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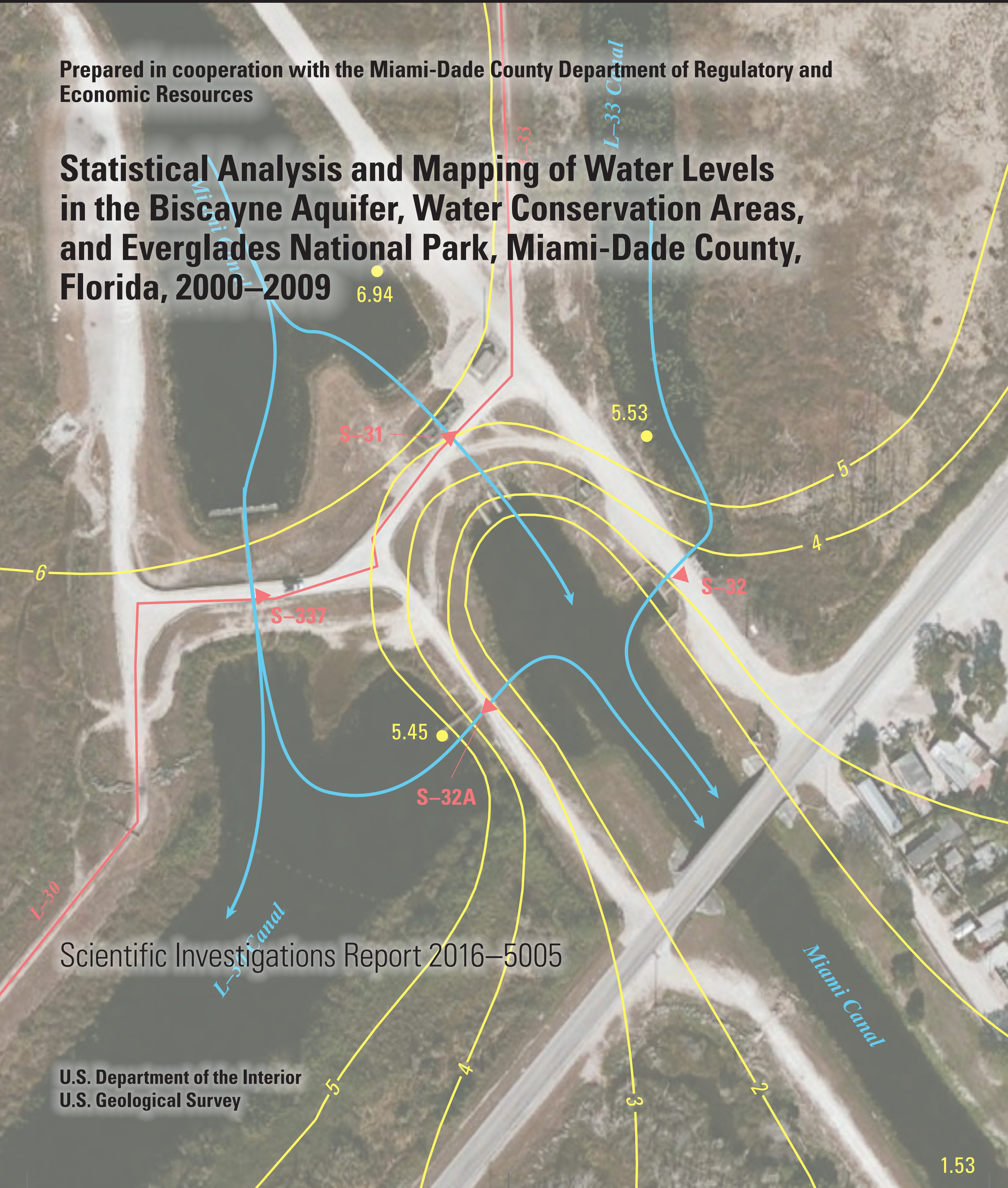
Statistical Analysis and Mapping of Water Levels in the Biscayne Aquifer, Water Conservation Areas, and Everglades National Park, Miami-Dade County, Florida, 2000–2009



Scientific Investigations Report 2016–5005

U.S. Department of the Interior
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Cover image. Contours of the altitude of the 50th percentile of October water levels for water years 2000 to 2009 near the junction of the Miami Canal and the L-33 and L-30 canals, and inferred flow directions, Miami-Dade County, Florida (see figure 6, p. 13).

Statistical Analysis and Mapping of Water Levels in the Biscayne Aquifer, Water Conservation Areas, and Everglades National Park, Miami-Dade County, Florida, 2000–2009

By Scott T. Prinos and Joann F. Dixon

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U.S. Department of the Interior
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U.S. Department of the Interior
SALLY JEWELL, Secretary

U.S. Geological Survey
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[Available for downloading at http://dx.doi.org/10.3133/sir20165005]

Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha)
acre	0.4047	square hectometer (hm^2)
acre	0.004047	square kilometer (km^2)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow	
cubic feet per second (ft^3/s)	0.0283	cubic meters per second (m^3/s)

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88), unless otherwise indicated.

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Altitude, as used in this report, refers to distance above the vertical datum.

Abbreviations

EDB	Emergency detention basin
ENP	Everglades National Park
FGDC	Federal Geographic Data Committee
FKAA	Florida Keys Aqueduct Authority
GIS	Geographic information system
krig	Kriging
M-D RER	Miami-Dade County Department of Regulatory and Economic Resources
NAVD 88	North American Vertical Datum of 1988
NGVD 29	National Geodetic Vertical Datum of 1929
NPS	National Park Service
SFWMD	South Florida Water Management District
TIN	Triangulated irregular network
topo	Topographic
USGS	U.S. Geological Survey
WCA	Water conservation area
WY	Water year

Statistical Analysis and Mapping of Water Levels in the Biscayne Aquifer, Water Conservation Areas, and Everglades National Park, Miami-Dade County, Florida, 2000–2009

By Scott T. Prinos and Joann F. Dixon

Abstract

Statistical analyses and maps representing mean, high, and low water-level conditions in the surface water and groundwater of Miami-Dade County were made by the U.S. Geological Survey, in cooperation with the Miami-Dade County Department of Regulatory and Economic Resources, to help inform decisions necessary for urban planning and development. Sixteen maps were created that show contours of (1) the mean of daily water levels at each site during October and May for the 2000–2009 water years; (2) the 25th, 50th, and 75th percentiles of the daily water levels at each site during October and May and for all months during 2000–2009; and (3) the differences between mean October and May water levels, as well as the differences in the percentiles of water levels for all months, between 1990–1999 and 2000–2009. The 80th, 90th, and 96th percentiles of the annual maximums of daily groundwater levels during 1974–2009 (a 35-year period) were computed to provide an indication of unusually high groundwater-level conditions. These maps and statistics provide a generalized understanding of the variations of water levels in the aquifer, rather than a survey of concurrent water levels. Water-level measurements from 473 sites in Miami-Dade County and surrounding counties were analyzed to generate statistical analyses. The monitored water levels included surface-water levels in canals and wetland areas and groundwater levels in the Biscayne aquifer.

Maps were created by importing site coordinates, summary water-level statistics, and completeness of record statistics into a geographic information system, and by interpolating between water levels at monitoring sites in the canals and water levels along the coastline. Raster surfaces were created from these data by using the triangular irregular network interpolation method. The raster surfaces were contoured by using geographic information system software. These contours were imprecise in some areas because the software could not fully evaluate the hydrology given available information; therefore, contours were manually modified where necessary. The ability to evaluate differences in water levels between 1990–1999 and 2000–2009 is limited in some areas because most of the monitoring sites did not have 80 percent complete records for one or both of these periods. The quality of the analyses was limited by (1) deficiencies in spatial coverage; (2) the combination of pre- and post-construction water levels in areas where canals, levees, retention basins, detention basins, or water-control structures were installed or removed; (3) an inability to address the potential effects of the vertical hydraulic head gradient on water levels in wells of different depths; and (4) an inability to correct for the differences between daily water-level statistics. Contours are dashed in areas where the locations of contours have been approximated because of the uncertainty caused by these limitations. Although the ability of the maps to depict differences in water levels between 1990–1999 and 2000–2009 was limited by missing data, results indicate that near the coast water levels were generally higher in May during 2000–2009 than during 1990–1999; and that inland water levels were generally lower during 2000–2009 than during 1990–1999. Generally, the 25th, 50th, and 75th percentiles of water levels from all months were also higher near the coast and lower inland during 2000–2009 than during 1990–1999. Mean October water levels during 2000–2009 were generally higher than during 1990–1999 in much of western Miami-Dade County, but were lower in a large part of eastern Miami-Dade County.

Introduction

Statistical analyses and maps showing temporal and spatial variations in water levels in the Biscayne aquifer, water conservation areas (WCAs), and the Everglades National Park (ENP), in Miami-Dade County, Florida (fig. 1), are necessary for urban planning and development. Water levels and flows in the county are carefully managed with a complex system of canals, levees, retention basins, WCAs, and water-control structures (fig. 1). The poor drainage, low topography, and proximity of the county to the ocean and the Florida Bay make it susceptible to flooding, storm surge, and saltwater intrusion.

La Niña periods have resulted in prolonged droughts in the study area (Prinos and others, 2014). The water table in the shallow, karstic limestone Biscayne aquifer is commonly near the land surface in parts of the urban and rural areas of the county and may rise above land surface during wet periods (fig. 2). In the western half of the county, in the ENP and WCAs, water levels that are commonly above land surface are maintained behind levees and water-control structures (figs. 1 and 2). Analyses and maps of water levels are used to address water management and urban development challenges including (1) prevention and mitigation of saltwater intrusion from the ocean into the Biscayne aquifer; (2) storage of water to use during droughts; (3) removal or storage of excess water during floods; (4) design of public and private infrastructure to avoid flooding; and (5) planning of land use and development. Meeting each of these challenges requires an understanding of the altitude of the water table and its seasonal and long-term variations.

Data from the 1990–1999 water years (WY) (October 1 to September 30) were used to create maps of the altitude of the water table (Lietz and others, 2002). A new set of maps and statistics was needed to provide an updated understanding of water levels and to evaluate any changes since this period. In 2012, the U.S. Geological Survey (USGS), in cooperation with the Miami-Dade County Department of Regulatory and Economic Resources (M-D RER), initiated a study to develop maps and statistics depicting representative low, high, and mean water-table altitudes using water monitoring data during 2000–2009. This analysis included comparison of water-table altitudes during 2000–2009 to those during the last mapped period, 1990–1999, to determine whether the water-table altitude has changed over time. The frequency of annual maximum water levels was also evaluated at groundwater monitoring locations where data were sufficient for this analysis. Years referenced in this study always refer to the water year, which is defined as the period from October 1 to September 30. The current study furthers the USGS science strategy goals of improving understanding of water availability, and evaluating changes and variability in water resources.

Purpose and Scope

The purpose of this report is to describe the analytical procedures used for statistical analysis and mapping of water levels in the Biscayne aquifer, the WCAs, and ENP, in Miami-Dade County, Florida, between 2000 and 2009 and to document the results and limitations of these analyses and maps. The report includes (1) maps of mean daily water levels and maps of the 25th, 50th, and 75th percentiles of daily water levels during 2000–2009 in Miami-Dade County; (2) maps showing the differences in the statistics of water levels between 1990–1999 and 2000–2009; and (3) a table providing the results of a frequency analysis of annual maximums of daily water levels during 1974–2009. These statistical analyses provide a representation of mean, high, and low water-level conditions in the surface-water levels and groundwater levels in Miami-Dade County. Analysis of the water-table altitude includes surface-water levels, when and where the water level in the aquifer extends above land surface, such as in marshes, lakes, and canals. Water levels are above land surface for much of the year in the WCAs and the ENP, which together represent about one-half the land area of the county (fig. 1).

Maps were created to show the results of statistical analyses of water levels at the end of the dry season (May), at the end of the wet season (October), and throughout the year (all months). Maps that can be used to evaluate differences between water levels during 1990–1999 and 2000–2009 were produced by computing means and percentiles of dry season, wet season, and all water levels for both of these periods, computing differences in these statistics on a site-by-site basis, and contouring of the resulting values. Representative water levels in the aquifer are mapped by interpolating between the point values measured at each site. The frequency analysis of annual maximums of daily water levels is provided for 60 sites that had the most complete historical record between 1974 and 2009.

Commonly, maps of the water table are based on water-level measurements collected from individual monitoring wells over a short time period such as days or weeks. Maps created from synoptic measurements can provide a snapshot of water levels in the aquifer during that period. However, because of frequent changes in well-field withdrawals, rainfall patterns, and the transfer of water in canals and other water-control structures in Miami-Dade County, water-levels used in synoptic mapping can be misrepresentative of prevailing water levels in the aquifer. The maps provided in this report represent statistical summaries of the measured water levels at surface-water and groundwater monitoring sites to describe representative high and low water levels in the aquifer.

Description of Study Area

The study area is Miami-Dade County, which is located in southeast Florida and is bordered on the east by the Atlantic Ocean and on the south by the Florida Bay (fig. 1). The county's 1,900-square-mile (mi^2) land area (U.S. Census Bureau, 2012) is relatively flat and poorly drained. Most of the county's estimated 2,591,000 residents (U.S. Census Bureau, 2012) live in an area of about 600 mi^2 that is concentrated within about 15 miles (mi) of the Atlantic Ocean or Biscayne Bay. Along the eastern coast, a low coastal ridge ranges in altitude from 6.4 to 22 feet (ft; fig. 2; Hoffmeister and others, 1967; Lietz and others, 2002; converted from National Geodetic Vertical Datum of 1929 [NGVD 29] to North American Vertical Datum of 1988 [NAVD 88]). The land-surface altitude for approximately 70 percent of the county, however, is below 4.4 ft (Prinos and others, 2014). Prior to urban development, most of Miami-Dade County was covered by a shallow, freshwater marsh named the Everglades. Urban development occurred initially along the coastal ridge in eastern Miami-Dade County. Early in the 20th century, canals were dug and the coastal ridge was breached to drain part of the Everglades.

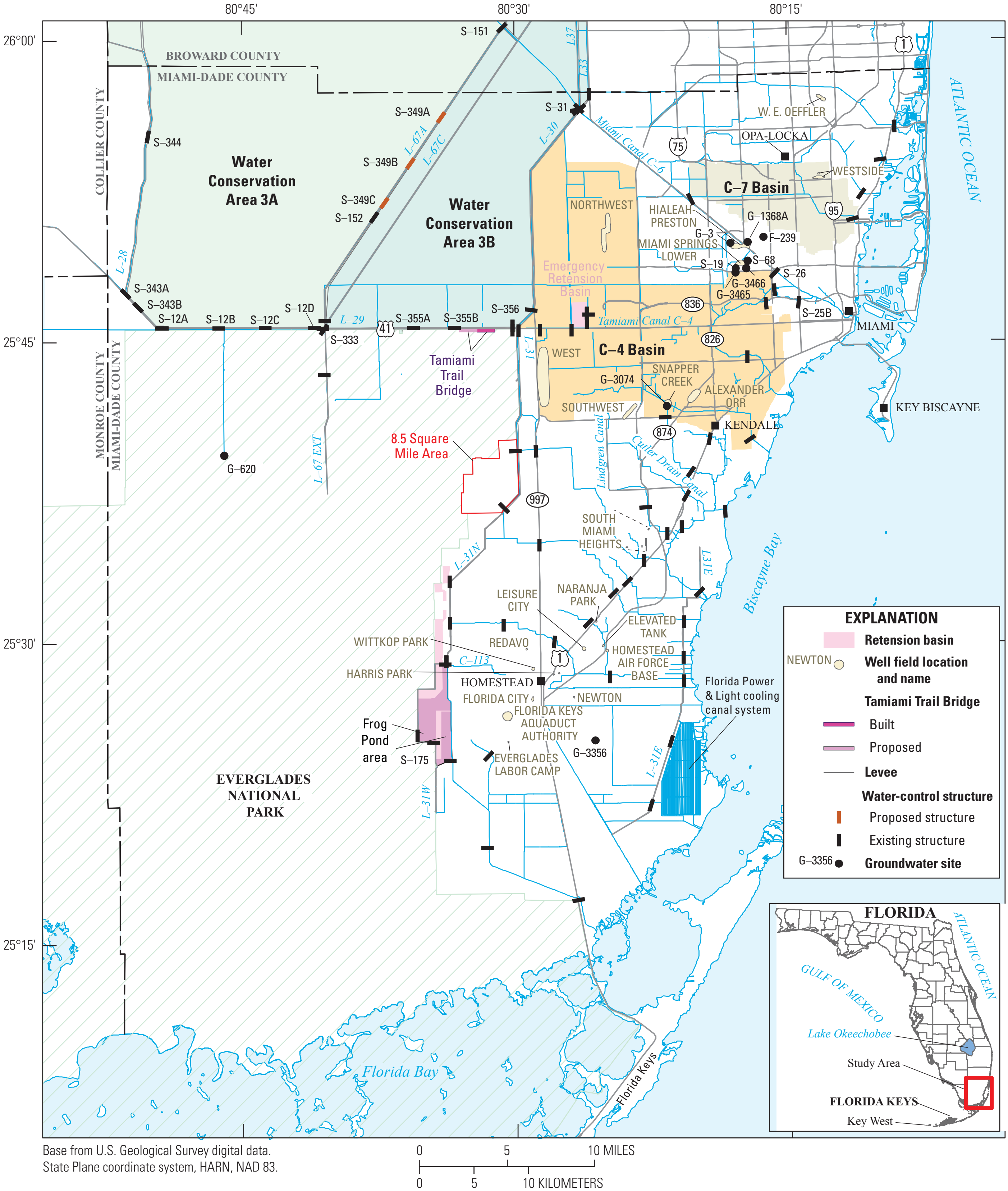


Figure 1. Location of the study area, well fields, water-control structures, water conservation areas (WCAs), selected drainage, retention, or detention basins, and Everglades National Park, Miami-Dade County, Florida.

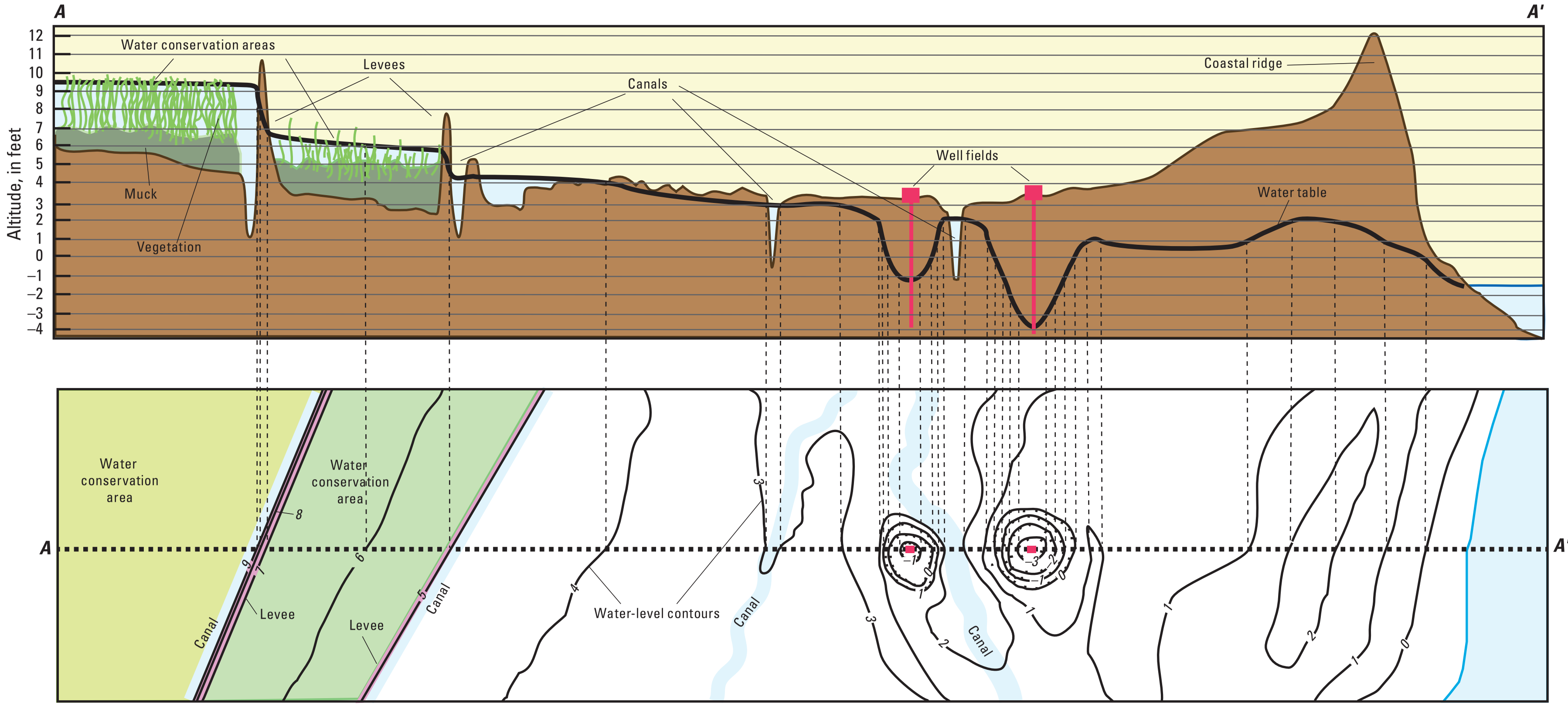


Figure 2. Generalized diagram showing examples of the types of interactions among the water table, topography, and anthropogenic features found within the study area, and the effects of these features on contours of the water table.

Hydrology

The western half of the county contains remnants of the historic Everglades, called the ENP, and WCAs 3A and 3B (fig. 1). The water in the WCAs and ENP is retained behind a series of levees (figs. 1 and 2). In the WCAs and the ENP, the water table is generally above land surface for much of the year, but may fall below land surface during extended dry periods. Water levels in the developed areas of the county are usually lower than in the WCAs, and for the most part are lower than water levels in the ENP. In some areas, the water table is drawn down to a depth below sea level by withdrawals from well fields (fig. 2), which could lead to the intrusion of saltwater from the ocean. To reduce saltwater intrusion, water-control structures that maintain water levels were installed in most of the canals near the coast. Water in the WCAs can be directed south into the Everglades or east or southeastward toward the coast through a series of canals and water-control structures, each of which acts like a step.

The water table is in a shallow, highly permeable limestone and sand aquifer named the Biscayne aquifer. The Biscayne aquifer is an important drinking-water source for Miami-Dade County and the Florida Keys (Marella, 2009). During the first half of the 20th century, much of the area was drained for urban development. As a result, saltwater from the bay or ocean has intruded about 460 mi^2 of the Biscayne aquifer in Miami-Dade County as of 2011. (Prinos and others, 2014).

Climate

South Florida's latitude and its proximity to the Atlantic Ocean and the Gulf of Mexico produce a wet/dry tropical climate (Hagemeyer, 2012). The wet season typically extends from about mid-May through the beginning of October each year (fig. 3). The wet season is characterized by after-noon thunderstorms, with relatively heavy rainfall that is

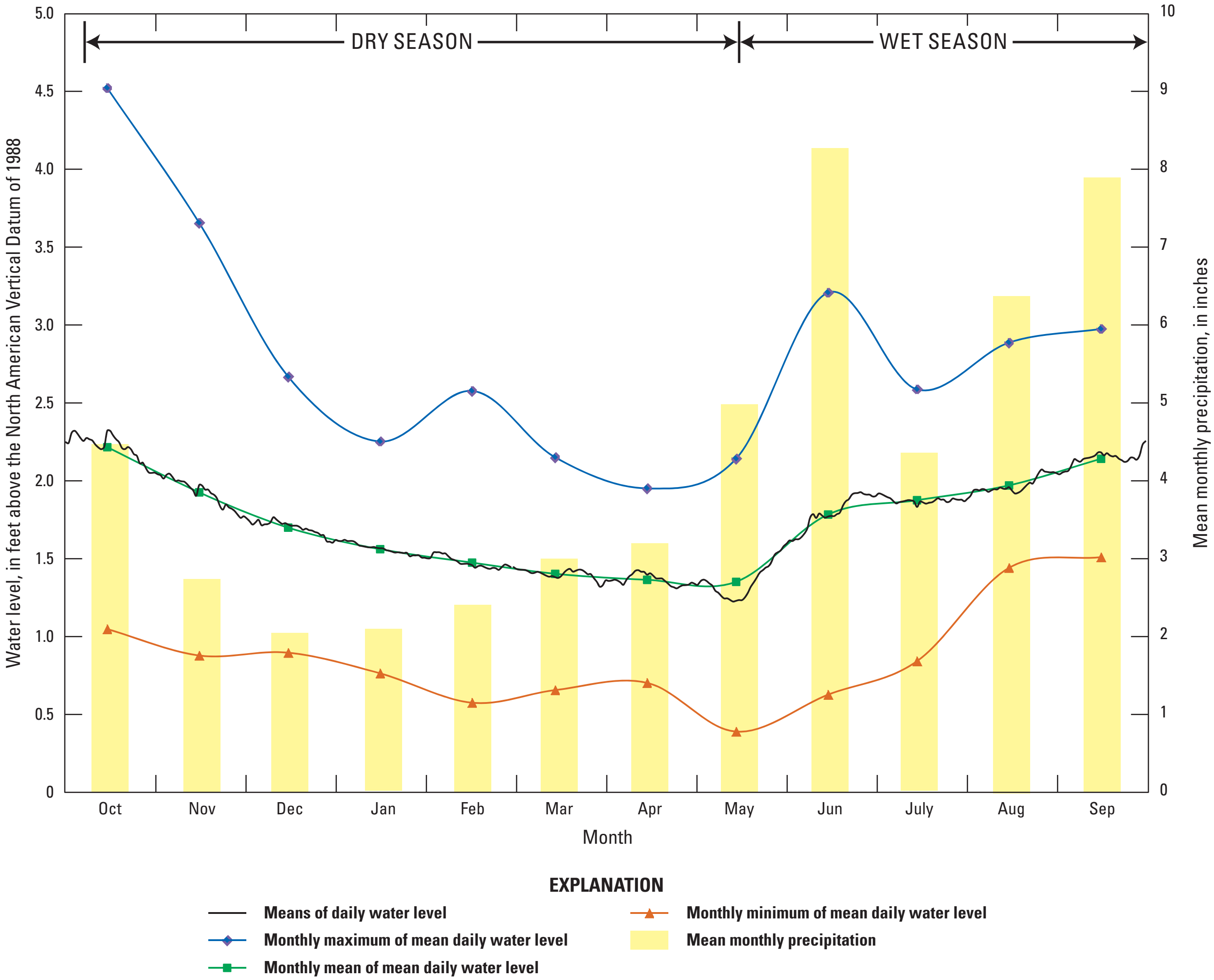


Figure 3. Means of daily water levels at 99 of the surface-water and groundwater monitoring sites that have ≥ 95 percent complete record during the 1989–2009 water years, monthly maximum, mean, and minimum of these daily mean water levels, and mean monthly precipitation (The Weather Channel, 2013) in Miami-Dade County, Florida. Water-level statistics were determined using data from table 2–1. Period of record for the monthly precipitation statistics is unspecified.

augmented, sometimes tremendously, by rainfall from tropical storms and hurricanes. The dry season typically extends from October to mid-May and is characterized by low humidity and solar radiation that greatly reduce the occurrence of afternoon thunderstorms. During droughts, the dry season may extend into June. The means of daily water levels from 99 surface-water and groundwater monitoring sites in Miami-Dade County for October 1, 1989, to September 30, 2009, indicate that water levels in the county typically reach a maximum at the beginning of October and a minimum in mid-May (fig. 3).

Previous Studies

The altitude of the water table in Dade County (now Miami-Dade County) has been mapped since the 1940s. The maps made in the early 1940s provide an understanding of the drainage in the county prior to the installation of water-control structures around 1945. Cross and Love (1942) and Brown and Parker (1945) created maps of water levels in northeastern Miami-Dade County. Maps show water levels on May 27, 1940, July 15, 1940, September 30, 1940, July 26, 1941, and February 3, 1942. Parker and others (1955) provided detailed water-table maps for several areas in the county including west of Hialeah, southeastern Miami-Dade County, the Opa-Locka area, and the Hialeah-Preston and Miami Springs well-field areas. Sherwood and Klein (1958, 1960) made three maps showing mean annual water levels, mean yearly high water levels, and mean October water levels during 1940–1957, and one water-table map of water levels during 1960 in Miami-Dade County. Meyer (1969) made five maps showing hydrologic conditions in eastern Miami-Dade County during 1959–67. Swayze mapped water levels in the Biscayne aquifer in Miami-Dade County, in April and October 1978 (1981a, b); near the Alexander Orr and Southwest well fields in May and October 1978 (1979, 1980f) and May 1980 (1980a); and near the Hialeah-Preston and Miami Springs well fields in May and October 1978 (1980c, e), October 1979 (1980d), and May 1980 (1980b). Ratzlaff mapped water levels in the Biscayne aquifer in March and October 1979 (1981a, c), and May 1980 (1981b). Klein (1986a, b) mapped the water table near the Northwest well field during May 19–24 and October 10–16, 1984. Lietz (1991) and Sonenshein and Koszalka (1996) mapped the altitude of the water table in the Biscayne aquifer in Miami-Dade County. Sonenshein and Koszalka (1996) also provided hydrographs of selected wells and water-level duration curves of water levels during 1984–1993. Lietz and others (2002) mapped the results of annual and seasonal statistics of water levels recorded during 1990–94 and 1995–99. They computed the differences in water levels between these two periods and created a table and maps of the 5-, 10-, and 25-year recurrence water levels. Lietz and others (2002) used the USGS software program PEAKFQ (Thomas and others, 1998) for a frequency analysis of annual maximum daily water levels from 58 USGS continuous groundwater monitoring wells having at least 10 years of data. The approach of the current study was patterned after the study of Lietz and others (2002), with the exception of the frequency analysis of annual maximum water levels.

Methods of Data Analysis

Data analysis involved several steps that included (1) data compilation and editing, (2) analyses of statistics and missing data, (3) development of the geographic information system (GIS) framework for generating automated map contours, and (4) manual modifications of the contours based on an understanding of the hydrology of the system. A number of additional analyses were considered, but not implemented during the current study, including (1) application of flood-frequency analysis for the purpose of determining high water levels likely to recur in 5-, 10-, and 25-year time intervals, (2) estimation of missing records by using correlations of water-level data from proximal sites, and (3) removing long-term trends prior to the frequency analysis of annual maximum water levels. The reasons for rejecting these analyses are discussed in appendix 1 and provided to possibly aid in the planning of future studies.

Data Compilation and Editing

Water-level monitoring data from sites in Miami-Dade County and extending 12 to 16 mi into neighboring counties were used for analysis. These data were obtained from the USGS, the South Florida Water Management District (SFWMD), and the National Park Service (NPS), ENP. Sites include groundwater monitoring wells and surface-water monitoring sites. In the Everglades and the WCAs, where water levels are typically above land surface, many of the sites are surface-water monitoring sites. Barrier islands were not included in the mapping evaluation because of a lack of monitoring data for these areas.

Data used for the analysis consisted of a combination of daily mean and daily maximum water levels because the organizations that manage the data collection provide different daily statistics. The USGS Caribbean-Florida Water Science Center typically publishes the daily maximum of hourly water levels recorded at groundwater monitoring wells, whereas the daily mean of water levels recorded every hour or every 15 minutes at surface-water monitoring sites are published. The SFWMD usually provides the daily mean of water levels recorded at groundwater monitoring and surface-water monitoring sites, but also publishes the daily maximum and minimum water levels at sites on the downstream side of coastal water-control structures. The NPS provided daily mean water levels. Daily maximum water levels were available for the majority of groundwater monitoring sites, and daily mean water levels were available for most of the surface-water monitoring sites; therefore, these were the daily statistics that were used for mapping.

The USGS, SFWMD, and NPS store data in separate database files based on the attributes of the data. Water-level data from an individual monitoring site may be stored in one or more files. Multiple files may be used to store (1) water levels recorded upstream or downstream of a structure at the same site, (2) different daily statistics computed from the same unit value data (hourly, 15 minute, 20 minute, or stage change), (3) data from different monitoring devices at the same site, and (4) different periods of record at the same site, such as when a site was destroyed and rebuilt. The SFWMD creates an alphanumeric designator called a DBKEY for each site, and may create additional DBKEYs for different types or periods of data from the same site. Water-level data from 613 database files were available for analysis (appendix 2). The data from some of the sites have been copied into multiple databases. In these instances, the data provided by the collecting agency were generally used, rather than the copied data, because some of the copied data may have become corrupted during the transfer, or did not include corrections made after they had been copied. Some exceptions were made if the data were not readily accessible from the original collecting agency. Where it was feasible to do so, data recorded during different periods at the same site were merged to create a complete dataset. After these corrections, mergers, and deletions, 498 database files from 473 unique sites were available for analysis (appendix 3).

Most of the water levels were referenced to the NGVD 29 or the NAVD 88. Some files contained water levels that were referenced to a local datum rather than a national datum. Although these data are useful for evaluating change at a specific site and could eventually be referenced to a national datum, they could not be used in this study.

Summary statistics and hydrographic comparisons were used to review water-level data and to eliminate erroneous data. Erroneous values were removed or corrected, and water levels referenced to the NGVD 29 were adjusted to the NAVD 88 by using the software package Corpscon 6.0.1 developed by the U.S. Army Corps of Engineers.

Evaluation of Missing Data and Spatial Coverage

Maps showing the network coverage given various completeness of water-level record criteria were created to evaluate the effect of missing records on spatial coverage. By using these maps, it was determined that the maximum amount of missing records that would still allow fairly good spatial coverage was 20 percent, therefore during mapping, a site's data would need to be at least 80 percent complete for each of the periods evaluated. In some areas, few or no sites met this criteria (table 1); therefore, the statistical analyses of water-level data from sites with less than 80 percent complete record were considered, but to a lesser extent.

About 340 sites have water-level records that are at least 80 percent complete during October, May, and all months of the 2000–2009 period. Fewer database files met the completeness of record criteria for both the 1974–2009 and 1990–1999 periods of comparison and for the frequency analysis of maximum annual water levels during the 1974–2009 period. Only about 80 database files met the completeness of record criteria during the 1974–2009 period (table 1), and of these files, only 46 met the additional requirements for frequency analysis.

Table 1. Number of sites in the study area meeting a range of completeness of record criteria for the months of October and May, and for all months during the 1974–2009, 1990–1999, and 2000–2009 water years, in and near Miami-Dade County, Florida.

[WYs, water years; ≥, greater than or equal to; highlighted row represents the completeness of record criteria selected for the study]

Completeness of record criteria, in percent	Number of sites meeting the completeness of record criteria								
	All	May	October	All	May	October	All	May	October
	1974–2009 WYs			1990–1999 WYs			2000–2009 WYs		
≥99	12	25	18	61	92	81	156	229	186
≥95	56	58	50	107	123	102	284	287	259
≥90	64	63	60	142	149	139	323	315	316
≥80	78	79	76	184	184	168	339	336	338
≥70	91	92	88	202	208	199	343	351	345
≥60	146	147	139	218	227	216	363	382	362
≥50	175	179	170	253	274	250	395	405	397
≥40	259	264	239	293	305	287	419	425	416
≥30	324	325	323	323	325	318	450	458	453
≥20	354	353	354	328	331	328	473	473	474
≥10	441	440	428	331	332	330	484	482	484
≥0	498	498	498	498	498	498	498	498	498

Statistical Analysis of Water Levels

Using available data, statistical analyses of the daily and annual water levels were computed that were used for quality assurance and for mapping of water levels in the county. The mean, count, maximum, minimum, standard deviation, variance, and number of standard deviations of the minimum and maximum from the mean of daily water levels during the 1990–2009 period were computed to help detect erroneous data. To create the necessary information for mapping, the mean and the 25th, 50th, and 75th percentiles of daily water levels during the 2000–2009 period were computed from measurements recorded during (1) October, (2) May, and (3) all months, as well as the differences between these statistics during the 1990–1999 and 2000–2009 periods. For computation of percentiles, the Microsoft Excel exclusive percentile function was used rather than the inclusive percentile function. Given the data being analyzed, the equation for the exclusive percentile function yielded somewhat higher, and thus more conservative, water levels. The equation for the exclusive percentile function also corresponds more directly to the traditional definition of a percentile as being a value below which a certain percentage of the data lie.

The 80th, 90th, and 96th percentiles of the annual maximums of daily groundwater levels during the 1974–2009 period were computed to provide an indication of unusually high groundwater levels in the aquifer. In addition to a requirement that the data for this analysis be at least 80 percent complete during this period, data for each individual year within this period were also required to be at least 80 percent complete to ensure that the annual maximum for each year was based on reasonably complete data. Given these criteria, 46 database files were available for analyses.

Geographic Information System Development

The site coordinates, summary water-level statistics, and completeness of record statistics were imported into a GIS. Water-level information from monitoring sites on canals were used to interpolate water levels in each segment of the canal using a routing system. The water levels from these interpolations were assigned to a series of locations (called control points) that traced the course of each of the monitored canals. The distribution of control points along the canals was relatively dense, but it was most dense near the water-control structures where water levels changed the most. Water levels were not monitored or estimated near many smaller canals or canal reaches. A series of control points was created adjacent to those levees that have sufficient proximal monitoring to evaluate the water levels along those levees. Water levels were measured in many of the canals that are adjacent to and run parallel to levees. The control points in these canals and the control points based on other sites adjacent to the levees were used to provide an understanding of the difference in water levels caused by a levee. In some instances, however, no sites were immediately adjacent to the levees to aid in this determination.

Water levels at the coast were estimated by using the water-level statistics from selected tail-water monitoring sites at the coastal water-control structures nearest to the coast. The lowest of the water-level values recorded at the sites in each area were used because water levels at the selected sites could potentially be increased by discharge through the canals to the Biscayne Bay. The water-level values were assigned to a series of control points along the coastline. This estimation may not be optimal because of the potential for increased water levels caused by discharge through the coastal structures, but it was the closest approximation possible given available information.

One set of control points was created for each of 16 maps (pls. 1–16) by using the statistics computed from water-level data from each canal monitoring site and each coastal structure. These sets of control points were merged with the statistical analysis and site location information from surface-water and groundwater monitoring sites to create a GIS shapefile. The triangulated irregular network (TIN) interpolation method was selected to create a water-level surface that could be contoured after several of the ArcGIS interpolation methods, such as spline, spline with barriers, topographic (topo) to raster, and kriging (krig), were tested. The points in the shapefile were input into the ArcGIS tool “Create TIN” to create a TIN surface. Lakes, canals, well fields, and major roads also were used as input features in this tool. The resulting TIN surface and the ArcGIS tool Surface Contour were used to create the water-level contours.

Manual Modifications of Contours

All of the water-level contours generated with the Surface Contour tool had to be manually modified because the contours typically had very sharp bends that are not characteristic of water levels in aquifers. Automatic smoothing of contours can eliminate some of the bends but it also may cause contours to overlap each other, or shift away from the locations through which they should pass based on known water levels. All contours were manually smoothed on a segment-by-segment basis to ensure that the contours did not overlap and that they passed through water-control structures or other points where necessary.

The water table in the Biscayne aquifer and surface-water features are considered to be connected. Abrupt changes in surface-water levels are often caused by the water management system of the county (fig. 2). For example, there are typically abrupt changes in water levels in the Miami Canal, at the water-control structures S-26, S-31, and S-151 (fig. 4). One or more contour lines are drawn to pass through a water-control structure when and where the difference in water levels between the upstream and downstream sides of the structure is greater than the contour interval. Even though contours are frequently drawn through the structures, in some places contours are drawn upstream or downstream of these structures based on interpolation of water levels between surface-water monitoring sites. The 50th percentiles of water levels in the Miami Canal for all months, for example, are 1.19 ft on the downstream side of S-31 and 0.94 ft on the upstream side of S-26; therefore, water levels in the canal decrease less than 1 ft between these two sites (fig. 4). In some instances, contours of the water table may intersect with other water management features, such as levees, where these features create abrupt changes in water levels (fig. 2).

Some well fields in the study area have water supply wells on either side of a canal. The cones of depression created by these supply wells have previously been interpreted to have merged into one cone of depression under the canal (see for example, Swayze, 1980e; Ratzlaff, 1981c; Lietz and others, 2002). If the canal was isolated from the water levels in the aquifer by low permeability sediments or a shallow, relatively impermeable unit, this interpretation could be correct; however, the interpretation used during the current study is that the water table intersects with the canal as shown in figure 2.

Where water-level data were sparse, the manual modifications to automatically generated contours were much more extensive. During the period of study, for example, water levels near the L-67C canal were not published (fig. 1). Unpublished monitoring data on both sides of the L-67C canal in November 2011 and December 2012 indicated a maximum difference of about 0.8 ft (Judson Harvey, U.S. Geological Survey, written commun., May 8, 2013). Contours that intersected this canal or that were very close to it were interpreted based on the assumption that some of the change in water levels between monitoring sites in this area occurred at the levee, but these contours are shown as dashed lines on maps because of the uncertainty in this assumption. Another area where the automatically generated contours were extensively modified is in WCA 3A (fig. 1). In this area, monitoring data near the L-67A and L-28 canals were insufficient for the automatically generated contours to depict water levels accurately.

All of the statistics of daily water levels during 1990–1999 and 2000–2009 were used to create the automatically generated water-level contours. These contours were then manually adjusted, approximated, or eliminated where datasets were less than 80 percent complete. Many of the smaller canals in the county lacked water-level monitoring sites; therefore, values could not be assigned to control points that trace the routes of these canals. Even though sites located as far as 16 mi into neighboring counties were used, the contours near the edges of maps were affected by diminished data availability; therefore, the final maps were cropped so that they extend only 3 to 4 mi into neighboring counties.

Results of Statistical Analyses

Analyses included (1) statistical analyses of water levels during 2000–2009, (2) analysis of changes in water levels between 1990–1999 and 2000–2009 and (3) a frequency analysis of annual maximums of daily water levels during 1974–2009. The statistical analyses of water levels during 2000–2009 included computation of the mean and the 25th, 50th, and 75th percentiles of daily water levels computed from measurements recorded during October, May, and all months.

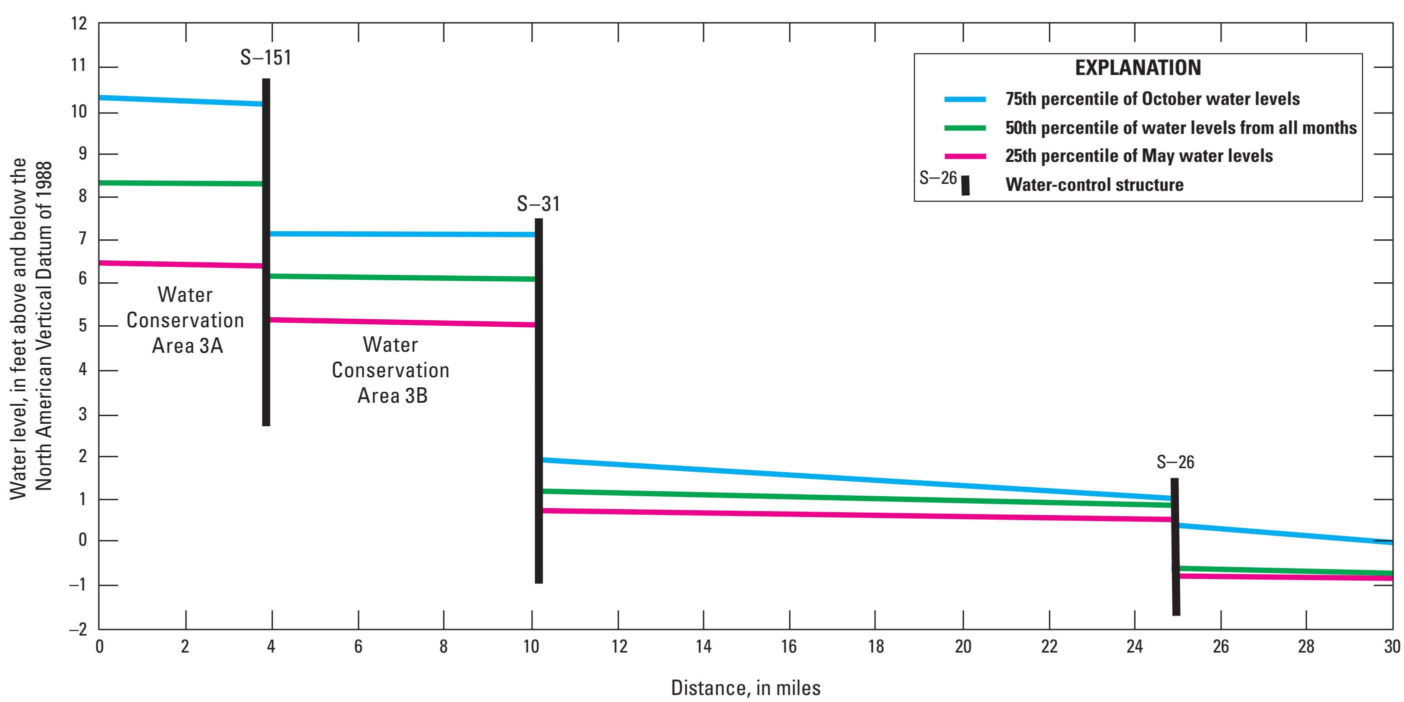


Figure 4. Water levels in the Miami Canal from Water Conservation Area 3A to its mouth during the 2000 to 2009 water years. See figure 1 for the locations of the Miami Canal, Water Conservation Areas, and water-control structures.

The analysis of changes in water levels between the 1990–1999 and 2000–2009 periods was based on computation and comparison of these same statistics for both periods (appendix 5). The 80th, 90th, and 96th percentiles of the annual maximums of daily water levels during 1974–2009 were computed (appendix 4), as well as the count, mean, maximum, minimum, standard deviation, variance, and number of standard deviations of the minimum and maximum from the mean of daily water levels during this same period (appendix 6).

Sixteen maps were created to depict prevailing water-level conditions in the Biscayne aquifer, WCAs, and ENP (pls. 1–16; table 2). The contours and data points shown in plates 1–16 are also provided as downloadable GIS layer filers in appendix 7, available through a U.S. Geological Survey data release (Prinos and Dixon, 2016). An index map showing the locations of sites used for the analysis is provided in appendix 8.

In some areas, water-level data for mapping were sparse, given the requirement of an 80 percent complete record, because most of the monitoring sites were recently installed. Each of the plates show the sites that had at least 80 percent complete record, and those that did not. This information can be examined to gain a better understanding of the precision of the maps. Although it is possible to view the GIS shape files of the contours at any scale, in some areas where monitoring is widely separated the contours can only be considered approximations; conversely where monitoring information is dense the locations of the contours are more precise. A GIS shape file showing the location of each site used for mapping, and the statistics of water levels recorded at these sites is provided (appendix 7), so that users can understand the spacing of information used to draw the contours.

Water Levels During 2000–2009

The eleven maps showing prevailing water-level conditions in the Biscayne aquifer, WCAs, and the ENP during 2000–2009 (plates 1–11) show the configuration of the water table under a variety of conditions. The mean, 25th, 50th, and 75th percentiles of water levels during May and October provide an understanding of the range in water levels that typically occur at the end of the dry and wet seasons, respectively. The 25th, 50th, and 75th percentiles of all water levels collected during 2000–2009 provide an understanding of the typical range of water levels during this period. The mapped data indicate that water levels are generally highest in WCA 3A and lowest near the southern and eastern coasts (pls. 1–11).

A close hydraulic connection exists between groundwater and surface water as a result of the highly transmissive nature of the unconfined Biscayne aquifer. Water-control structures, levees, and canals also affect the hydrology in Miami-Dade County. These effects are evident in the contour lines on plates 1–11. Given an assumption that the Biscayne aquifer is relatively homogeneous and isotropic, groundwater flow lines can be inferred that are generally perpendicular to the contour lines. In some instances, the groundwater flow directions inferred from the contours upstream of water-control structures indicate that groundwater flows away from the canal, whereas downstream of the structure the inferred flow direction is toward the canal. These flow directions correspond to “losing,” and “gaining” canal reaches, respectively. For example, see the 1- and 2-ft contour lines near water-control structure S-148 on plate 2. In these instances, groundwater

Table 2. Listing of the maps of water levels, Miami-Dade County, Florida.

Plate number	Explanation
Plate 1	Mean of May water levels during the 2000–2009 water years
Plate 2	Mean of October water levels during the 2000–2009 water years
Plate 3	25th percentile of May water levels during the 2000–2009 water years
Plate 4	50th percentile of May water levels during the 2000–2009 water years
Plate 5	75th percentile of May water levels during the 2000–2009 water years
Plate 6	25th percentile of October water levels during the 2000–2009 water years
Plate 7	50th percentile of October water levels during the 2000–2009 water years
Plate 8	75th percentile of October water levels during the 2000–2009 water years
Plate 9	50th percentile of water levels from all months during the 2000–2009 water years
Plate 10	25th percentile of water levels from all months during the 2000–2009 water years
Plate 11	75th percentile of water levels from all months during the 2000–2009 water years
Plate 12	Difference between May mean water levels from the water-year periods 1990–1999 and 2000–2009
Plate 13	Difference between October mean water levels from the water-year periods 1990–1999 and 2000–2009
Plate 14	Difference between the 25th percentiles of all water levels for water-year periods 1990–1999 and 2000–2009
Plate 15	Difference between the 50th percentiles of all water levels for water-year periods 1990–1999 and 2000–2009
Plate 16	Difference between the 75th percentiles of all water levels for water-year periods 1990–1999 and 2000–2009

flow is inferred to be through the ground and around the water-control structures.

The WCA 3A is surrounded on the western, southern, and eastern sides by the levees L-28, L-29, and L-67A, respectively. The effects of these levees on water levels in the WCA 3A are shown on plates 1–11. Surface water in the WCA 3A can flow westward through structure S-344; southward through water-control structures S-12A, S-12B, S-12C, S-12D, S-343A, and S-343B; and (or) eastward through structures S-151 and S-333. Water passing through the S-12A–D structures enters the ENP, and water passing through S-333 enters a continuation of the L-29 canal (fig. 5).

In the ENP, flow inferred from the contour lines is generally in a southerly direction toward the coast or in a southeasterly direction toward the intricate system of levees, structures, and canals in urban Miami-Dade County (pls. 1–11). In the ENP at a distance of more than about 7 mi south of the Tamiami Canal and 3 mi west of the L-31, L-31N, and L-31W canals, the water-level contours are evenly spaced and gently curved, which is typical in natural systems.

Several water-level contour lines nearly intersect (pls. 1–11). One such area is where water from WCA3B flows eastward through the S-31 structure into the Miami Canal and (or) through structure S-337 into the L-30 canal (fig. 6). Depending on water-control structure operations, water in the L-30 canal can flow either southwest or northeast through the S-32A structure into the Miami Canal. Water in the L-33 canal can flow south through the S-32 structure into the Miami Canal. The contours of the water table in this area are controlled by a complex intersection of levees and water-control structures (fig. 6).

Mean water levels at the end of the wet season (October) in WCA 3A were about 2 ft higher than the mean water levels at the end of the dry season (May) (pls. 1 and 2). In WCA 3A, the 75th percentile of water levels in October is about 9 to 10 ft (pl. 8). This is about 2 to 3 ft higher than the 25th percentile of water levels in May of 6 to 8 ft (pl. 3). With the exception of well fields, mean water levels were generally lowest in the ENP near the southern coast where they were about 0 to 1 ft in October and about 0 to –1 ft in May. In the WCAs and in urban Miami-Dade County, the shapes of contours generally reflect the locations of levees, water-control structures, and the cones of depression associated with well fields. Water levels in urban Miami-Dade County that are outside the cones of depression ranged from about 0 to 4 ft in October (pl. 2) and from about 0 to 3 ft in May (pl. 1) during 2000–2009.

All water-level maps show cones of depression at the Alexander Orr, Hialeah-Preston, Miami Springs, Snapper Creek, and Southwest well fields (pls. 1–11). Cones of depression at the Florida Keys Aqueduct Authority (FKAA), Northwest, and West well fields also are shown on some of the maps. There may be cones of depression at all active well fields, especially during the dry season, but given the monitoring information available and a contour interval of 1 ft, some cones of depression may not be evident on the maps. The map of the 25th percentile of water levels in May (pl. 3) indicated larger and deeper cones of depression than the map of the 75th percentile of water levels in October (plate 8) at all of the well fields where cones of depression are evident.

Changes in Water Levels Between 1990–1999 and 2000–2009

The accuracy of evaluating water-level changes in the WCAs and the ENP between 2000–2009 and 1990–1999 was limited by the large number of monitoring sites that did not have an 80 percent complete record for both of the periods (pls. 12–16). For this reason, many contour lines on plates 12–16 are approximated, and the statistical results cited in this section may have been affected. The numerical differences in water levels cited in the remainder this section, between 1990–1999 and 2000–2009, at specific locations, have been obtained by cross-referencing locations shown in plates 12–16 with the computed water-level differences shown in appendix 7.

The differences in mean May water levels and percentiles of water levels during all months for the 10-year periods 1990–1999 and 2000–2009 indicate that water levels were generally lower during the 2000s than during the 1990s (appendix. 7; pls. 12, 14–16). The mean of all differences between the water-level statistics computed for these periods ranged from –0.10 to –0.31 ft (table 3). Considering all of the statistical comparisons of water levels during these periods, approximately two to five times more sites indicated decreased water levels than those indicating an increase. This finding could be explained in part by the difference in the 10-year total of annual mean (by water year) rainfall at the National Oceanic and Atmospheric Administration, National Climatic Data Center stations, Everglades, Fort Lauderdale, Hialeah, Miami International Airport, and Royal Palm Ranger Station. Rainfall at these stations was 27 inches (in.) greater during 1990–1999 than during 2000–2009 (fig. 7).

Mean October water levels were slightly higher on average during 2000–2009 than during 1990–1999 (appendix. 7; pl. 13; table 3). Although most of the analyses of the differences in water levels indicate that they were lower during 2000–2009 than during 1990–1999, water levels were generally higher at most of the sites near the coast, including most of the tail-water monitoring sites at coastal water-control structures. These increases could be related, at least in part, to the effects of sea-level rise. McNoldy (2014) reported an increase in sea level of about 3.7 in. (0.31 ft) at the tide station at Virginia Key during 1996–2014. Near the coast, increases in water levels of 0.01 to 0.37 ft were indicated at 11 of the 12 coastal water-control structure, tail-water monitoring stations that had nearly complete data for 1990–2009. The largest increases in water levels are evident in October when comparing the two10-year periods (appendix. 7; pl. 13), and the smallest increases are evident when comparing the 25th percentiles of water levels between these periods (appendix. 7; pl. 14).

Mean May water levels were generally 0.01 to 1.15 ft lower during 2000–2009 than during 1990–1999 except near

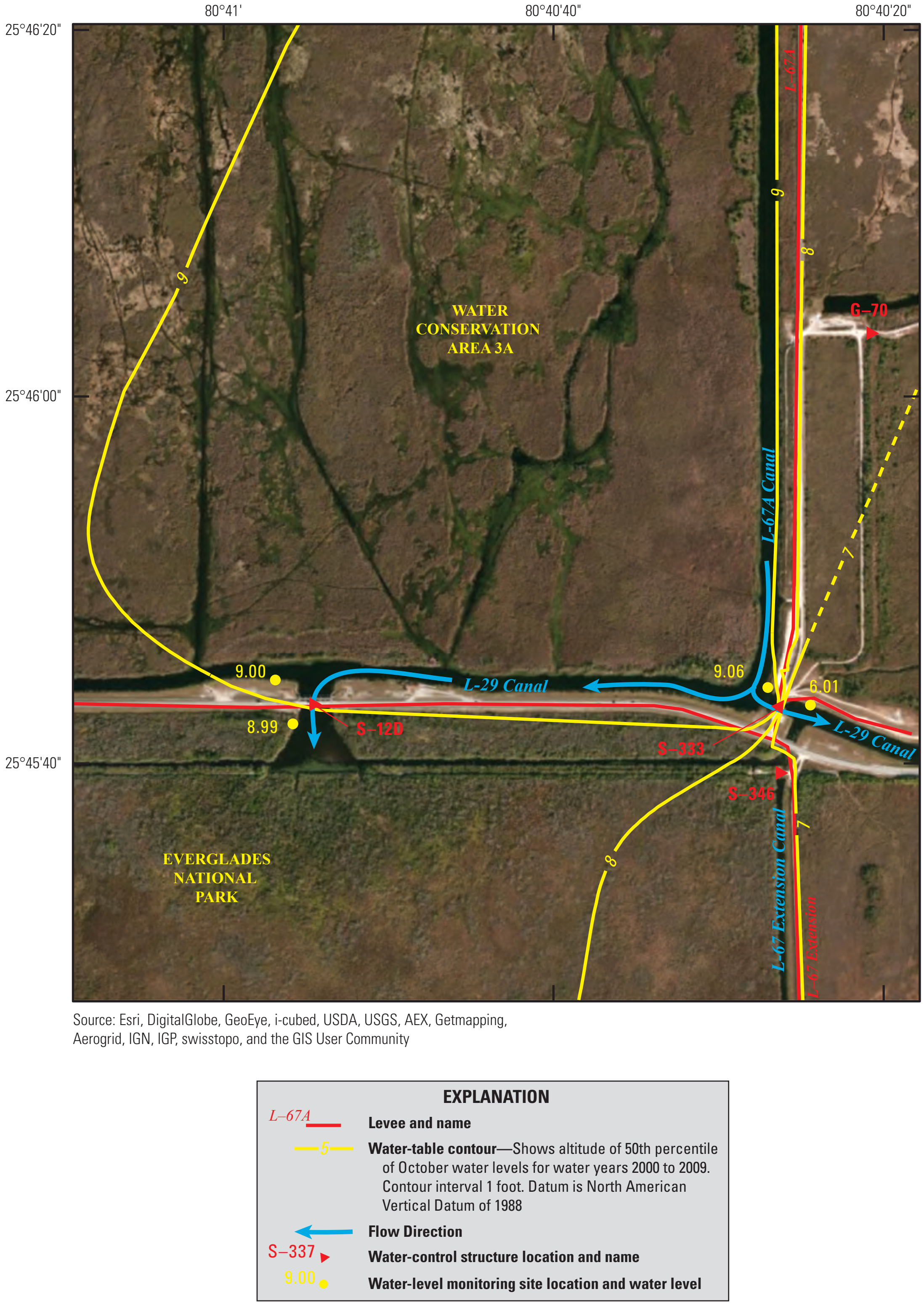
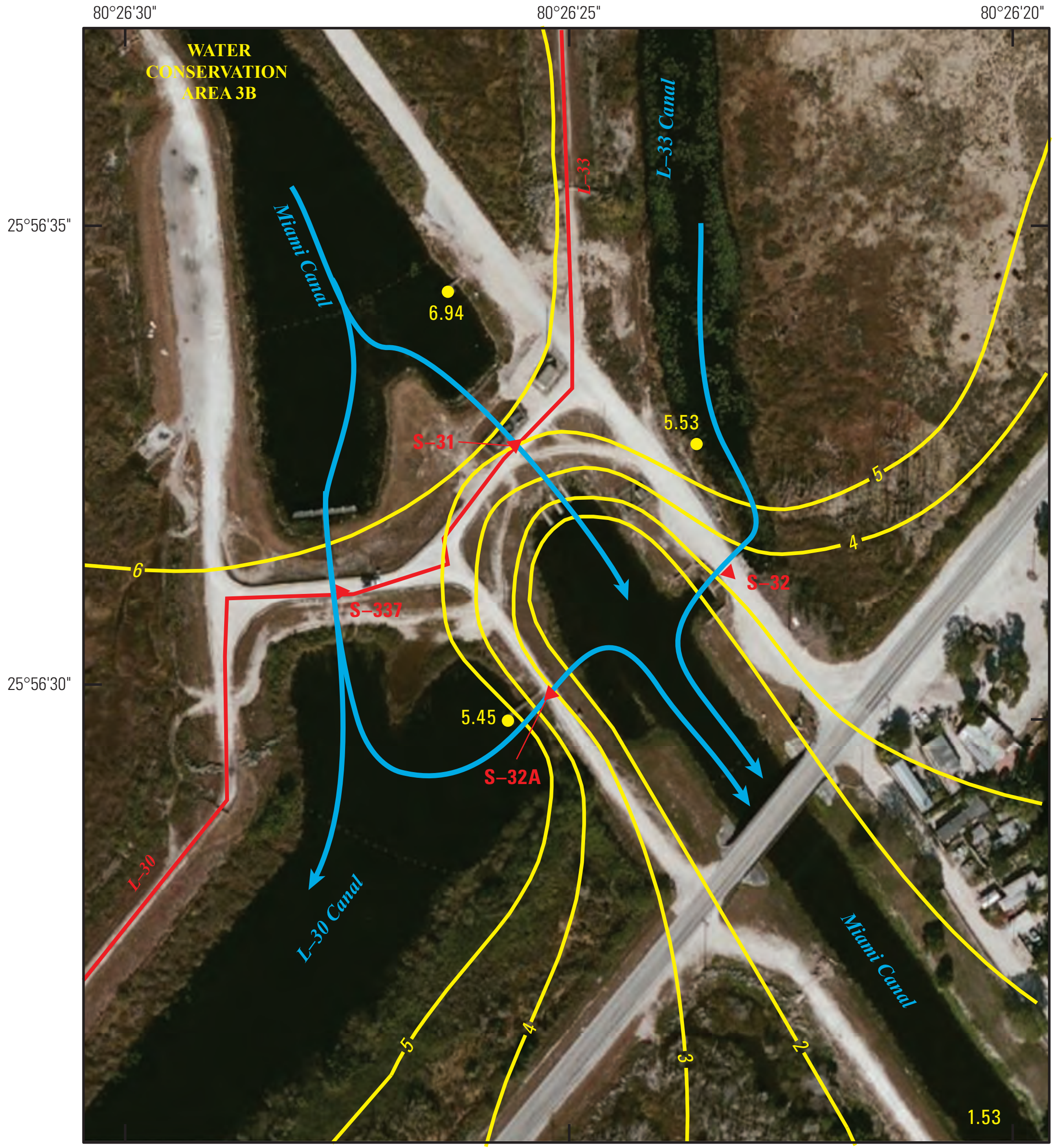


Figure 5. Contours of the altitude of the 50th percentile of October water levels for water years 2000 to 2009 near water-control structure S-12D and the junction of the L-29, L-67A, and L-67 extension canals, and inferred flow directions, Miami-Dade County, Florida.



Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

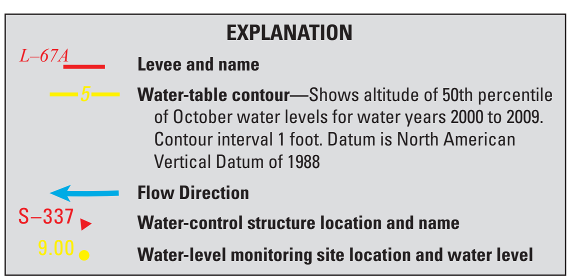
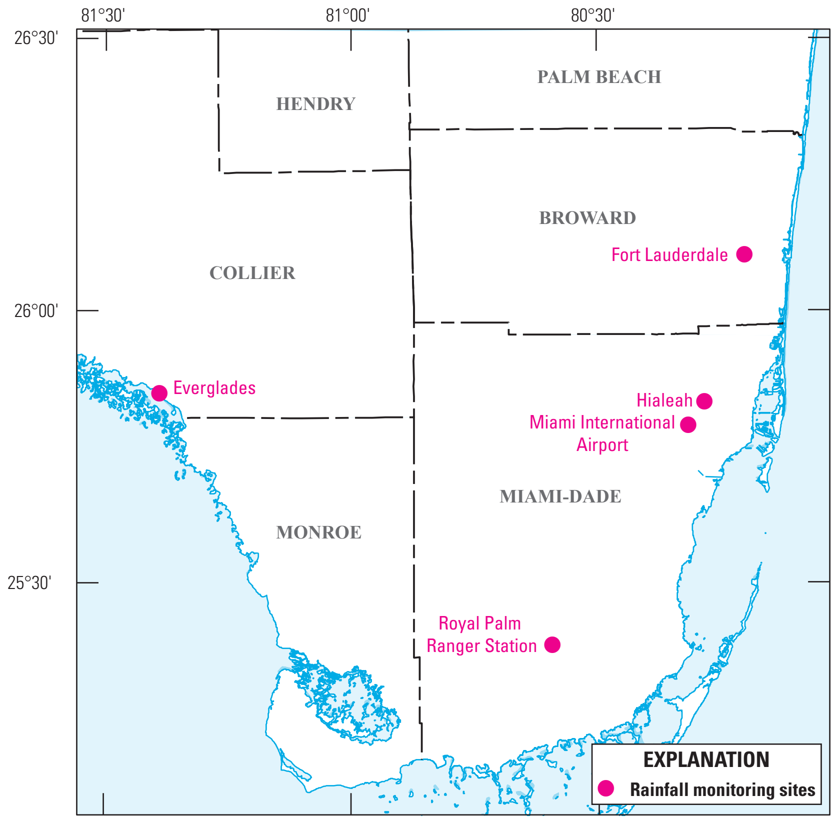


Figure 6. Contours of the altitude of the 50th percentile of October water levels for water years 2000 to 2009 near the junction of the Miami Canal and the L-33 and L-30 canals, and inferred flow directions, Miami-Dade County, Florida.



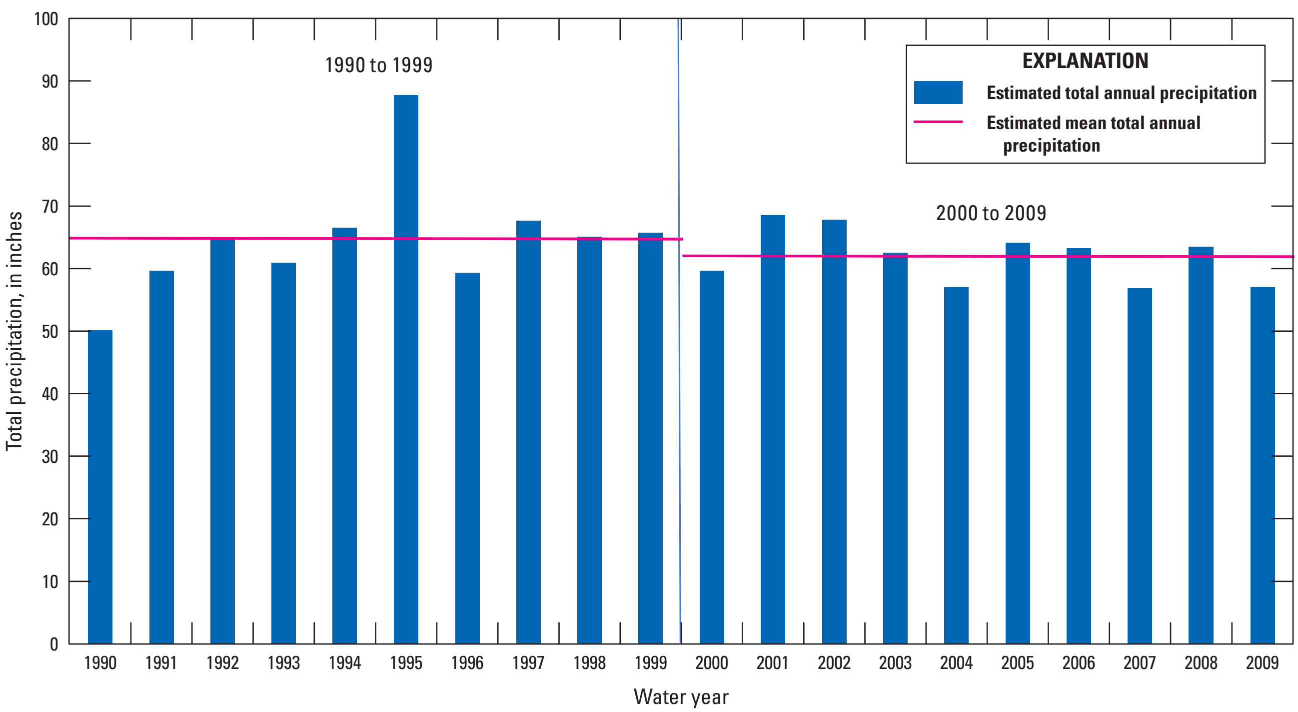


Figure 7. *A*, Selected National Oceanic and Atmospheric Administration, National Climatic Data Center stations in or near Miami-Dade County, and *B*, estimated total annual precipitation at these stations and estimated means of total annual precipitation during the periods 1990 to 1999 and 2000 to 2009.

the coast and several other isolated areas (appendix. 7; pl. 12). Water levels were lower by 0.5 to 1.15 ft in several broad areas (see –0.5- and –1.0-ft depression contours on pl. 12) including (1) near the intersection of the L-67A and the Miami Canals, (2) near the northeastern edge of the ENP, (3) in the vicinity of the new retention basins near the Frog Pond area, and (4) south and west of the S-12 water-control structures (S-12A–S-12D). The greatest decreases were 2.23 ft near the center of the Hialeah-Preston well field and 1.3 ft near the center of the Southwest well field. The greatest increase was 2.13 ft in the Alexander Orr well field. Mean May water levels increased by 0.63 ft near the center of the Northwest well field.

Mean October water levels during 2000–2009 were generally higher than during 1990–1999 in much of western Miami-Dade County, but were lower in a large part of eastern Miami-Dade County (pl. 13). Mean October water levels in the ENP were generally 0.01 to 0.89 ft higher during 2000–2009 than during 1990–1999, except in an area extending in a southwest direction from the edge of the Frog Pond area (appendix. 7; fig. 1; pl.13). In a large urbanized area in eastern Miami-Dade County, mean October water levels were generally lower by 0.01 to 0.73 ft (appendix. 7; pl. 13). The largest decreases from the 1990s to the 2000s were 2.68 ft and 1.84 ft within the Hialeah-Preston and Snapper Creek well fields, respectively. Mean October water levels increased by 1.31 ft near the center of the Northwest well field. Changes in water levels at the Hialeah-Preston and Northwest well fields may reflect reduced withdrawals that occurred at the Hialeah-Preston well field during1983–1992 (fig. 8). During this same time, withdrawals from the Northwest well field were increased to compensate.

Throughout most of the county, the 25th percentile of all water levels was 0.01 to 1.24 ft lower during 2000–2009 than during 1990–1999, except for a number of areas including (1) near the coast where water levels were up to 0.38 ft higher in some areas, (2) near the Northwest and Alexander Orr well fields where water levels were as much as 1.9 ft higher, and (3) near the Hialeah-Preston, Snapper Creek, and Southwest well fields where water levels were as much as 1.77 ft lower (appendix. 7; pl. 14). The 50th percentile of all water levels was 0.01 to 1.19 ft lower in most of the county during 2000–2009 than during 1990–1999, except (1) in an area in the central ENP where water levels were as much as 0.13 ft higher, (2) in two areas in the vicinity of the new retention basins near L-31N and the Frog Pond area where water levels were as much as 0.54 ft higher, (3) in an area near the C-111 canal where water levels were as much as 0.31 ft higher, (4) in several areas near the coast where water levels were as much as 0.29 ft higher, (5) near the center of the Alexander Orr well field where water levels were 2.35 ft higher, and (6) near the center of the Hialeah-Preston well field where water levels were 3.27 ft lower (appendix. 7; pl. 15). Following a similar pattern, the 75th percentile of all water levels was generally 0.01 to 1.01 ft lower in the 2000s than in the 1990s in much of the county. Exceptions include (1) near the coast and parts of the ENP in the vicinity of the new retention basins near L-31N and the Frog Pond area, where water levels were as much as 0.28 ft higher, (2) an area near the C-111 canal where water levels were as much as 0.24 ft higher, (3) near the center of the Alexander Orr well field where water levels were 2.9 ft higher, and (4) the Hialeah-Preston and Miami Springs well fields where water levels were as much as 3.22 ft lower (appendix. 7; pl. 16).

Frequency Analysis of Annual Maximums of Daily Water Levels During 1974–2009

In Miami-Dade County, the water table is so shallow and the bedrock so permeable that if rainfall is sufficient, the water table may extend above the land surface in some areas. The 80th, 90th, and 96th percentiles of the annual maximums of daily groundwater levels during 1974–2009 (a 35-year period) were computed to provide an indication of unusually high groundwater-level conditions (appendix 4). The 80th, 90th, and 96th percentiles of daily groundwater levels provide

Table 3. Summary of the differences in the computed statistics of water levels during the water-year periods 1990 to 1999 and 2000 to 2009, Miami-Dade County, Florida.

Description of summary statistic	May mean water levels (Plate 12)	October mean water levels (Plate 13)	25th percentile of all water levels (Plate 14)	50th percentile of all water levels (Plate 15)	75th percentile of all water levels (Plate 16)
Number of site files for which a difference could be computed	325	322	328	328	328
Average of all differences computed (feet)	–0.31	0.05	–0.17	–0.15	–0.10
Number of sites indicating an increase in water levels	51	195	63	75	107
Number of sites indicating a decrease in water levels	274	127	256	244	215
Ratio of site files indicating decreases, relative to those indicating increases	5.4	0.7	4.1	3.3	2.0

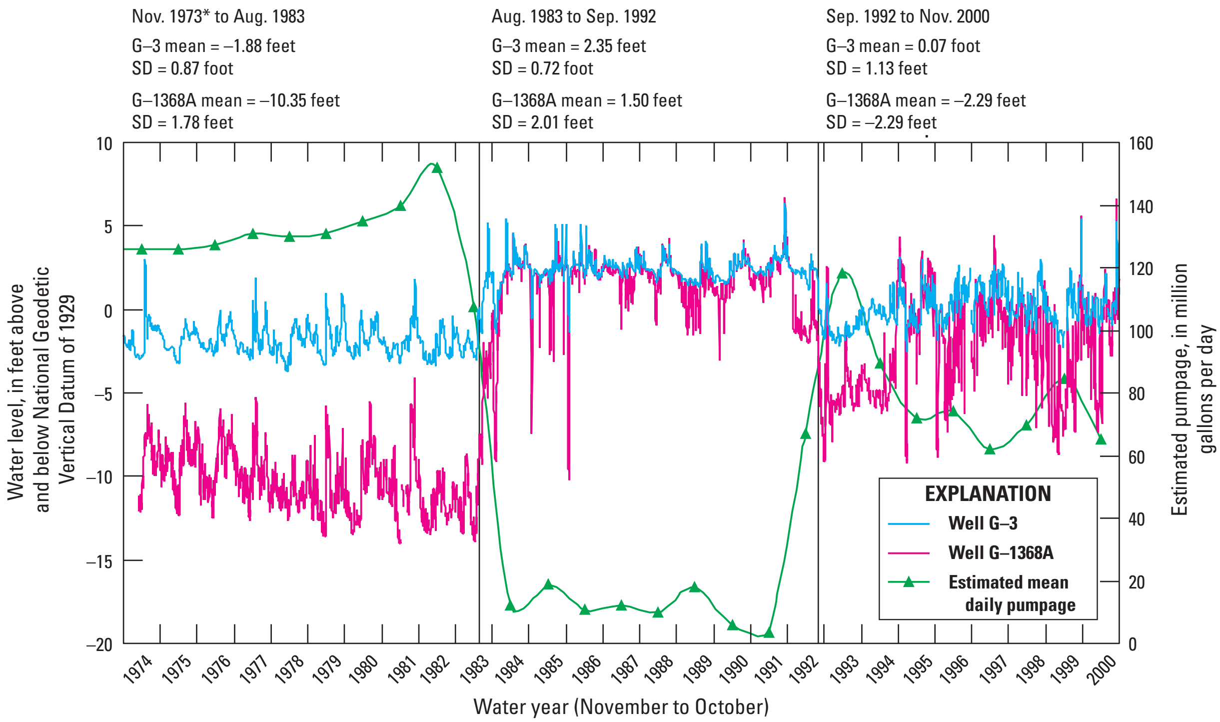


Figure 8. Hydrograph showing variation in water levels at wells G-3 and G-1368A and estimated mean daily pumpage based on annual pumpage totals during water years 1974–2000 in the Hialeah-Preston and Miami Springs well fields, of Miami-Dade County, Florida. [Modified from Prinos, 2005. Prinos (2005) defined a water year as November 1 to October 31, a wet season as June 1 to October 31, and a dry season as November 1 to May 31, which differ from the definitions of water year and seasons used for the current study. SD, standard deviation; see table 8–1 and figure 8–1 for well information]

an indication of the highest water levels that had a 20, 10, or 4 percent probability of occurring in a given year, during the period analyzed; however, these statistics are not intended to be used as a predictive tool. These percentiles can only provide an indication of water levels that can be considered relatively high, but cannot be used to predict the recurrence intervals of these high water levels. Percentiles of annual maximum water levels were computed only for groundwater monitoring sites with at least an 80 percent complete record, after individual years with less than an 80 percent complete record were eliminated. Only 46 monitoring sites met the completeness of record criteria; therefore, the results of this analysis are provided in a table (appendix 4) rather than as water-level maps.

Mapping Limitations

The amount of information available for the current mapping study was greater than that used for any previous studies. Nonetheless, the analysis was limited by (1) insufficiencies in the spatial coverage of the existing monitoring network, (2) insufficient information to evaluate temporal changes in the water management system in some areas, and (3) an inability to resolve differences in water levels that could be related to well depth. Some of these limitations could be addressed by improving the monitoring network.

Spatial Coverage of Monitoring Sites

The monitoring network used for the current study included more surface-water and groundwater monitoring sites than most of the previous water-table mapping studies in the study area, but the sites were not evenly distributed across the study area. Instead, wells are concentrated in selected areas. The monitoring network is large because it monitors the effects of a complex water management system as well as numerous well fields. The water management system (1) conveys surface water through canals, (2) preserves wetland areas, (3) stores rainfall runoff in detention ponds to reduce flooding and provide water supply during the dry season, and (4) maintains water levels in the aquifer near the coast to mitigate saltwater intrusion. During 1990–2009, the NPS, SFWMD, and the USGS added many new wells in the ENP and WCAs, which increased the spatial coverage.

Many of the previous mapping studies used more wells than the current study to estimate water-table altitudes near the well fields. For example, the study area of Cross and Love

(1942) covered only about one-twelfth the area of the current study (234 versus 2,944 mi^2) but used more groundwater monitoring wells than the current study (200 versus 189). Parker and others (1955) used about 60 groundwater monitoring wells to map the area around the Hialeah-Preston and Miami Springs well field, but the current study used only 7 wells in that area. Klein (1986a, 1986b) used about 15 wells within the cone of depression of the Northwest well field, whereas the current study used 4 wells in this same area. Swayze (1980f) used about 70 groundwater monitoring wells to map water levels near the Alexander Orr and Southwest well fields, whereas the current study had 12 wells in this area.

One of the reasons for the better spatial resolution of previous studies near the well fields is that they used data from both recorder-equipped and semi-annually measured groundwater monitoring wells. Most of the semi-annually measured wells were discontinued at the end of the 1994 water year. The current study used data from water-level recorders, which provide a better temporal understanding of changes in water levels, albeit given their fewer numbers, poorer spatial resolution.

Fewer data are available for water years 1990–1999 than for water years 2000–2009 (table 1). Many of the sites with data during 2000–2009 did not have sufficiently complete data during 1990–1999 for comparison of water levels during these two periods. The contour lines showing the changes in water levels between 1990–1999 and 2000–2009 are approximated in many places because of incomplete datasets. Inside the periphery of WCA 3A (fig. 1), most of the monitoring sites were recently installed. Of the 21 sites in WCA 3A, only 8 had 80 percent complete record, and 5 of these sites were clustered within a 0.04-mi^2 area.

Some levees did not have proximal monitoring sites located on both sides. Where water-level monitoring sites are widely separated and have a levee that passes between them, it is uncertain how much of the difference in water levels between the sites is related to distance and how much of the difference is caused by the levee itself.

Changes in the Water Management System

Changes to the water management system in some areas during 2000–2009 resulted in water-level statistics for these areas that represent a combination of pre- and post-construction levels; therefore, these statistics are not fully representative of either past or current water-level conditions in these areas. Retention basins were constructed near the Frog Pond area and near the L-31N canal beginning in 2002 (Muñoz-Carpena and Li, 2003), and a 500-cubic-foot-per-second (ft^3/s) pump station was installed. The locations of water-level contours in the Frog Pond area and near the L-31N canal are approximated because of these changes. Water deliveries to the ENP were increased under an interim operational plan that included maintaining high water levels in the C-111 canal, while keeping the gate at the S-175 structure closed (Muñoz-Carpena and Li, 2003). An initiative was undertaken between 2000 and 2011 to lower canal levels in the C-4 basin during floods through the installation of 600-ft^3/s pumps at structures S-25B and S-26 on the Tamiami and Miami Canals, respectively, and a 1,000-acre emergency detention basin (EDB) and supply canal to allow the diversion of flood water from the C-4 basin (Miami-Dade County Emergency Management, 2011). The bottom and sides of the C-4 canal were also smoothed during the project to improve water flow in the canal (Federal Emergency Management Agency, 2013). The changes in the C-4 basin to reduce flooding may have affected the 80th, 90th, and 96th percentiles of maximum annual water levels in this area, but may not have affected the contours shown on the maps because the changes were designed to reduce water levels only during extreme events, rather than during normal conditions.

To provide flood mitigation, the 8.5 Square Mile Area (fig. 1) underwent modifications to the hydrology of the area, including completion of the L-357W perimeter levee, the C-357 seepage canal, and the S-357 pump station in 2009 (Collis, 2012; World Heritage Centre, 2013). The pump station is designed to withdraw water from the south end of the C-357 canal into the L-357 detention area. Few data are available to use in evaluation of water levels in this area because monitoring in the C-357 canal began in November 2008 at the north end of the canal and in April 2009 at the pump station. The maps showing the 25th, 50th, and 75th percentiles of data from May, as well as the mean of May water levels, and the 25th percentile of water levels from all months, indicate a depression in water levels near the C-357 canal (pls. 1, 3, 4, 5, and 10). The maps showing the 50th to 75th percentiles of data indicate that water levels are mounded in the detention area (The mound is too small to see in the maps on pls. 9 and 11, see GIS layers of maps [appendix 7]). These observations are uncertain, however, because of the scarcity of data, particularly for the month of October. For this reason, the locations of contours in this area are typically approximated.

Numerous additional changes are being made to the water management system, which in some areas may limit the future applicability of the maps produced during this study. These changes include a project planned for the C-7 Basin to implement the same types of modifications that were made to the C-4 Basin (Federal Emergency Management Agency, 2013) and a project initiated in September 2009 to increase annual flow volumes to the ENP by 92 percent (U.S. Army Corps of Engineers, 2013). Within and near the ENP, a number of small projects have begun that affect the hydrology of the area. For example, a 1-mi segment of the Tamiami Trail has been replaced by a bridge that will allow sheet flow from the L-29 south into the Everglades. Water levels in the L-29 had previously been limited to 7.5 ft, but the changes made by this project will allow water levels in the canal of up to 8.5 ft (Brown and Leslie, 2013). The C-111 Spreader Canal Western Project, approved July 21, 2012, will “create a nine-mile hydraulic ridge adjacent to ENP that will keep more of the natural rainfall and water flows within Taylor Slough" (Baisden and Morrison, 2013). The C-111 Spreader Canal Western Project includes a 590-acre aboveground detention area in the Frog Pond area (fig. 1), installation of two 225-ft^3/s pumps, plugs in some existing canals, and modification of operations of existing water management protocols. Additional changes are planned to increase flow in the ENP:

- Installation of water-control structures S-355A and S-355B in the L-29 levee to allow water from WCA3B to flow south into the L-29 canal and then southward into the ENP under the new Tamiami Road bridge (Brown and Leslie, 2013).
- Replacement of an additional 2.6 mi of the Tamiami Trail roadbed with bridges (World Heritage Centre, 2013).
- Installation of new water-control structure, S-152, consisting of 10 60-in. culverts will allow a maximum flow of 750 ft^3/s in the L-67A levee to allow water to flow east from WCA3A into WCA3B (Baisden, 2013).
- Creation of a 3,000-ft gap in the L-67C levee and back-filling of several 1,000-ft segments of the L-67C canal to allow sheet flow from S-152 into WCA3B.
- Degradation of the 9 mi of the L-67 extension (L-67 EXT) levee to restore natural flow in this area.
- Installation of structures S-345A, B, and C through the L-67A and L-67C levees.
- Installation of structures S-349A, B, and C in the L-67A canal.
- Degradation of the remaining 5 mi of the L-67 extension (L-67 EXT) canal and levee.
- An increase in the pumping capacity of S-356 and modifications to the operating schedules of the water management system.

These changes will likely alter flows and water levels in parts of the ENP and the WCAs to the point that the maps completed during this study may be of limited use in parts of these areas in the near future. An increased frequency of map development combined with added monitoring in these areas may be required to keep pace with ongoing changes.

Importance of Monitoring Well Depth

Ideally, only shallow monitoring wells, screened no deeper than the minimum depth of the water table, would be used for this analysis because vertical head gradients may alter the water levels in deeper monitoring wells relative to shallow wells at the same location. Semi-confining beds in the Biscayne aquifer can cause water levels to differ in wells drilled to different depths. These effects are expected to be small; however, the potential effect of well depth or local geology conditions on water levels is not accounted for in this analysis.

The maps were created by using the assumption that the water table in the aquifer intersects surface-water features. In the current study, the contours showing the cones of depression in the aquifer are drawn so that they do not cross canals. Instead, the cones of depression are bisected by the canals. For example, monitoring well G-3074 is 40 ft deep and is on the bank of the Snapper Creek Canal, yet it typically has water levels that are lower than water levels in the canal. This difference in water levels may be caused by semi-confining beds beneath the canal that isolate water levels in the aquifer to some extent from water levels in the canal; therefore, at some depth below the canal, the separate cones of depression likely merge into one, as drawn by Lietz and others (2002). Nonetheless, because the goal of the current study was to map the water table itself, the canals are treated as divides.

Potential Monitoring Network Improvements

Future maps could be improved by adding monitoring sites at the Alexander Orr, Everglades Labor Camp, Florida City, Harris Park, Homestead Air Force Base, Leisure City, Naranja Park, Newton, Northwest, Southwest, and Wittkop Park well fields (fig. 1). Evaluation of the sizes and shapes of cones of depression depends upon having enough monitoring sites. Wells are already monitored on the periphery of the well-field protection areas of the Leisure City and Wittkop Park well fields, but continuous water-level data are needed from near the centers of these well fields to map the depths of the cones of depression. A new well near the Everglades Labor Camp is 0.3 mi from the supply wells, but water-level data from closer to the center of the well field are needed. The Alexander Orr and Southwest well fields each have only one monitoring well. Data from these wells provide an indication of the maximum depth of the cone of depression but do not enable detailed mapping of the shape of the cone of depression. New groundwater monitoring wells were installed near the Newton and West well fields in March 2009. Surface-water monitoring sites and a series of nested groundwater monitoring sites were installed at the Snapper Creek well field during 2010. Continued monitoring of some of these sites could aid future mapping efforts.

Eleven surface-water monitoring sites were added in the Frog Pond area and near L-31N between 2001 and 2009. The water-level data provided by these sites were generally less than 80 percent complete during the 2000–2009 period, but if these sites continue to be monitored, the data could benefit future studies. Additional surface-water and groundwater monitoring sites within and just outside the retention basins would be needed to evaluate water levels in this area for future maps. Eleven monitoring sites were installed in the EDB between 2004 and 2006. All but one of these sites are surface-water monitoring sites; most of these sites are at the water-control structures and are used to measure the changes in water levels across these structures. Some additional monitoring within the EDB, along its boundary, and just outside of it could improve the accuracy of maps in this area.

Monitoring on both sides of the L-67C levee could help with evaluating the effect of this levee on water levels in the area. The centers of the WCAs and the ENP are monitored, but additional monitoring closer to the levees would facilitate more accurate maps, particularly if automation of mapping is desired. Monitoring near the Lindgren Canal and headwaters of the Cutler Drain Canal could improve understanding of water levels in this area, which may be affected by water levels in the canal and the cone of depression of the Southwest well field (fig. 1). More monitoring on the east side of the levee at the L-28 canal could aid in evaluation of the change of water levels across this levee. Where changes are being made to the water management system, additional monitoring could be helpful, particularly where new detention basins, levees, and water-control structures or pumps are being installed (see the Changes in the Water Management System section of this report). Many new monitoring sites have been added near the Florida Power and Light cooling canal system, and monitoring data from these sites could improve future maps if the data are made available for use. Installation of new monitoring sites in advance of changes to the water management system could create a baseline for evaluating future changes in water levels.

Summary and Conclusions

Maps of the altitude of the water table in Miami-Dade County are necessary for urban planning and development. Creation of these water-table maps involved (1) data compilation and editing, (2) statistical analysis and evaluation of the effects of missing records on analytical results, (3) development of the geographic information system (GIS) framework for generating automated contours, and (4) manual modifications of the contours based on an understanding of the hydrology of the system.

As part of a study conducted by the U.S. Geological Survey, in cooperation with the Miami-Dade County Department of Regulatory and Economic Resources, site coordinates, summary water-level statistics, and completeness of record statistics were imported into a GIS. Water levels were interpolated between monitoring sites in the canals and assigned to a series of relatively densely spaced locations (called control points) that traced the course of each primary canal. The values of water-level statistics from selected tail-water monitoring sites at water-control structures nearest to the coast were assigned to a series of control points that traced the shape of the coastline. The canal and shoreline control points were merged with the information from surface-water and groundwater monitoring sites to create a GIS shapefile. The triangulated irregular network interpolation method was used to create a raster surface that could be contoured. Contours were created by using the ArcGIS tool Surface Contour. All of the contours had to be manually smoothed on a segment-by-segment basis to ensure that the contours did not overlap and that they passed through water-control structures where necessary. Where insufficient monitoring data were available for mapping, manual modifications to automatically generated contours were made and contours were eliminated or approximated as necessary.

Sixteen water-level maps were created that show (1) the mean of daily water levels measured during October and May of the water years 2000–2009, (2) the 25th, 50th, and 75th percentiles of daily water levels measured during October, May, and all months during this same period, and (3) the differences in October and May mean water levels, as well as the differences in the percentiles of water levels from all months that occurred between the 1990–1999 and 2000–2009 periods. The 80th, 90th, and 96th percentiles of the annual maximums of daily water levels during the 1974–2009 period were computed and provide an indication of water levels that can be considered unusually high.

The ability to evaluate changes in water levels between the 1990–1999 and 2000–2009 periods is limited in some areas because most of the monitoring sites did not have a sufficiently complete (80 percent) records for both of these periods. The quality of the analysis was limited by (1) deficiencies in spatial coverage, (2) the combination of pre- and post-construction water levels in areas where retentions basins, canals, levees, or water-control structures were installed or removed, (3) an inability to address the potential effects of the vertical hydraulic head gradient in the aquifer on water levels collected in wells of different depths, and (4) an inability to correct for the differences between daily water-level statistics. Although these factors limited our ability to depict differences in water levels between 1990–1999 and 2000–2009, the resulting maps indicate that water levels near the coast were generally higher during 2000–2009 and that water levels were generally lower except during October.

The applicability of the maps may be limited in some areas where the changes currently being made to the water management system are extensive. Recently installed monitoring sites will improve the accuracy of future water-level maps. Additional monitoring in the following areas could improve future maps: (1) the Frog Pond and the L-31N canal, (2) the Lindgren Canal and headwaters of the Cutler Drain Canal, (3) the boundaries of the ENP and WCAs, (4) on both sides of the L-67C levee, and (5) in areas where changes are being made to the water management system. The cones of depression of the Alexander Orr, Everglades Labor Camp, Florida City, Harris Park, Homestead Air Force Base, Leisure City, Naranja Park, Newton, Northwest, Southwest and Wittkop Park well fields could possibly be better defined if additional monitoring sites were added.

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Appendix 1. Analytical Considerations

Changes in water management and water usage, as well as temporal and spatial limitations in data prevented implementation of some approaches that were initially considered for the current study. Statistical approaches that were considered and rejected include (1) a flood-frequency analysis, (2) estimation of missing records by establishing correlations between proximal sites, (3) compensation for the difference between the maximum and mean of daily water levels, and (4) removal of long-term trends from water-level data prior to analysis of statistics.

Consideration of a Flood-Frequency Analysis

As part of this study, a flood-frequency analysis was considered but not implemented because in this study area some of the assumptions of this analysis are most likely violated. The U.S. Army Corps of Engineers (1993) states that when conducting flood-frequency analysis, "…values should be adjusted to natural (unimpaired) conditions before an analytical frequency analysis is made" and that "…care should be exercised when there has been significant change in upstream storage regulation during the period of record to avoid combining unlike events into a single series. In such a case, the entire record should be adjusted to a uniform condition…" and that "projects that have existed in the past have affected the rates and volumes of flows, and the recorded values must be adjusted to reflect uniform conditions in order that the frequency analysis will conform to the basic assumption of homogeneity." Similarly, the Hydrology Subcommittee (1982) explains that flood-flow frequency analyses are based on the assumptions that (1) flood flows are not affected by climatic trends or cycles, (2) flow rates are a sample of random and independent events, (3) the record is not affected by different types of flooding events, such as floods resulting from snowmelt rather than rainfall, and (4) only records that represent relatively constant watershed conditions should be used for frequency analysis.

The assumption that flows are not affected by climatic trends or cycles is likely violated in the study area because for "South Florida in particular, the influences of the low-frequency climate phenomena, such as the El Nino Southern Oscillation (ENSO) and the Atlantic Multi-decadal Oscillation (AMO), have been identified with aggregate annual or seasonal rainfall variations" (Kwon and others, 2009). The assumption that values should be adjusted to natural conditions is violated because the natural hydrology of south Florida has been and is being extensively altered by the installation of water-control structures, canals, pump stations, levees, and well fields (see the Changes in the Water Management System section of this report) and because changes in this infrastructure and operation of the hydrologic management system have been ongoing. These changes have been so extensive and so numerous that adjusting all data to natural or uniform conditions for analysis would be impractical.

The assumption that only records that represent relatively constant watershed conditions should be used for frequency analysis is violated because numerous changes to the water management system have been made during the last 100 years, some of which occurred during the current study, and many additional changes are planned (see the Changes in the Water Management System section of this report). Changes in water levels caused by the C-4 Basin initiative and variations in withdrawals at the Hialeah-Preston and Miami Springs well fields are just two of the many extensive modifications to the hydrology of Miami-Dade County that violate the assumptions described by the Hydrology Subcommittee (1982) and the U.S. Army Corps of Engineers (1993). The purpose of the C-4 Basin initiative (see Changes in the Water Management System section of this report) was to reduce flooding in this area; therefore, the extreme high water events that would be evaluated by the flood-frequency analysis would almost certainly be affected by these changes. Water levels near the Hialeah-Preston and Miami Springs well fields have been affected by changes in withdrawals at these well fields (see figure 8 in the main report). Mean water levels in wells G-3 and G-1368A during August 1983–September 1992 are about 4 and 12 ft higher, respectively, than during November 1973–August 1983 and about 2 and 4 ft higher, respectively, than during September 1992–November 2000. While maximum water levels in both wells were frequently higher than 3 ft above NGVD 29 during August 1983–September 1992, they were never higher than this level during November 1973–August 1983 and were rarely higher than this during September 1992–November 2000. Adjusting these data to unimpaired or uniform conditions is impractical because withdrawals at the well field were different each year (see figure 8 in the main report).

During this study period, many additional modifications were made to hydrologic management in Miami-Dade County, including (1) changes in withdrawals at the Northwest well field that mirror those at the Hialeah-Preston and Miami Springs well fields, (2) installation and modification of berms along the Tamiami Canal to prevent flooding, (3) installation of French drains designed to increase groundwater recharge and reduce flooding, (4) redesign of the management structure in the Frog Pond area near Homestead, including installation of new pumps, levees, and water-control structures, (5) changes in the management of water levels at Lake Okeechobee, which is a water reservoir for southern Florida, and (6) implementation of water-use restrictions for several periods of differing durations to reduce withdrawals from the aquifer. Additional changes were made near the end of, or shortly after, this study (see the Changes in the Water Management System section of this report).

Verdi and Dixon (2011) did not attempt to compute flood-frequency estimates for most canals south of Lake Okeechobee, rather, "[s]treamgages were only considered for the analysis if 10 or more years of peak-flow data were available in the record, and if peak flows were not substantially affected by trends, dam regulation, flood-retarding reservoirs, tides, urbanization, or channelization."

Another reason for not computing flood-frequency analysis in south Florida is that most of the sites with sufficient data from water years 1974–2009 are groundwater monitoring wells. The method described in Bulletin 17B of the Hydrology Subcommittee (1982) involves fitting a Pearson Type II distribution to the logarithms of the yearly maximum water levels. This method, however, was originally developed for evaluating flood flow frequencies in natural streams rather than the groundwater levels to which they were applied. Yet, different types of monitoring sites (such as river, canal, lake, or groundwater monitoring sites) may have different types of frequency distributions. For example, the Water Information Coordination Program, Advisory Committee on Water Information (2013) cautions that unlike natural streams,

> "…lake levels do not have the natural zero value and the extreme variability and skewness of flood flows so the use of log transforms of lake levels may not be necessary or beneficial. Thus, Bulletin 17-B should not be applied blindly or dogmatically to lake levels… No distribution has been established for lake level frequency analysis, as the log-Pearson III distribution for stream flow peaks. Extrapolate the lake-level frequency curve only with extreme caution: the form of the lake-level frequency curve is not known and lake levels may be much more sensitive to lake-shore topography than the peak flows are to flood plain topography."

Similar to lakes, groundwater monitoring wells may not have a natural zero, and some of the maximum annual groundwater levels in the study area are negative.

Estimation of Missing Record

If water-level data from proximal sites are highly correlated, missing record can theoretically be estimated. Estimation of missing record has already been done for short periods of record in the WCAs and for some surface-water monitoring sites with missing record where water levels are related to water levels collected at sites that are upstream or downstream of the site. One of the approaches considered at the onset of this study was to estimate missing record using correlation with water levels at other sites.

The data from most of the groundwater monitoring sites in Miami-Dade County are generally not highly correlated enough to be used for estimating missing values, however, as indicated by a study to evaluate the extent of correlation in water levels by Prinos (2005). Data from the majority of the wells in the network generally were not correlated with that of other wells during the wet and dry seasons with an average coefficient of 0.95 or greater, and in some instances, the temporal variation in seasonal correlation between water-level data of wells did not remain constant during the period of record (Prinos, 2005; fig. 1–1). Temporal variation in the correlations of water-level data is a great concern for the current study because the statistical analyses are being used to compare water levels during different periods. Most of the sites in the ENP and the WCAs do not have complete records for the period evaluated for this study. Newly installed monitoring sites cannot be used to compute correlation coefficients for estimation of water levels prior to their installation.

Adjusting Daily Values

Ideally, the water table should be mapped by using the same daily water-level statistic from all sites, but the USGS usually computes the daily mean water level from surface-water monitoring sites and the daily maximum water level from groundwater monitoring sites. The daily water-level statistics could not be recomputed so that the same daily statistic could be used from all sites because the hourly water levels had not been computed for most of the period of examination. Estimating daily maximum groundwater levels from daily mean water levels, or the reverse, was impractical because in the highly permeable Biscayne aquifer, the differences between the daily maximum and daily mean water levels vary, depending on the intensity of each rainfall event (fig. 1–2). During periods without rainfall, the mean and the maximum water levels in wells are nearly identical, but during rainfall events, the differences between mean and maximum water levels vary spatially and temporally, in a way that could not be adjusted for unless every monitoring site had its own rainfall gage and a rating between rainfall and groundwater level were determined for each site. No correction factor or equation was found that could adequately correct for these differences. The differences in maximum and mean water levels shown in figure 1–2 are from three sites in different parts of Miami-Dade County: well F-239 is near the Hialeah-Preston and Miami Springs well fields, well G-620 is in the ENP, and well G-3356 is in southeast Miami-Dade County. On average, the difference between the daily maximum and mean water levels at these sites was only 0.02 to 0.07 ft, but during the wet season, when the intensity and frequency of rainfall increase, the variability of the differences between daily water-level statistics increased (fig. 1–2). Maximum differences ranged from 0.68 to 1.49 ft. Although this issue could not be addressed during the current study, the USGS began publishing computed hourly values for groundwater sites beginning on October 1, 2007. These data will allow the computation of the same daily water-level statistic from all sites.

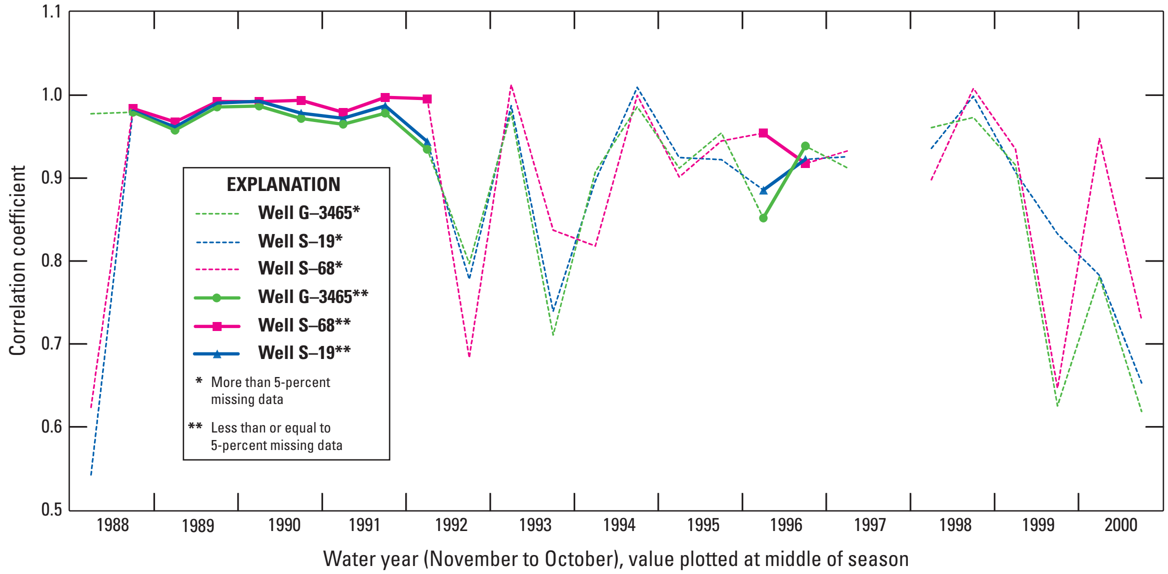

Figure 1–1. Graph showing variation in seasonal correlation between water-level data from well G-3466 and from wells G-3465, S-19, and S-68 in Miami-Dade County, Florida, during water years 1988–2000. [Modified from Prinos (2005). Prinos (2005) defined a water year as November 1 to October 31, a wet season as June 1 to October 31, and a dry season as November 1 to May 31, which differ from the definitions of water year and seasons used for the current study.]

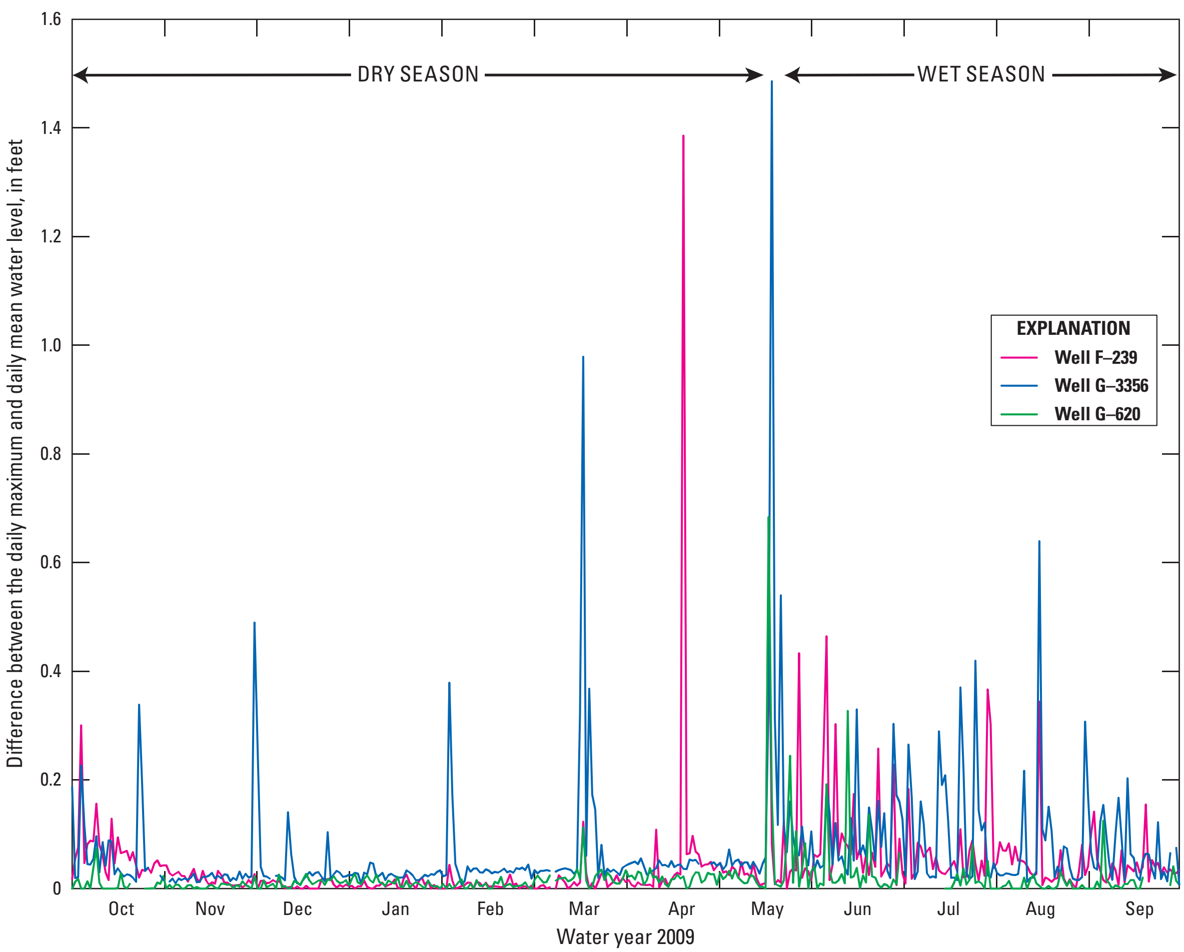

Figure 1–2. Differences between the daily maximum and daily mean water levels during the 2009 water year at selected sites in Miami-Dade County, Florida.

Removing Long-Term Trends

In some instances, a long-term trend needs to be removed from water-level data prior to analysis. If, for example, a site has a large, long-term, unidirectional, and linear trend in water levels, and if the goal of the analysis is to understand the normal annual range in water levels, then adjusting for this trend prior to computing the mean annual range would be important because the trend would increase this range. Prinos and others (2002) found that many groundwater monitoring wells open to the Biscayne aquifer have small upward trends (0.01 to 0.04 foot per year) in water levels during 1974–1999. Prinos and others (2014), however, showed that during 1974–1990 there were a number of extended droughts and that since that time there have been far fewer droughts. The small upward trends in water levels during 1974–1999 identified by Prinos and others (2002), therefore, appear to be related to this pattern of drought and wet years, and so they were not removed because these variations in rainfall may be tied to climate cycles (Kwon and others, 2009), rather than long-term unidirectional changes.

Some of the largest temporal changes in water levels in Miami-Dade County are abrupt, and they result from shifting withdrawals between well fields (see figure 8 in the main report). These changes in water levels are not unidirectional or linear, and they may be repeated as a result of future changes in withdrawals; therefore, removing these trends would be inappropriate. Long-term trends were not removed from the data prior to computing the means and percentiles of water levels during the 1990–1999 and 2000–2009 periods because this would remove part of the difference that this analysis was intended to detect and also because most of the long-term changes in water levels appear to be cyclic or readily reversible rather than unidirectional. For these reasons, the trends were not removed prior to computing percentiles of the annual maximums of daily water levels.

References Cited

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Appendix 2. Raw Data

Raw data, consisting of daily water-level data recorded at monitoring sites in or near Miami-Dade County, Florida, during the 1974–2009 water years, collected by the USGS, NPS, and SFWMD, are provided as a U.S. Geological Survey data release (Prinos and Dixon, 2016). The row titled “Notes” describes some of the edits that were made, such as elimination of sites and merging of data collected at the same site. Appendix 2 provides the data prior to these edits. Table 3–1 provides the data after these and other edits were made.

See Prinos and Dixon (2016), file Table 2–1, available at http://dx.doi.org/10.5066/F78S4N0D.

Reference Cited

Prinos, S.T., and Dixon, J.F., Data, statistics, and geographic information system files, pertaining to mapping of water levels in the Biscayne aquifer, Water Conservation Areas, and Everglades National Park, Miami-Dade County, Florida, 2000–2009—Scientific data associated with USGS SIR 2016–5005: U.S. Geological Survey Data Release, http://dx.doi.org/10.5066/F7M61H9W.

Appendix 3. Edited Data

Edited daily water-level data recorded at monitoring sites in and near Miami-Dade County, Florida, during the 1974–2009 water years are provided as a U.S. Geological Survey data release (Prinos and Dixon, 2016). The row titled "Notes" describes some of the edits that were made, such as merging of data collected at the same site. The SFWMD sometimes has two or more database files for the same site that are listed under separate DBKEYs. Some of these files were merged, and a new DBKEY is listed in the appendixes that is a combination of the DBKEYs of the merged files.

See Prinos and Dixon (2016), file Table 3–1, available at http://dx.doi.org/10.5066/F7513W9F.

Reference Cited

Prinos, S.T., and Dixon, J.F., Data, statistics, and geographic information system files, pertaining to mapping of water levels in the Biscayne aquifer, Water Conservation Areas, and Everglades National Park, Miami-Dade County, Florida, 2000–2009—Scientific data associated with USGS SIR 2016–5005: U.S. Geological Survey Data Release, http://dx.doi.org/10.5066/F7M61H9W.

Appendix 4. Percentiles of the Annual Maximums of Daily Water Levels

The 80th, 90th, and 96th percentiles of the annual maximums of daily water levels recorded at monitoring sites in and near Miami-Dade County, Florida, during the 1974–2009 water years are provided as a U.S. Geological Survey data release (Prinos and Dixon, 2016).

See Prinos and Dixon (2016), file Table 4–1, available at http://dx.doi.org/10.5066/F71834K3.

Reference Cited

Prinos, S.T., and Dixon, J.F., Data, statistics, and geographic information system files, pertaining to mapping of water levels in the Biscayne aquifer, Water Conservation Areas, and Everglades National Park, Miami-Dade County, Florida, 2000–2009—Scientific data associated with USGS SIR 2016–5005: U.S. Geological Survey Data Release, http://dx.doi.org/10.5066/F7M61H9W.

Appendix 5. Statistics of Daily Water Levels Used to Create Maps of the Water Table in Miami-Dade County, Florida

The mean and the 25th, 50th, and 75th percentiles of daily water levels during the 2000–2009 water-year period computed from measurements recorded during (1) October, (2) May, and (3) all months, as well as the differences between these statistics during the 1990–1999 and 2000–2009 water years are provided through a U.S. Geological Survey data release (Prinos and Dixon, 2016).

See Prinos and Dixon (2016), file Table 5–1, available at http://dx.doi.org/10.5066/F7WH2N2C.

Reference Cited

Prinos, S.T., and Dixon, J.F., Data, statistics, and geographic information system files, pertaining to mapping of water levels in the Biscayne aquifer, Water Conservation Areas, and Everglades National Park, Miami-Dade County, Florida, 2000–2009—Scientific data associated with USGS SIR 2016–5005: U.S. Geological Survey Data Release, http://dx.doi.org/10.5066/F7M61H9W.

Appendix 6. Statistics of Daily Water Levels

The (1) mean, (2) count, (3) maximum, (4) minimum, (5) percentage of complete record, (6) standard deviation, (7) number of standard deviations of the minimum and maximum from the mean, and (8) variance of daily water levels recorded at monitoring sites in and near Miami-Dade County, Florida, during the 1974–2009 period are provided in a U.S. Geological Survey data release (Prinos and Dixon, 2016).

See Prinos and Dixon (2016), file Table 6–1, available at http://dx.doi.org/10.5066/F7RR1W96.

Reference Cited

Prinos, S.T., and Dixon, J.F., Data, statistics, and geographic information system files, pertaining to mapping of water levels in the Biscayne aquifer, Water Conservation Areas, and Everglades National Park, Miami-Dade County, Florida, 2000–2009—Scientific data associated with USGS SIR 2016–5005: U.S. Geological Survey Data Release, http://dx.doi.org/10.5066/F7M61H9W.

Appendix 7. Geographic Information System Files

Geographic Information System (GIS) files depicting the contours from and data points shown in plates 1–16 are also provided as downloadable GIS layer filers through a U.S. Geological Survey Data Release (Prinos and Dixon, 2016). Metadata are included in these files. Users should view the Federal Geographic Data Committee (FGDC) metadata because it provides important distribution information that other metadata formats do not include. The metadata describe the conditions of usage. The column "LineType" in the attribute table should be used to indicate where the lines are shown as solid or dashed and where contours should be shown as depressions. The column "Contour" provides the altitude of each contour referenced to the NAVD 88.

An ArcGIS point file (AllSites.shp) is also provided in the GIS files that includes the data provided in appendix 5. This file provides the statistical results that were used to create the contours. These statistical results are provided in attribute table columns that correspond to each map plate. These columns are labeled Map1–Map16 and are described in Prinos and Dixon (2016, table 7–1). Six columns are provided that can be used to determine the completeness of record for each site during the periods evaluated. The columns are labeled beginning with letters "PrctCmp" or "PcntCmp." To confirm that users are depicting the contours or points correctly, users should compare their maps to plates 1–16 provided as part of this report.

Reference Cited

Prinos, S.T., and Dixon, J.F., Data, statistics, and geographic information system files, pertaining to mapping of water levels in the Biscayne aquifer, Water Conservation Areas, and Everglades National Park, Miami-Dade County, Florida, 2000–2009—Scientific data associated with USGS SIR 2016–5005: U.S. Geological Survey Data Release, http://dx.doi.org/10.5066/F7M61H9W.

See Prinos and Dixon (2016), files:
Map 01 (http://dx.doi.org/10.5066/F7GF0RJQ)
Map 02 (http://dx.doi.org/10.5066/F7BP00VT)
Map 03 (http://dx.doi.org/10.5066/F76W985D)
Map 04 (http://dx.doi.org/10.5066/F73776SD)
Map 05 (http://dx.doi.org/10.5066/F7ZG6QBK)
Map 06 (http://dx.doi.org/10.5066/F7TQ5ZMV)
Map 07 (http://dx.doi.org/10.5066/F7PZ56WH)
Map 08 (http://dx.doi.org/10.5066/F7K64G42)
Map 09 (http://dx.doi.org/10.5066/F7FF3QFS)
Map 10 (http://dx.doi.org/10.5066/F79S1P3B)
Map 11 (http://dx.doi.org/10.5066/F7610XDC)
Map 12 (http://dx.doi.org/10.5066/F72805QG)
Map 13 (http://dx.doi.org/10.5066/F7XG9P7N)
Map 14 (http://dx.doi.org/10.5066/F7SQ8XGG)
Map 15 (http://dx.doi.org/10.5066/F7NZ85QP)
Map 16 (http://dx.doi.org/10.5066/F7J67F14)
Points for Maps (http://dx.doi.org/10.5066/F7DJ5CP8)
Table 7–1 (http://dx.doi.org/10.5066/F7N014MM)

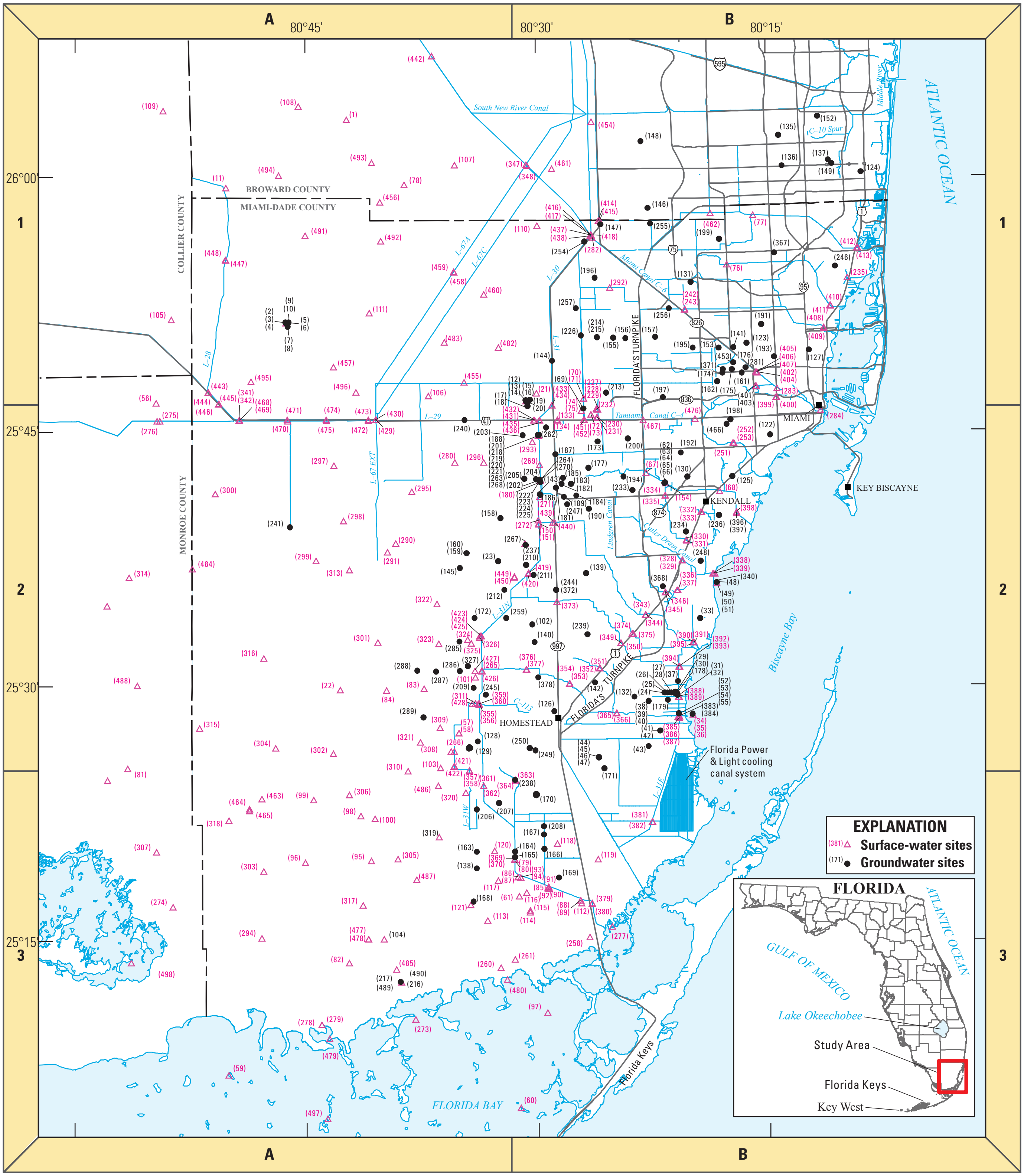
Table 7–1. Description of columns in the ArcGIS point file "MapStats." This file can be downloaded from http://dx.doi.org/10.3133/sir20165005.

[SFWMD, South Florida Water Management District]

Column name	Description
OBJECTID	A unique identifier for the map point
Longitude	Longitude
Latitude	Latitude
SiteName	Site Name
SiteID	Site identifier or SFWMD DBKEY
Provider	Data Provider
DailyStat	Daily water level statistic
SiteType	Site type
OrigVertDatum	Original vertical datum
FinVertDatum	Final vertical datum
ConFactor	Vertical conversion factor used (feet)
Map1	Mean of May water levels during the 2000–2009 water years
Map2	Mean of October water levels during the 2000–2009 water years
Map3	25th percentile of May water levels during the 2000–2009 water years
Map4	50th percentile of May water levels during the 2000–2009 water years
Map5	75th percentile of May water levels during the 2000–2009 water years
Map6	25th percentile of October water levels during the 2000–2009 water years
Map7	50th percentile of October water levels during the 2000–2009 water years
Map8	75th percentile of October water levels during the 2000–2009 water years
Map9	50th percentile of water levels from all months during the 2000–2009 water years
Map10	25th percentile of water levels from all months during the 2000–2009 water years
Map11	75th percentile of water levels from all months during the 2000–2009 water years
Map12	Difference between May mean water levels from the water-year periods 1990–1999 and 2000–2009
Map13	Difference between October mean water levels from the water-year periods 1990–1999 and 2000–2009
Map14	Difference between the 25th percentiles of all water levels for water-year periods 1990–1999 and 2000–2009
Map15	Difference between the 50th percentiles of all water levels for water-year periods 1990–1999 and 2000–2009
Map16	Difference between the 75th percentiles of all water levels for water-year periods 1990–1999 and 2000–2009
PrctCmpAll0009	Percentage of complete water-level record during the 2000 to 2009 water years
PrctCmpMay0009	Percentage of complete water-level record for the months of May during the 2000 to 2009 water years
PrctCmpOct0009	Percentage of complete water-level record for the months of October during the 2000 to 2009 water years
PrctCmpAll9099	Percentage of complete water-level record during the 1990 to 1999 water years
PcntCmpMay9099	Percentage of complete water-level record for the months of May during the 1990 to 1999 water years
PcntCmpOct9099	Percentage of complete water-level record for the months of October during the 1990 to 1999 water years
Notes	Additional information concerning the site or data

Appendix 8. Index Map of Sites Used for Analysis

An index map of sites used for this study is provided as a supplemental file (fig. 8–1; http://dx.doi.org/10.3133/sir20165005). Associated with this map is table 8–1 that provides (1) the site name, (2) the site identifier or SFWMD DBKEY, (3) the site type, (4) map grid location, and (5) the map index number. The index map is gridded into two columns, designated A and B, and three rows, designated 1–3. Table 8–1 and figure 8–1 can help users find the location of a given site.



Base from U.S. Geological Survey digital data.
State Plane coordinate system, HARN, NAD83

0 5 10 MILES
0 5 10 KILOMETERS

Figure 8–1. Variation in water levels at wells G-3 and G-1368A and estimated mean daily pumpage based on annual pumpage totals during water years 1974–2000 in the Hialeah-Preston and Miami Springs well fields, of Miami-Dade County, Florida. [Larger version of this map can be downloaded from http://dx.doi.org/10.3133/sir20165005.]

Table 8–1. Index of sites used to map the water table of the Biscayne aquifer in Miami-Dade County, 2000–2009.

[GW, groundwater; SW, surface water]

Site name	Site identifier	Site type	Index map grid location	Index number
3A-5 IN WATER CONSERVATION AREA 3A	260324080421900	SW	A1	1
3AS3W1_G	M6884	GW	A1	2
3AS3W1_G	PT035	GW	A1	3
3AS3W1_H	M6883	SW	A1	4
3AS3W2_G	M6885	GW	A1	5
3AS3W2_G	PT036	GW	A1	6
3AS3W3_G	M6887	GW	A1	7
3AS3W3_G	PT037	GW	A1	8
3AS3W4_G	M6886	GW	A1	9
3AS3W4_G	PT038	GW	A1	10
3A-SW_B	JA342	SW	A1	11
3BS1W1_G	M6890	GW	B1	12
3BS1W1_G	PT039	GW	B1	13
3BS1W1_H	M6889	SW	B1	14
3BS1W2_G	M6891	GW	B1	15
3BS1W2_G	PT040	GW	B1	16
3BS1W3_G	M6892	GW	B2	17
3BS1W3_G	PT041	GW	B2	18
3BS1W4_G	M6893	GW	B1	19
3BS1W4_G	PT042	GW	B1	20
3B-SE_B	15934	SW	B1	21
A13	A13	SW	A2	22
ANGEL	7103	GW	A2	23
BBCMW1	VM883	GW	B2	24
BBCMW2	VM885	GW	B2	25
BBCMW3	VM887	GW	B2	26
BBCMW4G1	VM889	GW	B2	27
BBCMW4G2	VM891	GW	B2	28
BBCMW5G1	VM893	GW	B2	29
BBCMW5G2	VM895	GW	B2	30
BBCMW6G1	VM897	GW	B2	31
BBCMW6G2	VM899	GW	B2	32
BBCW1	TA890	GW	B2	33
BBCW10	UO853	SW	B2	34
BBCW10GW1	TA918	GW	B2	35
BBCW10GW2	TA920	GW	B2	36
BBCW2	TA892	GW	B2	37
BBCW3GW1	TA894	GW	B2	38
BBCW3GW2	TA896	GW	B2	39
BBCW3GW2	VB275	GW	B2	40
BBCW4	TA898	GW	B2	41
BBCW4	VB276	GW	B2	42
BBCW5	TA900	GW	B2	43

Table 8–1. Index of sites used to map the water table of the Biscayne aquifer in Miami-Dade County, 2000–2009.—Continued

[GW, groundwater; SW, surface water]

Site name	Site identifier	Site type	Index map grid location	Index number
BBCW6GW1	TA902	GW	B2	44
BBCW6GW1	VB277	GW	B2	45
BBCW6GW2	TA904	GW	B2	46
BBCW6GW2	VB278	GW	B2	47
BBCW8	UO851	SW	B2	48
BBCW8GW1	TA910	GW	B2	50
BBCW8GW1	W3858	GW	B2	49
BBCW8GW2	TA912	GW	B2	51
BBCW9GW1	TA914	GW	B2	52
BBCW9GW1	VB279	GW	B2	53
BBCW9GW2	TA916	GW	B2	54
BBCW9GW2	VB280	GW	B2	55
BCNPA9	16761	SW	A1	56
BERM3_H	PT648	SW	A2	57
BERM3_T	PT650	SW	A2	58
BK	BK	SW	A3	59
BN	BN	SW	B3	60
C-111 WETLAND, EAST OF FIU LTER TSPH5	251740080311200	SW	B3	61
C2GSW1	OU844	SW	B2	62
C2GSW1_GW1	OU846	GW	B2	63
C2GSW1_GW2	OU848	GW	B2	64
C2GW1_GW1	OU427	GW	B2	65
C2GW1_GW2	OU836	GW	B2	66
C2SW1	OU840	SW	B2	67
C2SW2	OU842	SW	B2	68
C4GW1	TA539	GW	B2	69
C4SW1	TS275	SW	B1	70
C4SW1	TV982	SW	B1	71
C4SW2	TA608	SW	B2	73
C4SW2	TV983	SW	B2	72
C4SW3	TA541	SW	B2	75
C4SW3	TV984	SW	B2	74
C8.S28Z	4144	SW	B1	76
C9.S29Z	4146	SW	B1	77
CA3AVG	15943	SW	A1	78
CANAL 111 AT S-18-C NEAR FLORIDA CITY, FL	2290769	SW	B3	79
CANAL 111 AT S-18-C NEAR FLORIDA CITY, FL	2290769	SW	B3	80
CN	CN	SW	A2	81
CP	CP	SW	A3	82
CR2	CR2	SW	A2	83
CR3	CR3	SW	A2	84
CT27R	CT27R	SW	B3	85
CT50A	CT50A	SW	B3	86

Table 8–1. Index of sites used to map the water table of the Biscayne aquifer in Miami-Dade County, 2000–2009.—Continued

[GW, groundwater; SW, surface water]

Site name	Site identifier	Site type	Index map grid location	Index number
CT50R	CT50R	SW	B3	87
CV1N	CV1N	SW	B3	88
CV1NR	CV1NR	SW	B3	89
CV5N	CV5N	SW	B3	90
CV5NR	CV5NR	SW	B3	91
CV5S	CV5S	SW	B3	92
CV9N	CV9N	SW	B3	93
CV9NR	CV9NR	SW	B3	94
CY2	CY2	SW	A3	95
CY3	CY3	SW	A3	96
DK	DK	SW	B3	97
DO1	DO1	SW	A3	98
DO2	DO2	SW	A3	99
DO3	DO3	SW	A3	100
DS3	PT601	SW	A2	101
DUCLOS_G	DU535	GW	B2	102
E112	E112	SW	A2	103
E146	E146	SW	A3	104
EDEN 1 IN BIG CYPRESS NATIONAL PRESERV	255138080534201	SW	A1	105
EDEN 10 IN WATER CONSERVATION AREA 3-B	254707080370201	SW	A1	106
EDEN 12 IN WATER CONSERVATION AREA 3-A	260042080351701	SW	A1	107
EDEN 14 IN WATER CONSERVATION AREA 3-A	260410080452701	SW	A1	108
EDEN 6 IN BIG CYPRESS NATIONAL PRESERV	260355080541401	SW	A1	109
EDEN 7 IN WATER CONSERVATION AREA 3-B	255708080295501	SW	B1	110
EDEN 8 IN WATER CONSERVATION AREA 3-A	255200080405001	SW	A1	111
EP1R	EP1R	SW	B3	112
EP9	EP9	SW	A3	113
EPGW	EPGW	SW	B3	114
EPSW	EPSW	SW	B3	115
EVER6	EVER6	SW	B3	116
EVER7	EVER7	SW	A3	117
EVER8	EVER8	SW	B3	118
EVERGLADES 1 IN C-111 BASIN NR HOMESTE	251946080254800	SW	B3	119
EVERGLADES 4 IN C-111 BASIN NR HOMESTE	252036080324300	SW	A3	120
EVERGLADES 5A IN C-111 BASIN NR HOMEST	251716080342100	SW	A3	121
F-179	254444080144801	GW	B2	122
F-239	255008080161801	GW	B1	123
F-291	260010080085001	GW	B1	124
F-319	254217080171801	GW	B2	125
F-358	252829080285101	GW	B2	126
F-45	254943080121501	GW	B1	127
FRGPD2_G	E9683	GW	A2	128
FROGP_G	15929	GW	A2	129

Table 8–1. Index of sites used to map the water table of the Biscayne aquifer in Miami-Dade County, 2000–2009.—Continued

[GW, groundwater; SW, surface water]

Site name	Site identifier	Site type	Index map grid location	Index number
G-1074B	254215080201503	GW	B2	130
G-1166R	255344080195600	GW	B1	131
G-1183	252918080234201	GW	B2	132
G119_H	16555	SW	B2	133
G119_T	16556	SW	B2	134
G-1223	260219080141101	GW	B1	135
G-1225	260032080135701	GW	B1	136
G-1226	260053080105701	GW	B1	137
G-1251	251922080340701	GW	A3	138
G-1362	263630080264801	GW	B2	139
G-1363	253233080301001	GW	B2	140
G-1368A	254950080171202	GW	B1	141
G-1486	253012080261401	GW	B2	142
G-1487	254054080295401	GW	B2	143
G-1488	254830080284201	GW	B1	144
G-1502	252656080350301	GW	A2	145
G-1636	255807080224301	GW	B1	146
G-1637	255707080255001	GW	B1	147
G-2034	260653080184901	GW	B1	148
G-2035	260040080104401	GW	B1	149
G211_H	15134	SW	B2	150
G211_T	15135	SW	B2	151
G-2900	260325080113901	GW	B1	152
G-3	254950080180801	GW	B1	153
G-3074	254157080214002	GW	B2	154
G-3253	255027080245501	GW	B1	155
G-3259A	255026080240302	GW	B1	156
G-3264AR	255030080221401	GW	B1	157
G-3272	253952080321501	GW	A2	158
G-3273	283	GW	A2	159
G-3273	5738	GW	A2	160
G-3327	254823080163701	GW	B1	161
G-3329	254752080181501	GW	B1	162
G-3336	252007080335701	GW	A3	163
G-3338_G	QS274	GW	B3	164
G-3339_G	QS276	GW	B3	165
G-3349_G	QS278	GW	B3	166
G-3350_G	QS280	GW	B3	167
G-3353	251724080341401	GW	A3	168
G-3354	251855080283401	GW	B3	169
G-3355	252332080300501	GW	B3	170
G-3356	252502080253901	GW	B2	171
G-3437	253400080340401	GW	A2	172

Table 8–1. Index of sites used to map the water table of the Biscayne aquifer in Miami-Dade County, 2000–2009.—Continued

[GW, groundwater; SW, surface water]

Site name	Site identifier	Site type	Index map grid location	Index number
G-3439	254421080260201	GW	B2	173
G-3465	254823080175201	GW	B1	174
G-3466	254834080171601	GW	B1	175
G-3467	254839080162301	GW	B1	176
G-3473	254248080263801	GW	B2	177
G-3549	252933080210001	GW	B2	178
G-3550	252906080213101	GW	B2	179
G-3551	254158080294501	GW	B2	180
G-3552	254138080284401	GW	B2	181
G-3553	254152080282101	GW	B2	182
G-3554	254152080274501	GW	B2	183
G-3555	254111080272501	GW	B2	184
G-3556	254213080281501	GW	B2	185
G-3557	254112080294201	GW	B2	186
G-3558	254334080284401	GW	B2	187
G-3559	254445080295001	GW	B2	188
G-3560	254108080231301	GW	B2	189
G-3561	254022080263601	GW	B2	190
G-3562	255112080151901	GW	B1	191
G-3563	254340080203601	GW	B2	192
G-3564	254917080143301	GW	B1	193
G-3565	254218080241801	GW	B2	194
G-3566	254951080194901	GW	B1	195
G-3567	255358080260901	GW	B1	196
G-3568	254657080214401	GW	B1	197
G-3570	254536080172601	GW	B2	198
G-3571	255616080180301	GW	B1	199
G-3572	254432080240401	GW	B2	200
G-3574	254446080295501	GW	B2	201
G-3575	254206080294701	GW	B2	202
G-3576	254442080305201	GW	B2	203
G-3577	254207080300201	GW	B2	204
G-3578	254210080304801	GW	B2	205
G-3619	252243080335501	GW	A3	206
G-3620	252312080320301	GW	A3	207
G-3621	252115080293701	GW	B3	208
G-3622	252955080340701	GW	A2	209
G-3626	253708080304201	GW	B2	210
G-3627	253632080321101	GW	B2	211
G-3628	253539080320501	GW	A2	212
G-3676	254720080253002	GW	B1	213
G-3760	255035080255401	GW	B1	214
G-3761	255035080255402	GW	B1	215

Table 8–1. Index of sites used to map the water table of the Biscayne aquifer in Miami-Dade County, 2000–2009.—Continued

[GW, groundwater; SW, surface water]

Site name	Site identifier	Site type	Index map grid location	Index number
G-3763	251241080385302	GW	A3	216
G-3764	251241080385301	GW	A3	217
G-3778	S3008	GW	B2	218
G-3779	S3010	GW	B2	219
G-3780	S3012	GW	B2	220
G-3781	S3014	GW	B2	221
G-3784	S3016	GW	B2	222
G-3785	S3018	GW	B2	223
G-3786	S3020	GW	B2	224
G-3787	S3022	GW	B2	225
G-3818	255036080270501	GW	B1	226
G420_H	T0998	SW	B2	227
G420_T	T1000	SW	B2	228
G420S_H	TS277	SW	B2	229
G422_H	TS007	SW	B2	230
G422_T	TS009	SW	B2	231
G423_T	UK541	SW	B2	232
G-551	254130080234501	GW	B2	233
G-553	253902080202501	GW	B2	234
G58_H	15729	SW	B1	235
G-580A	254000080181002	GW	B2	236
G-596	253937080304001	GW	B2	237
G-613	252425080320001	GW	B3	238
G-614	253258080264301	GW	B2	239
G-618	254500080360001	GW	A2	240
G-620	254000080460001	GW	A2	241
G72_H	16275	SW	B1	242
G72_T	16276	SW	B1	243
G-757A	253537080284401	GW	B2	244
G-789	252928080332401	GW	A2	245
G-852	255437080103201	GW	B1	246
G-855	254038080280201	GW	B2	247
G-860	253718080192301	GW	B2	248
G-864	252612080300701	GW	B2	249
G-864A	252619080310201	GW	B2	250
G93_H	87960	SW	B2	251
G93_T	15144	SW	B2	252
G93_T	SH501	SW	B2	253
G-968	255600080270001	GW	B1	254
G-970	255709080223701	GW	B1	255
G-973	255209080212801	GW	B1	256
G-975	255208080274001	GW	B1	257
HC	HC	SW	B3	258

Table 8–1. Index of sites used to map the water table of the Biscayne aquifer in Miami-Dade County, 2000–2009.—Continued

[GW, groundwater; SW, surface water]

Site name	Site identifier	Site type	Index map grid location	Index number
HUMBLE_G	15933	GW	A2	259
JBTS	FH187	SW	A3	260
JOE BAY 2E, NEAR KEY LARGO, FL	251355080312800	SW	B3	261
KROME_G	15930	GW	B2	262
L31NN	S3102	SW	B2	263
L31NS	S3104	SW	B2	264
L31NT	JJ835	SW	A2	265
L31W	L31W	SW	A2	266
LASPAL	W4109	SW	B2	267
LEVEE 31 NORTH EXTENSION AT 1 MILE NR WEST M	22907647	SW	B2	268
LEVEE 31 NORTH EXTENSION AT 3 MILE NR WEST MI	2290765	SW	B2	269
LEVEE 31 NORTH EXTENSION AT 4 MILE NR WEST MI	2290766	SW	B2	270
LEVEE 31 NORTH EXTENSION AT 5 MILE NR WEST MI	2290767	SW	B2	271
LEVEE 31 NORTH EXTENSION AT 7 MILE NR WEST MI	2290768	SW	B2	272
LM	LM	SW	A3	273
LN	LN	SW	A3	274
LOOP1_H	DO544	SW	A2	275
LOOP1_T	DO545	SW	A2	276
MANATEE BAY CREEK NEAR HOMESTEAD, FL	251549080251200	SW	B3	277
MCCORMICK CREEK AT MOUTH NEAR KEY LARG	251003080435500	SW	A3	278
MCCORMICK CREEK AT MOUTH NEAR KEY LARG	251003080435500	SW	A3	279
MET-1 IN EVERGLADES NATIONAL PARK	254313080351700	SW	A2	280
MIAMI CANAL AT NW36 ST, MIAMI,FL	02288600	SW	B1	281
MIAMI CANAL EAST OF LEVEE 30 NEAR MIAMI, FL	02287395	SW	B1	282
MRMS1	PT133	SW	B1	283
MRMS4	PT139	SW	B2	284
MRSHOPB1	253237080350100	GW	A2	285
MRSHOPC1	253052080345800	GW	A2	286
MRSHOPC2	253051080363200	GW	A2	287
MRSHOPC3	253054080374400	GW	A2	288
MRSHOPD1	252809080372300	GW	A2	289
N.E. SHARK RIVER SLOUGH NO. 4 NORTH OF	253828080391100	SW	A2	290
N.E. SHARK RIVER SLOUGH NO. 5, SOUTH O	253753080393600	SW	A2	291
N.W. WELLFIELD CANAL NR DADE BROWARD LEVEE NR	2287497	SW	B1	292
NESRS3_B	15923	SW	B2	293

Table 8–1. Index of sites used to map the water table of the Biscayne aquifer in Miami-Dade County, 2000–2009.—Continued

[GW, groundwater; SW, surface water]

Site name	Site identifier	Site type	Index map grid location	Index number
NMP	NMP	SW	A3	294
NORTHEAST SHARK RVR SLOUGH NO1 NR COOP	254130080380500	SW	A2	295
NORTHEAST SHARK RVR SLOUGH NO2 NR COOP	254315080331500	SW	A2	296
NP201	NP201	SW	A2	297
NP202	NP202	SW	A2	298
NP203	NP203	SW	A2	299
NP205	NP205	SW	A2	300
NP206	NP206	SW	A2	301
NP44	NP44	SW	A2	302
NP46	NP46	SW	A3	303
NP62	NP62	SW	A2	304
NP67	NP67	SW	A3	305
NP72	NP72	SW	A3	306
NR	NR	SW	A3	307
NTS1	NTS1	SW	A2	308
NTS10	NTS10	SW	A2	309
NTS14	NTS14	SW	A2	310
NTS18	NTS18	SW	A2	311
OT	OT	SW	A2	312
P33	P33	SW	A2	313
P34	P34	SW	A2	314
P35	P35	SW	A2	315
P36	P36	SW	A2	316
P37	P37	SW	A3	317
P38	P38	SW	A3	318
R127	R127	SW	A3	319
R158	R158	SW	A3	320
R3110	R3110	SW	A2	321
RG1	RG1	SW	A2	322
RG2	RG2	SW	A2	323
RG3	RG3	SW	A2	324
RG4	RG4	SW	A2	325
RG5	RG5	SW	A2	326
RUTZKE_G	15928	GW	A2	327
S118_H	15694	SW	B2	328
S118_T	15695	SW	B2	329
S119_H	15187	SW	B2	330
S119_T	15185	SW	B2	331
S120_H	3882	SW	B2	332
S120_T	3884	SW	B2	333
S121_H	3888	SW	B2	334

Table 8–1. Index of sites used to map the water table of the Biscayne aquifer in Miami-Dade County, 2000–2009.—Continued

[GW, groundwater; SW, surface water]

Site name	Site identifier	Site type	Index map grid location	Index number
S121_T	3890	SW	B2	335
S122_H	3894	SW	B2	336
S122_T	3896	SW	B2	337
S123_H	5731	SW	B2	338
S123_T	6768	SW	B2	339
S123V	TA766	SW	B2	340
S14_H	VM750	SW	A2	341
S14_T	VM752	SW	A2	342
S148_H	16188	SW	B2	343
S148_T	16189	SW	B2	344
S149_H	3942	SW	B2	345
S149_T	W3957	SW	B2	346
S151_H	15552	SW	B1	347
S151_T	15553	SW	B1	348
S165_H	16185	SW	B2	349
S165_T	16186	SW	B2	350
S166_H	15543	SW	B2	351
S166_T	15544	SW	B2	352
S167_H	16182	SW	B2	353
S167_T	16183	SW	B2	354
S174_H	V7565	SW	A2	355
S174_T	V7567	SW	A2	356
S175_H	15282	SW	A2	357
S175_T	15283	SW	A2	358
S176_H	12287	SW	A2	359
S176_T	12288	SW	A2	360
S177_H	P0869	SW	A3	361
S177_T	13155	SW	A3	362
S178_H	P8675	SW	B3	363
S178_T	P8677	SW	B3	364
S179_H	16179	SW	B2	365
S179_T	16180	SW	B2	366
S-18	255526080143001	GW	B1	367
S-182A	253549080214101	GW	B2	368
S18C_H_Merged	5776+87999	SW	B3	369
S18C_T_Merged	5787+88000	SW	B3	370
S-19	254832080175001	GW	B1	371
S194_H	3954	SW	B2	372
S194_T	3956	SW	B2	373
S195_H	3960	SW	B2	374
S195_T	3962	SW	B2	375
S196_H	3966	SW	B2	376
S196_T	3968	SW	B2	377

Table 8–1. Index of sites used to map the water table of the Biscayne aquifer in Miami-Dade County, 2000–2009.—Continued

[GW, groundwater; SW, surface water]

Site name	Site identifier	Site type	Index map grid location	Index number
S-196A	253029080295601	GW	B2	378
S197_H	HA459	SW	B3	379
S197_T	HA463	SW	B3	380
S20_H	13037	SW	B3	381
S20_T	13038	SW	B3	382
S20F_H	6569	SW	B2	383
S20F_T	6570	SW	B2	384
S20FNV	TA805	SW	B2	385
S20FSV	TA807	SW	B2	386
S20FWV	TA802	SW	B2	387
S20G_H	6585	SW	B2	388
S20G_T	6590	SW	B2	389
S21_H	6597	SW	B2	390
S21_T	6598	SW	B2	391
S21A_H	6601	SW	B2	392
S21A_T	6602	SW	B2	393
S21AV	TA798	SW	B2	394
S21V	TA759	SW	B2	395
S22_H	6605	SW	B2	396
S22_T	6606	SW	B2	397
S22V	TA763	SW	B2	398
S25_H	6609	SW	B1	399
S25_T	6610	SW	B1	400
S25B_H	6613	SW	B1	401
S25B_T	6614	SW	B1	402
S25BM_H	T0954	SW	B1	403
S25BM_T	T0956	SW	B1	404
S26_H	6617	SW	B1	405
S26_H	T1042	SW	B1	406
S26_T	6618	SW	B1	407
S27_H	6621	SW	B1	408
S27_T	6622	SW	B1	409
S28_H	6625	SW	B1	410
S28_T	6626	SW	B1	411
S29_H	6629	SW	B1	412
S29_T	6630	SW	B1	413
S30_H	6637	SW	B1	414
S30_T	6638	SW	B1	415
S31_H_Merged	6640+S1495	SW	B1	416
S31_T_Merged	6641+S1497	SW	B1	417
S32_H_Merged	6897+SP542	SW	B1	418
S331_H_Merged	15721+P6926	SW	B2	419
S331_T_Merged	15723+P6928	SW	B2	420

Table 8–1. Index of sites used to map the water table of the Biscayne aquifer in Miami-Dade County, 2000–2009.—Continued

[GW, groundwater; SW, surface water]

Site name	Site identifier	Site type	Index map grid location	Index number
S332_H	15667	SW	A2	421
S332_T	15668	SW	A2	422
S332B_H	PK920	SW	A2	423
S332B_T	PK922	SW	A2	424
S332BN_T	SI524	SW	A2	425
S332C_H	UT722	SW	A2	426
S332CS_T	TB038	SW	A2	427
S332DX1_T	WN154	SW	A2	428
S333_H	15616	SW	A2	429
S333_T	15617	SW	A2	430
S334_H	DJ184	SW	B2	431
S334_T	DJ185	SW	B2	432
S335_H	DJ189	SW	B1	433
S335_T	DJ190	SW	B1	434
S336_H	16712	SW	B2	435
S336_T	DU546	SW	B2	436
S337_H_Merged	VM807+6894	SW	B1	437
S337_T_Merged	6688+SP553	SW	B1	438
S338_H	15587	SW	B2	439
S338_T	15588	SW	B2	440
S340_H_Merged	P0890+15554	SW	A1	441
S340_T_Merged	3992+15555	SW	A1	442
S343A_H	16194	SW	A1	443
S343A_T	16195	SW	A1	444
S343B_H	16197	SW	A1	445
S343B_T	16198	SW	A1	446
S344_H	16200	SW	A1	447
S344_T	16201	SW	A1	448
S357_H	WN173	SW	B2	449
S357_T	WN175	SW	B2	450
S380_H	SJ230	SW	B2	451
S380_T	SJ232	SW	B2	452
S-68	254857080171101	GW	B1	453
S9BFS	16545	SW	B1	454
SHARK RIVER SLOUGH NO.1 IN CONS.3B NR	254754080344300	SW	A1	455
SITE 64 IN CONSERVATION AREA 3A NR COO	255828080401301	SW	A1	456
SITE 65 IN CONSERVATION AREA 3A NR COO	254848080432001	SW	A1	457
SITE 69 IN CONSERVATION AREA 3BNR COOPERTOWN, FL	255300080370001	SW	A1	458
SITE 69 IN CONSERVATION AREA 3BNR COOPERTOWN, FL	255300080370001	SW	A1	459
SITE 71 IN CONSERVATION AREA 3B NR COO	255250080335001	SW	A1	460
SITE 76 IN CONSERVATION AREA 3B NR AND	260037080303401	SW	B1	461

Table 8–1. Index of sites used to map the water table of the Biscayne aquifer in Miami-Dade County, 2000–2009.—Continued

[GW, groundwater; SW, surface water]

Site name	Site identifier	Site type	Index map grid location	Index number
SNAKE CREEK CANAL AT NW67 AVE NR HIALEAH, FL	02286200	SW	B1	462
SP	SP	SW	A3	463
SR1	SR1	SW	A3	464
SR2	SR2	SW	A3	465
SYLVA_G	W1955	GW	B2	466
T5_H	UA639	SW	B2	467
TAMIAMI CANAL AT S-12-A, NR MIAMI, FL	254543080491101	SW	A2	469
TAMIAMI CANAL AT S-12-A, NR MIAMI, FL	254543080491101	SW	A2	468
TAMIAMI CANAL AT S-12-B NR MIAMI, FL	2289019	SW	A2	471
TAMIAMI CANAL AT S-12-B NR MIAMI, FL	2289019	SW	A2	470
TAMIAMI CANAL AT S-12-D NEAR MIAMI, FL	254543080405401	SW	A2	472
TAMIAMI CANAL AT S-12-D NEAR MIAMI, FL	254543080405401	SW	A2	473
TAMIAMI CANAL BELOW S-12-C, NEARMIAMI, FLA	2289041	SW	A2	474
TAMIAMI CANAL BELOW S-12-C, NEARMIAMI, FLA	2289041	SW	A2	475
TAMIAMI CANAL NEAR CORAL GABLES, FL	2289500	SW	B2	476
TAYLOR SLOUGH WETLAND AT E146 NR HOMESTEAD, FL	251457080395800	SW	A3	477
TAYLOR SLOUGH WETLAND AT E146 NR HOMESTEAD, FL	251457080395800	SW	A3	478
TB	TB	SW	A3	479
TC	TC	SW	A3	480
TE	TE	SW	A3	481
TI-8 IN WATER CONSERVATION AREA 3-B	254957080322801	SW	A1	482
TI-9 IN WATER CONSERVATION AREA 3-B	255014080355801	SW	A1	483
TMC	TMC	SW	A2	484
TR	TR	SW	A3	485
TSB	TSB	SW	A3	486
TSH	TSH	SW	A3	487
UPSTREAM BROAD RIVER NEAR EVERGLADES C	253047080555600	SW	A2	488
UPSTREAM TAYLOR RIVER NEAR HOMESTEAD,	251241080385300	SW	A3	490
UPSTREAM TAYLOR RIVER NEAR HOMESTEAD,	251241080385300	SW	A3	489
W-11 IN WATER CONSERVATION AREA 3-A	255634080450001	SW	A1	491
W-14 IN WATER CONSERVATION AREA 3-A	255614080400601	SW	A1	492
W-15 IN WATER CONSERVATION AREA 3-A	260051080404001	SW	A1	493
W-18 IN WATER CONSERVATION AREA 3-A	260007080464401	SW	A1	494
W-2 IN WATER CONSERVATION AREA 3-A	254759080483201	SW	A1	495
W-5 IN WATER CONSERVATION AREA 3-A	254721080414301	SW	A1	496
WB	WB	SW	A3	497
WE	WE	SW	A3	498

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