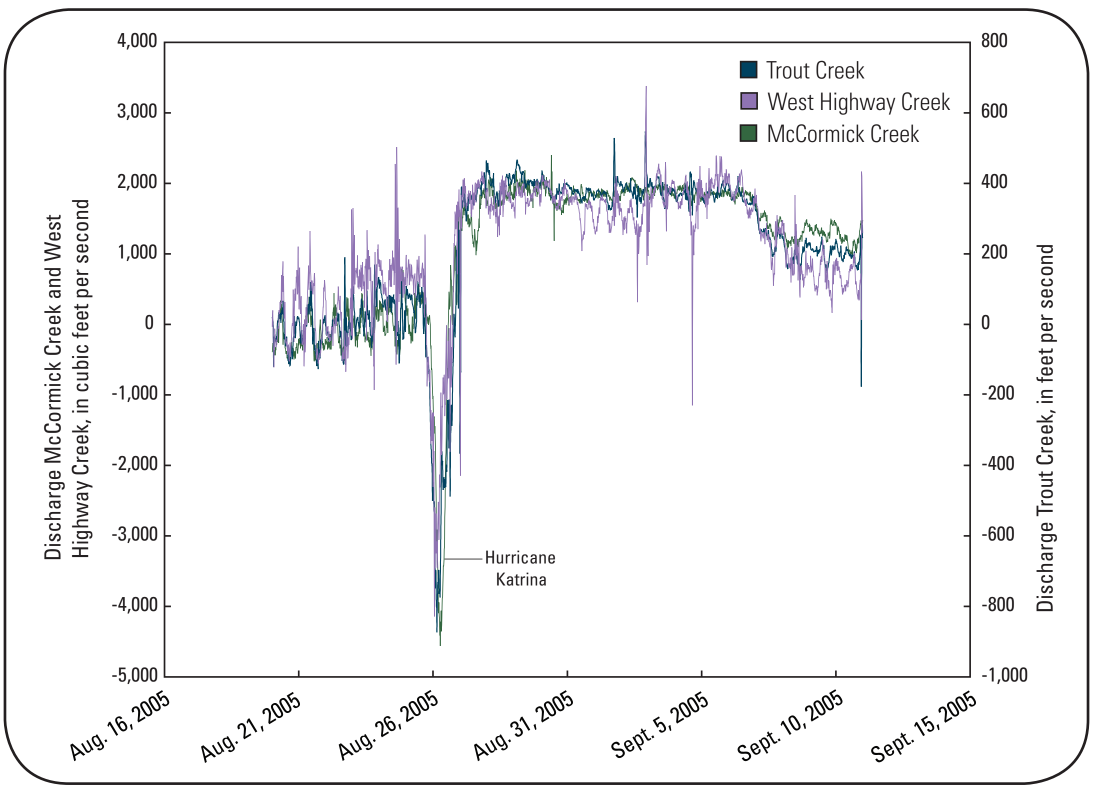


**Figure 5.** Creek discharges at West Highway, Trout, and McCormick Creeks before, during, and after Hurricane Katrina.

(1) the hurricanes moving at different speeds (not windspeed) across the Florida Peninsula, (2) landfall location, and (3) rainfall amount over the southern Everglades wetlands. Wilma produced heavy amounts of rain, which occurred much farther north of Florida Bay. Consequently, freshwater contribution to northeastern Florida Bay from Wilma was greatly reduced by means of diversion of runoff by northern canals into the Atlantic Ocean. When combined, Katrina and Wilma provided about 78 percent of the total freshwater discharge to northeastern Florida Bay in 2005. This result highlights the importance of accurately capturing extreme storm events, specifically extreme rainfall events. This is especially important when attempting to predict freshwater discharge to the coast from the Everglades wetlands, a common goal of many hydrodynamic models being built to assess CERP scenarios.

## Impact on Creek Discharge

Katrina and Wilma were important climatologic events in 2005 that resulted in the highest recorded water levels (fig. 6) and outflow of fresh water from the Everglades wetlands into northeastern Florida Bay (for McCormick, Trout, and West Highway Creeks) (fig. 4) since monitoring began in 1996. Hurricanes and tropical storms are critical components of the south Florida hydrologic cycle. These storms cause dramatic and often rapid changes in water level, salinity, and discharge into northeastern Florida Bay as well as adjacent marine estuaries. Hydrologic data collected by the USGS coastal monitoring network are critical to understanding complex ecological issues including effects on biota, land use, and future impacts on wetlands from human activities and natural occurrences. As restoration changes are made throughout the coming years, monitoring will be a critical component in gaging whether the desired goals are being met and if they are reasonable when the possible effects of climate change are considered.

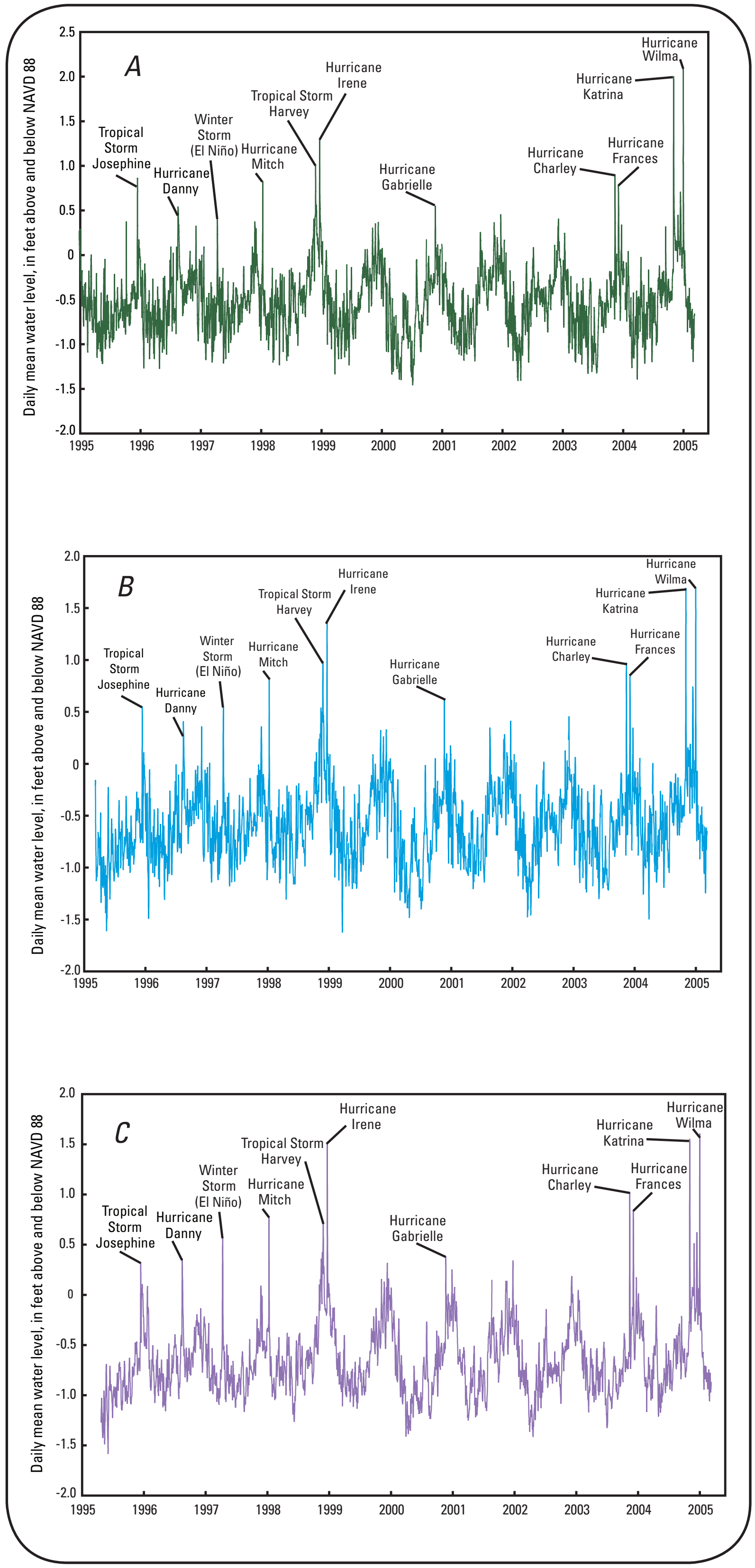


**Figure 6.** Historical dates of hurricanes, tropical storms, and daily mean water levels at McCormick (*A*), Trout (*B*), and West Highway (*C*) Creeks in northeastern Florida Bay, 1996–2005.

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