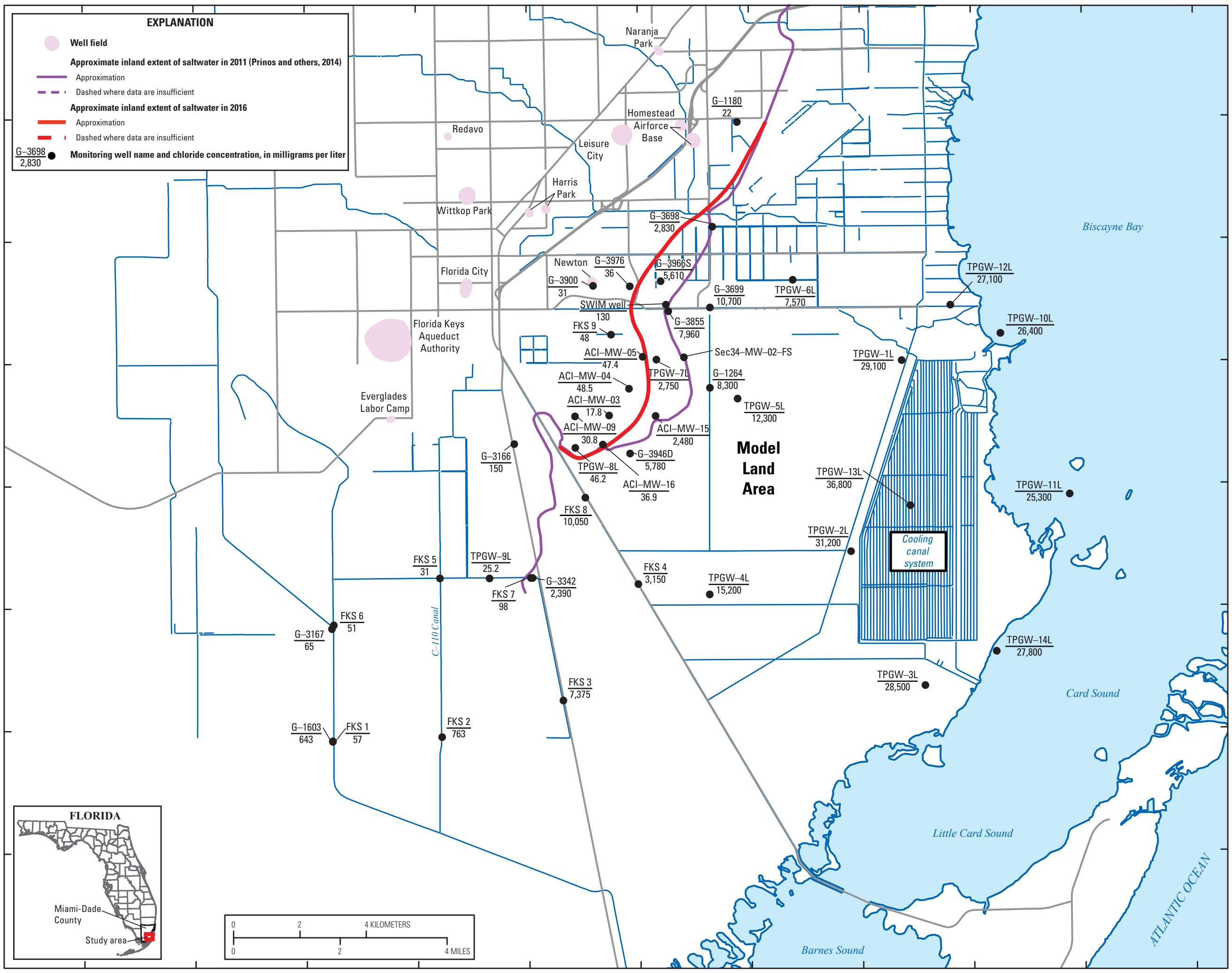
Prepared in cooperation with Miami-Dade County

Map of the Approximate Inland Extent of Saltwater at the Base of the Biscayne Aquifer in the Model Land Area of Miami-Dade County, Florida, 2016



Scientific Investigations Map 3380

U.S. Department of the Interior
U.S. Geological Survey

Cover. Map showing the approximate extent of saltwater at the base of the Biscayne aquifer in the Model Land Area of Miami-Dade County, Florida, 2016. See https://doi.org/10.3133/sim3380 for map sheet.

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U.S. Department of the Interior
RYAN K. ZINKE, Secretary

U.S. Geological Survey
William H. Werkheiser, Acting Director

U.S. Geological Survey, Reston, Virginia: 2017

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Contents

Sheet

[Available from https://doi.org/10.3133/sim3380]

Conversion Factors

SI to Inch/Pound

Multiply	By	To obtain
	Length	
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Area	
square kilometer (km^2)	247.1	acre
square kilometer (km^2)	0.3861	square mile (mi^2)
	Volume	
liter (L)	0.2642	gallon (gal)
liter (L)	61.02	cubic inch (in^3)
	Flow rate	
meter per year (m/yr)	3.281	foot per year (ft/yr)
	Mass	
gram (g)	0.03527	ounce, avoirdupois (oz)
kilogram (kg)	2.205	pound, avoirdupois (lb)
	Electrical conductivity	
siemens per meter (S/m)	10,000	microsiemens per centimeter (µS/cm)

Electrical conductivity σ in microsiemens per centimeter [μS/cm] can be converted to electrical resistivity ρ in ohm-meters [ohm m] as follows: $\rho = 10{,}000/\sigma$.

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

°F = (1.8 × °C) + 32

Datum

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

Supplemental Information

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 °C).

Concentrations of chemical constituents in water are given in milligrams per liter (mg/L).

Abbreviations

bls	below land surface
GIS	geographic information system
TSEMIL	time-series electromagnetic-induction log (dataset)
USGS	U.S. Geological Survey

Map of the Approximate Inland Extent of Saltwater at the Base of the Biscayne Aquifer in the Model Land Area of Miami-Dade County, Florida, 2016

By Scott T. Prinos

Abstract

The inland extent of saltwater at the base of the Biscayne aquifer in the Model Land Area of Miami-Dade County, Florida, was mapped in 2011. Since that time, the saltwater interface has continued to move inland. The interface is near several active well fields; therefore, an updated approximation of the inland extent of saltwater and an improved understanding of the rate of movement of the saltwater interface are necessary. A geographic information system was used to create a map using the data collected by the organizations that monitor water salinity in this area. An average rate of saltwater interface movement of 140 meters per year was estimated by dividing the distance between two monitoring wells (TPGW-7L and Sec34-MW-02-FS) by the travel time. The travel time was determined by estimating the dates of arrival of the saltwater interface at the wells and computing the difference. This estimate assumes that the interface is traveling east to west between the two monitoring wells. Although monitoring is spatially limited in this area and some of the wells are not ideally designed for salinity monitoring, the monitoring network in this area is improving in spatial distribution and most of the new wells are well designed for salinity monitoring. The approximation of the inland extent of the saltwater interface and the estimated rate of movement of the interface are dependent on existing data. Improved estimates could be obtained by installing uniformly designed monitoring wells in systematic transects extending landward of the advancing saltwater interface.

Introduction

Seawater began intruding the Biscayne aquifer of Miami-Dade County early in the 20th century because of a decline in the fresh groundwater level, estimated to have been 2.9 meters (m) below predrainage conditions near Miami (Prinos and others, 2014). By 2011, approximately 1,200 square kilometers (km^2) of the mainland part of the Biscayne aquifer were intruded by saltwater (Prinos and others, 2014). Intrusion of the Biscayne aquifer by saltwater is a concern because it can render the water unpotable in affected parts of the aquifer. The maximum concentration of chloride allowed in drinking water is 250 milligrams per liter (mg/L; U.S. Environmental Protection Agency, 2014), whereas saltwater-intruded parts of the aquifer commonly have water with chloride concentrations of 1,000 mg/L or greater.

The inland extent of saltwater at the base of the Biscayne aquifer was last mapped by Prinos and others (2014) in 2011. Since that time, saltwater has continued to intrude beneath the Model Land Area. This area is a relatively flat and poorly drained wetland area in southeastern Miami-Dade County that is bordered on the east and south sides by Biscayne Bay, Card Sound, Little Card Sound, and Barnes Sound. A system of canals, water control structures, and levees regulate the flow of surface water in this area. There is an extensive system of cooling canals in the eastern part of this area that has been hypersaline at times (Hughes and others, 2010).

In the Model Land Area, the saltwater interface is near several active well fields; therefore, an updated approximation of the inland extent of saltwater and an improved understanding of the rate of movement of the saltwater interface are necessary. The U.S. Geological Survey (USGS), in cooperation with Miami-Dade County, mapped the approximate inland extent of saltwater in the Model Land Area in 2016 and approximated the average rate of movement of the saltwater interface in this area based on data collected between 2007 and 2014. This study aligns directly with the strategic science direction for the Water discipline outlined in USGS Circular 1309 (U.S. Geological Survey, 2007) by quantifying, forecasting, and securing freshwater for America's future. The purpose of this report is to provide a map of the saltwater interface (2016), an estimate of the rate of interface movement given the dates of arrival at two wells, and a description of the methodologies used to arrive at these results. The analyses and estimates are based on available data from existing monitoring wells in the Model Land Area.

Mapping the Approximate Inland Extent of the Saltwater Interface

The approximate inland extent of saltwater in the Biscayne aquifer was determined by using (1) chloride concentration and specific conductance of water samples collected from monitoring wells, (2) water conductivity profiles collected in long open-interval wells, and (3) time-series electromagnetic-induction log (TSEMIL) datasets collected in polyvinyl-chloride-cased monitoring wells. This information was provided by EAS Engineering, Inc., the Florida Keys Aqueduct Authority, the Florida Power & Light Company, the South Florida Water Management District (SFWMD), and the USGS. Almost all of the data provided by the SFWMD for this study area had been collected by the other four organizations, so they are mostly redundant. The information was entered into a geographic information system (GIS) for analysis and mapping. Data used to make the map are available as a data release (Prinos, 2017).

Sampling, analysis, and quality assurance procedures of the organizations collecting salinity data in the study area vary. Procedures used by the Florida Power & Light Company for sampling and quality assurance are described in the Turkey Point Quality Assurance Project Plan (Florida Power & Light Company, 2011). These procedures are likely among the most stringent used by organizations collecting salinity data in the study area. This plan was drafted jointly by the Florida Department of Environmental Protection, the Florida Power & Light Company, and the SFWMD and was approved by the SFWMD. Procedures for sampling by the USGS are generally based on those described in the USGS field manual, but procedures have been modified for expediency and efficacy of routine, long-term saltwater intrusion monitoring (U.S. Geological Survey, variously dated; Lee Massey, U.S. Geological Survey, written commun., March 7, 2017). EAS Engineering, Inc., and the Florida Keys Aqueduct Authority base their sampling on the specifications of the Florida Department of Environmental Protection (Florida Department of Environmental Protection, 2008). To ensure the quality of analyzed samples, the USGS laboratory participates in the Branch of Quality Systems Standard Reference Sample Semi-Annual Proficiency Testing Project. EAS Engineering, Inc., and the Florida Power & Light Company use laboratories that are certified through the National Environmental Laboratory Accreditation Program. Participation in this accreditation program likely assures that sample analyses are accurate; however, the USGS cannot completely verify this accuracy without reviewing the results of the accreditation testing for each laboratory used.

The approximate saltwater interface is represented by the 1,000-mg/L isochlor at the base of the Biscayne aquifer. The word “approximate” is used because the spatial distribution of monitoring wells is generally insufficient to create a precise representation. The accuracy and precision of this approximation is best evaluated on a location-by-location basis, based on the available monitoring wells. The locations of the monitoring wells and the chloride concentration values are shown on the map (sheet 1, available at https://doi.org/10.3133/sim3380). The line depicting the approximate inland extent of saltwater is dashed where the monitoring well distribution is insufficient to create a reasonably accurate and precise approximation.

The TSEMIL-derived vertical profiles of bulk conductivity provide additional qualitative insights for mapping, such as detection of any influxes of conductive water that do not correspond to the open interval of the well and temporal changes in the depth of the top of the saltwater interface. Where water conductivity profiles were used for monitoring, chloride concentrations were estimated by using a relation based on a linear regression of the chloride concentration and specific conductance as described in appendix 1.

The majority of the monitoring wells used for this analysis have short open intervals (about 1.5 meters [m] or less), but 37 percent have open intervals of 8 to 40 m (Prinos, 2017). The long open-interval wells are not ideal for salinity monitoring for the reasons summarized in Prinos (2013) and Prinos and Valderrama (2015), but they are the only wells available at some locations.

Approximating the Rate of Movement of the Saltwater Interface

The saltwater interface in the study area is advancing at an estimated average rate of 140 meters per year (m/yr). This estimate is based on limited data because there are few wells in this area where the date of arrival of the saltwater interface can be ascertained. Most wells were installed either after the saltwater interface had already passed the location or where the saltwater interface has not yet arrived. The estimate is based on data from monitoring wells Sec34-MW-02-FS and TPGW-7L, monitored by EAS Engineering, Inc., and the Florida Power & Light Company, respectively. Data from well TPGW-7L and selected conductance profiles from well Sec34-MW-02-FS are available in Prinos (2017). Well TPGW-7L is open to the aquifer from 24 to 26 m below land surface (bls), which is near the depth of the base of the Biscayne aquifer at this location (Fish and Stewart, 1991). The chloride concentration in water samples from well TPGW-7L increased from 180 to 825 mg/L between December 3, 2013, and March 11, 2014, and from 825 to 1,300 mg/L between March 11, 2014, and June 9, 2014. Water conductance profiles were collected from well Sec34-MW-02-FS. The maximum conductance of the profiles was found at a depth of about 25 m bls. Using equations 1 and 2 (appendix 1), conductance values measured at this depth equate to chloride concentrations of about 190, 530, 930, and 1,400 mg/L for November 12, 2007, January 15, 2008, April 4, 2008, and May 15, 2008, respectively.

The average rate of saltwater interface movement was estimated by dividing the distance between the wells (830 m) by the difference between the interpolated dates of arrival of chloride concentrations of 250 and 1,000 mg/L at each well. The interpolated dates of arrival at well Sec34-MW-02-FS were November 22, 2007, and April 8, 2008, for concentrations of 250 and 1,000 mg/L, respectively. The interpolated dates of arrival at well TPGW-7L were December 13, 2013, and April 13, 2014, for concentrations of 250 and 1,000 mg/L, respectively. Given these dates and the distance between these wells, the estimated rate of movement of the front is 137 m/yr based on a chloride concentration of 250 mg/L, and the estimated rate based on a concentration of 1,000 mg/L is 138 m/yr. These estimates can be rounded to an average estimate of 140 m/yr. This rate of movement was used to help interpolate the location of the 1,000-mg/L isochlor in the Model Land Area.

This estimate assumes that the direction of front movement is parallel to a line passing through these two well locations, and that the rate of front movement is constant. Use of this rate for interpolating the position of the saltwater interface elsewhere in the study area assumes that (1) effective porosity is uniform throughout this area, (2) direction of front movement is east to west, and (3) that the rate of front movement is the same throughout this area. Additional monitoring is needed to evaluate these assumptions (see Monitoring Network Improvements section of this report). Given the stated assumptions, the saltwater interface may move under the Newton well field by 2026. This estimate of future movement may be conservative because withdrawals from the well field may influence the rate and direction of travel.

Monitoring Network Improvements

Within the map, the line depicting the approximation of the inland extent of the saltwater interface is dashed near the Card Sound Road Canal and in the area around the C-110 Canal because there were insufficient data for an accurate delineation of the interface. These areas were previously mapped by using helicopter electromagnetic surveys (Fitterman and Prinos, 2012) and time-domain electromagnetic soundings (Fitterman and others, 2011). Monitoring in these areas currently consists of only a few wells that are too far from the expected current location of the interface to provide relevant information. Monitoring near the edge of the elongated extension of saltwater that had intruded along the Card Sound Road Canal (Prinos and others, 2014) is almost nonexistent.

Given the rate of movement of the saltwater interface estimated in this investigation, the chloride concentrations of samples from some of the monitoring wells on the freshwater side of the interface may not exceed 1,000 mg/L for many years. Monitoring well FKS 9, for example, is 0.86 km from the estimated location of the saltwater interface. The 1,000-mg/L isochlor may not arrive at this well until 2023, if the rate of movement of the saltwater interface proceeds at the average rate estimated in this study. Better estimates of the rates of movement are needed before 2023, particularly because the rate of movement may not be constant. Monitoring well FKS 5 is even farther from the approximated location of the saltwater interface than well FKS 9. The rate and direction of movement of the saltwater interface near well FKS 5 are unknown. If the rate of movement were the same as that between wells Sec34-MW-02-FS and TPGW-7L, the 1,000-mg/L isochlor may not reach this well for 26 years if the interface moves northward, or 17 years if the interface moves westward. Water managers would most likely need to have a better understanding of the location of the saltwater interface, its rate of movement, and direction of movement than currently provided near FKS 5.

Differences in the design, placement, quality of chemical analyses, and type of monitoring can add uncertainty to this analysis. The analysis of the rate of movement of the saltwater interface between monitoring wells Sec34-MW-02-FS and TPGW-7L, for example, required a number of estimations, including the relation between specific conductance and chloride, the relation between pumped water samples and in situ measurements of conductance, and the conversion of conductance to specific conductance. These relations and conversions increase uncertainty.

Some monitoring wells, such as well Sec34-MW-02-FS and many of the wells monitored by the Florida Keys Aqueduct Authority, are designed to monitor the depth of the top of the saltwater interface through the collection of water conductivity profiles and water samples from multiple depths. Because these wells have long open intervals, the sample results may be influenced by flow within the well bore during sampling or under ambient conditions (Prinos, 2013; Prinos and Valderrama, 2015). Although several organizations base their sampling on the Standard Operating Procedures of the Florida Department of Environmental Protection, Prinos (2013) states that these procedures “call for sampling of long open-interval wells by pumping from near the top of the water column or top of the open interval, which could result in samples that are not representative of maximum salinity in the aquifer.” Uncertainty is also increased because some analyses are performed in the field as opposed to in a laboratory that participates in a quality assurance testing program (see the Mapping the Approximate Inland Extent of the Saltwater Interface section of this report).

Estimates of the rate of movement of the interface could be improved by placing monitoring wells along a transect, spaced at distances that would allow timely detection of any variations in the rate of movement of the saltwater interface, and parallel to the direction of movement of the interface. If four or five such transects were installed in the county, the resulting data could be used to evaluate spatial differences in the rates of movement of the saltwater interface at locations where the interface is encroaching. Collecting TSEMIL datasets in wells in each transect could provide information on how the depth of the interface is changing. Using consistent monitoring methods at wells in each transect could reduce the uncertainty in the estimated rate of movement.

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Appendix 1. Estimation of Chloride Concentrations at Wells Where Conductivity Profiles Were Used for Monitoring

At locations where water conductivity profiles were used for monitoring, chloride concentrations were estimated by using a relation based on a linear regression of the chloride concentration and specific conductance of 16,184 water samples collected between November 28, 1940, and September 26, 2016, from 178 monitoring sites sampled by the USGS in southern Florida (table 1–1). All of these sample results are available through the USGS National Water Information System website (U.S. Geological Survey, 2016). The relation is expressed as

$$cc = 0.3458sc - 176.32 \quad (1)$$

where

cc is the chloride concentration in milligrams per liter, and

sc is the specific conductance in microsiemens per centimeter.

Conductance was converted to specific conductance using the following relation (Carlson, [n.d.]).

$$sc = c/(1 + r(T - 25)) \quad (2)$$

where

c is the actual conductance measured in microsiemens per centimeter,

T is the temperature of the sample in degrees Celsius, and

r is the temperature correction coefficient for the sample.

The TSEMIL-derived vertical profiles of bulk conductivity provide additional qualitative insights for mapping, such as detection of any influxes of conductive water that do not correspond to the open interval of the well and temporal changes in the depth of the top of the saltwater interface.

The majority of the monitoring wells used for this analysis have short open intervals (about 1.5 meters [m] or less), but 37 percent have open intervals of 8 to 40 m (Prinos, 2017). The long open-interval wells are not ideal for salinity monitoring for the reasons summarized in Prinos (2013) and Prinos and Valderrama (2015), but they are the only wells available at some locations.

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Table 1–1. Listing of U.S. Geological Survey monitoring sites in southern Florida from which water samples were collected to evaluate specific conductance and chloride concentration.

[USGS, U.S. Geological Survey]

USGS station identifier	Site name
262313080044401	PB -1457
262209080044702	PB -1669
261100080140401	G -1212
261122080083401	G -1232
260547080105801	G -2352
260920080092201	G -2898
260551080111901	G -2957
261740080054101	G -2893
255916080090401	G -1435
255910080085802	G -2294
255919080091202	G -2409
255919080091203	G -2410
255936080091701	G -2477
255936080091702	G -2478
255916080092001	G -2965
260037080100700	Hollywood Canal at Hollywood Blvd, Hollywood, FL
260104080101300	Hollywood Canal at Johnson St, Hollywood, FL
260225080095800	Hollywood Canal at N29 Ave, Hollywood, FL
260212080112500	Hollywood Canal at N46 Ave, Hollywood, FL
260132080094900	Hollywood Canal at Taft St, Hollywood, FL
260041080093101	G -2425
260041080093102	G -2426
260120080093401	G -2441
260155080092002	G -2612
260026080095801	G -2956
254943080121501	F - 45
254841080164401	G - 571
255350080105801	G - 894
254107080165201	G - 896
254201080173001	G - 901
254106080174601	G -1009B
252947080235301	G -1180
254813080161501	G -1351
254833080155801	G -1354
255222080123001	G -3224
254457080160301	G -3229
254946080172601	G -3250
252714080260901	G-3976

USGS station identifier	Site name
255453080110801	G-3978
254601080150301	G-3977
254156080172101	G -3607
252814080244101	G -3698
252652080244301	G -3699
252650080252701	G -3855
253253080221201	G -3885
253527080195401	G -3886
253924080174601	G -3887A
253924080174602	G -3887B
254542080145901	G -3888A
254542080145902	G -3888B
254542080145903	G -3888C
253948080250701	G -3897
254152080282601	G -3898
253419080223701	G -3899
252718080264901	G -3900
252506080300601	G -3901
252431080261001	G -3946D
252431080261002	G -3946S
255011080124501	G -3947
255515080103601	G -3948D
255515080103602	G -3948S
255733080195601	G -3949D
255733080195602	G -3949I
255733080195603	G -3949S
254824080155301	G -3964
254500080162801	G -3965
252719080253601	G -3966D
252719080253602	G -3966S
253335080213501	G -3967
255315080111501	F - 279
254828080161501	G - 354
254335080170501	G - 432
254855080163701	G - 548
253652080183701	G - 939
253202080232601	G -3162
253831080180204	G -3313C
253831080180206	G -3313E
255358080114101	G -3601
255116080120601	G -3602

Table 1–1. Listing of U.S. Geological Survey monitoring sites in southern Florida from which water samples were collected to evaluate specific conductance and chloride concentration.—Continued

[USGS, U.S. Geological Survey]

USGS station identifier	Site name
254908080125201	G -3603
254722080152201	G -3604
254629080143101	G -3605
254341080174001	G -3606
254108080170601	G -3608
254005080171601	G -3609
253819080183201	G -3610
253710080184701	G -3611
253457080195501	G -3612
253024080231001	G -3615
253027080234701	G -3700
253214080224601	G -3701
253334080213601	G -3702
254822080125501	G -3704
255625080094901	G -3705
261302081473901	C - 489
261156081475801	C - 516
261002081483701	C - 525
261018081484101	C - 526
261200081483001	C - 528
260549081441901	C - 600
261802081354801	C - 688
261347081351201	C - 953
261620081464402	C -1004R
261604081480901	C -1059
261311081480101	C -1061
260137081375901	C -1063
262228081361902	C -1080
261403080070801	G -2149
260342080115902	G -2264
261446080062801	G -2445
261724080054603	G -2693
260242080101101	G -2697
261643080055901	G -2752
261740080054101	G -2893
261304080072501	G -2896
261030080083301	G -2897
260804080092701	G -2899
260325080113901	G -2900
260638080104801	G -2902
255843080090901	G -2903
260534080110801	G -2904
262839081503100	L - 735
262022081464201	L - 738
263532081592202	L -1136
263813081552801	L -2640
263819081585801	L -2701
263955082083102	L -2820
263117082051002	L -2821
264053081572501	L -4820
262513081472002	L -5668R
261926081454702	L -5745R
264123080053801	PB - 809
263044080035102	PB -1195
262755080040101	PB -1707
262803080041101	PB -1714
263453080031501	PB -1717
263633080031401	PB -1723
265550080070701	PB -1732
265611080080201	PB -1733
265006081042502	GL - 334I
265006081042501	GL - 334S
265006081042503	GL - 334D
264912081024602	GL -332S
264912081024601	GL -332
264843080591502	GL - 333I
264843080591501	GL - 333S
264843080591503	GL - 333D
264532080545902	HE -1145S
264532080545901	HE -1145
264343080511601	PB -1843S
264343080511602	PB -1843I
264343080511603	PB -1843D
264154080480302	PB -1822S
264154080480301	PB -1822
264050080435502	PB -1842I
264050080435501	PB -1842S
264050080435503	PB -1842D
264814080414302	PB -1819S
264814080414301	PB -1819
264926080394503	PB -1848D
264930080394703	PB -1847D

Table 1–1. Listing of U.S. Geological Survey monitoring sites in southern Florida from which water samples were collected to evaluate specific conductance and chloride concentration.—Continued

[USGS, U.S. Geological Survey]

USGS station identifier	Site name
265138080375802	PB -1818S
265138080375801	PB -1818
265142080374202	PB -1817S
265142080374201	PB -1817
265208080373902	PB -1845I
265208080373901	PB -1845S
265208080373903	PB -1845D
265200080373101	PB -1846S
265428080364502	PB -1816S
265428080364501	PB -1816
265519080364902	PB -1815S
265519080364901	PB -1815
265701080363103	PB -1844D
265701080363102	PB -1844I
265701080363101	PB -1844S
265839080365202	M -1369I
265839080365201	M -1369D

For more information about this publication, contact:
Director, Caribbean-Florida Water Science Center
U.S. Geological Survey
4446 Pet Lane, Suite 108
Lutz, FL 33559
(813) 498-5000

Or visit the USGS Caribbean-Florida Water Science Center website at:
https://fl.water.usgs.gov

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