Technical Notes

ERA # 441

THE 2004 & 2005 HURRICANES IMPACT ON GROUNDWATER LEVELS IN SOUTH FLORIDA

by

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EXECUTIVE SUMMARY

The South Florida Water Management area was impacted by eight hurricanes and tropical systems in 2004 and 2005. During the 2004 hurricane season, the District endured three hurricanes along with an extra-tropical system remnant from Hurricane Ivan. Hurricane Charley made landfall on the southwest coast during August 12–16, Frances on the northeast coast during September 4–8, and Jeanne taking a near identical path as Frances did on the northeast coast during September 24–28. A remnant storm from Hurricane Ivan passed through South Florida during September 19–23. All of these storms dropped heavy rainfall. In addition, high surface water flows and high lake levels were experienced.

During the 2005 hurricane season, the District endured two hurricanes: Hurricane Katrina from the east during August 24–27, and Hurricane Wilma from the west during October 22–25. An earlier hurricane, Hurricane Dennis, contributed rainfall to the District in areas of southwest Florida and the Florida Keys during July 8–10, but made landfall in the Florida panhandle out of the District's boundaries. Hurricane Rita contributed rainfall to the District during September 19–21 as it headed west through the Florida Straits. Compared to historical data on tropical systems, the combined impact of the 2004 and 2005 hurricane seasons on the District was a rare event. The 2004 and 2005 hurricanes impacted groundwater by recharging the various aquifers.

This report incorporates high resolution data collected from a number of South Florida Water Management District and U.S. Geological Survey groundwater monitoring wells that represent South Florida spatially and geologically. The groundwater level data for each well was analyzed for the 2004 and 2005 calendar years in order to associate changes that occurred and properly connect them to the tropical systems that occurred during that timeframe. Groundwater levels were taken before each tropical system occurred and compared to the maximum level occurring during the time to illustrate the changes in water levels resulting from rainfall and recharge. Historical data included maximum, minimum, and mean levels as well as changes in levels associated with each tropical system for each well. In addition, radar rainfall during the 2004 and 2005 hurricane seasons in the District area are presented to show intensity and spatial coverage.

During the 2004 and 2005 hurricane seasons, recharge was most prominent for the surficial aquifer system when rains occurred near Lake Okeechobee and/or in the Upper East Coast Planning Area. Palm Beach County appears to be more responding for recharge and this is probably due to canal recharge as there are more canals in Palm Beach County than Martin and St. Lucie counties.

The Biscayne aquifer system, much like the surficial aquifer system, also relies on canal recharge and, therefore, can benefit from rainfall north of Broward and Dade counties that is canalized through these counties. Most large increases in recharge came from rainfall that fell directly on Broward and Dade counties or in east Collier and Monroe counties over Everglades National Park and Big Cypress Preserve.

The Intermediate aquifer system was the least represented geologic unit in the study with only two monitoring wells. For the most part, these groundwater wells did not recharge significantly with every tropical system. However, heavy rainfall in the Lower Kissimmee Basin and west of Lake Okeechobee showed a better response for these wells. This response is likely due to a relatively sparse expanse of this aquifer system compared to the other three aquifer systems. The Floridan Aquifer System recharged during periods of heavy rainfall in regions near southern Orange County and northern Osceola County also known as the Upper Kissimmee Basin. The Floridan aquifer runs beneath the Intermediate, thus, rainfall in the Upper Kissimmee Basin follows its lower confining unit and settles beneath the intermediate aquifers. This may be the reason that these wells displayed slight increases in elevation levels whereas others rose significantly.

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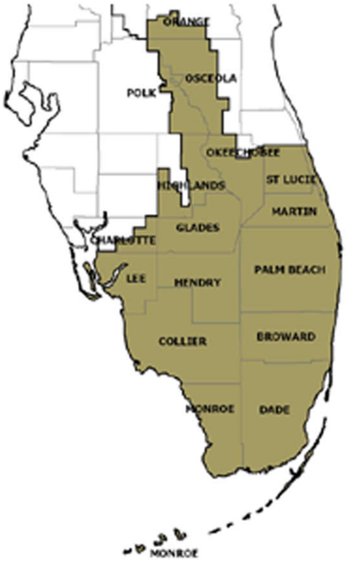
I. INTRODUCTION

SOUTH FLORIDA WATER MANAGEMENT DISTRICT

The South Florida Water Management District (SFWMD or District) has jurisdiction of 17,000 square miles. It encompasses all or portions of 16 counties, 31 percent of Florida's land area, and 40 percent of the population. **Figure 1** illustrates District jurisdiction and the counties included in its boundaries.



Formerly known as the Central and Southern Florida Flood Control District (CSFFCD), the history of the District dates back to a 1949 Florida legislation act that, in alliance with the U.S. Army Corps of Engineers, that was initiated to complete projects that would in turn provide flood protection, adequate water supply, prevent saltwater intrusion, encourage agricultural and urban development, and protect fish and wildlife. Growing concerns on preserving the environment provoked the National Environmental Protection Act of 1969. This proceeding, coupled with the Water Resources Act of 1972, broadened the authority of the CSFFCD and required control and regulation of water supplies and their uses, prompting a change in names to the South Florida Water Management District in 1976 (Fernald and Purdum, 1998).

Figure 1. Counties included within SFWMD boundaries and jurisdiction.

For planning purposes, the District is divided up into four sections known as planning areas. These areas are the Kissimmee Basin, Upper East Coast, Lower East Coast, and Lower West Coast. A map outlining these four water supply planning areas is shown in **Figure 2.**

The major hydrologic components within the District's boundaries are the Upper Kissimmee Chain of Lakes, Lower Kissimmee Basin, Lake Okeechobee, Lake Istokpoga Surface Water Management basin, Everglades Agricultural Area, Caloosahatchee Basin, St. Lucie Basin, and Everglades Protection Area (Abtew et al., 2006b).

At the center of the hydrologic system is Lake Okeechobee with a central role in water management operations. The lake provides water to surrounding communities and farms, stores surface water, and is also used to manage canal water levels in Palm Beach, Broward, and Miami-Dade counties. Major sources of inflow to Lake Okeechobee are the Upper Kissimmee Watershed (made up of the Upper Kissimmee Chain of Lakes: lakes Myrtle, Alligator, Mary Jane, Gentry, East Tohopekaliga, Tohopekaliga, and Kissimmee), the Lower Kissimmee River Basin and the Lake Istokpoga Surface Water Management basin. Other sources of inflow include rainfall, the Fisheating Creek, the Taylor Creek-Nubbin Slough Basin, reverse flow from the Caloosahatchee River and the St. Lucie Canal and back pumping from the Everglades Agricultural Area (Abtew and Huebner, 2002).

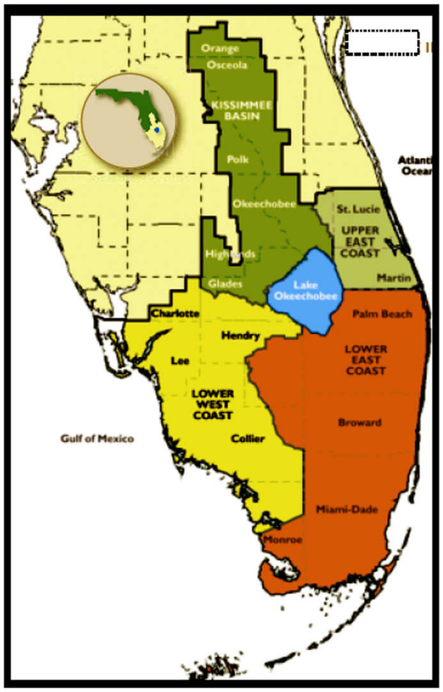


Figure 2. Water supply planning regions within SFWMD.

TROPICAL SYSTEMS

Tropical systems are part of the hydrometeorology of South Florida and a tropical system's unpredictable occurrences and large aerial coverage can have lasting effects on storage and conveyance systems, especially when soils are already saturated and storage capabilities have already been maximized (Abtew et al., 2006a). However, tropical systems can also play an imperative role in recharging aquifers and lifting areas out of drought due to high intensity and often long durational periods of rainfall.

Tropical systems are a normal aspect of the earth's climatic regime. During the colder months of a year, there is a greater difference in temperatures between the polar and tropical regions of the globe. This temperature gradient invites jet-stream winds to strengthen and also strengthens low pressure systems that set the stage for storms. These storms mix up air by transporting warm air towards the poles and cold air away from the poles (Chaston, 1996).

During summer and early fall, the temperature difference between the poles and the tropics is less extreme and therefore jet-streams are weaker and strong low pressure systems rare. Although less extreme, a differential in temperature is still present. Therefore, nature develops the hurricane, a tropical low pressure system that forms independent of cold and warm air fronts or the jet stream (Chaston, 1996). According to Chaston (1996), a hurricane is nature's way of transporting heat energy, moisture, and momentum from the tropics to the poles in order to decrease the temperature differential and preserve the current climate of the earth.

The most vulnerable part of the United States to be subjected to hurricanes is the southeastern states of South Carolina, Georgia, and Florida. Hurricane statistics reveal that these states can routinely expect to be struck fully or partially by tropical storms and hurricanes nearly annually (Chaston, 1996). Two deciding factors play a role in subjecting this area to tropical systems. Sea surface temperatures in this region of the Atlantic Ocean are typically in the low to mid 80 degrees Fahrenheit (˚F). Sometimes the Gulf of Mexico is in the upper 80 ˚F during summer months. Hurricanes thrive on warm waters at or above 79 ˚F and without strong winds from other weather systems that diminish convection. Strong shearing systems from the mainland usually pass north of these states during hurricane season, thus, allowing tropical systems to maintain or increase their strength and size when passing over these warm, coastal waters. Secondly, unless strong troughs of wind occur over the southeast, a tropical systems path will likely not change as it would if it were to occur farther north and come under the influence of the upper-level winds, mainly the "westerly" trade winds. Therefore, not much is present to divert the path of a hurricane once it has formed and begins to move towards this coastal region (Chaston, 1996).

Groundwater is one of Florida's most valuable natural resources. About 93 percent of Florida's population depends on groundwater for drinking water. Groundwater is also used for irrigation in agriculture, mining, and industrial processes. Florida ranked fifth in the nation in the use of fresh groundwater in a 1995 study (Fernald and Purdum, 1998).

The source of all freshwater in Florida is precipitation. Water not lost in evapotranspiration is either flowing in surface water bodies or stored in groundwater reservoirs termed aquifers. Aquifers are underground layers of sufficiently permeable rock from which economically useful quantities of water are yielded to springs or can be extracted through wells (Fernald and Purdum., 1998). Florida is covered nearly everywhere by sands that overlie thick sequences of limestone and dolomite of which most all of the aquifer systems are composed. By percolating through these often unconsolidated soils, freshwater can recharge these aquifers, replenishing amounts that are pumped out for uses. This action is termed recharge and varies in aquifers. Aquifers are composed of sedimentary units of rock that differ in composition and depositional history and, therefore, display different characteristics, permeability being the most important for water storage.

Aquifer systems consist of two or more aquifers that are connected hydraulically. In an aquifer system, a change in the conditions of one aquifer affects all the others throughout the system. There are three major aquifer systems that are used for water supply in South Florida: the surficial aquifer system, the intermediate aquifer system, and the Floridan aquifer system. The extent of these aquifers is shown in **Figure 3.**

Surficial Aquifer

The surficial aquifer system (SAS) is an unconfined system that includes all aquifers present at or near the land surface and consists of mostly sand, sandy clay, silt, clay, sandstone, limestone, and shell beds. Being an unconfined aquifer is a means to say there is no confining layer of geologic matter topping the aquifer. The aquifer is essentially open and its top portion is the water table that is recharged directly by natural rainfall. Unconfined systems are also referred to as non-artesian systems. Non-artesian systems lack the pressure of a top confining layer deterring the groundwater from springing out of the ground when tapped into by wells or when changes in geology present openings to the surface.

In some areas, clay deposits are thick enough to divide the SAS into two or more separate layers, but generally the SAS is undivided. The SAS is widely used for drinking water throughout the District by coastal municipalities and by individual household wells (Fernald and Purdum, 1998).

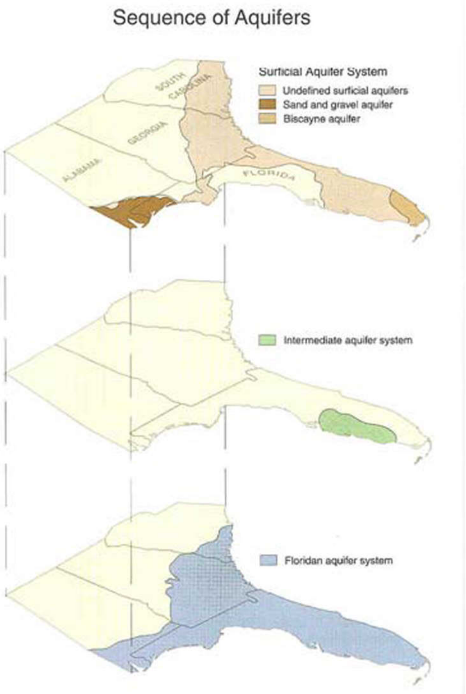


Figure 3. Area and extent of three major aquifer systems in Florida (Fernald and Purdum., 1998).

Depth of the SAS varies throughout Florida. Within District boundaries, the aquifer's thickness averages slightly below 100 feet thick. In areas of St. Lucie County, the aquifer ranges from tens of feet to several hundred feet. In Palm Beach and Martin counties the SAS is over 200 feet thick in some areas (Fernald and Purdum, 1998).

Recharge of the SAS is from precipitation that percolates down through the overlying soil. A large amount of precipitation is deterred from recharging by being returned to the atmosphere through evapotranspiration processes or by moving quickly along short flow paths and discharging into nearby lakes and streams. Another source of recharge for the SAS, especially near the coastlines, is water pushed upward from the underlying Floridan aquifer system due to the artesian, or confining, pressure below the Floridan aquifer. Conversely, there are also areas in which the underlying confining layer is missing due to unconformities, has been dissolved, or has been faulted resulting in passages for groundwater to drain down into and recharge the Floridan. (Fernald and Purdum, 1998).

Biscayne Aquifer

The Biscayne aquifer is a relatively shallow, unconfined aquifer named after the Biscayne Bay. Due to merging with the floor of the Biscayne Bay and the Atlantic Ocean, the Biscayne aquifer is also referred to as a coastal aquifer. The Biscayne aquifer is actually a portion of the vast SAS, but due to its importance as a local source of water to Broward and Miami-Dade counties, it is most always presented separately as its own unit.

The Biscayne is the most important source of water supply in southeastern Florida. Consisting of a permeable limestone, often referred to as the Fort Thompson formation, the Biscayne is the most productive of the shallow non-artesian aquifers in the area and is one of the most permeable in the world. This permeability is due to the large amounts of Oolitic Limestone found on the southeast coast. With very high vertical permeability, rainwater simply percolates down and into the water table (Parker et al., 1955).

The Biscayne stretches as far north as coastal Palm Beach County and as far south as southern Miami-Dade County. It also underlies the Everglades north into Broward County and west into parts of Monroe and Collier counties. Permeability and thickness is greatest farther south and east in the aquifer, as it thins to the west and north.

The Biscayne aquifer increases in thickness toward the east and extends under the Biscayne Bay where it merges with the ocean floor at around 240 feet below sea level. It averages around 100 feet below sea level under most of the eastern coastal ridge and is shallowest to the west beneath the Everglades and Big Cypress National Preserve soils, where it averages a depth of 5 feet below sea level. It is in these areas that the Biscayne can be recharged pending two restraints. The mucky soil bottoms of these regions must allow water to percolate down to the aquifer or the water table must be below the surface and not discharging into the Everglades (Parker et al., 1955).

The Biscayne aquifer as well as the surficial aquifer rests on the Floridan aquiclude, a geologic unit comprised of clays, silts, marls, dense limestone, and fine sediments with mixtures of sand, fine gravel, and shells—all being of extremely low permeability. Groundwater in the Biscayne aquifer follows this confining unit and flows south to southeast and uses the Biscayne Bay as a natural outlet for subsurface flow. Although, aquicludes are capable of absorbing water slowly, they are essentially watertight foundations on which aquifers are able to rest and transgress (Parker et al., 1955). The Floridan aquiclude also serves as the upper confining unit for the underlying Floridan aquifer system.

Floridan Aquifer

The Floridan aquifer system underlies a total area of about 100,000 square miles from southern Alabama, southeastern Georgia, southern South Carolina, and all of Florida. It is composed of thick sequences of carbonate rocks (limestone and dolomite) that are of Tertiary age that range from Paleocene to early Miocene. Being the most prolific aquifer system in Florida and one of the most productive aquifer systems in the world, it serves as a major source of water supplies to cities, for irrigation to agriculture, and is also used in mining.

Within the District's boundaries the Floridan generally consists of Oldsmar Formation, Avon Park Formation and Ocala Limestone, with its most productive units being within the Eocene aged Avon Park Formation. These thick sequences of carbonate rock exist throughout the Floridan separating it into three distinct units. The middle confining unit, serving as an intermediate aquiclude, is comprised of lower Avon Park Formation and divides the aquifer into the two areas termed the Upper and Lower Floridan aquifers (SFWMD, 2000). This same confining unit is advantage for disposing of residential and industrial waste water by injecting it into the Lower Floridan in places like Brevard County. In addition, surface runoff is routinely diverted into the Floridan in the Orlando area. (Fernald and Purddum, 1998). The Lower Floridan aquifer is very brackish. For this reason the Upper Floridan is more commonly used as the source for drinking and irrigation waters (Randazzo and Jones, 1997).

The Mid-Hawthorn Formation also is prevalent in the Floridan aquifer system. This series is of Miocene epoch aged deposits and is a very complex mix of phosphate and carbonate bearing sediments. This series varies by location and has many facies changes. The variance mainly affects its permeability, thus, its potential for storing groundwater. For the Kissimmee Basin and parts of the Upper East Coast Planning Area where the Floridan is tapped, the Hawthorn is comprised of sediments with characteristically low permeability resulting in an upper confining layer on the Upper Floridan aquifer that provides pressure and artesian characteristics to the aquifer. In the Lower West Coast Planning Area, the Mid-Hawthorn's sediment permeability changes allowing enough saturation to occur to develop major parts of the Intermediate aquifer system (Fernald and Purdum, 1998).

Areas of the Floridan aquifer that is of greater importance to the District, from a management standpoint, is found throughout the Kissimmee River Basin in parts of Orange, Osceola, and Polk counties. Municipalities of south-central Orange County, like Orlando, get their drinking water from the Upper Floridan. Osceola and Polk counties are important recharge areas for the aquifer (SFWMD, 2000). It is in this region where the geologic units that confine it begin to thin when over the peninsular arch and actually become exposed at the surface in some areas and disappear in others. This allows rainfall and runoff from the highlands of eastern Polk County, the highest point in the District (~170 feet above sea level) to enter the aquifer directly. In this area, the aquifer is recharged, on average, by 3–20 inches/year (SFWMD, 2000).

The Floridan aquifer ranges from 200 feet thick in northern Florida/Alabama border to around 3,400 feet thick in central and peninsular Florida (Randazzo and Jones, 1997). In southern Florida it begins to rise again but is still deeply buried, averaging a depth of 900 feet near Miami and 800 feet near Everglades City (Parker et al., 1955). The aquifer thickens sharply to the south and to the southeast from this area and eventually becomes the lower confining unit for the Biscayne aquifer in southeast Florida (Parker et al., 1955).

Intermediate Aquifer System

The Intermediate Aquifer System (IAS) consists of several water bearing geologic units located between the overlying surficial aquifers and above the underlying Floridan aquifer system. The Intermediate aquifer is comprised mainly of sand interblended with limestone and dolomotized limestone from the Hawthorn Group along with sand, limestone, and shell beds from the Tamiami Formation. The limestone beds yield larger volumes of water than sand or dolomite.

The IAS is actually divided up into three aquifers: the Hawthorn, Lower Tamiami, and Tampa. This classification is not used much in this complex sequence due to many regional facies changes that occurred during formation of the sediments that overlay the Hawthorn. Much of the IAS is underlined with clay that hydraulically separates it from the Floridan and also confines the Floridan. Breaks or thinning in this layer allows groundwater to spring up from the Floridan and recharge the IAS. The groundwater typically moves downward following the upper confining unit and follows a short flow path before it discharges into a surface drainage such as a lake, river, or estuary when the upper confining unit is absent. The IAS does not yield as much water as the other aquifers and, therefore, is only used when water from SAS or the Floridan Aquifer System (FAS) is not adequate in quantity or quality. For example, parts of Charlotte, Lee, and Collier counties by the Gulf Coast where populations are dense and salt water intrusion is increasing use the IAS (Fernald and Purdum, 1998). **Figure 4a** shows the major aquifers in South Florida and regional primary water groundwater sources.

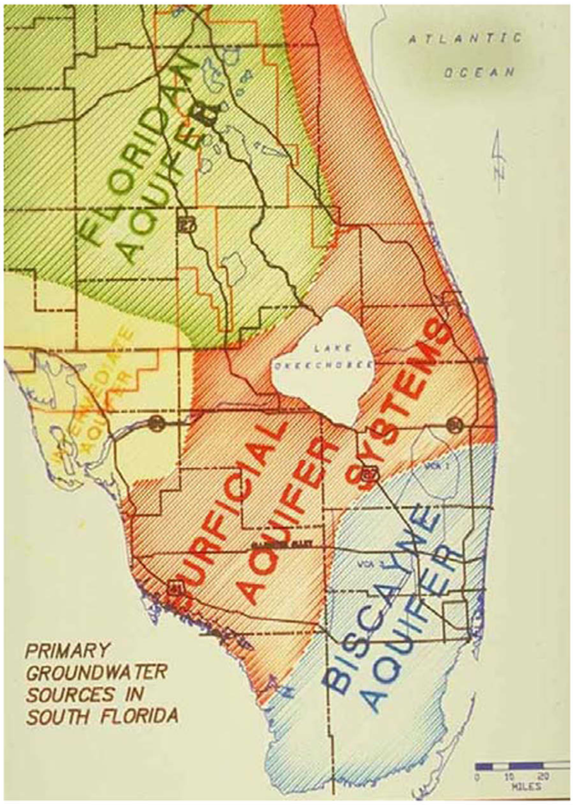


Figure 4a. South Florida aquifers and groundwater use.

II. OBJECTIVE

Documenting hydrologic events, helps provide important information that can be used in water management decision making. It is the purpose of this document to illustrate the effects that 2004 and 2005 hurricanes had on groundwater resources of the District area.

To fulfill the objective of this report, an analysis of several District and U.S. Geological Survey (USGS) groundwater wells was performed to illustrate the effects that 2004 and 2005 hurricanes rainfall had on groundwater level. Historical data was analyzed from representative wells from the network of groundwater monitoring wells in the District. The selected wells include the major aquifers of South Florida and also are representative of all counties in the District except for Monroe and Charlotte. There were 38 wells selected for the 2004 study and 39 wells for the 2005 study. **Figure 4b** shows the layout of the monitoring well network throughout the District. Tables 1 through 4 in Appendix B groups each well by the county as well as by aquifer. Historical minimum, maximum, and mean water level values as well as calendar year minimum, maximum, and mean values for 2004 and 2005 are listed in Tables 1 and 2 of Appendix B. Tables 3 and 4 of Appendix B illustrate maximum groundwater level values reached during each hurricane. Values marked in bold blue type represent maximum elevations for wells during that calendar year. Values marked in italic red type represent historical maximum elevations reached for the groundwater monitoring wells. These values show the amount of recharge that occurs during these tropical systems and were used to estimate how much the water level in each well rose during each hurricane of the 2004 and 2005 seasons. These values were calculated by subtracting the antecedent average daily water level from maximum water level reached after the respective hurricane. In this report, graphs of change in groundwater level are presented to illustrate how subsurface water levels changed during each hurricane. In addition, throughout this report several hydrograph figures have been provided that depict time series of daily average water levels for the monitoring wells during the 2004 and 2005 calendar years. Trends of rising elevations in groundwater levels are discernable at the occurrence of each hurricane and succeeding days as depicted in several histogram figures.

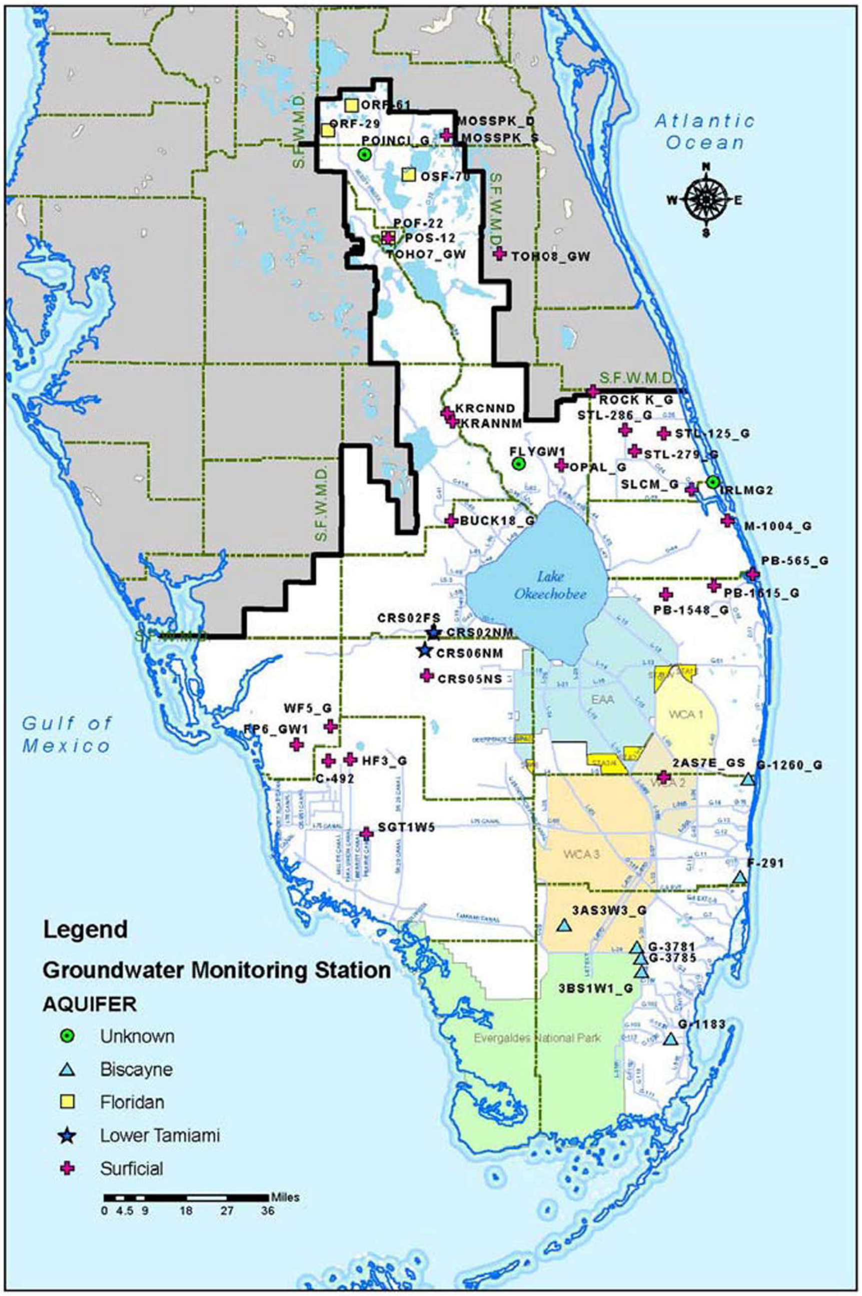


Figure 4b. Groundwater well locations used in this study.

III. THE 2004 HURRICANE SEASON IN SOUTH FLORIDA

During the 2004 hurricane season, the District endured three hurricanes along with an extra-tropical system remnant from Hurricane Ivan. Hurricane Charley made landfall on the southwest coast during August 12–16, Frances on the northeast coast during September 4–8, and Jeanne taking a near identical path as Frances did on the northeast coast during September 24–28. A remnant storm from Hurricane Ivan passed through South Florida during September 19–23. All of these storms dropped heavy rainfall. In addition, high surface water flows and high lake levels were experienced. Four hurricanes in less than a seven-week period area is a rare event occurring once in more than 100 years (Abtew et al., 2006b). For these four hurricanes, the District area rainfall impacts are shown with radar rainfall estimates in Figures 1a through 1d in Appendix A.

Hurricane Charley

Hurricane Charley originated as a tropical wave off the coast of Africa on August 4. It slowly increased in strength as it crossed the Atlantic and developed into a Category 4 hurricane shortly before making landfall in southwest Florida near Cayo Costa. Pasch's (2005) cyclone report for the National Hurricane Center reported that Charley poured slightly over 5 inches of rain on the Kissimmee Basin and considerably more rainfall on Florida's east coast than west. Charley, moving in a north-northeastward manner, eventually emerged in the Atlantic near Daytona Beach and struck other states along the southeast coast (Pasch et al., 2005). **Figure 5a** illustrates how Hurricane Charley intensified in 12 hour increments. The figure also shows its path from the Atlantic through the Caribbean and Gulf and onto land in southwestern Florida.

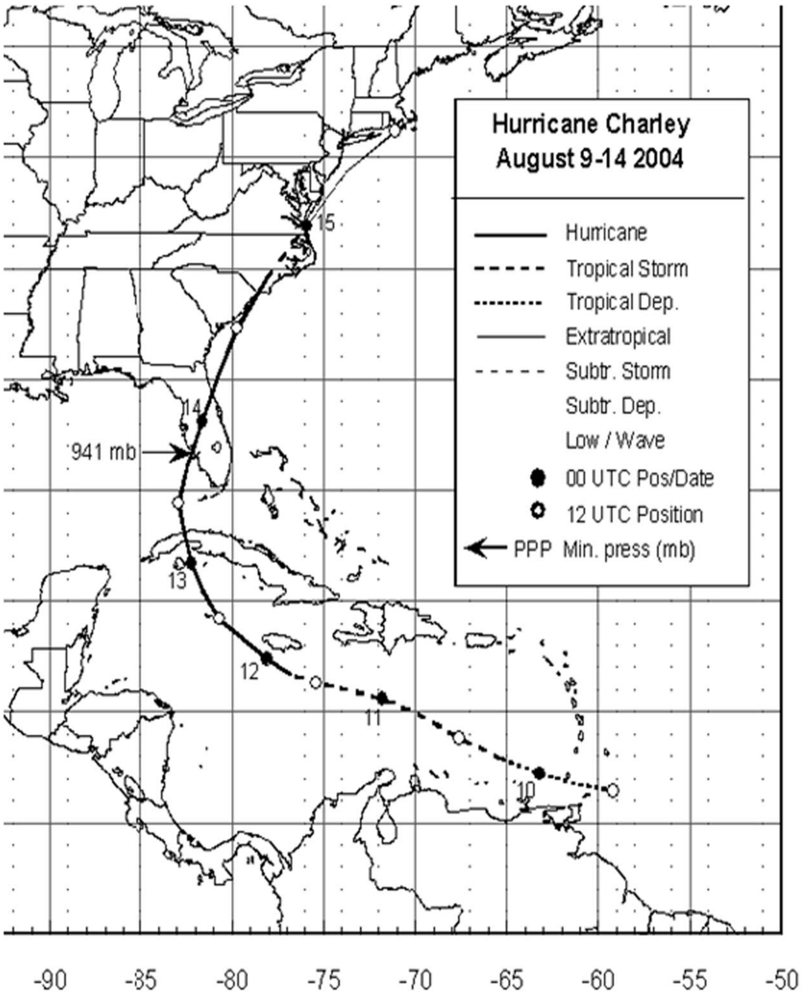


Figure 5a. Path and development of Hurricane Charley from August 9–14, 2004 (Pasch et al., 2005).

Figure 5b depicts change in groundwater level for several monitoring wells over the District area. According to the *2006 South Florida Environmental Report*, the Upper Kissimmee and East Caloosahatchee regions received the most rainfall during Hurricane Charley, averaging over 3.5 inches. Miami-Dade and Broward counties received the least rainfall of all other regions. Well SGT1W5 of Collier County increased in elevation by 0.437 ft during the rainfall. This increase elevated the groundwater well to 12.259 ft NGVD 1929, the maximum for the 2004 calendar year.

In the upper east coast, groundwater monitoring well PB-1548_G from Palm Beach County increased 1.465 ft, MOSSPK_D from Orange County increased 1.403 ft, and KRCNND from Okeechobee County increased by 1.223 ft. Increases in these surficial well groundwater levels at far apart locations show the spatial coverage of the hurricane. Hydrographs of these surficial aquifer wells with marked peaks during Hurricane Charley are shown in **Figure 5c.**

Wells OSF-70 from Osceola County and ORF-61 from Orange County each significantly rose 2.19 and 2.083 ft, respectively. Both wells draw from the FAS and are located in the Upper Kissimmee Basin planning area. This is an important region for recharge for the Floridan. Much of its top confining layer reaches the surface or is not present allowing water to percolate right into the vast aquifer's top layer termed the Upper Floridan. Groundwater then follows the bottom confining layers of clay and silt and flows beneath the IAS towards South Florida (Randazzo and Jones, 1997). Rises in wells like these suggest considerable temporal periods of recharge to the FAS from the hurricane related rainfall. The hurricane rainfall also caused some flooding of the upper chain of lakes in the Kissimmee Basin further aiding recharge to the Floridan. Hydrographs of these FAS wells with marked peaks during Hurricane Charley are shown in **Figure 5d.**

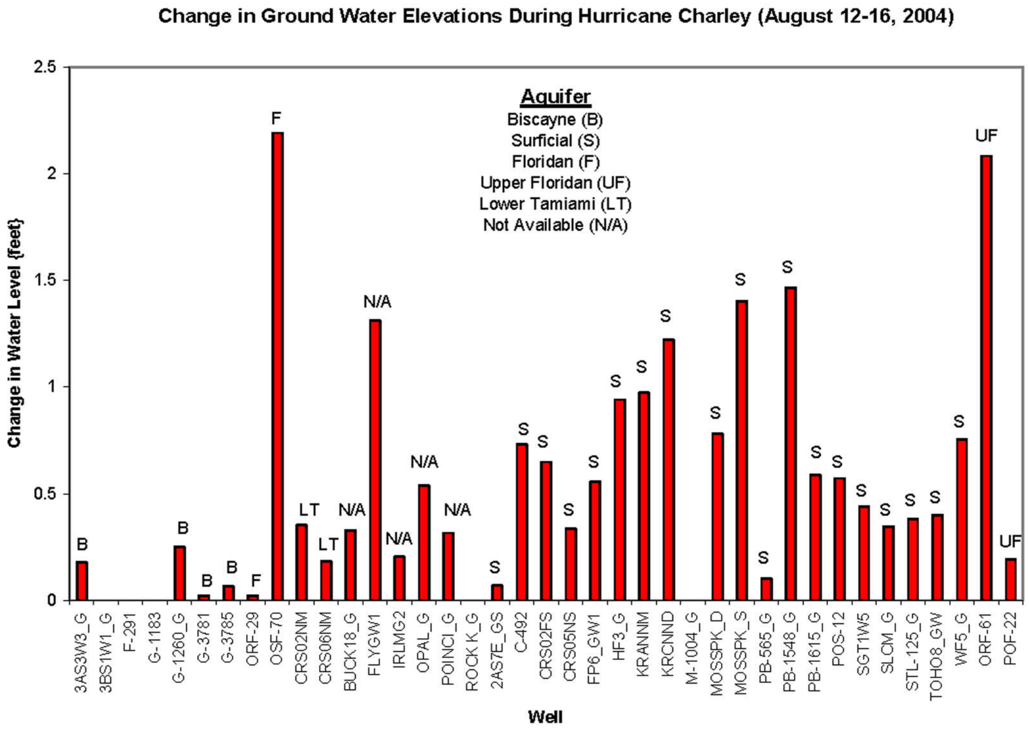


Figure 5b. Change in groundwater elevation during Hurricane Charley (August 12–16, 2006).

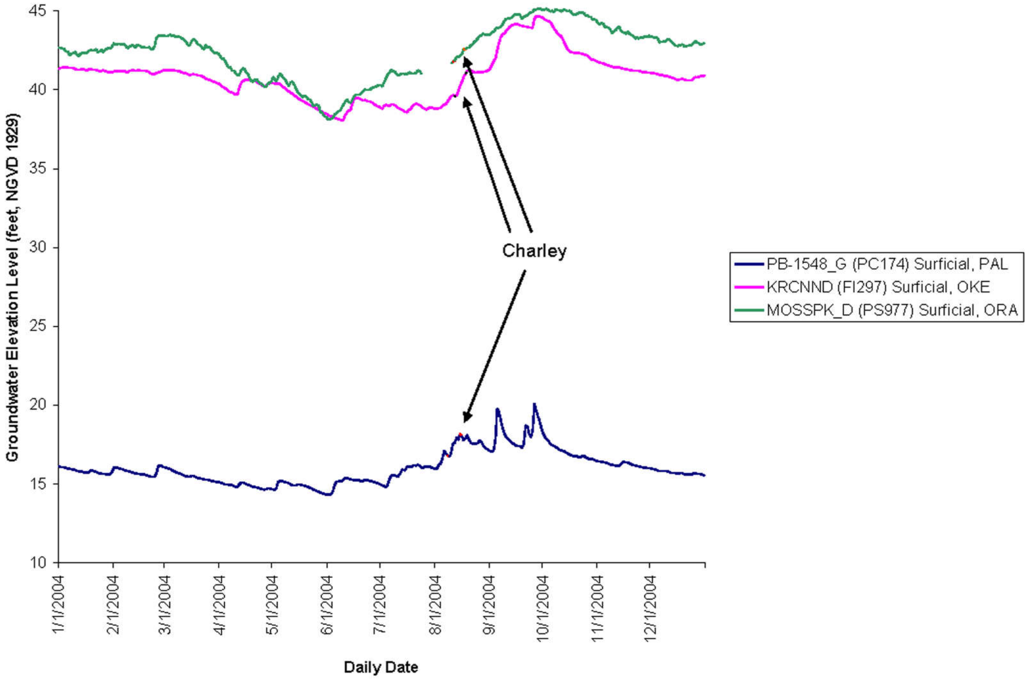


Figure 5c. Hydrograph of three groundwater wells drawing from the surficial aquifer during the 2004 calendar year. Peaks caused by Hurricane Charley rainfall are labeled with arrows.

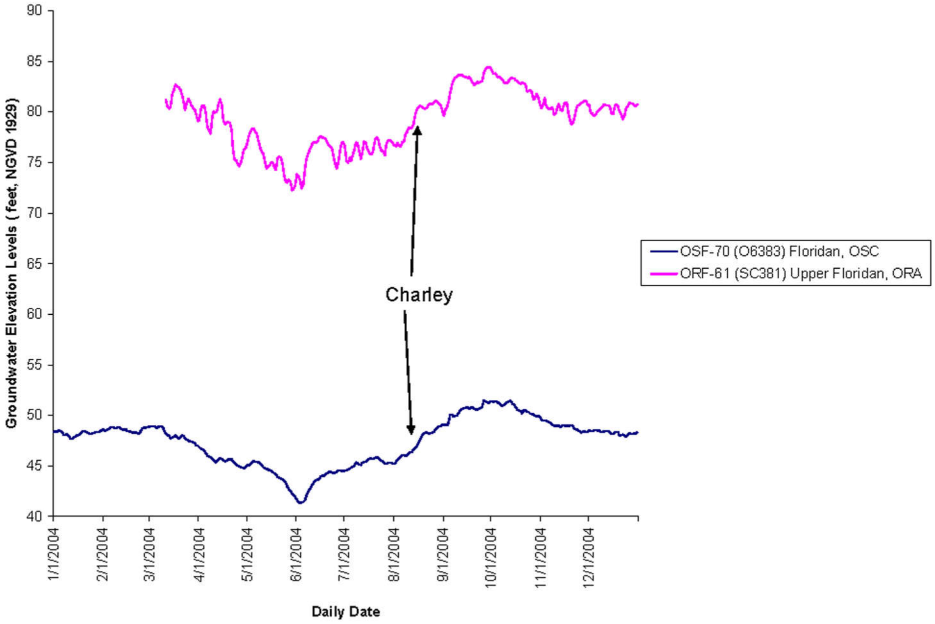


Figure 5d. Hydrograph of two groundwater wells drawing from the Floridan aquifer during the 2004 calendar year. Peaks caused by Hurricane Charley rainfall are labeled with arrows.

Hurricane Frances

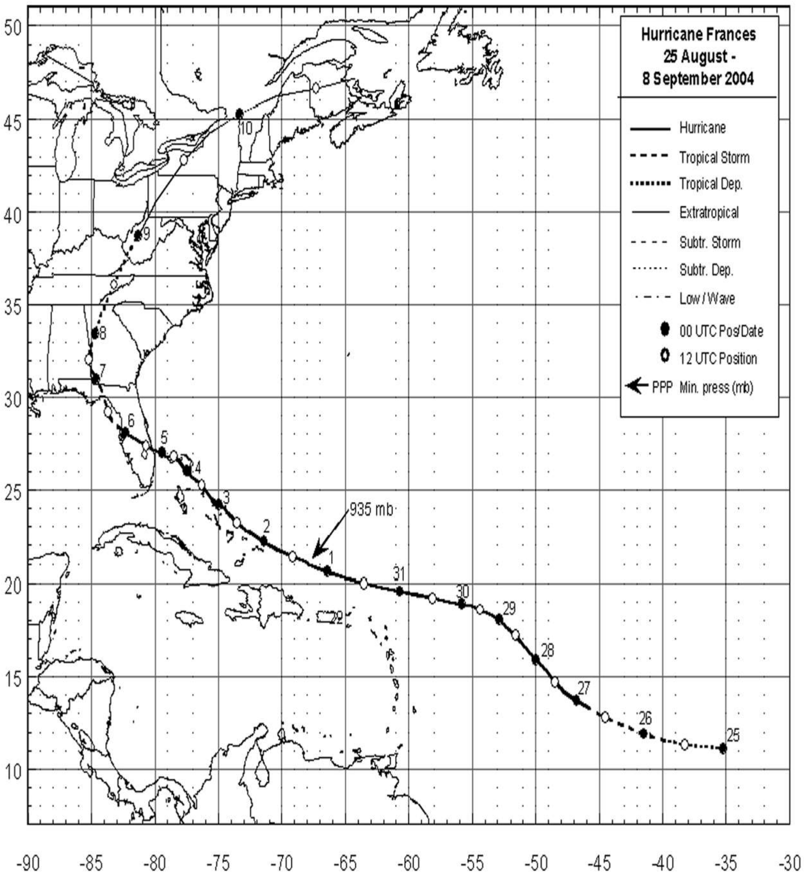


Figure 6a. Path and development of Hurricane Frances from August 25 through September 8, 2004 (Bevin et al., 2004).

Hurricane Frances originated as a tropical wave off the coast of Africa on August 21. The wave moved westward, gradually developing from a tropical depression to a tropical storm to a Category 2 hurricane before making landfall near Hutchinson Island on September 5 (**Figure 6a**). After reaching the Gulf of Mexico, it turned north-northeast when influenced by the westerly winds in Alabama and Georgia, and followed this path until it dissipated near the Gulf of St. Lawrence in Canada (Beven et al., 2004).

Frances crossed the Floridan peninsula, dumping notable levels of rainfall at several areas along the east coast and in the Kissimmee Basin. According to the *2006 South Florida Environmental Report*, the highest five-day rainfall amount was 15.57 inches of rain that fell at Palm Beach International Airport in West Palm Beach.

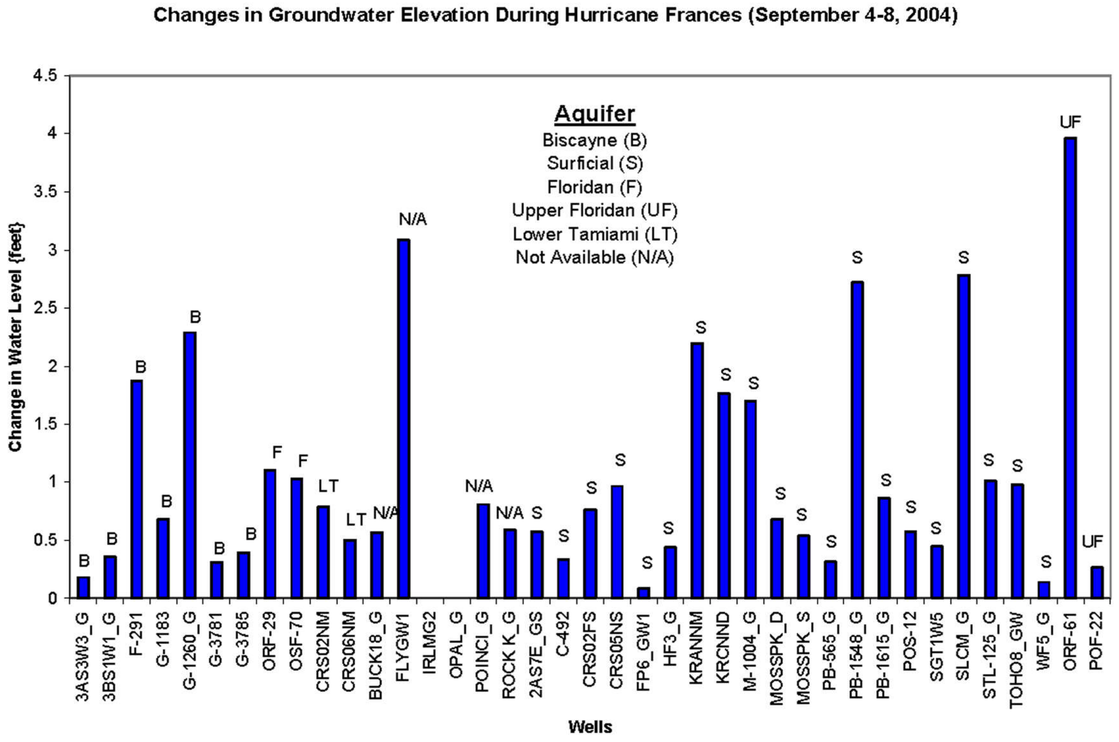


Figure 6b. Changes in groundwater elevation during Hurricane Frances (September 4–8, 2006).

Other areas in the Upper East Planning Area that received considerable amounts of rainfall were Lake Okeechobee with 5.9 inches and Martin and St. Lucie counties with a 9.55 inch five-day rainfall maximum. (Abtew et al., 2006b). Heavy rainfall in Palm Beach, Okeechobee, Martin, and St. Lucie counties is reflected with elevated surficial levels in groundwater monitoring wells: PB-1548_G, KRANNM, KRCNND, M-1004_G, and SLCM_G (**Figure 6b**). MOSSPK_S of Orange County and TOHO8_GW of Osceola County both passed historical maximums for groundwater elevation in their surficial aquifer wells (Table 3, Appendix B). The sharpest increase among these wells occurred at SLCM_G which rose 2.782 ft. Hydrographs of these surficial aquifer wells with marked peaks during Hurricane Frances are shown in **Figure 6c**.

During this system, less rainfall fell on the west coast than the east coast. Rainfall gauges from Everglades National Park and Big Cypress Basin reported values of 2.36 and 4.17 inches associated with the hurricane. The Southwest Coast rainfall area recorded a maximum 5.14 inches of rainfall in a five-day period. (Abtew et al., 2006b). This trend is further illustrated in **Figure 6b** upon viewing that the least affected surficial aquifer well was FP6_GW1 from Lee County, which only rose 0.086 ft. This small rise was enough to elevate this well to 17.665 ft NGVD 1929, which set the maximum elevation for this groundwater well for the 2004 calendar year. This well illustrates well the cumulative effect that a rainy period can have on groundwater wells. Additionally, wells WF5_G of Lee County only rose 0.139 ft and C-492 of Collier County was slightly elevated by 0.330 ft.

The Lower East Coast Planning Area also received noteworthy amounts of rainfall during the system, with a rain gauge in Pembroke Pines, a suburb between Miami and Ft. Lauderdale, recording a 5.97 inch five-day maximum rainfall (Abtew et al., 2006b). Notable changes can be seen in wells G-1260_G and F-291 located in Broward County, and these BAS wells increased by about

2.290 and 1.870 ft, respectively. F-291, a USGS groundwater monitoring well, reached a maximum elevation of 3.250 feet National Geodetic Vertical Datum (NGVD) during the system. Hydrographs of these Biscayne aquifer wells with marked peaks during Hurricane Frances are shown in **Figure 6d.**

The largest change for this system took place at well site ORF-61 in Orange County. This FAS well rose 3.962 ft after the Kissimmee Basin was hit hard by rainfall during the passing of a hurricane for the second time within two weeks. An Upper Kissimmee rain gauge near by measured a five-day maximum rainfall value of 8.22 inches (Abtew et al., 2006b). A hydrographs of the FAS well, ORF-61, with marked peaks during Hurricane Frances is shown in **Figure 6e.**

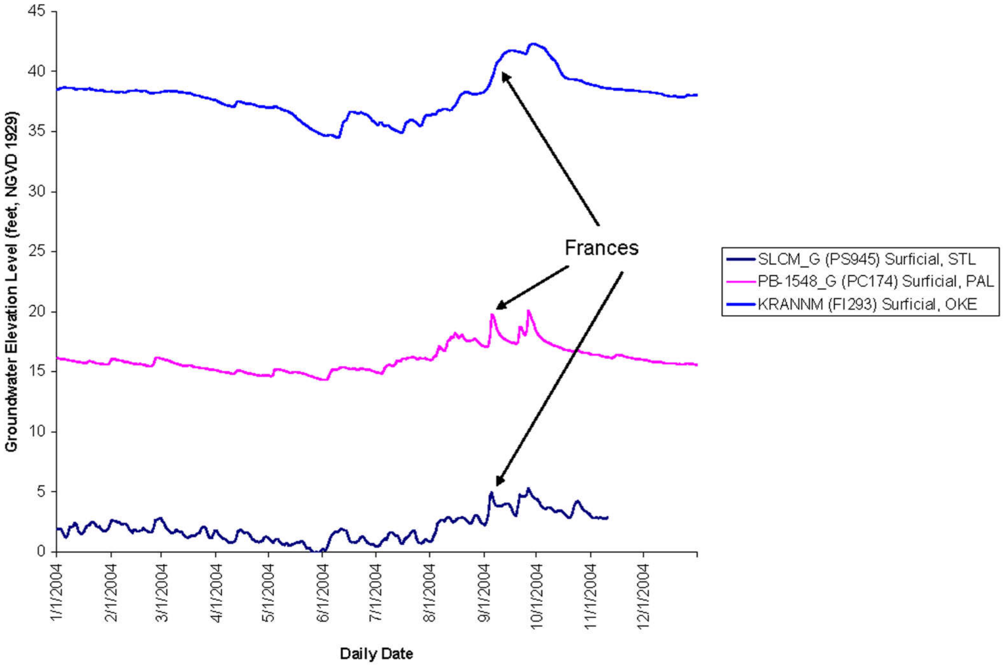


Figure 6c. Hydrograph of three groundwater wells drawing from the surficial aquifer during the 2004 calendar year. Peaks caused by Hurricane Frances rainfall are labeled with arrows.

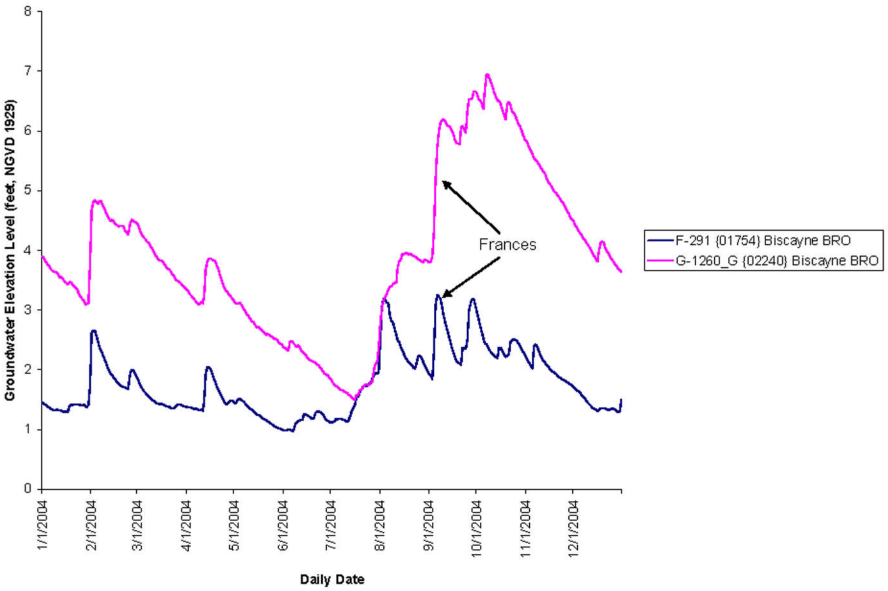


Figure 6d. Hydrograph of two groundwater wells drawing from the Biscayne aquifer during the 2004 calendar year. Peaks caused by Hurricane Frances rainfall are labeled with arrows.

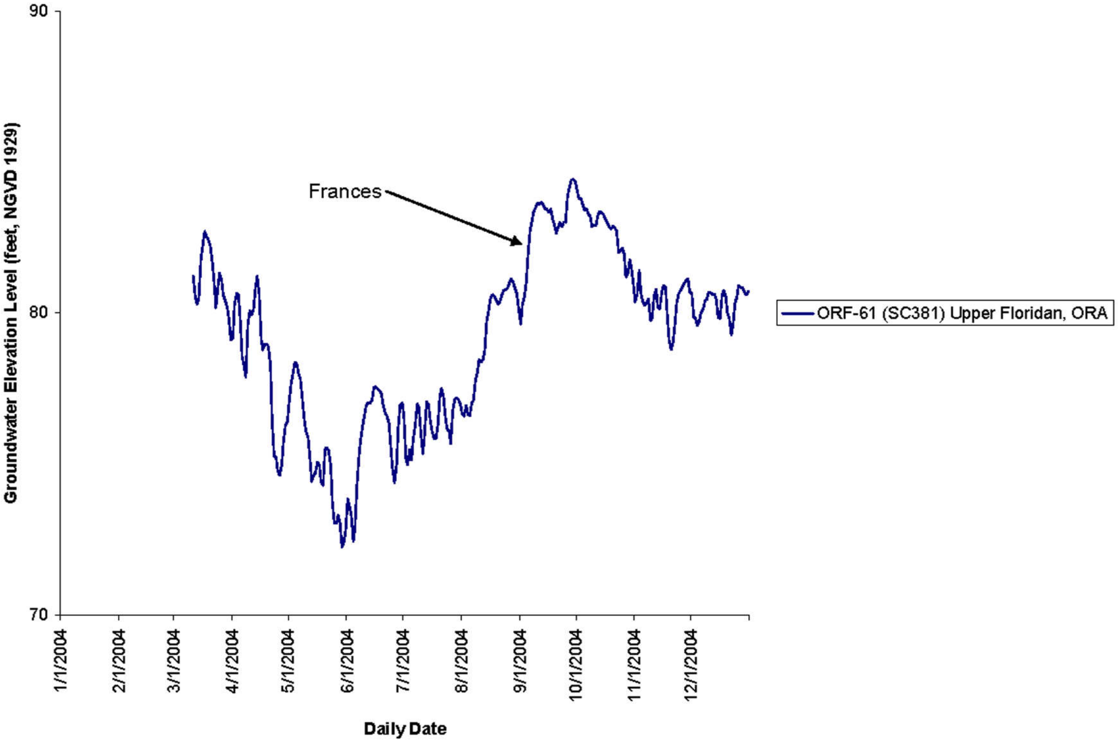


Figure 6e. Hydrograph of a groundwater well drawing from the Floridan aquifer during the 2004 calendar year. Peaks caused by Hurricane Frances rainfall are labeled with arrows.

Hurricane Ivan

Hurricane Ivan originated as a tropical wave off the coast of Africa on August 31. Development ensued as the storm moved in a westward direction gaining strength as it traveled between the Caribbean Islands and South America. On September 5, Ivan officially became a hurricane about 1000 miles east of Tobago in the southern Windward Islands. Over the next week Hurricane Ivan underwent several periods of rapid intensification and weakening (**Figure 7a**).

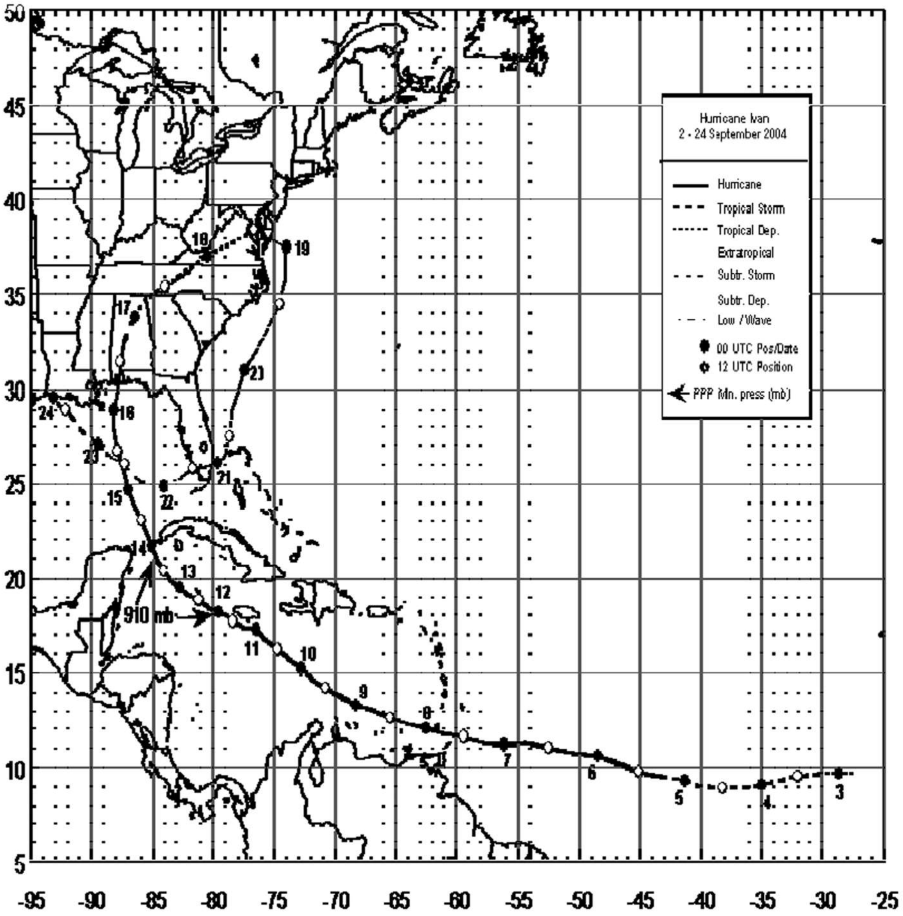


Figure 7a. Path and development of Hurricane Ivan from September 2–24, 2004 (Stewart et al., 2004).

Ivan reached Category 5 strength three different times and passed through Grenada, Jamaica, Cayman Islands, and western Cuba. Once in the Gulf, Ivan slowed and changed directions several times before heading north where it made landfall as a Category 3 hurricane just west of Gulf Shores, Alabama. Ivan's eye was approximately 40 to 50 miles in diameter which resulted in high winds for the southeastern region of Alabama and western Florida panhandle. Ivan caused flash floods and many tornadoes in the southeastern region of the United States. Ivan reduced in strength to a tropical depression and merged with a frontal system developing into an extra-tropical low pressure system as it moved northeast towards the Carolinas. Once it reached the Atlantic, the tropical low system turned around and headed south-southwest making landfall in South Florida on the morning of September 21 dropping heavy rains in St. Lucie, Martin, and Palm Beach counties. Later that day, the remnants of Ivan crossed into the gulf where the system developed into a tropical storm yet again. Finally, Ivan headed northwest making landfall in southwest Louisiana and the upper Texas coastline. Ivan finally dissipated on September 24 after covering a track over 5,600 miles long for a duration of 22.5 days (Stewart, 2004).

Figure 7b illustrates changes in groundwater wells during the extra-tropical system Ivan. Rather large increases in surficial aquifer groundwater wells suggest that the storm released heavy rainfall on the state's east coast in St. Lucie, Palm Beach, and Martin counties. The *2006 South Florida*

Environmental Report confirms this with the largest five-day maximum rainfall values occurring along the Martin-St. Lucie border with a value of 9.22 inches, the Everglades Agricultural Area in Palm Beach County with 5.96 inches and an additional rain gauge in Palm Beach County recording 4.27 inches (Abtew et al., 2006b). SLCM_G, a St. Lucie County well, increased the sharpest, elevating 1.754 ft in four days. Palm Beach County wells PB-565_G and PB-1548_G also each rose 1.200 and 1.424 ft, respectively. M-1004, of Martin County, rose 1.080 ft. A hydrograph for surficial monitoring wells is depicted with marked peaks during extra-tropical system Ivan in **Figure 7c.**

Several wells of the Kissimmee Basin also rose. The Lower Kissimmee Basin received slightly more rainfall than the upper region with five-day maximum rainfall values of 3.41 inches occurring south of Lake Kissimmee and 2.49 inches falling near Orlando (Abtew et al., 2006b). Two noteworthy increases were for two FAS wells ORF-29 in Orange County which increased by 1.43 ft, and OSF-70 in Osceola County which was elevated by 0.632 ft. A hydrograph for FAS monitoring well ORF-29 is depicted with marked peaks during extra-tropical system Ivan in **Figure 7d.**

The lowest five-day rainfall maximum was recorded in Water Conservation Area 3 (WCA-3) of Broward County and a value of 2.93 inches was recorded at Miami International Airport (Abtew et al., 2006b) Therefore, large increases were not present for the Biscayne aquifer wells, but all of them did increase during the time period. Well G-1183 increased the most with a value of 0.330 ft, while 3AS3W3_G increased the least by 0.128 ft.

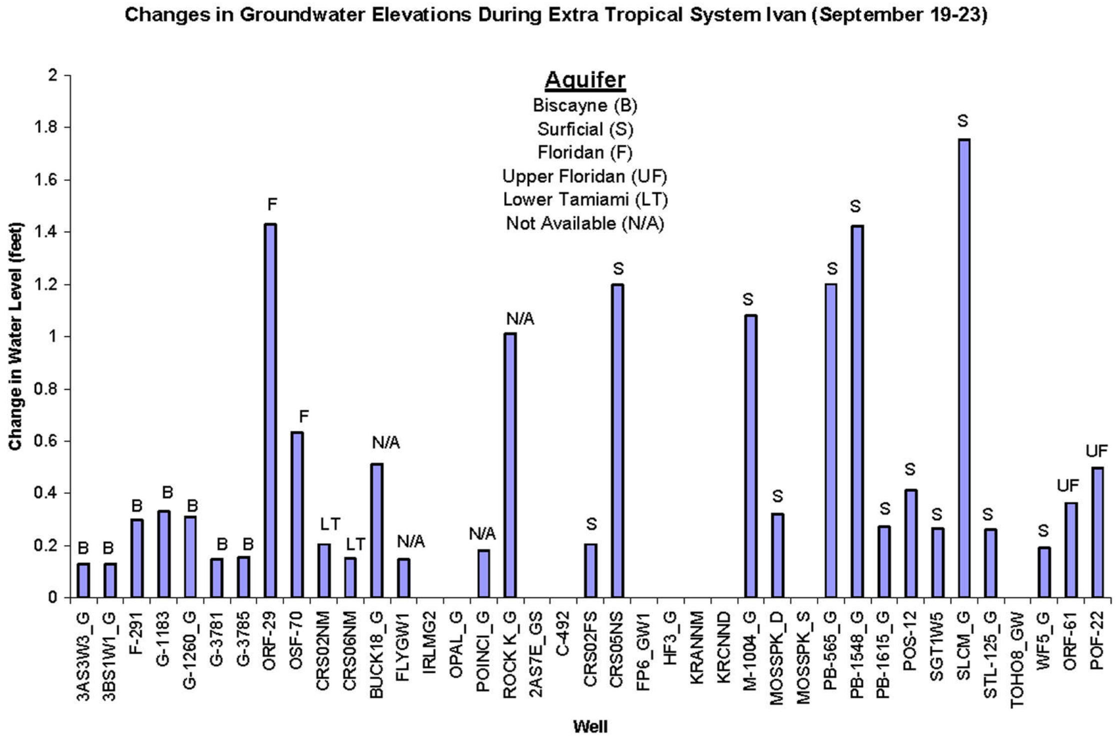


Figure 7b. Changes in groundwater elevation during extra-tropical system Ivan (September 19–23, 2006).

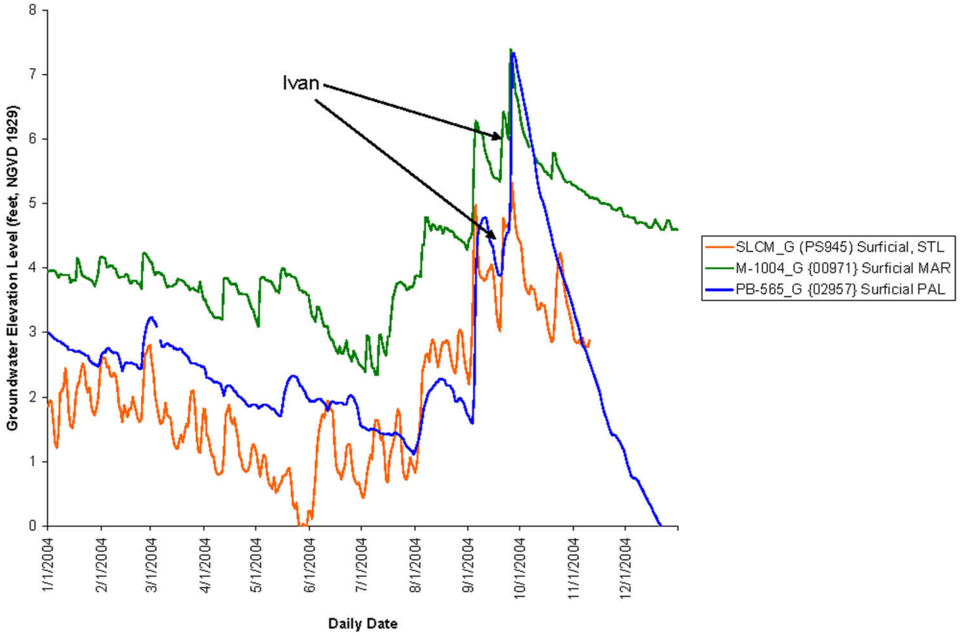


Figure 7c. Hydrographs of three groundwater wells drawing from the surficial aquifer during the 2004 calendar year. Peaks caused by rainfall falling from Hurricane Ivan's extra-tropical system are labeled with arrows.

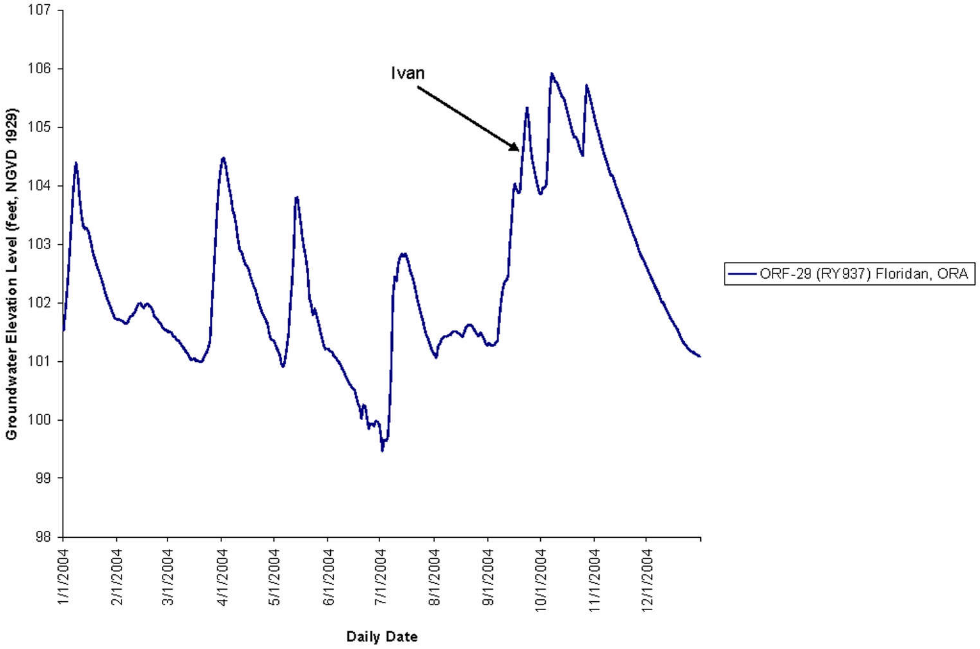
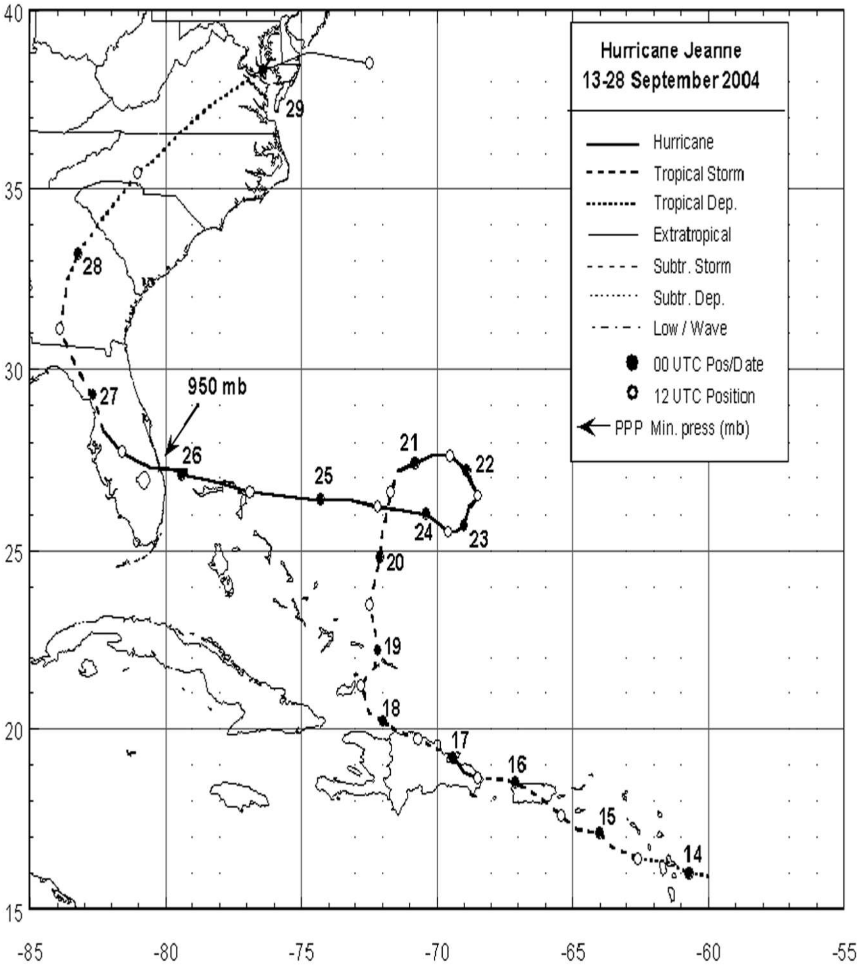


Figure 7d. Hydrograph of a groundwater well drawing from the Floridan aquifer during the 2004 calendar year. Peaks caused by rainfall falling from Hurricane Ivan's extra-tropical system are labeled with arrows.



Hurricane Jeanne

Hurricane Jeanne originated from a tropical wave off the coast of Africa that moved west into the tropical Atlantic Ocean, forming a tropical depression on September 13 near Leeward Islands. Jeanne slowly developed into a hurricane due to complications in the storm path caused in part by Ivan's bizarre behavior. Eventually Jeanne developed into a hurricane as it passed east-northeast of the Bahamas and made landfall on the east coast of Florida as a Category 3 on the south end of Hutchinson Island (**Figure 8a**). Heavy rains were dumped on central Florida as Jeanne moved west 30 miles north of Tampa and moved north to Central Georgia (Lawrence and Cobb, 2004).

Figure 8a. Path and development of Hurricane Jeanne from September 13–28, 2004 (Lawrence and Cobb, 2004).

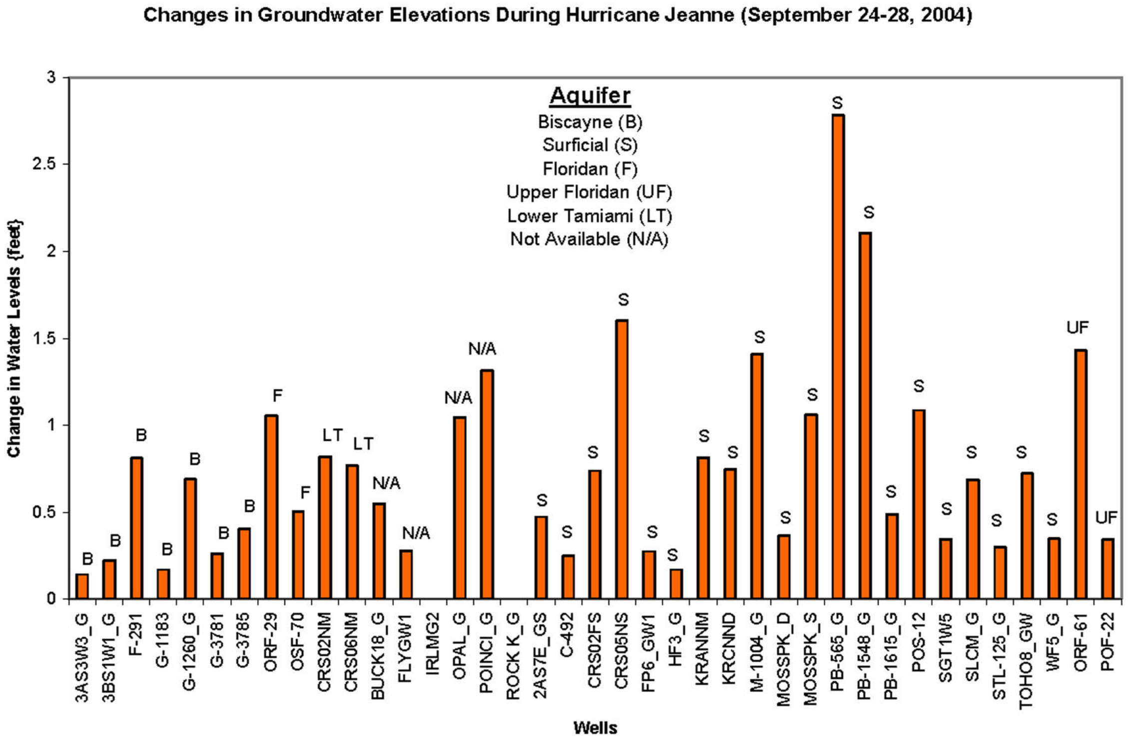


Figure 8b. Changes in groundwater elevation during Hurricane Jeanne (September 24–28, 2004).

Figure 8b shows the change in groundwater well levels during Hurricane Jeanne. According to five-day maximum rainfall values from the *2006 South Florida Environmental Report*, Jeanne dumped heavy rains in several regions: 11.99 inches in the Upper Kissimmee, 10.2 inches in the Lower Kissimmee, and 10.55 inches over Lake Okeechobee, elevating lake and stream stage to keep canals full (Abtew et al., 2006b). Likewise, surficial and Floridan aquifer wells also increased in those areas. Two wells in Palm Beach County increased the most (PB-565_G up 2.780 ft and PB-1548_G up 2.106 ft). In addition to these wells, ORF-61 and ORF-29, two FAS wells in the Kissimmee Basin in Orange County, each increased significantly by 1.430 and 1.057 ft, respectively. Hydrographs for the surficial aquifer wells with marked peaks during Hurricane Jeanne are shown in **Figure 8c,** while hydrographs for FAS wells with marked peaks during Hurricane Jeanne are shown in **Figure 8d.**

Two IAS groundwater wells also increased in level. These wells are labeled "LT" for Lower Tamiami, as they draw from the bottom of the Tamiami formation, a geologic sequence that overlies the Hawthorn group (Fernald and Purdum, 1998). Both CRS02NM of Glades County and CRS06NM of Hendry County increased in elevation by 0.819 and 0.769 ft, respectively. Hydrographs of these IAS wells with marked peaks during Hurricane Jeanne are shown in **Figure 8e.**

Groundwater monitoring wells F-291 and G-1260_G of Broward County tap into the Biscayne aquifer and showed an increase in elevation. In Hollywood, Broward County, 3.35 inches of rainfall was observed, while 2.98 inches was the maximum rainfall recorded for Miami-Dade County (Abtew et al., 2006b). The canals were also elevated due to high rainfalls in the Kissimmee and Lake Okeechobee Basins. Elevation levels of groundwater wells F-291 and G-1260_G by 0.810 and 0.690 ft could be from canal recharge. Hydrographs of these Biscayne aquifer wells with marked peaks during Hurricane Jeanne are shown in **Figure 8f.**

Overall, Hurricane Jeanne's rainfall accounted for 11 groundwater wells to reach historical maximum levels and five other wells to reach annual maximum levels for the 2004 calendar year (Table 3, Appendix B).

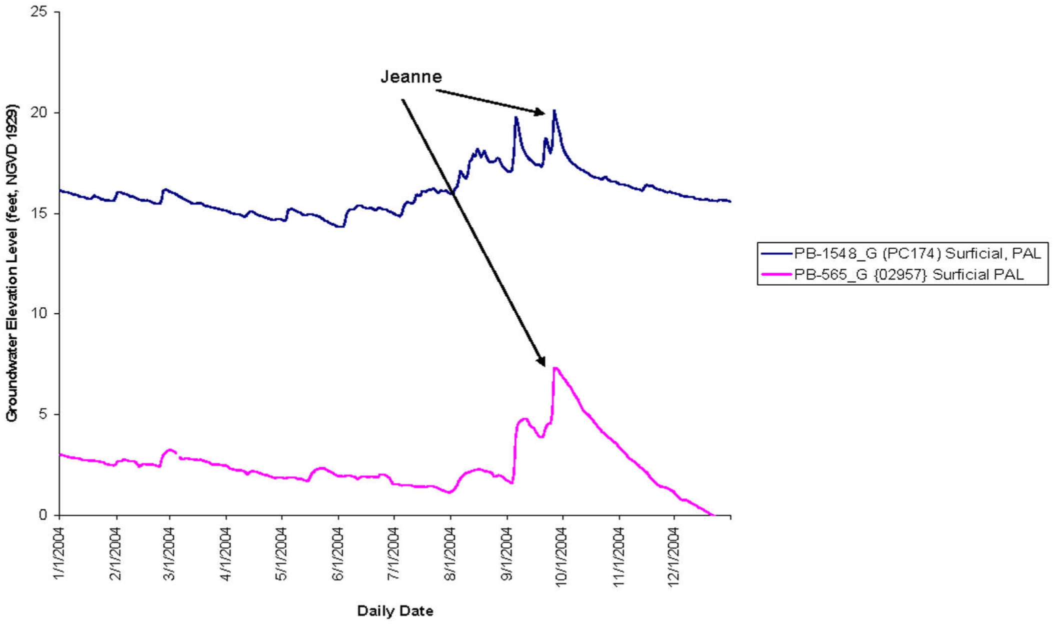


Figure 8c. Hydrograph of two groundwater wells drawing from the surficial aquifer during the 2004 calendar year. Peaks caused by Hurricane Jeanne rainfall are labeled with arrows.

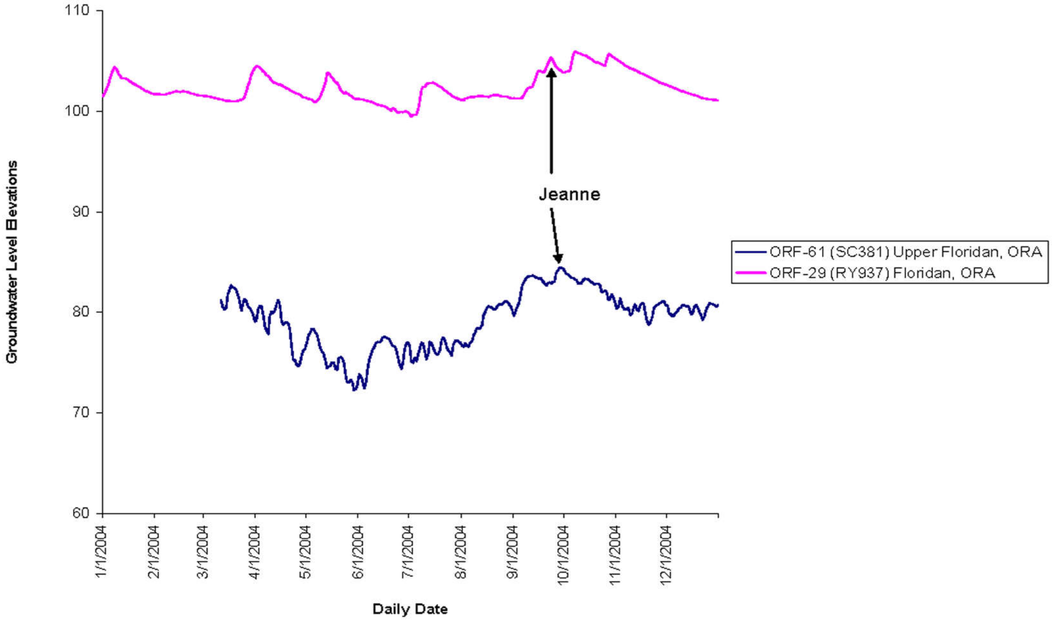


Figure 8d. Hydrograph of two groundwater wells drawing from the Floridan aquifer during the 2004 calendar year. Peaks caused by Hurricane Jeanne rainfall are labeled with arrows.

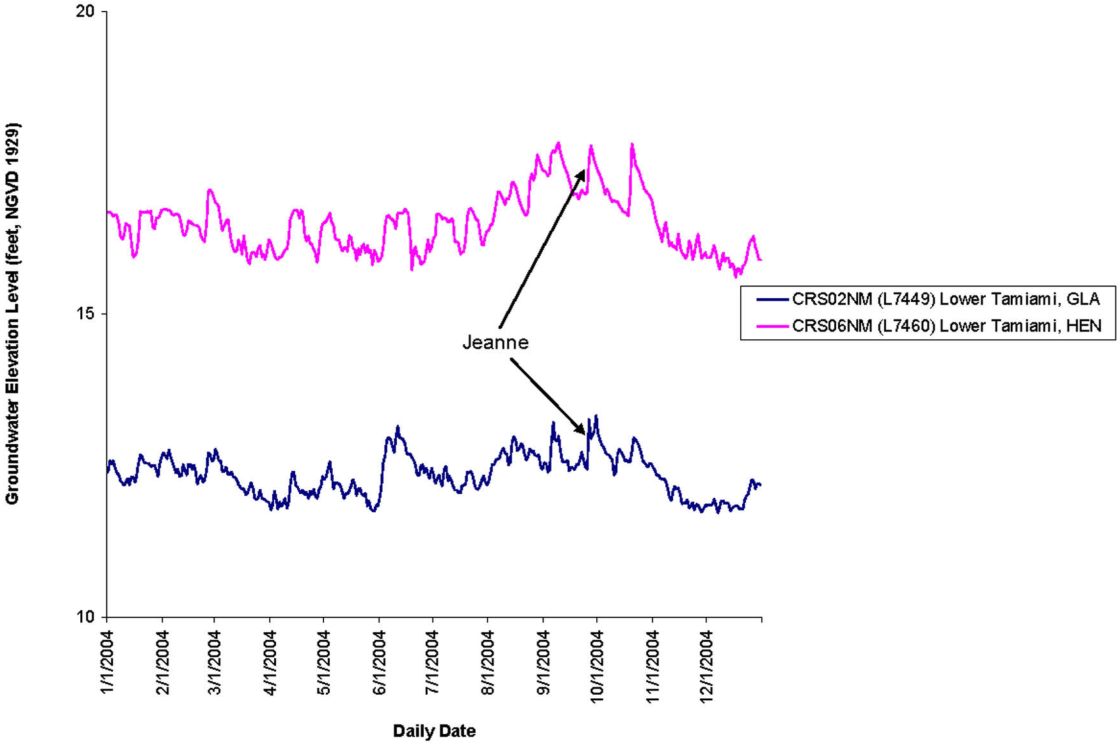


Figure 8e. Hydrograph of two groundwater wells drawing from the intermediate aquifer during the 2004 calendar year. Peaks caused by Hurricane Jeanne rainfall are labeled with arrows.

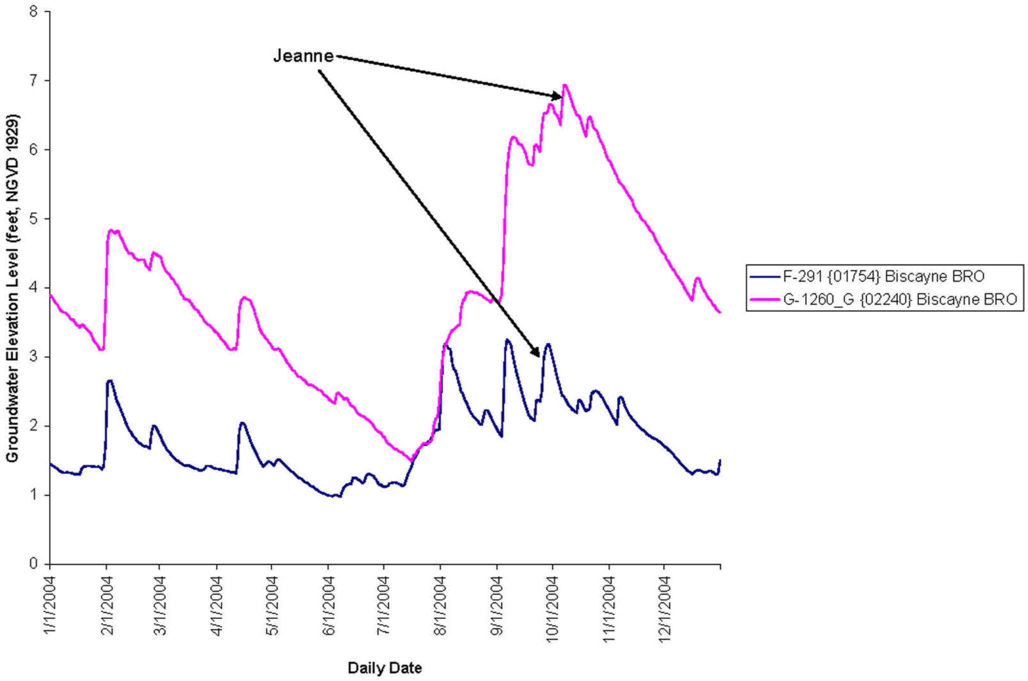


Figure 8f. Hydrograph of two groundwater wells drawing from the Biscayne aquifer during the 2004 calendar year. Peaks caused by Hurricane Jeanne rainfall are labeled with arrows.

IV. THE 2005 HURRICANE SEASON IN SOUTH FLORIDA

During the 2005 hurricane season, the District endured two hurricanes: Hurricane Katrina from the east during August 24–27, and Hurricane Wilma from the west during October 22–25. An earlier hurricane, Hurricane Dennis, contributed rainfall to the District in areas of southwest Florida and the Florida Keys during July 8–10, but made landfall in the Florida panhandle out of the District's boundaries. Hurricane Rita contributed rainfall to the District during September 19–21 as it headed west through the Florida Straits (Abtew et al., 2006a). Compared to historical data on tropical systems, the combined impact of the 2004 and 2005 hurricane seasons on the District was a rare event. Figures 2a through 2d in Appendix A show the District area impacted and estimates of rainfall from these four hurricanes.

Hurricane Dennis

Hurricane Dennis originated as a tropical wave off the coast of Africa on June 29. Heading west, convection began to increase as the wave turned into two weather systems. The western system lost organization over southeastern Caribbean as the eastern system continued to develop, becoming a tropical depression on July 4. The next day, the depression gathered strength, turned west-northwest, and became a tropical storm. Reaching hurricane strength on July 7, Dennis quickly developed into a Category 4 hurricane and made landfall in southeastern Cuba on July 8.

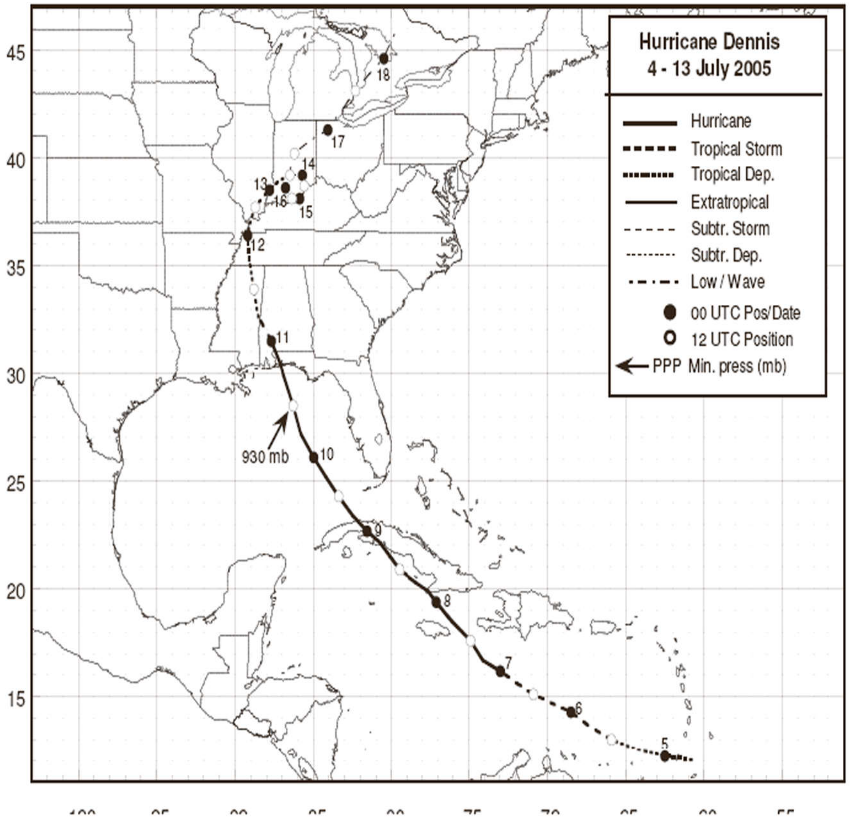


Figure 9a. Path and development of Hurricane Dennis from July 4 -13, 2005 (Beven, 2005).

Dennis' strength significantly reduced while passing over Cuba, but soon intensified again as it reached the Gulf of Mexico on July 9 (**Figure 9a**). As the hurricane crossed the Gulf of Mexico, it contributed rainfall to the Florida Keys and South Florida. Dennis made landfall on July 10, crossing over the western Florida panhandle and moving into southwestern Alabama where it was reduced to a tropical storm (Beven, 2005).

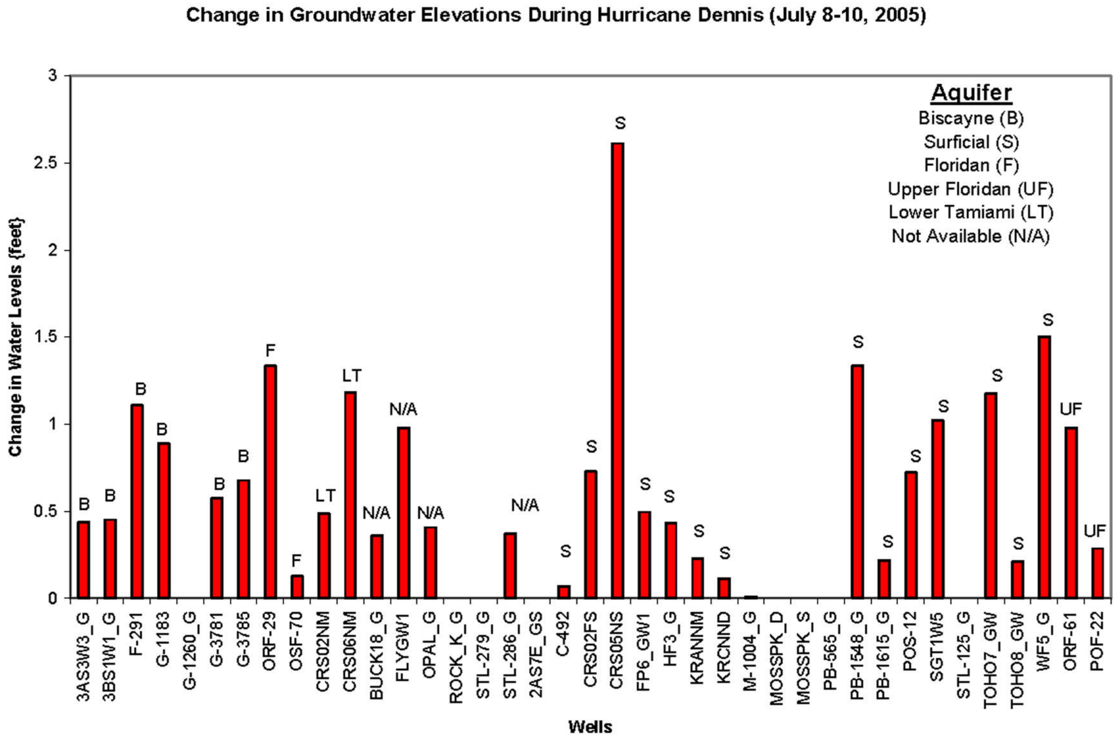


Figure 9b. Change in groundwater elevation during Hurricane Dennis (July 8–10, 2005).

Figure 9b displays the change in groundwater well elevations during Hurricane Dennis. This histogram exhibits an important point pertaining to recharge and the storms discussed throughout this report. Dennis grazed South Florida on its descent into the gulf and onto the panhandle's coast. Even still, heavy rainfall occurred throughout most the District and several aquifer levels changed. According to Abtew et al. (2006a), the western region of the Everglades Agricultural Area received the most rain, averaging 4.26 inches during this tropical system. The Southwest Coast and Big Cypress Basin also received heavy rainfall averaging 4.18 and 3.61 inches (Abtew et al., 2006a). Well HF3_G of Collier County reached a historical maximum elevation during the system, while well WF5_G increased in elevation enough to set the annual maximum for 2005 (Table 4, Appendix B). WF5_G was one of the wells closest to the hurricane's path and rose around 1.502 ft. The largest increase shown is from well CRS05NS in Hendry County, rising in elevation by 2.611 ft. Well PB-1548_G from the monitoring network in Palm Beach County experienced a significant change from other surficial wells on the upper east coast. This well rose by 1.338 ft, a significant change since Palm Beach County averaged the least amount of rainfall from this system in the District, around 1 inch (Abtew et al., 2006a). Three hydrographs depicting these surficial aquifer wells with marked peaks during Hurricane Dennis are shown in **Figure 9c.**

Monitoring wells ORF-29 and ORF-61, drawing from the FAS in Orange County, rose significantly with ORF-29 rising 1.335 ft and ORF-61 rising 0.980 ft. These increases followed rather light rainfall in the Upper and Lower Kissimmee basins with each region averaging less than 1.5 inches of rain (Abtew et al., 2006a). Hydrographs of these FAS wells with marked peaks during Hurricane Dennis are shown in **Figure 9d.**

The Eastern Caloosahatchee Basin had the third highest average rainfall with 3.96 inches (Abtew et al., 2006a). This allowed the IAS to rise in areas where the monitoring wells are located. CRS02NM of Glades County elevated 0.489 ft while CRS06NM rose 1.182 ft. Hydrographs of these IAS wells with marked peaks during Hurricane Dennis are shown in **Figure 9e.**

Broward and Miami-Dade counties averaged 2.72 and 2.37 inches of rainfall respectfully (Abtew et al., 2006a). As a result, the Biscayne aquifer wells from Miami-Dade and Broward counties also increased in elevation with F-291 rising 1.11 ft and G-1183 rising 0.890 ft. Hydrographs of these Biscayne aquifer wells with marked peaks during Hurricane Dennis are shown in **Figure 9f.**

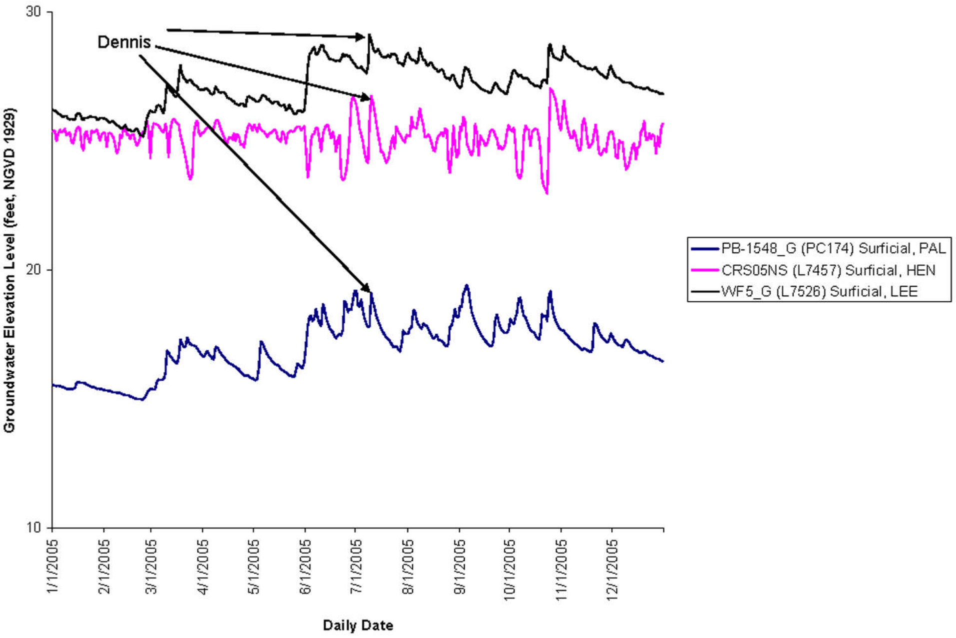


Figure 9c. Hydrograph of three groundwater wells drawing from the surficial aquifer during the 2005 calendar year. Peaks caused by Hurricane Dennis rainfall are labeled with arrows.

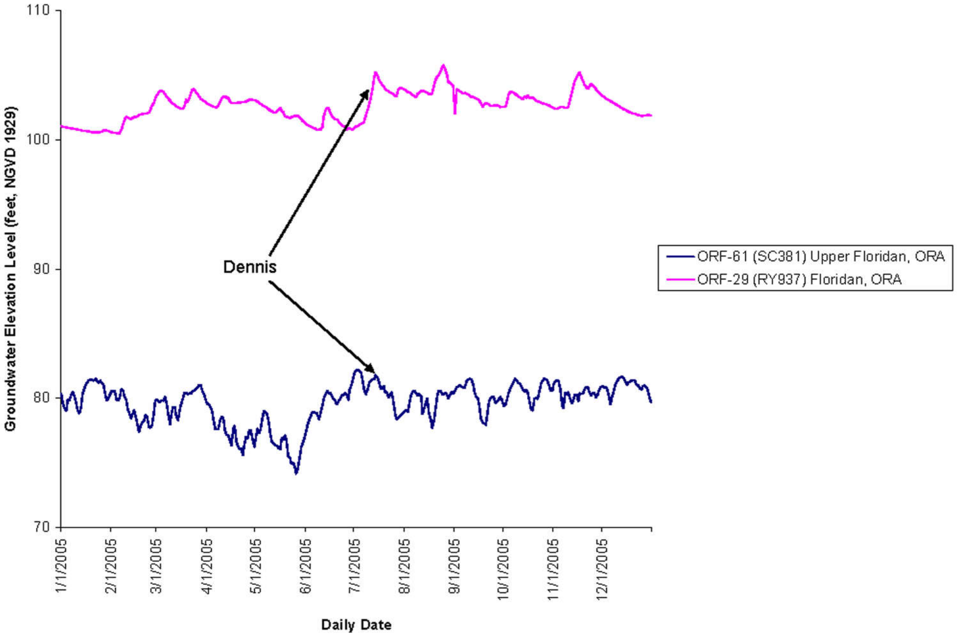


Figure 9d. Hydrograph of two groundwater wells drawing from the Floridan aquifer during the 2005 calendar year. Peaks caused by Hurricane Dennis rainfall are labeled with arrows.

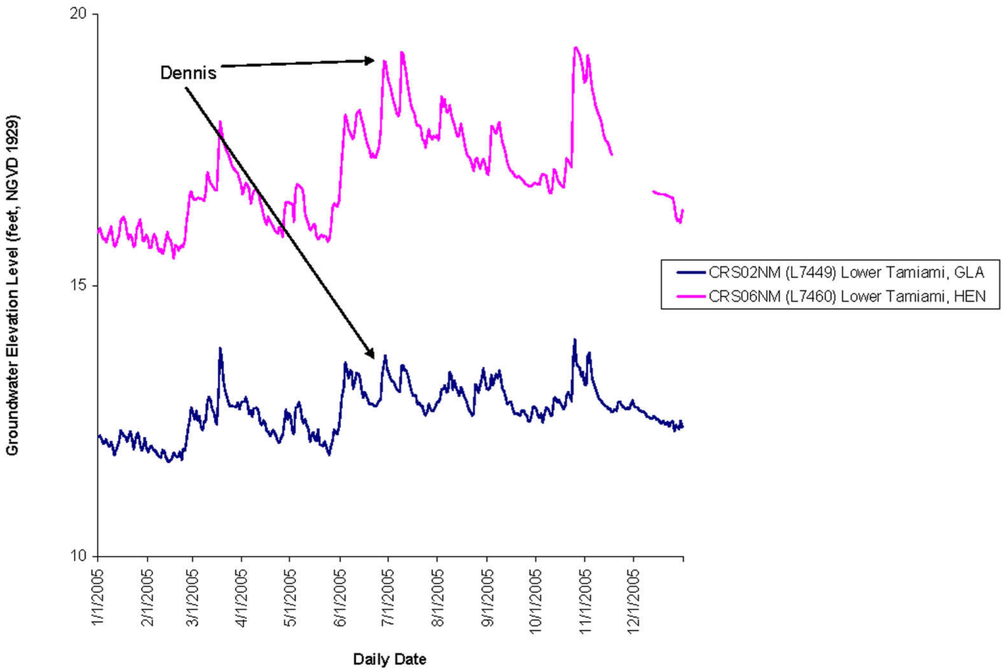


Figure 9e. Hydrograph of two groundwater wells drawing from the intermediate aquifer during the 2005 calendar year. Peaks caused by Hurricane Dennis rainfall are labeled with arrows.

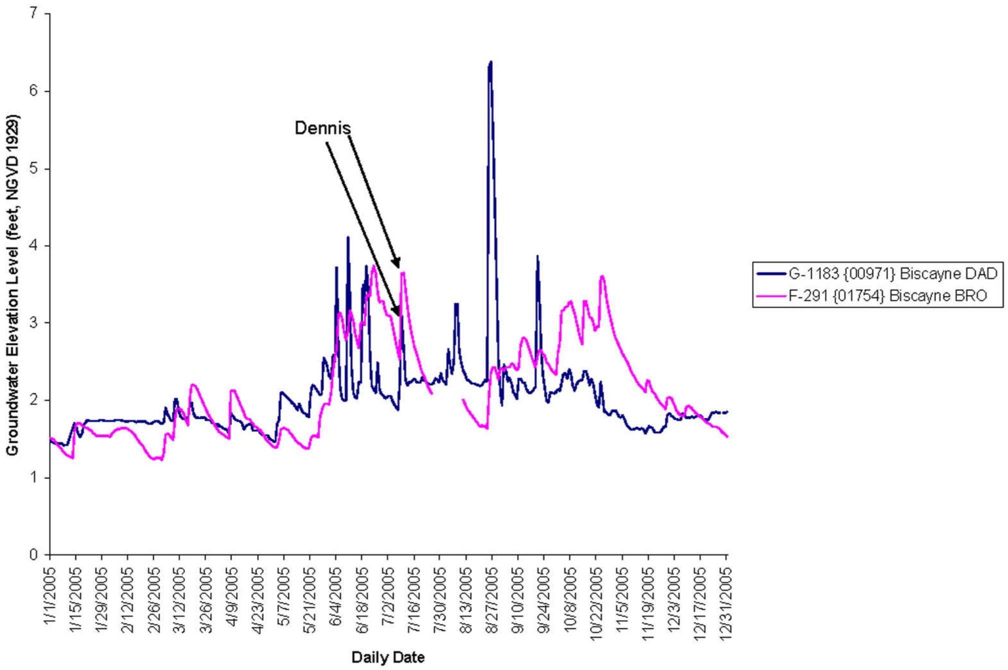


Figure 9f. Hydrograph of two groundwater wells drawing from the Biscayne aquifer during the 2005 calendar year. Peaks caused by Hurricane Dennis rainfall are labeled with arrows.

Hurricane Katrina

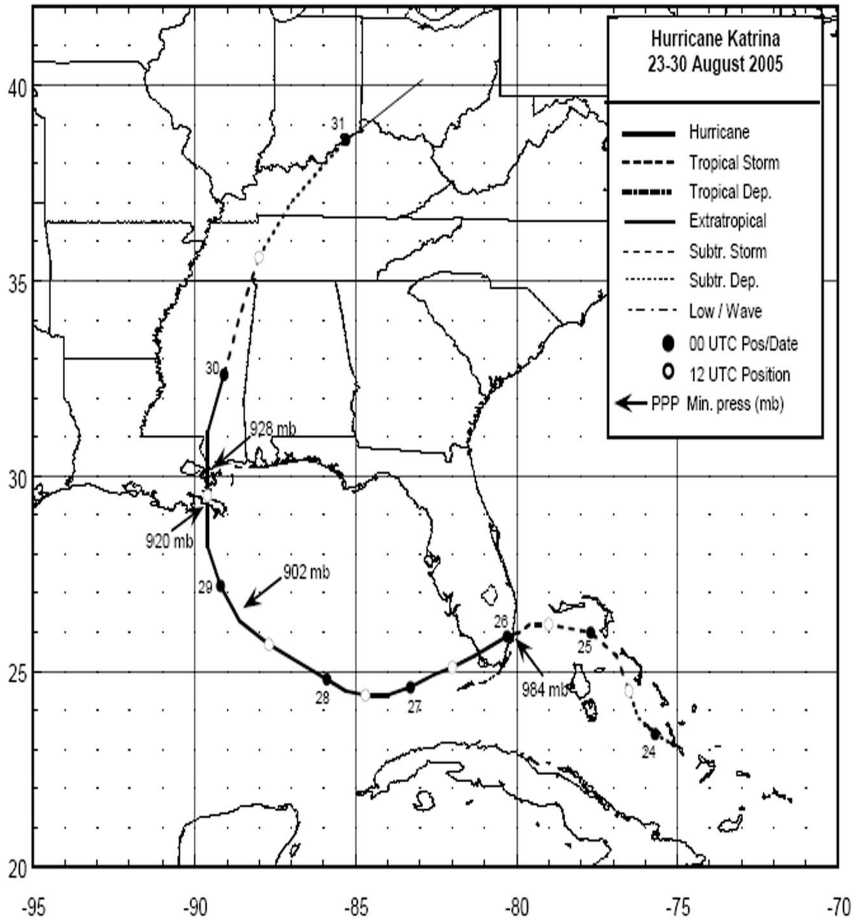


Figure 10a. Path and development of Hurricane Katrina during August 23-30, 2005 (Knabb et al., 2005).

Hurricane Katrina developed in a complex manner as a tropical wave, moving through the Leeward Islands, interacting with the remnants of Tropical Depression Ten, and forming large areas of showers and thunderstorms near Puerto Rico on August 19. This activity slowly moved northwest passing north of Hispaniola and consolidating east of the Turks and Caicos on the August 22. The system developed into Tropical Depression Twelve southeast of Nassau in the Bahamas on August 23 and continued to move west towards Florida. The following day, the system developed into Tropical Storm Katrina over the central Bahamas and continued to strengthen as convection increased. Katrina was estimated to reach Category 1 hurricane strength on August 25, less than two hours before it made landfall on the southeastern coast of Florida at the Miami-Dade County and Broward County line (**Figure 10a**). Katrina remained over land for about six hours, moving south-southwest through the southern tip of Florida. It dumped over a foot of rain in some areas before passing north of Cape Sable and moving into the Gulf of Mexico (Knabb et al., 2005).

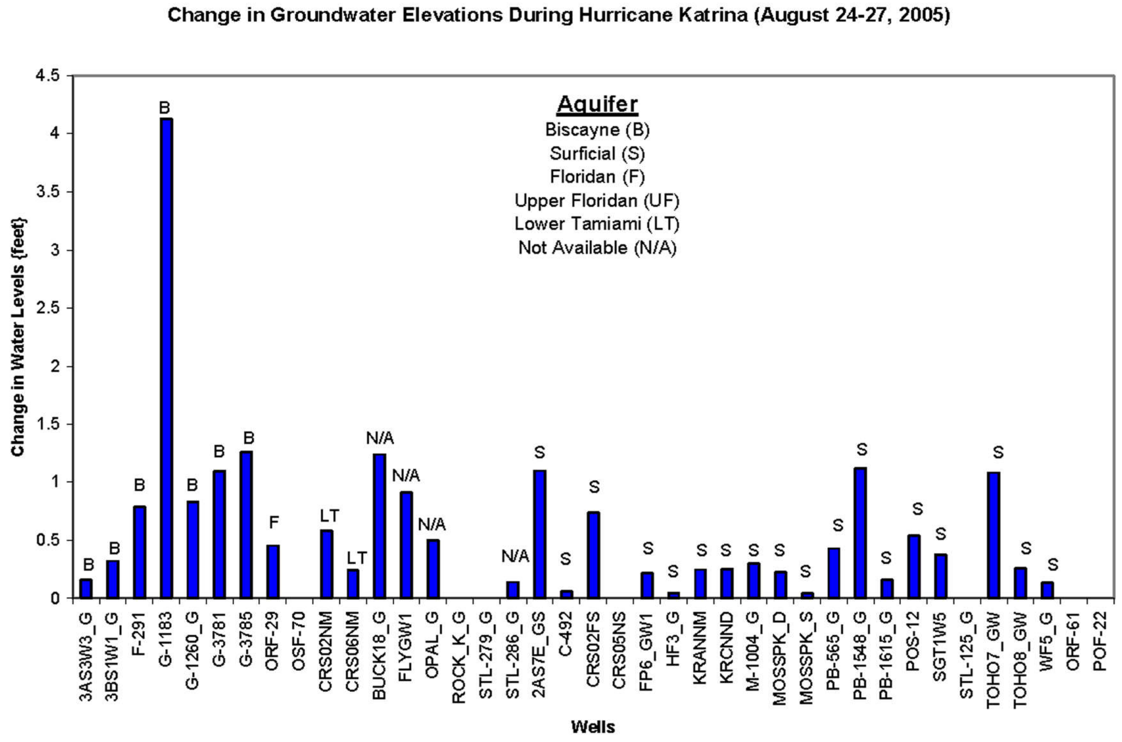


Figure 10b. Change in groundwater elevation during Hurricane Katrina (August 24–27, 2005).

Figure 10b illustrates groundwater elevations during Hurricane Katrina. For the most part, FAS wells of the Kissimmee Basin remained largely unaffected by the tropical system. The Upper Kissimmee Basin averaged the least amount of rainfall during this system with 1.05 inches (Abtew et al., 2006a). Surficial aquifer wells of this region, such as TOHO07_GW, rose 1.081 ft. This well is just north of Lake Tohopekaliga on Shingle Creek and was probably influenced by rainfall not related to the tropical system.

The largest increases in groundwater level can be seen in the Biscayne Aquifer cluster. Due to the path of Hurricane Katrina that moved across the southern tip of the Florida Peninsula. Areas such as the Everglades National Park and Miami-Dade County averaged the most rainfall with 6.93 inches and 6.27 inches, respectively (Abtew et al., 2006a). Every well in the groundwater monitoring network that draws from the Biscayne aquifer rose during this time interval, with F-291 and G-1260_G elevating 0.790 and 0.830 ft. G-3781 rose 1.097 ft, and G-3785 rose 1.260 ft, and G-1183, a USGS monitoring well, had the sharpest increase, rising over 4.130 ft in the four-day span. All three of these wells surpassed historical maximum values for groundwater elevations during Hurricane Katrina (Table 4, Appendix B). Hydrographs of these Biscayne wells with marked peaks during Hurricane Katrina are shown in **Figure 10c.**

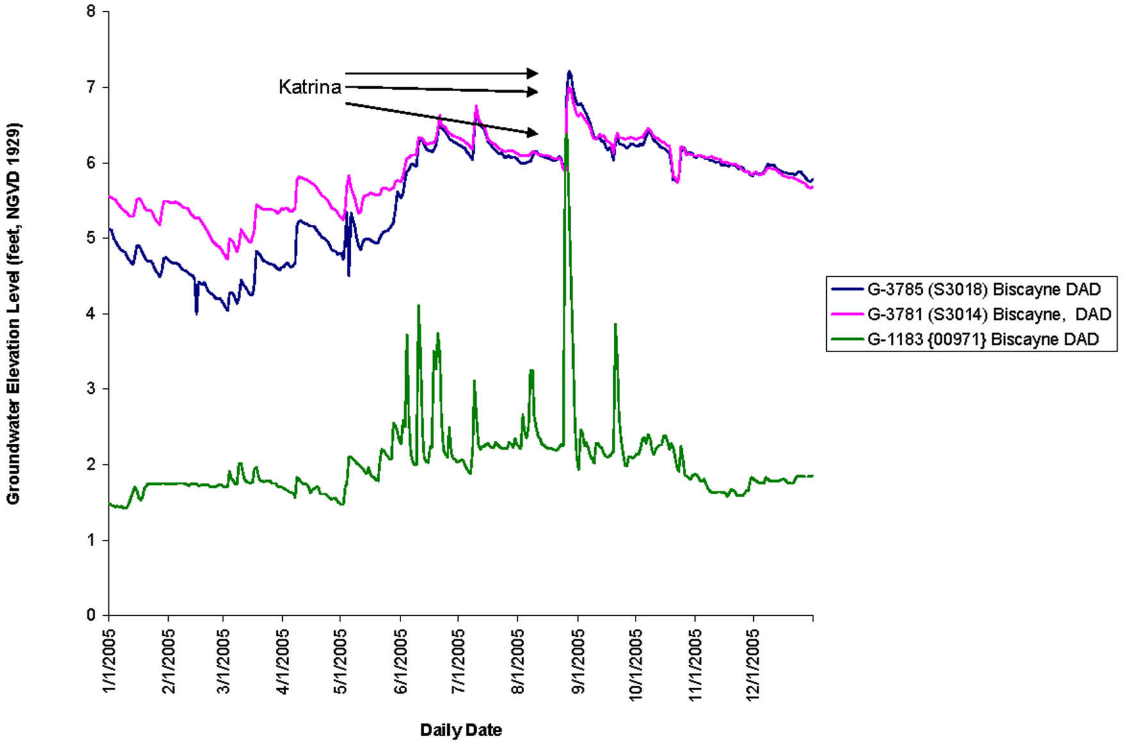


Figure 10c. Hydrograph of three groundwater wells drawing from the Biscayne aquifer during the 2005 calendar year. Peaks caused by Hurricane Katrina rainfall are labeled with arrows.

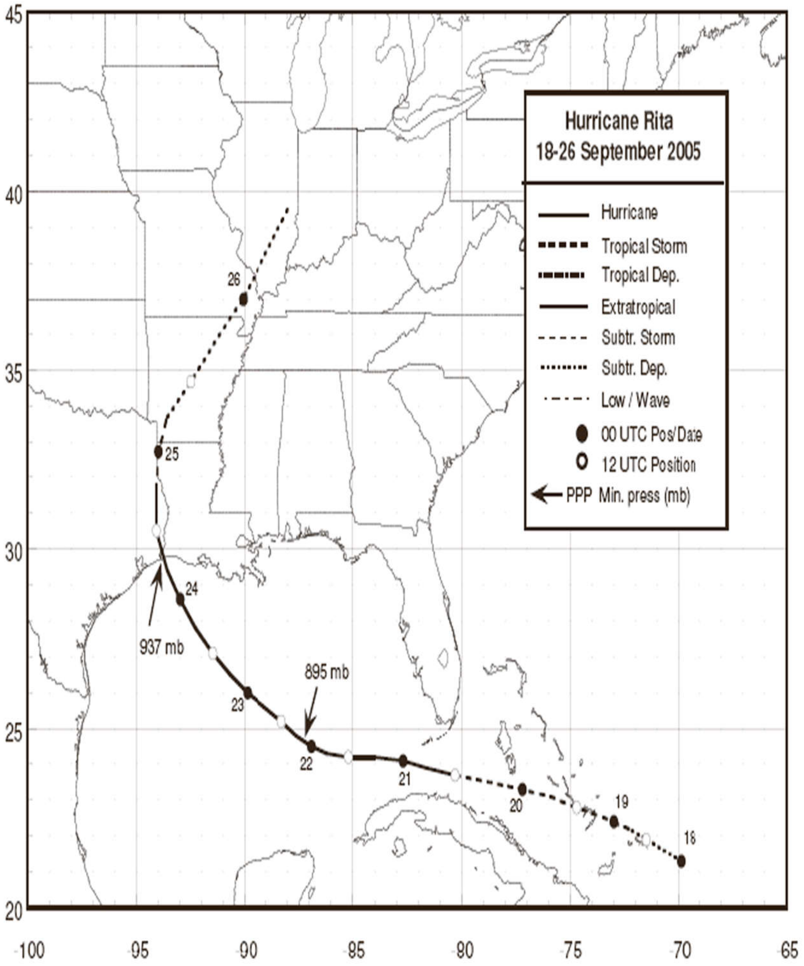


Figure 11a. Path and strength of Hurricane Rita during September 19-26, 2005 (Knabb et al., 2005).

Hurricane Rita

Hurricane Rita originated from a tropical wave that moved off the western coast of Africa on September 7, combining with a surface trough that detached from a southern moving central Atlantic cold front north of Puerto Rico on September 17. A tropical depression formed as the concentrated area of disturbed weather moved westward across Cuba and into the northwestern Caribbean Sea on September 18. By day break of the next morning, the depression had intensified into Tropical Storm Rita and soon developed hurricane strength on September 20 about 100 miles east-southeast of Key West. Rita passed 40 miles south of Key West later that day as a Category 2 hurricane and contributed to high rainfall, flooding, downed trees, and high storm surge (Knabb et al., 2005). The Everglades National Park, Miami-Dade County, Big Cypress Basin, Broward County, and WCA-3 were most affected (Abtew et al., 2006).

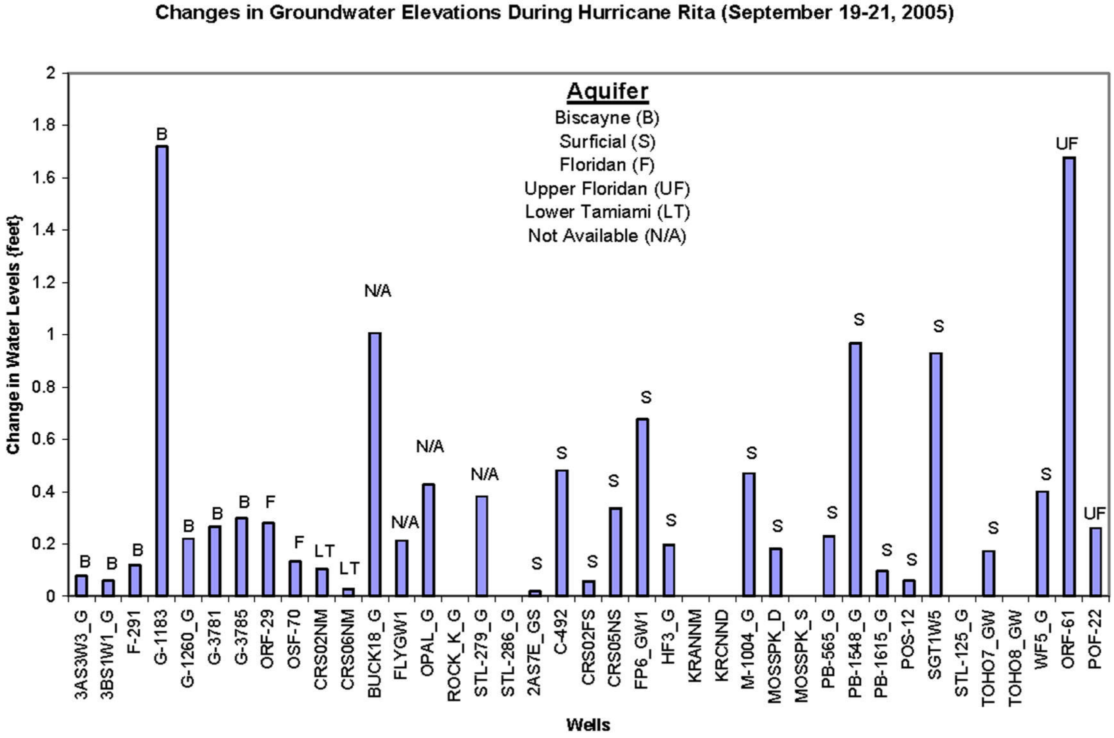


Figure 11b. Changes in groundwater elevations during Hurricane Rita (September 19–25, 2005).

Figure 11b displays elevation changes in the groundwater monitoring network during Hurricane Rita. According to Knabb's cyclone report to the National Hurricane Center, most of the heavy rainfalls during this hurricane took place on the gulf coast of Texas, Louisiana, and Mississippi. Rainfall in South Florida was scattered and sparse. The entire District averaged less than 1 inch of rainfall during the system. The highest average rainfalls occurred on the southern tip of South Florida and the Florida Keys. The Everglades National Park averaged 2.29 inches of rain while areas within Miami-Dade County averaged 2.17 inches (Abtew et al., 2006a). Consequently, every Biscayne aquifer well increased. G-1183 rose the sharpest, elevating to 1.720 ft. Hydrographs of these Biscayne aquifer wells with marked peaks during Hurricane Rita are shown in **Figure 11c.**

As Rita was the second tropical system in less than three weeks, several surficial aquifer wells likely increased in response to rainfall unassociated to the hurricane or perhaps from canal recharge due to elevated levels of lakes and streams.

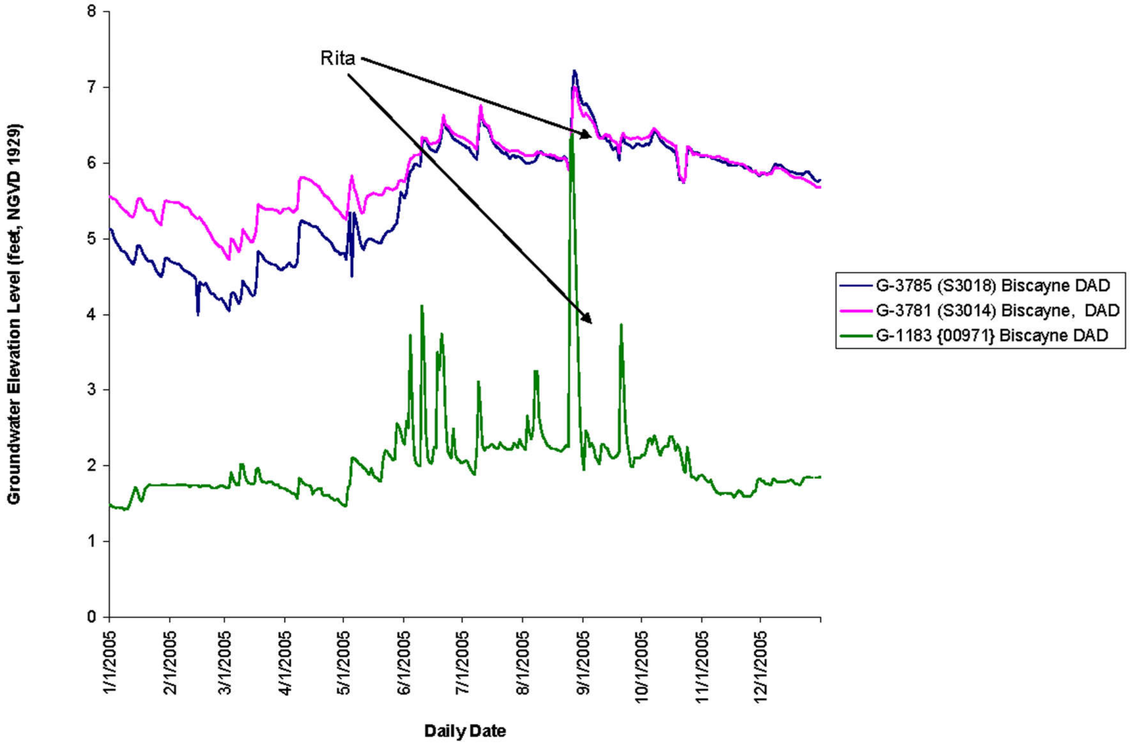


Figure 11c. Hydrograph of three groundwater wells drawing from the Biscayne aquifer during the 2005 calendar year. Peaks caused by Hurricane Rita rainfall are labeled with arrows.

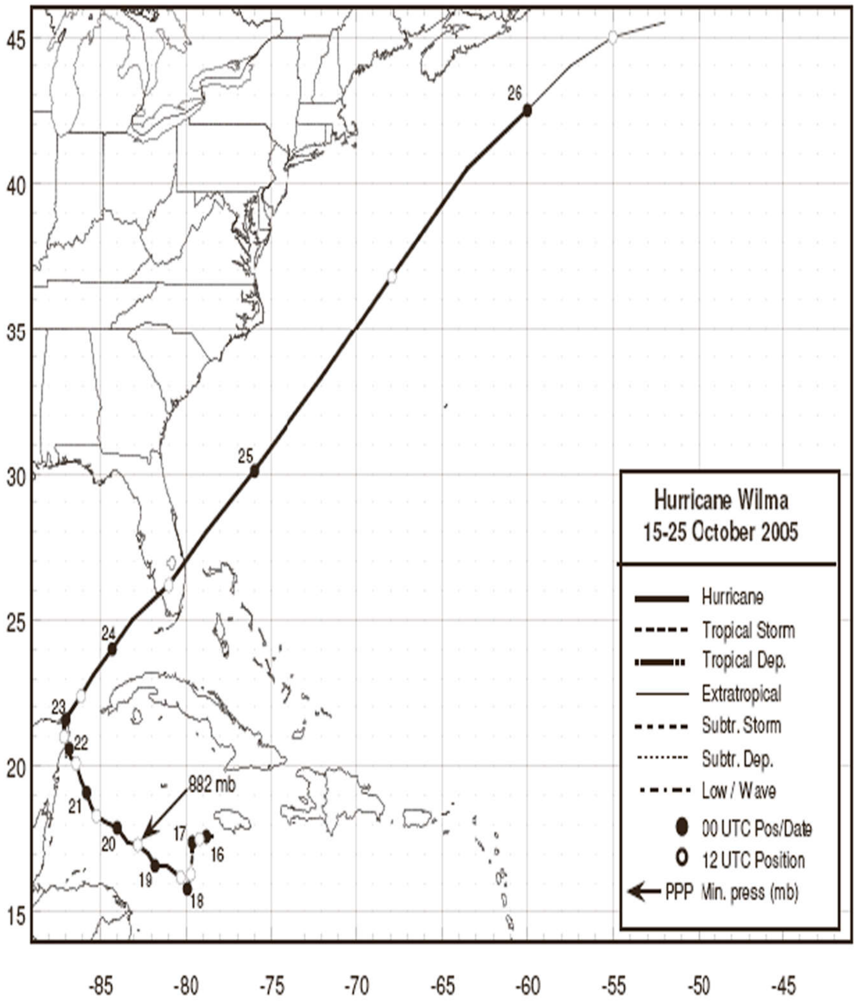


Figure 12a. Path and strength of Hurricane Wilma during, October 15-25, 2005 (Pasch et al., 2006).

Hurricane Wilma

Hurricane Wilma formed and became an extremely intense hurricane over the northwestern Caribbean Sea. It had the all-time lowest central pressure for an Atlantic Basin hurricane, and it devastated the northeastern Yucatan Peninsula. Wilma also inflicted extensive damage over southern Florida (Pasch et al., 2006).

Hurricane Wilma had a complicated beginning. An extra-tropical cyclone merged with a monsoon-like weather system and two tropical waves to form a disturbed weather system that eventually formed into a tropical depression on October 15 east-southeast of Grand Cayman. On October 18, Wilma became a hurricane moving west-northwestward. It increased to a Category 5 hurricane within one day, and arrived on October 21 on the island of Cozumel, Mexico, as a Category 4. The next day, Wilma crossed the Yucatan Peninsula into the Gulf of Mexico. On October 24, Wilma made landfall near Cape Romano as a Category 3 and crossed South Florida, reducing to a Category 2 (**Figure 12a**). Less than five hours later, Wilma emerged into the Atlantic Ocean. Although the rainfall from Wilma was not severe, the location and amount of runoff on an already highly elevated Lake Okeechobee, canal, and stream level affected the District hydraulically and environmentally more so than any other storm of the year (Abtew et al., 2006).

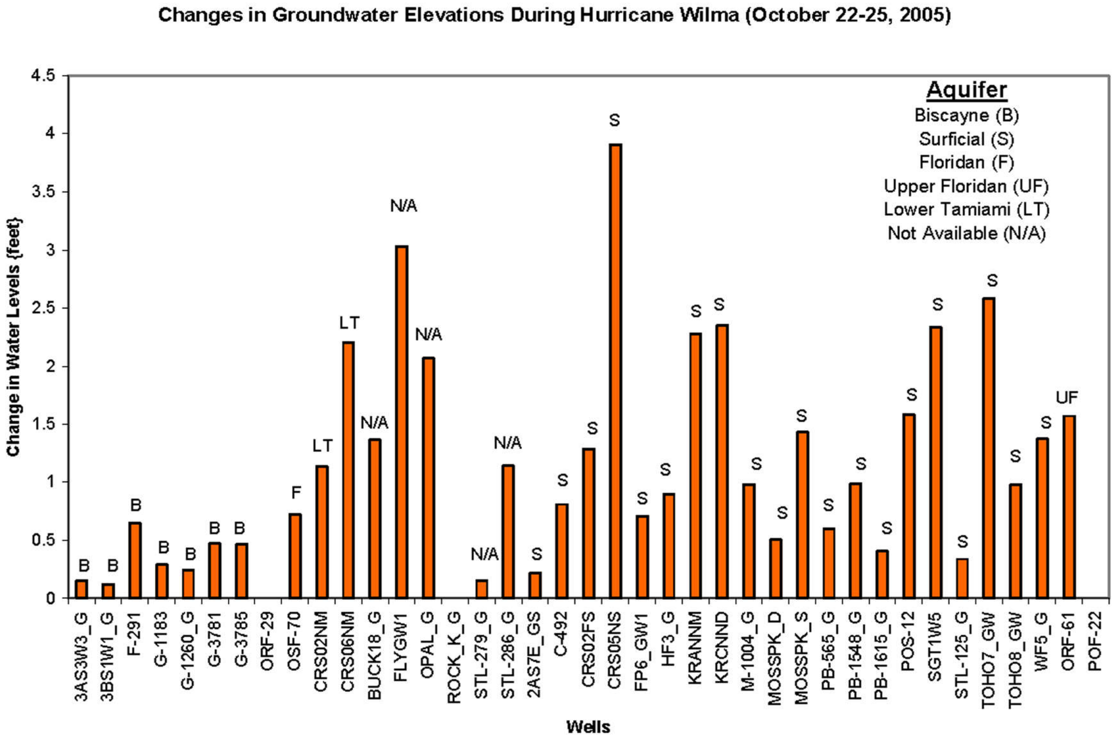


Figure 12b. Changes in groundwater elevations during Hurricane Wilma (October 22–25, 2005).

Wilma released a steady amount of rainfall in nearly every region of the District, accounting for three wells to reach historical maximum elevation levels and six others to set 2005 calendar year maximum elevation levels (Table 4, Appendix B). The Upper Kissimmee Basin averaged the most rainfall with 6.83 inches. The Lower Kissimmee Basin also received heavy rainfall, averaging 5.9 inches. The drainage from these two basins was supplemented by Lake Okeechobee, averaging 5.69 inches of rain and causing increases surface water flow through the canals. As such, the surficial aquifers recharged substantially. Another area that averaged significant amounts of rainfall was the Eastern Caloosahatchee River Basin, which had the second highest average with 6.19 inches which aided in recharge of the IAS.

Figure 12b illustrates elevation changes in the groundwater monitoring network in response to this rainfall from Hurricane Wilma. All wells, except for three, increased in elevation during this tropical system. The surficial wells had the sharpest increase with CRS05NS from Hendry County increasing the largest amount, 3.907 ft. Other surficial wells that rose significantly were TOHO7_GW near Lake Tohopekaliga, which elevated 2.582 ft and wells KRANNM and KRCNND in Okeechobee County, which elevated by 2.273 ft and 2.351 ft. respectively. Hydrographs of these surficial aquifer wells with marked peaks during Hurricane Wilma are shown in **Figure 12c**.

The sharpest increase in IAS wells for the two-year period occurred during this tropical system. Glade and Hendry county wells CRS02NM and CRS06NM rose about 1.138 ft and 2.206 ft, respectively, during the rainfall. Hydrographs of these IAS wells with marked peaks during Hurricane Wilma are shown in **Figure 12d**. Recharge of the FAS wells did not transpire substantially during this system. Well ORF-61 had a modest increase of 1.569 ft, considering the rise in surficial wells of the Kissimmee Basin.

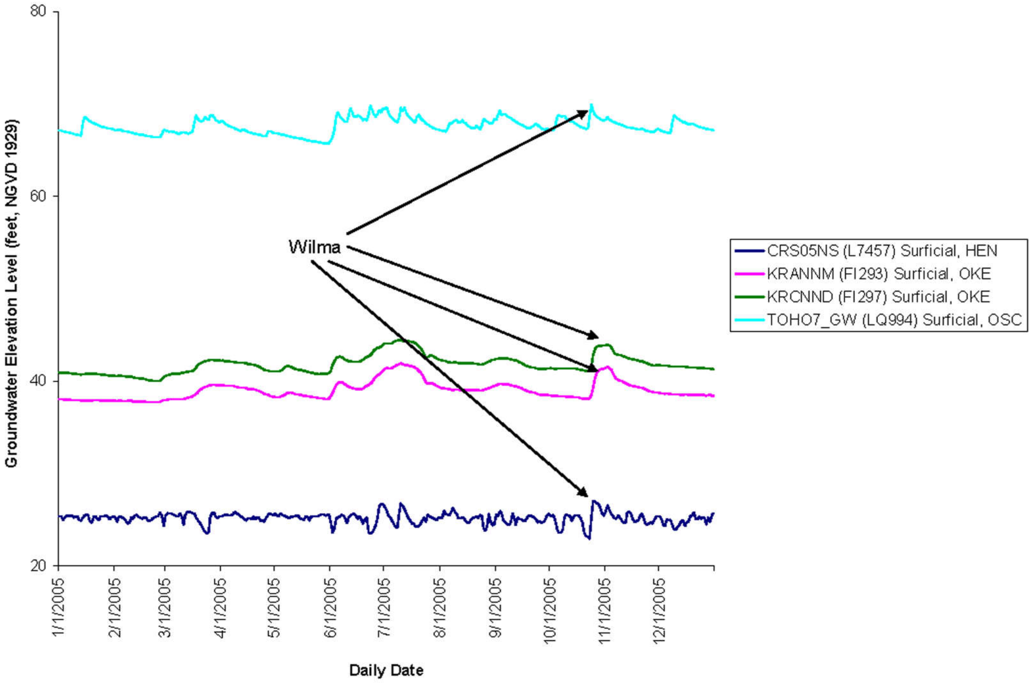


Figure 12c. Hydrograph of four groundwater wells drawing from the surficial aquifer during the 2005 calendar year. Peaks caused by Hurricane Wilma rainfall are labeled with arrows.

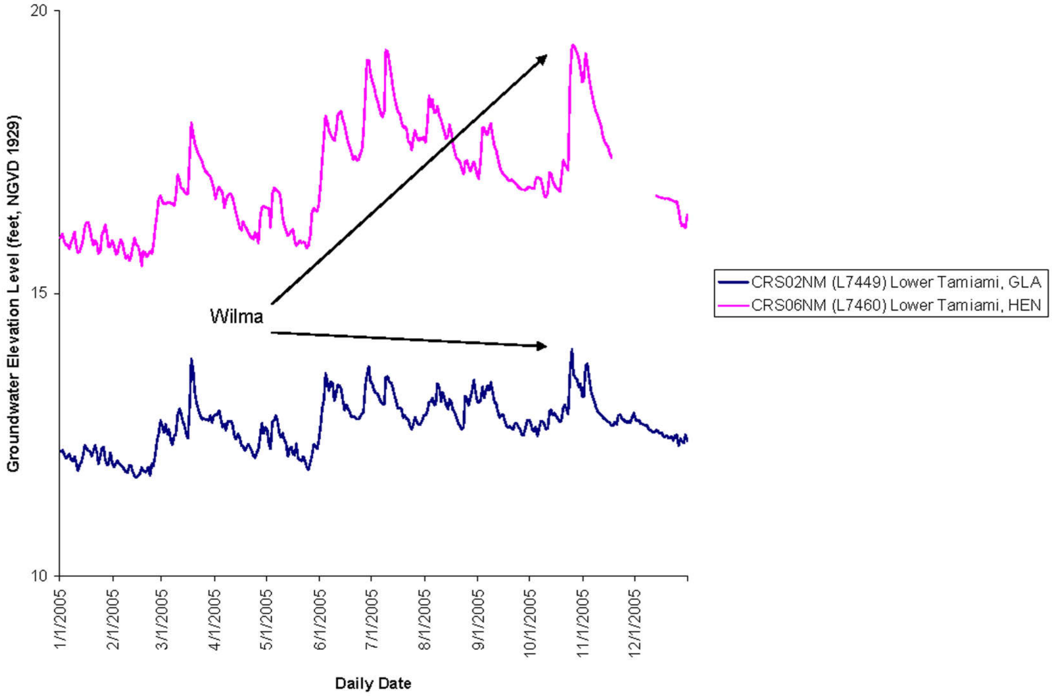


Figure 12d. Hydrograph of two groundwater wells that draw from the intermediate aquifer for 2005 calendar year. Peaks occurring due to Hurricane Wilma rainfall are labeled with arrows.

SUMMARY

Tropical systems are part of the hydrometeorology of South Florida. The strength of tropical systems ranges from tropical depression to Category 5 hurricane, with the hurricane as being one of the most destructive forces in nature. A tropical system with its unpredictable occurrences and large aerial coverage can have lasting effects on surface and sub-surface storage and conveyance systems. In addition to the destruction that these storms can invoke, heavy amounts of rainfall that accompany these storms play an important role in recharging the aquifer systems of South Florida and reassuring spatial quantities of groundwater, a most valuable natural resource.

Documenting hydrologic events provides important information for use in water management decision making. This report incorporates high resolution data collected and used from a number of South Florida Water Management District (SFWMD or District) and U.S. Geological Survey groundwater monitoring wells that represent South Florida spatially and geologically. The groundwater level data for each well was analyzed for the 2004 and 2005 calendar years in order to associate changes that occurred and properly connect them to the tropical systems that occurred during that timeframe. Groundwater levels were taken before each tropical system occurred and compared to the maximum level occurring during the system to illustrate the changes in elevation resulting from rainfall and recharge. Historical data included maximum, minimum, and mean levels as well as changes in levels associated with each tropical system for each well (Tables 1 through 4 in Appendix B). In addition, radar rainfall during the 2004 and 2005 hurricane seasons in the District area is shown in Figures 1 and 2 in Appendix A.

During the 2004 and 2005 hurricane seasons, recharge was most prominent for the surficial aquifer system when rains occurred near Lake Okeechobee and/or in the Upper East Coast Planning Area. Palm Beach County appears to be more responding for recharge and this is probably due to canal recharge as there are more canals in Palm Beach County than Martin and St. Lucie counties.

The Biscayne aquifer system, much like the surficial aquifer system, also relies on canal recharge and, therefore, can benefit from rainfall north of Broward and Dade counties that is canalized through these counties. Most large increases in recharge came from rainfall that fell directly on Broward and Dade counties or in east Collier and Monroe counties over Everglades National Park and Big Cypress Preserve.

The Intermediate aquifer system was the least represented geologic unit in the study with only two monitoring wells. For the most part, these groundwater wells did not recharge significantly with every tropical system. However, heavy rainfall in the Lower Kissimmee Basin and west of Lake Okeechobee showed a better response for these wells. This response is likely due to a relatively sparse expanse of this aquifer system compared to the other three aquifer systems. The Floridan Aquifer System recharged during periods of heavy rainfall in regions near southern Orange County and northern Osceola County also known as the Upper Kissimmee Basin. The Floridan aquifer runs beneath the Intermediate, thus, rainfall in the Upper Kissimmee Basin follows its lower confining unit and settles beneath the intermediate aquifers. This may be the reason that these wells displayed slight increases in elevation levels whereas others rose significantly.

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APPENDIX A

Figures 1a through 1d depict path and rainfall associated with the 2004 hurricanes Charley, Frances, Ivan, and Jeanne.

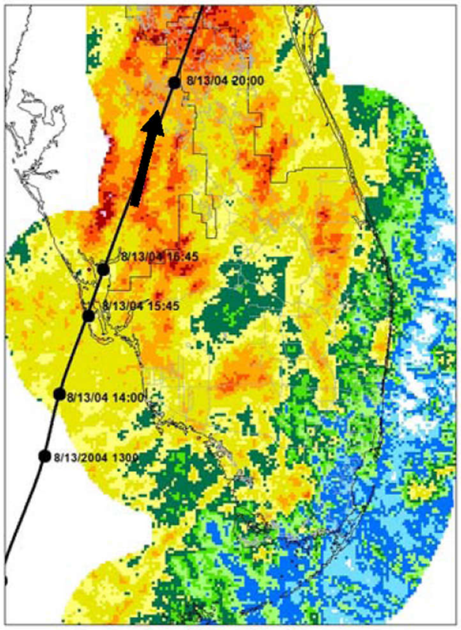


Figure 1a. Hurricane Charley's path and radar rainfall (August 12–16, 2004).

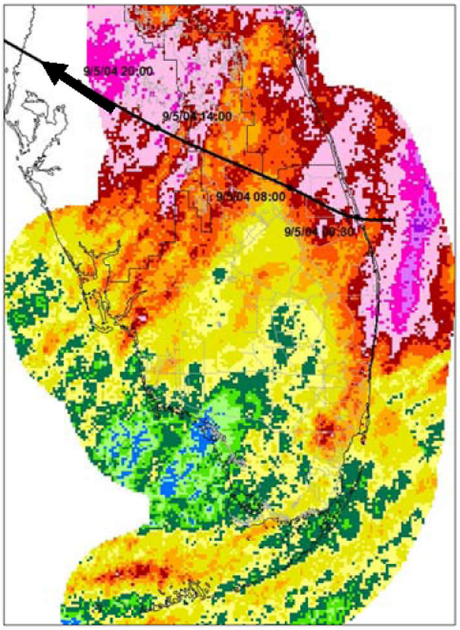


Figure 1b. Hurricane Frances's path and radar rainfall (September 4–8, 2004).

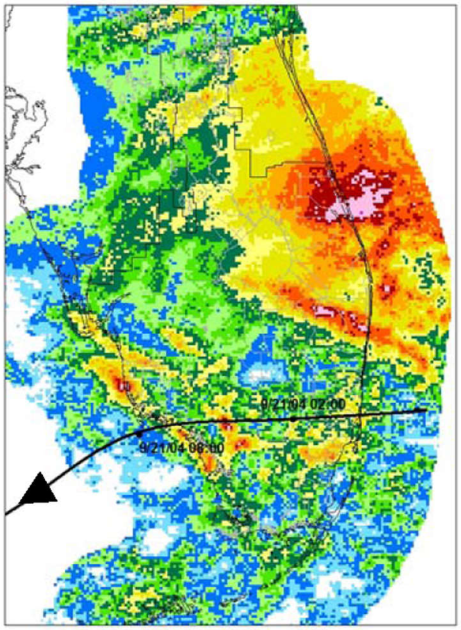


Figure 1c. Hurricane Ivan's path and radar rainfall (September 19–23, 2004).

Rainfall Amount (in.)

☐	0.000 - 0.096
🟦	0.097 - 0.100
🟦	0.101 - 0.250
🟦	0.251 - 0.500
🟩	0.501 - 0 750
🟩	0.751 - 1.000
🟩	1.001 - 1.500
🟨	1.501 - 2.000
🟨	2.001 - 3.000
🟧	3.001 - 4.000
🟧	4.001 - 5.000
🟥	5.001 - 6.000
🟪	6.001 - 8.000
🟪	8.001 - 10.000
🟪	10.001 12000
🟪	12.001 - 15000

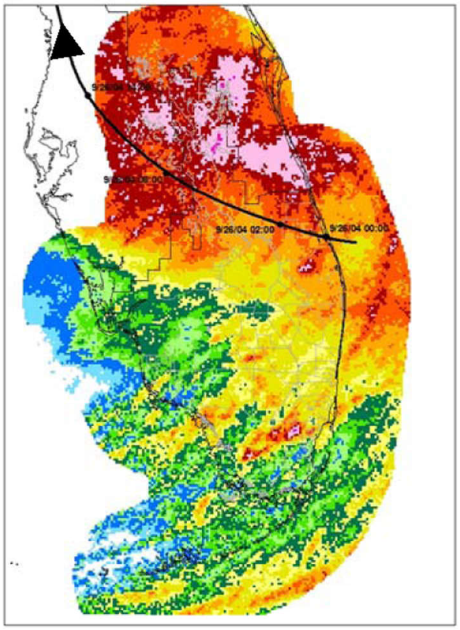


Figure 1d. Hurricane Jeanne's path and radar rainfall (September 24–28, 2004).

Figures 2a through 2d depict the path and rainfall associated with the 2005 hurricanes Dennis, Katrina, Rita, and Wilma.

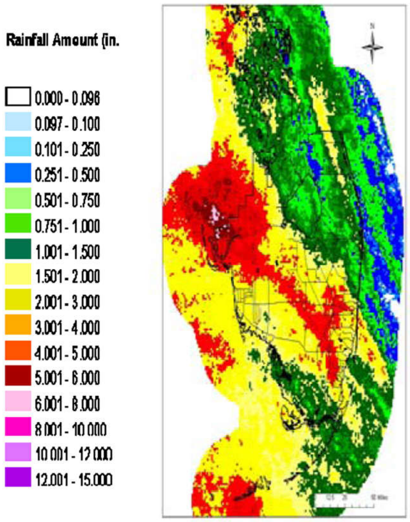


Figure 2a. Radar rainfall from Hurricane Dennis as it passed south of the Florida Keys (July 8-10, 2005).

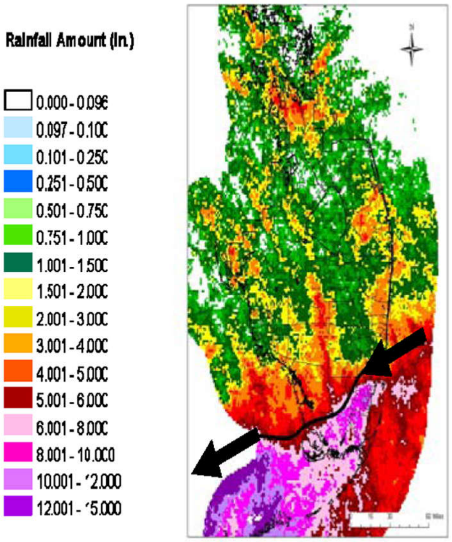
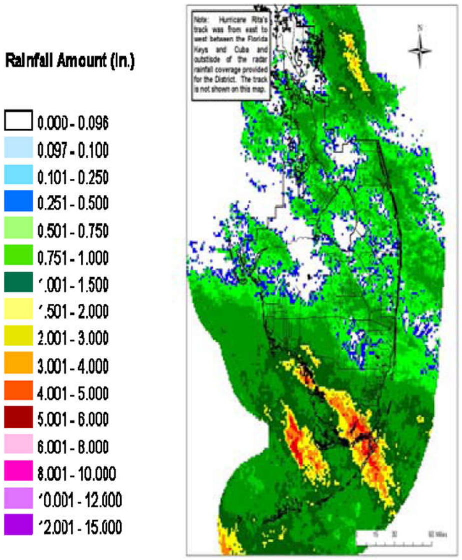


Figure 2b. Hurricane Katrina path and radar rainfall (August 24-27, 2005).



Note: Hurricane Rita's track was from east to west between the Florida Keys and Cuba and outside of the radar rainfall coverage provided for the District. The track is not shown on this map.

Figure 2c. Radar rainfall from Hurricane Rita as it passed through the Florida Straits (September 19-21, 2005).

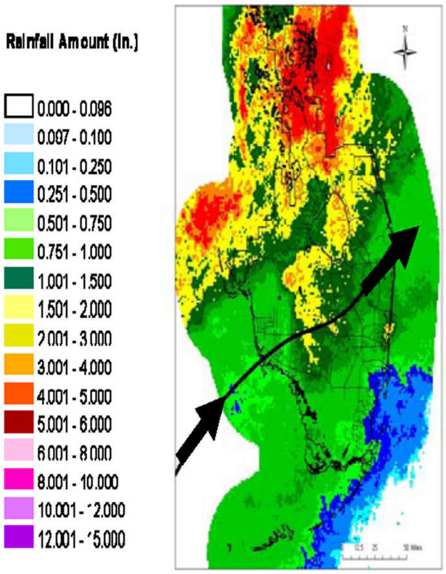


Figure 2d. Hurricane Wilma path and radar rainfall (October 22-25, 2005).

APPENDIX B

Table 1: Historical and 2004 calendar year data for groundwater monitoring well network

Station	DBKey	County	Aquifer	Historical Mean*	Historical Max/Min*	2004 Calendar Mean*	2004 Calendar Max/Min*
2AS7E_GS	MC730	BRO	Surficial	11.011	13.537 / 9.336	11.071	13.537 / 9.386
3AS3W3_G	PT037	DAD	Biscayne	9.916	11.193 / 8.365	9.701	11.067 / 8.482
3BS1W1_G	M6890	DAD	Biscayne	6.717	8.314 / 3.987	6.633	7.604 / 5.237
BUCK18_G	M6532	HIG	N/A	24.641	27.562 / 21.816	24.858	27.562 / 22.26
C-492**	02317	COL	Surficial	16.574	18.880 / 12.350	16.528	18.240 / 13.610
CRS02FS	L7464	GLA	Surficial	12.461	15.371 / 9.223	12.433	14.247 / 10.455
CRS02NM	L7449	GLA	Lower Tamiami	12.429	14.01 / 10.384	12.339	13.316 / 11.721
CRS05NS	L7457	HEN	Surficial	25.061	27.031 / 22.553	25.099	26.089 / 23.503
CRS06NM	L7460	HEN	Lower Tamiami	16.481	19.603 / 14.687	16.486	17.826 / 15.607
F-291*	01754	BRO	Biscayne	1.773	7.110 / 0.240	1.765	3.250 / 0.970
FLYGW1	M9900	OKE	N/A	35.886	39.711 / 32.389	35.821	39.046 / 33.86
FP6_GW1	FF802	LEE	Surficial	15.764	17.941 / 11.25	15.676	17.665 / 12.814

Table 1: Continued

Station	DBKey	County	Aquifer	Historical Mean*	Historical Max/Min*	2004 Calendar Mean*	2004 Calendar Max/Min*
G-1183**	00971	DAD	Biscayne	2.009	6.380 / -0.590	1.740	4.770 / 0.950
G-1260_G*	02240	BRO	Biscayne	3.533	9.410 / -0.710	3.914	6.940 / 1.490
G-3781	S3014	DAD	Biscayne	5.662	6.996 / 3.774	5.7	6.452 / 4.171
G-3785	S3018	DAD	Biscayne	5.287	7.213 / 3.354	5.227	6.318 / 3.583
HF3_G	L7553	COL	Surficial	21.166	23.267 / 18.743	21.176	22.888 / 18.785
IRLMG2	P1969	STL	N/A	1.522	2.747 / 0.626	1.316	2.008 / 0.933
KRANNM	FI293	OKE	Surficial	37.165	42.294 / 32.856	37.885	42.294 / 34.466
KRCNND	FI297	OKE	Surficial	40.053	44.664 / 36.185	40.805	44.664 / 38.057
M-1004_G**	03053	MAR	Surficial	4.625	9.340 / 1.930	4.213	7.400 / 2.340
MOSSPK_D	PS977	ORA	Surficial	42.549	45.157 / 37.759	42.361	45.157 / 38.095
MOSSPK_S	PS975	ORA	Surficial	61.24	63.092 / 59.048	61.319	63.092 / 59.443
OPAL_G	15579	OKE	N/A	32.356	35.303 / 28.954	31.949	35.303 / 29.488
ORF-29	RY937	ORA	Floridan	102.404	107.229 / 98.452	102.354	105.92 / 99.469
ORF-61	SC381	ORA	Upper Floridan	78.825	84.435 / 72.032	79.192	84.435 / 72.247

Table 1: Continued

Station	DBKey	County	Aquifer	Historical Mean*	Historical Max/Min*	2004 Calendar Mean*	2004 Calendar Max/Min*
OSF-70	O6383	OSC	Floridan	47.651	51.472 / 40.793	47.408	
PB-565_G**	02957	PAL	Surficial	3.156	11.390 / -1.190	2.437	7.330 / -0.430
PB-1548_G	PC174	PAL	Surficial	16.408	20.097 / 14.322	16.023	20.097 / 14.322
PB-1615_G	PC152	PAL	Surficial	24.115	25.38 / 21.681	23.702	25.38 / 21.681
POF-22	PT526	POL	Upper Floridan	60.756	62.986 / 56.701	60.271	62.986 / 56.701
POINCI_G	05062	OSC	N/A	61.858	64.696 / 58.139	62.366	64.438 / 59.739
POS-12	PT524	POL	Surficial	61.237	63.459 / 58.318	60.923	63.459 / 58.318
ROCK K_G	QS270	OKE	N/A	62.117	65.613 / 59.954	62.066	65.613 / 60.033
SGT1W5	PT049	COL	Surficial	9.086	12.323 / 1.713	9.139	12.259 / 6.462
SLCM_G	PS948	STL	Surficial	2.165	5.319 / -0.095	2.004	5.319 / -0.095
STL-125_G*	03209	STL	Surficial	16.924	21.170 / 14.610	16.573	18.930 / 14.900
TOHO8_GW	LQ996	OSC	Surficial	61.453	64.112 / 58.347	61.934	64.112 / 60.382
WF5_G	L7526	LEE	Surficial	26.653	29.243 / 23.769	26.731	29.243 / 24.661

**All historical and 2004 calendar year values are in feet NGVD 1929

* USGS groundwater monitoring wells

Table 2: Historical and 2005 calendar year data for groundwater monitoring well network

Station	DBKey	County	Aquifer	Historical Mean*	Historical Max/Min*	2005 Calendar Mean*	2005 Calendar Max/ Min*
2AS7E_GS	MC730	BRO	Surficial	11.011	13.537 / 9.336	11.411	12.73 / 10.042
3AS3W3_G	PT037	DAD	Biscayne	9.916	11.193 / 8.365	10.145	11.193 / 8.859
3BS1W1_G	M6890	DAD	Biscayne	6.717	8.314 / 3.987	7.079	8.28 / 5.716
BUCK18_G	M6532	HIG	N/A	24.641	27.562 / 21.816	25.17	27.442 / 22.987
C-492*	02317	COL	Surficial	16.574	18.880 / 12.350	16.808	18.310 / 14.580
CRS02FS	L7464	GLA	Surficial	12.461	15.371 / 9.223	13.276	15.371 / 10.734
CRS02NM	L7449	GLA	Lower Tamiami	12.429	14.01 / 10.384	12.835	14.01 / 12.318
CRS05NS	L7457	HEN	Surficial	25.061	27.031 / 22.553	25.285	27.031 / 22.948
CRS06NM	L7460	HEN	Lower Tamiami	16.481	19.603 / 14.687	17.368	19.386 / 16.154
F-291*	01754	BRO	Biscayne	1.773	7.110 / 0.240	2.124	3.740 / 1.230
FLYGW1	M9900	OKE	N/A	35.886	39.711 / 32.389	36.546	38.944 / 34.483
FP6_GW1	FF802	LEE	Surficial	15.764	17.941 / 11.25	16.395	17.652 / 14.085
G-1183*	00971	DAD	Biscayne	2.009	6.380 / -0.590	2.029	6.380 / 1.420
G-1260_G*	02240	BRO	Biscayne	3.533	9.410 / -0.710	4.826	7.780 / 2.090

Table 2: Continued

Station	DBKey	County	Aquifer	Historical Mean*	Historical Max/Min*	2005 Calendar Mean*	2005 Calendar Max/ Min*
G-3781	S3014	DAD	Biscayne	5.662	6.996 / 3.774	5.842	6.996 / 4.723
G-3785	S3018	DAD	Biscayne	5.287	7.213 / 3.354	5.559	7.213 / 3.994
HF3_G	L7553	COL	Surficial	21.166	23.267 / 18.743	21.584	23.267 / 19.555
KRANNM	F1293	OKE	Surficial	37.165	42.294 / 32.856	38.988	41.897 / 37.714
KRCNND	F1297	OKE	Surficial	40.053	44.664 / 36.185	41.784	44.464 / 39.98
M-1004_G*	03053	MAR	Surficial	4.625	9.340 / 1.930	4.924	6.010 / 3.980
MOSSPK_D	PS977	ORA	Surficial	42.549	45.157 / 37.759	43.128	44.814 / 41.517
MOSSPK_S	PS975	ORA	Surficial	61.24	63.092 / 59.048	61.359	63.021 / 59.931
OPAL_G	15579	OKE	N/A	32.356	35.303 / 28.954	32.655	34.819 / 30.735
ORF-29	RY937	ORA	Floridan	102.404	107.229 / 98.452	102.633	105.776 / 100.498
ORF-61	SC381	ORA	Upper Floridan	78.825	84.435 / 72.032	79.609	82.168 / 74.136
OSF-70	O6383	OSC	Floridan	51.398	54.125 / 45.668	48.662	50.194 / 45.254
PB-565_G*	02957	PAL	Surficial	3.156	11.390 / -1.190	4.924	6.010 / 3.980
PB-1548_G	PC174	PAL	Surficial	16.408	20.097 / 14.322	16.971	19.426 / 14.966
PB-1615_G	PC152	PAL	Surficial	24.115	25.38 / 21.681	24.346	25.183 / 23.036
POF-22	PT526	POL	Upper Floridan	60.756	62.986 / 56.701	61.49	62.587 / 60.129
POS-12	PT524	POL	Surficial	61.237	63.459 / 58.318	61.729	63.325 / 60.231
ROCKK_G	QS270	OKE	N/A	62.117	65.613 / 59.954	62.534	65.544 / 61.192

Table 2: Continued

Station	DBKey	County	Aquifer	Historical Mean*	Historical Max/Min*	2005 Calendar Mean*	2005 Calendar Max/ Min*
SGT1W5	PT049	COL	N/A	9.086	12.323 / 1.713	9.75	12.323 / 6.406
STL-125_G*	03209	STL	Surficial	16.924	21.170 / 14.610	17.526	18.410 / 15.420
STL-279_G	S1456	STL	N/A	20.456	22.314 / 19.736	20.720	21.681 / 20.058
STL-286_G	S7921	STL	N/A	21.239	23.454 / 18.983	21.295	22.696 / 20.563
TOHO7_GW	LQ994	OSC	Surficial	66.938	70.342 / 64.577	67.596	69.932 / 65.705
TOHO8_GW	LQ996	OSC	Surficial	61.453	64.112 / 58.347	62.534	63.738 / 61.199
WF5_G	L7526	LEE	Surficial	26.653	29.243 / 23.769	27.151	29.132 / 25.172

** All historical and 2005 calendar year values are in feet NGVD 1929

* USGS groundwater monitoring wells

Table 3: Groundwater elevation maximums and changes due to 2004 hurricanes

Station Information			2004 Storm Contributions to Ground Water Elevation Levels*							
Name	County	Aquifer	Hurricane Charley (August 12–16)		Hurricane Frances (September 4–8)		Hurricane Ivan (September 19–23)		Hurricane Jeanne (September 24–28)	
			Max	ΔElevation	Max	ΔElevation	Max	ΔElevation	Max	ΔElevation
2AS7E_GS	BRO	Surficial	11.468	+0.069	11.443	+0.571	12.788	-0.166	13.094	+0.472
3AS3W3_G	DAD	Biscayne	9.461	+0.176	10.249	+0.183	10.582	+0.128	10.733	+0.141
3BS1W1_G	DAD	Biscayne	6.705	-0.035	7.020	+0.361	7.084	+0.131	7.303	+0.224
BUCK18_G	HIG	N/A	27.421	+0.326	27.325	+0.567	27.166	+0.512	*27.562*	+0.550
C-492**	COL	Surficial	18.20	+0.730	18.130	+0.330	17.670	-0.240	17.680	+0.250
CRS02FS	GLA	Surficial	13.446	+0.647	14.006	+0.763	13.684	+0.205	**14.247**	+0.738
CRS02NM	GLA	Lower Tamiami	12.902	+0.351	13.211	+0.790	12.718	+0.205	13.256	+0.819
CRS05NS	HEN	Surficial	24.221	+0.335	25.729	+0.967	25.398	+1.199	25.308	+1.602
CRS06NM	HEN	Lower Tamiami	17.093	+0.183	**17.826**	+0.501	17.041	+0.151	17.776	+0.769
F-291**	BRO	Biscayne	2.490	-0.220	**3.250**	+1.870	2.370	+0.300	3.180	+0.810
FLYGW1	BRO	N/A	36.636	+1.309	38.724	+3.086	38.814	+0.148	**39.046**	+0.279
FP6_GW1	LEE	Surficial	17.548	+0.554	**17.665**	+0.086	17.124	-0.152	17.008	+0.276
G-1183**	DAD	Biscayne	1.760	-0.120	2.430	+0.680	2.000	+0.330	2.120	+0.170
G-1260_G**	BRO	Biscayne	3.950	+0.250	6.180	+2.290	6.080	+0.310	6.66	+0.690
G-3781	DAD	Biscayne	6.029	+0.020	6.195	+0.312	6.175	+0.148	6.369	+0.262
G-3785	DAD	Biscayne	5.792	+0.065	6.073	+0.395	5.98	+0.155	**6.318**	+0.406
HF3_G	COL	Surficial	22.807	+0.940	22.578	+0.440	21.841	-0.319	21.556	+0.169
IRLMG2	STL	N/A	1.287	+0.204	N/A	N/A	N/A	N/A	N/A	N/A
KRANNM	OKE	Surficial	37.712	+0.972	40.903	+2.193	41.652	-0.174	*42.294*	+0.814
KRCNND	OKE	Surficial	40.821	+1.223	43.569	+1.766	44.033	-0.084	*44.664*	+0.745

Table **3**: Continued

Station Information			2004 Storm Contributions to Ground Water Elevation Levels*							
Name	County	Aquifer	Hurricane Charley (August 12–16)		Hurricane Frances (September 4–8)		Hurricane Ivan (September 19–23)		Hurricane Jeanne (September 24–28)	
			Max	ΔElevation	Max	ΔElevation	Max	ΔElevation	Max	ΔElevation
M-1004_G**	MAR	Surficial	4.660	-0.130	6.280	+1.700	6.420	+1.080	**7.400**	+1.410
MOSSPK_D	ORA	Surficial	42.500	+0.780	44.374	+0.680	44.793	+0.321	*45.157*	+0.364
MOSSPK_S	ORA	Surficial	62.733	+1.403	*63.092*	+0.537	62.354	-0.239	63.026	+1.059
OPAL_G	OKE	N/A	33.718	+0.540	N/A	N/A	34.817	N/A	*35.303*	+1.046
ORF-29	ORA	Floridan	101.516	+0.020	102.45	+1.101	105.338	+1.43	105.086	+1.057
ORF-61	ORA	Upper Floridan	80.551	+2.083	83.586	+3.962	83.005	+0.363	*84.435*	+1.430
OSF-70	OSC	Floridan	48.234	+2.19	50.027	+1.029	51.391	+0.632	*51.472*	+0.506
PB-565_G**	PAL	Surficial	2.280	+0.100	4.780	+0.319	5.080	+1.200	**7.330**	+2.780
PB-1548_G	PAL	Surficial	18.197	+1.465	19.783	+2.72	18.724	+1.424	*20.097*	+2.106
PB-1615_G	PAL	Surficial	24.022	+0.586	24.924	+0.866	24.901	+0.271	*25.38*	+0.489
POF-22	POL	Upper Floridan	59.055	+0.191	59.649	+0.265	60.808	+0.497	61.095	+0.343
POINCI_G	OSC	N/A	64.216	+0.315	64.438	+0.811	63.228	+0.181	64.197	+1.316
POS-12	POL	Surficial	63.302	+0.571	63.459	+0.576	62.671	+0.411	63.340	+1.086
ROCK K_G	OKE	N/A	63.006	-0.633	62.078	+0.589	63.722	+1.012	63.722	-0.175
SGT1W5	COL	Surficial	**12.259**	+0.437	11.460	+0.446	10.631	+0.266	10.783	+0.344
SLCM_G	STL	Surficial	2.888	+0.343	4.978	+2.782	4.775	+1.754	*5.319*	+0.688
STL-125_G**	STL	Surficial	16.250	+0.380	18.560	+1.010	18.620	+0.260	*18.930*	+0.310
TOHO8_GW	OSC	Surficial	62.209	+0.399	*64.112*	+0.980	63.442	-0.127	64.018	+0.723
WF5_G	LEE	Surficial	28.931	+0.754	28.683	+0.139	28.145	+0.191	28.198	+0.349

*All groundwater elevation level units are in feet NGVD 1929

** Groundwater monitoring wells chosen from USGS

BOLD represents values that were annual maximums for groundwater elevation in that well

Italic represents values that were historical maximums for groundwater elevation in that well

Table 4: Groundwater elevation maximums and changes due to 2005 hurricanes

Station Information			2005 Storm Contributions to Ground Water Elevation Levels*							
Name	County	Aquifer	Hurricane Dennis (July 8-10)		Hurricane Katrina (August 24-27)		Hurricane Rita (September 19-21)		Hurricane Wilma (October 22-25)	
			Max	ΔElevation	Max	ΔElevation	Max	ΔElevation	Max	ΔElevation
2AS7E_GS	BRO	Surficial	N/A	N/A	11.572	+1.100	11.643	+0.018	12.297	+0.219
3AS3W3_G	DAD	Biscayne	10.806	+0.437	11.174	+0.158	11.023	+0.078	10.970	+0.151
3BS1W1_G	DAD	Biscayne	8.146	+0.451	8.139	+0.322	8.095	+0.061	8.077	+0.122
BUCK18_G	HIG	N/A	26.811	+0.361	26.105	+1.237	24.218	+1.006	**27.442**	+1.364
C-492**	COL	Surficial	18.160	+0.070	17.680	+0.060	17.110	+0.480	18.310	+0.810
CRS02FS	GLA	Surficial	15.009	+0.782	14.951	+735	13.999	+0.058	*15.371*	+1.283
CRS02NM	GLA	Lower Tamiami	13.528	+0.489	13.180	+0.584	12.705	+0.105	*14.010*	+1.138
CRS05NS	HEN	Surficial	26.752	+2.611	25.429	-0.975	25.429	+0.336	*27.031*	+3.907
CRS06NM	HEN	Lower Tamiami	19.301	+1.182	17.348	+0.240	17.012	+0.028	**19.386**	+2.206
F-291**	BRO	Biscayne	3.650	+1.110	2.430	+0.790	2.650	+0.120	3.610	+0.650
FLYGW1	BRO	N/A	38.845	+0.978	36.301	+0.910	34.843	+0.212	38.701	+3.033
FP6_GW1	LEE	Surficial	17.417	+0.496	17.288	+0.218	17.037	+0.676	**17.652**	+0.709
G-1183**	DAD	Biscayne	3.110	+0.890	*6.380*	+4.130	3.860	+1.720	2.240	+0.290
G-1260_G**	BRO	Biscayne	6.480	-0.080	5.660	+0.830	6.170	+0.220	7.570	+0.240
G-3781	DAD	Biscayne	6.753	+0.574	*6.996*	+1.097	6.394	+0.266	6.212	+0.471
G-3785	DAD	Floridan	6.718	+0.677	*7.213*	+1.260	6.334	+0.297	6.206	+0.468
HF3_G	COL	Surficial	*23.267*	+0.432	22.203	+0.044	21.374	+0.196	22.899	+0.898
KRANNM	OKE	Surficial	**41.897**	+0.230	39.236	+0.249	38.956	-0.161	40.358	+2.273
KRCNND	OKE	Surficial	*44.464*	+0.114	42.043	+0.251	41.651	-0.193	43.473	+2.351

Table 4: Continued

Station Information			2005 Storm Contributions to Ground Water Elevation Levels*							
Name	County	Aquifer	Hurricane Dennis (July 8-10)		Hurricane Katrina (August 24-27)		Hurricane Rita (September 19-21)		Hurricane Wilma (October 22-25)	
			Max	ΔElevation	Max	ΔElevation	Max	ΔElevation	Max	ΔElevation
M-1004_G**	MAR	Surficial	5.270	+0.010	4.880	+0.300	5.480	+0.470	5.980	+0.980
MOSSPK_D	ORA	Surficial	44.242	-0.108	42.255	+0.222	42.768	+0.181	44.354	+0.505
MOSSPK_S	ORA	Surficial	62.254	-0.301	60.815	+0.041	60.363	-0.082	62.949	+1.43
OPAL_G	OKE	N/A	33.748	+0.407	32.741	+0.498	31.900	+0.427	**34.819**	+2.067
ORF-29	ORA	Floridan	103.251	+1.335	**105.776**	+0.455	102.840	+0.280	102.964	-0.122
ORF-61	ORA	Upper Floridan	81.289	+0.980	80.551	-0.361	79.782	+1.677	81.508	+1.569
OSF-70	OSC	Floridan	49.761	+0.129	48.869	-0.059	48.688	+0.134	50.189	+0.722
PB-565_G**	PAL	Surficial	3.900	-0.030	3.390	+0.430	3.320	+0.230	5.100	+0.600
PB-1548_G	PAL	Surficial	19.104	+1.338	18.138	+1.119	18.001	+0.968	19.172	+0.987
PB-1615_G	PAL	Surficial	24.749	+0.218	24.482	+0.159	24.610	+0.096	**25.183**	+0.407
POF-22	POL	Upper Floridan	60.988	+0.286	62.177	-0.070	61.814	+0.260	61.675	-0.074
POS-12	POL	Surficial	63.096	+0.723	62.271	+0.542	61.239	+0.059	63.322	+1.585
ROCK_K_G	OKE	N/A	64.319	-0.426	63.024	-0.182	62.934	-0.397	61.723	-0.100
SGT1W5	COL	Surficial	12.139	+1.024	12.247	+0.378	11.398	+0.928	12.057	+2.335
STL-125_G**	STL	Surficial	18.220	-0.010	17.840	-0.090	17.230	-0.060	18.070	+0.340
STL-279_G	STL	N/A	21.308	-0.047	20.897	-0.214	21.293	+0.381	20.707	+0.154
STL-286_G	STL	N/A	21.460	+0.373	21.036	+0.139	20.843	-0.228	22.394	+1.139
TOHO7_GW	OSC	Surficial	69.612	+1.177	68.374	+1.081	67.628	+0.172	**69.932**	+2.582
TOHO8_GW	OSC	Surficial	63.457	+0.212	62.802	+0.257	62.629	-0.123	63.206	+0.981
WF5_G	LEE	Surficial	**29.132**	+1.502	27.574	+0.135	27.245	+0.400	28.744	+1.375

*All groundwater elevation level units are in feet NGVD 1929

** Groundwater monitoring wells chosen from USGS

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