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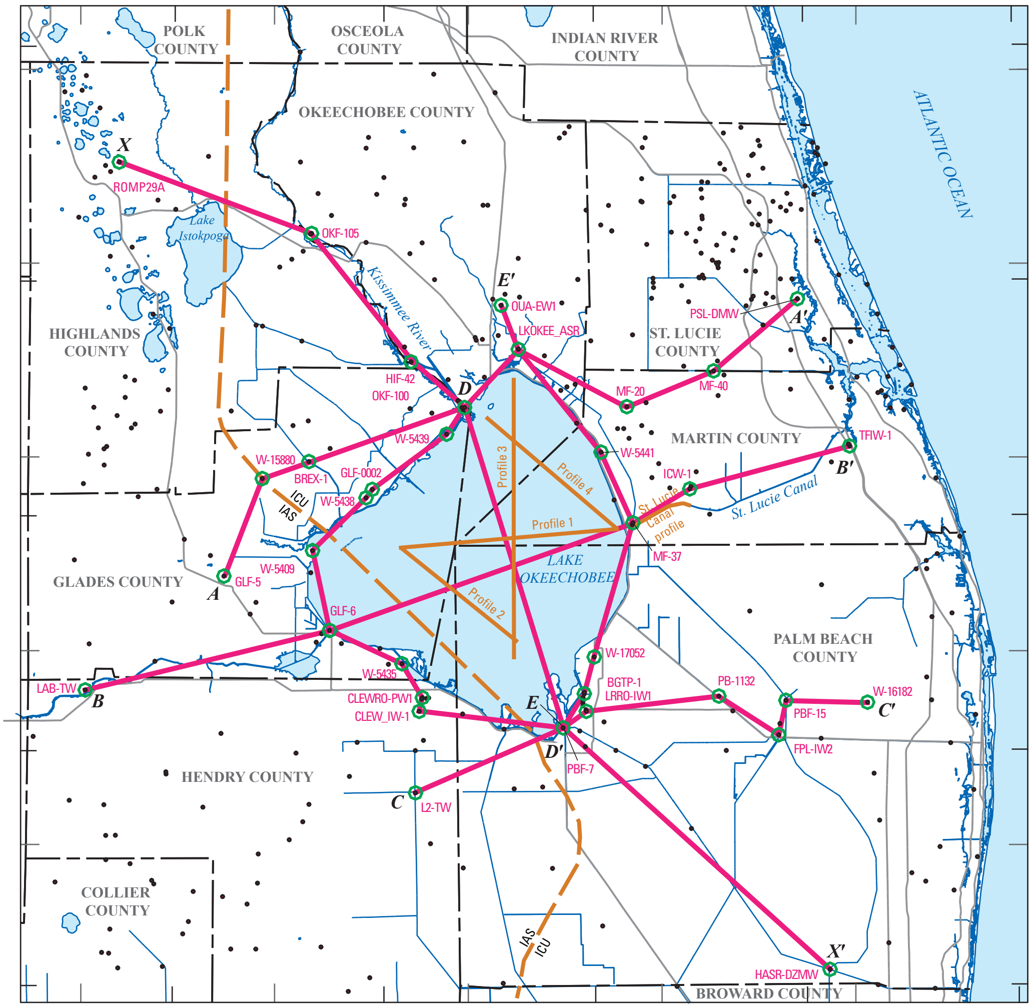
Hydrogeologic Framework and Geologic Structure of the Floridan Aquifer System and Intermediate Confining Unit in the Lake Okeechobee Area, Florida



Pamphlet to accompany

Scientific Investigations Map 3288

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

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Conversion Factors

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Flow rate	
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29).

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.

Hydrogeologic Framework and Geologic Structure of the Floridan Aquifer System and Intermediate Confining Unit in the Lake Okeechobee Area, Florida

By Ronald S. Reese

Abstract

The successful implementation of aquifer storage and recovery (ASR) as a water-management tool requires detailed information on the hydrologic and hydraulic properties of the potential water storage zones. This report presents stratigraphic and hydrogeologic sections of the upper part of the Floridan aquifer system and the overlying confining unit or aquifer system in the Lake Okeechobee area, and contour maps of the upper contacts of the Ocala Limestone and the Arcadia Formation, which are represented in the sections. The sections and maps illustrate hydrogeologic factors such as confinement of potential storage zones, the distribution of permeability within the zones, and geologic features that may control the efficiency of injection, storage, and recovery of water, and thus may influence decisions on ASR activities in areas of interest to the Comprehensive Everglades Restoration Plan.

Introduction

The injection of potable water into an aquifer for later withdrawal, commonly referred to as aquifer storage and recovery, or ASR, has been proposed as a water-management strategy as part of the Comprehensive Everglades Restoration Plan (CERP) to help meet the water needs of agricultural, municipal, and recreational users, and for Everglades ecosystem restoration in central and southern Florida (U.S. Army Corps of Engineers and South Florida Water Management District, 1999). Excess water collected during the wet season is injected into an aquifer through an ASR well, stored, and withdrawn when needed during the dry season using the same well. Injected and recovered water from CERP ASR wells is intended to be used for maintaining water levels in Lake Okeechobee and wetland areas, and reduction of surface-water flows to estuaries and bays during storm events. To be economically viable, each well must have an operational capacity of 5 million gallons per day (Mgal/d) during injection (recharge) or withdrawal (recovery). Optimal application of ASR requires knowledge of the presence of extensive, permeable storage zones and their confinement, suitable water quality in these zones, and suitable source-water supplies.

The principal aquifer used for ASR in southern Florida is the Upper Floridan aquifer of the Floridan aquifer system. This system, consisting of the Upper Floridan aquifer, a middle confining unit, and the Lower Floridan aquifer, is overlain by the intermediate confining unit or intermediate aquifer system (Miller, 1986).

A regional hydrogeologic framework of the Floridan aquifer system constructed under the CERP ASR Regional Study provides maps and hydrogeologic sections of major permeable zones in the system, including the Upper Floridan aquifer, in central and southern Florida (Reese and Richardson, 2008). Since preparation of this preliminary regional hydrogeologic framework, additional data have been collected in a seven-county area around Lake Okeechobee that allow for a more detailed identification of geologic features and a more refined hydrogeologic framework of the Floridan aquifer system, both of which are important to consider for ASR implementation (fig. 1). The additional data include data from wells that have been drilled into the Floridan aquifer system since 2004 (table 1); water-based seismic-reflection data from beneath Lake Okeechobee and the St. Lucie Canal (Collier Consulting, Inc., 2007); results of a study of the distribution of fractures within the Floridan aquifer system based on borehole image data collected from test wells in the study area (Emily Richardson, South Florida Water Management District, written commun., 2007); and lineaments mapped in south Florida using Landsat multispectral scanner false color images (June Mirecki, U.S. Army Corps of Engineers, written commun., 2004). To address the need for an updated and refined hydrogeologic framework of the Floridan aquifer system and detailed geologic information, the U.S. Geological Survey (USGS), in cooperation with the U.S. Army Corps of Engineers, conducted a study from 2010 to 2012 under CERP as part of the final hydrogeologic framework study for the regional ASR program.

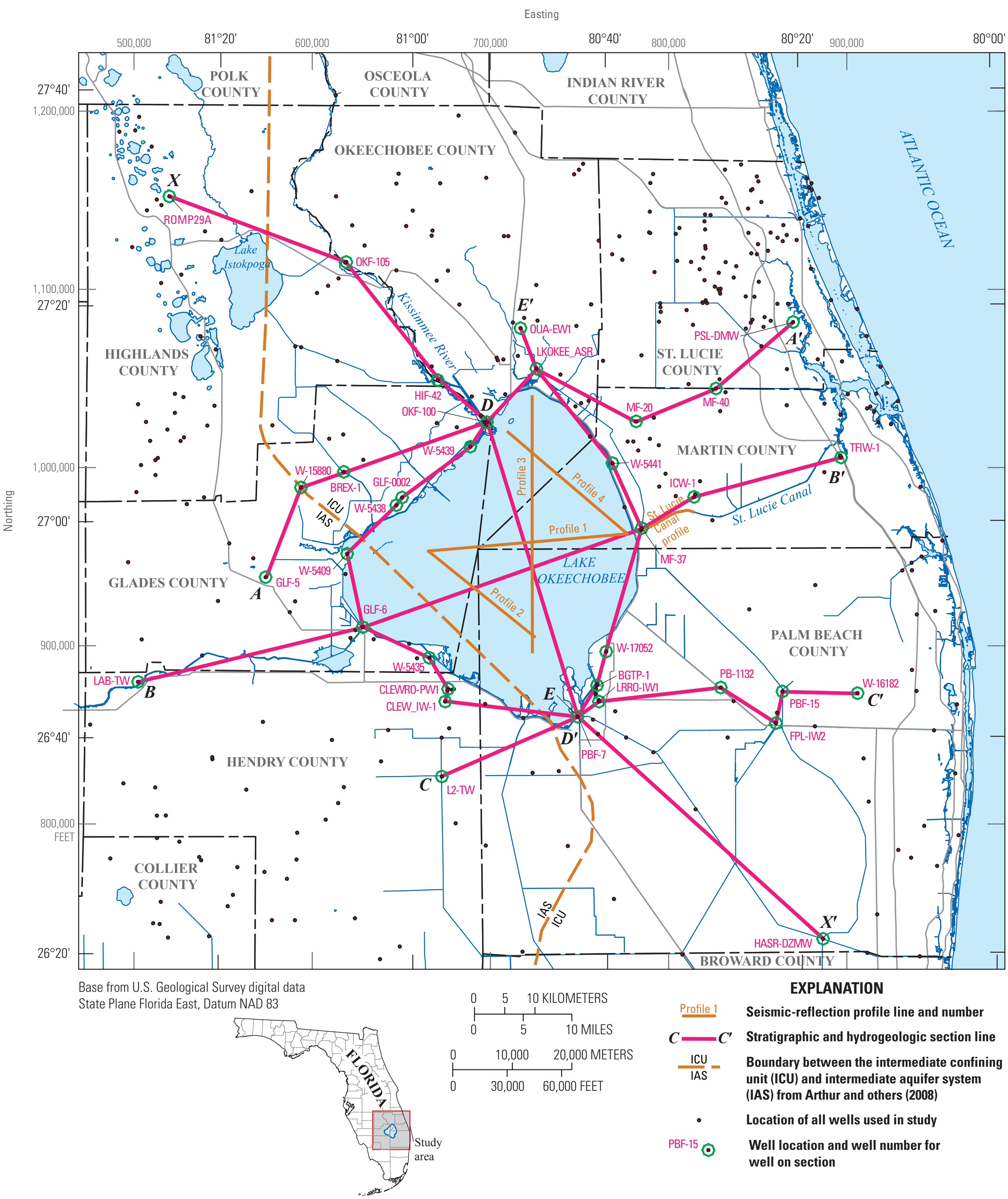


Figure 1. Map of study area showing wells used, seismic-reflection profiles, and stratigraphic and hydrogeologic section lines.

Table 1. Selected wells used to update the hydrogeologic framework of the Floridan aquifer system in the Lake Okeechobee study area, Florida.

[ASR, aquifer storage and recovery; FPL, Florida Power and Light; MW, monitoring well; RO, reverse osmosis water treatment; SFWMD, South Florida Water Management District; USACE, U.S. Army Corps of Engineers; USGS, U.S. Geological Survey; WTP, water treatment plant; WWTF, wastewater treatment facility]

SFWMD Station Name	Name/Description	Total Depth (feet)	Owner
	Glades County		
BREX-1	Brighton Seminole Reservation ASR test	1,616	Brighton Seminole
EXKR-MW18	Kissimmee River ASR MW	890	USACE
	Hendry County		
CLEW_IW-1	RO WTP injection well	3,505	City of Clewiston
CLEWRO-PW1	RO production well 1	1,450	City of Clewiston
CLEWRO-PW2	RO production well 2	1,200	City of Clewiston
CLEWRO-PW3	RO production well 3	1,250	City of Clewiston
CLEWRO-PW4	RO production well 4	1,253	City of Clewiston
	Highlands County		
HIF-42	Paradise Run exploratory well 1	1,802	SFWMD
	Martin County		
EXPM-1	Port Mayaca Exploratory ASR	1,380	SFWMD/USACOE
MF-40	Allapattah Ranch exploratory well on C-23 Canal	1,240	SFWMD
TFIW-1	Tropical Farms RO WTP injection well 1	3,200	Martin County Utilities
	Okeechobee County		
EXKR-1	Kissimmee River Exploratory ASR	953	USACE
EXKR-MW1	Kissimmee River ASR storage zone MW	880	USACE
EXKR-MW19	Kissimmee River ASR MW	880	USACE
OKF-105	S65C test well	2,500	SFWMD
OKF-106	Taylor Creek ASR pilot site Upper Floridan MW	818	SFWMD
OLI-IW1	Okeechobee Landfill injection well 1	3,506	Okeechobee Landfill, Inc.
OLI-MW1	Okeechobee Landfill MW 1	2,152	Okeechobee Landfill, Inc.
OUA-EW1	Cemetery Road WWTF injection well 1	3,200	Okeechobee Utility Authority
	Osceola County		
OSF-104	S65A exploratory well	2,500	SFWMD
	Palm Beach County		
BGTP-1	Belle Glade RO test production well 1	1,450	City of Belle Glade
BGTP-2	Belle Glade RO test production well 2	1,650	City of Belle Glade
FPL_FAW1	FPL West County Energy Center production well 1	1,700	FPL
FPL-IW2	FPL West County Energy Center injection well 2	3,250	FPL
LR_PW3	Lake Regions RO	1,450	Palm Beach County
LR_PW4	Lake Regions RO	1,450	Palm Beach County
LR_PW5	Lake Regions RO	1,450	Palm Beach County
LR_PW6	Lake Regions RO	1,450	Palm Beach County
LR_PW7	Lake Regions RO	1,450	Palm Beach County
LR_PW8	Lake Regions RO	1,350	Palm Beach County
LRRO-IW1	Lake Regions RO WTP injection well 1	3,500	Palm Beach County
PBF-15	L-8 Canal test well	2,300	SFWMD

Purpose and Scope

The purposes of this report are to (1) present a refined hydrogeologic framework of the intermediate confining unit or intermediate aquifer system and Floridan aquifer system and (2) identify geologic features that may affect confinement of ASR storage zones in the Floridan aquifer system and the recovery of injected freshwater in the study area. This report presents six stratigraphic and hydrogeologic sections of the Floridan aquifer system, extending from the upper part of the Lower Floridan aquifer to the land surface. Lithostratigraphic boundaries and marker horizons identified include, from oldest to youngest: the upper surface of the lower Avon Park Formation, the upper surface of the Avon Park Formation, the upper surface of the Ocala Limestone, the upper surface of the Suwannee Limestone, the upper surface of the lower Arcadia Formation, and the upper surface of the Arcadia Formation. Hydrogeologic units identified include, from shallowest to deepest: the surficial aquifer system, the intermediate confining unit or intermediate aquifer system, the Upper Floridan aquifer, the middle semiconfining unit 1, the Avon Park permeable zone, the middle semiconfining unit 2, the uppermost major permeable zone of the Lower Floridan aquifer, and the Lower Floridan confining unit. Contour maps of the upper contacts of the Ocala Limestone and Arcadia Formation also are presented.

Study Methods

Data from 363 wastewater-injection, water-supply, ASR, test, and monitoring wells were used to construct cross sections of hydrogeologic and geologic units and maps of geologic contacts. General information for these wells is stored in the South Florida Water Management District's (SFWMD) hydrogeologic database DBHYDRO (South Florida Water Management District, 2013), and in the USGS Ground Water Site Inventory (GWSI) database (appendix 1). The primary well identifier used in this study is the SFWMD station name (appendix 1).

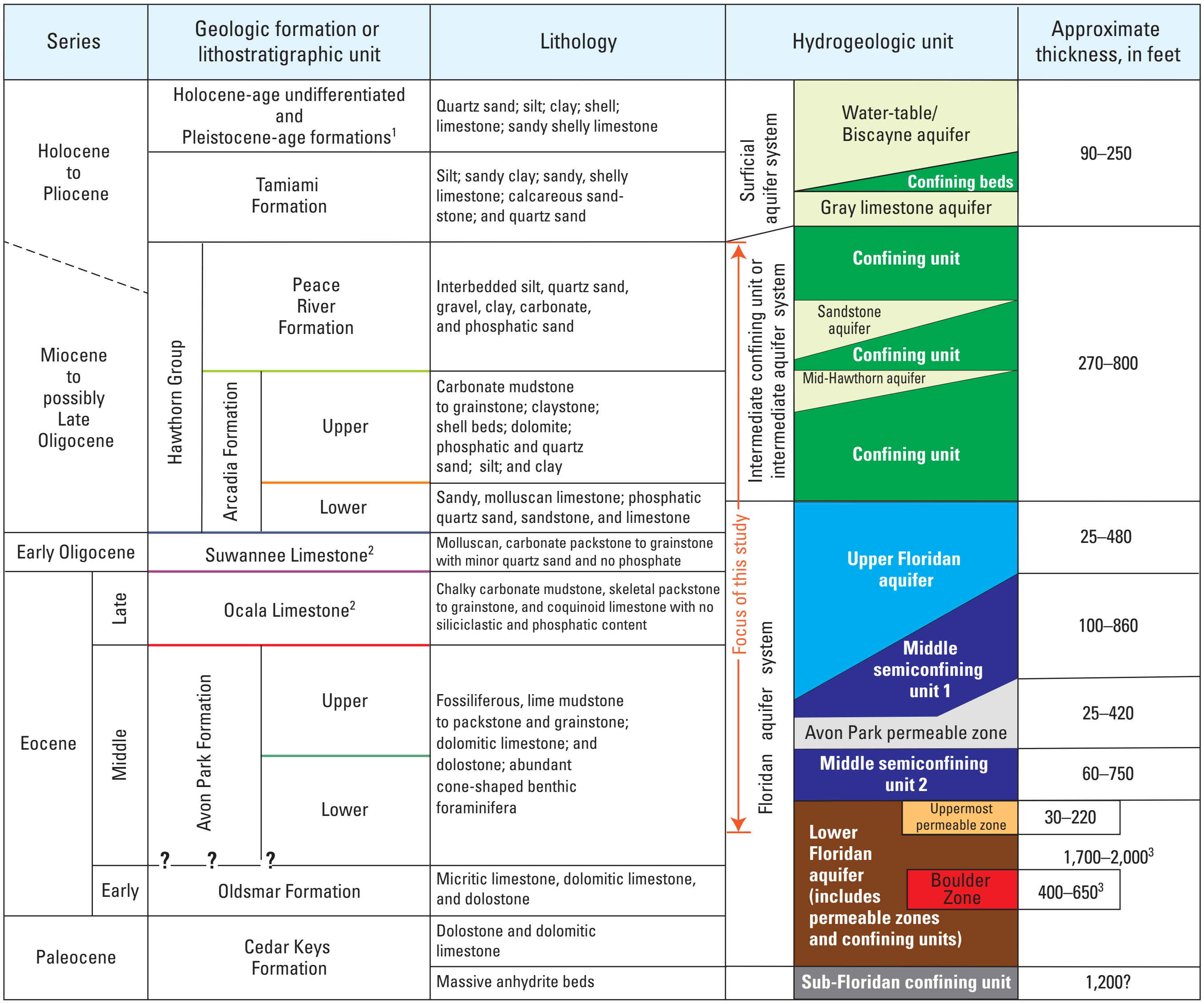
Upper formation contacts and marker horizons identified in this study were defined on the basis of available lithologic descriptions and borehole geophysical data, including gamma ray (GR), sonic interval transit time, and resistivity data. Lithologic data were obtained from the Florida Geological Survey (2012), several previous studies (Cunningham and others, 2001b; Reese and Memberg, 2000; Ward and others, 2003), SFWMD well construction reports, and other well construction reports. The well construction reports are available in DBHYDRO. Recognizable patterns in the borehole geophysical data were used to correlate stratigraphic units between wells. Hydrogeologic unit boundaries for major permeable zones and flow zones in the Floridan aquifer system were identified using borehole geophysical data, including flowmeter, borehole fluid resistivity, fluid temperature, GR, caliper, formation resistivity (composite resistivity of rock and groundwater), and sonic interval transit time (related to formation porosity) data. Hydraulic packer and aquifer test data also were used to help identify the permeable zone boundaries.

The depths of formation contacts in all wells used in constructing the maps and stratigraphic and hydrogeologic cross sections, the source, if other than interpreted in this study, and the types of data available and used are given in appendix 2. The types of data used to determine these boundaries have been given a quality rating of 1 through 5, with 1 being the most complete and reliable and 5 being lithologic description only.

Maps of the upper contacts of the Suwannee Limestone and Arcadia Formation and the base of the Peace River Formation, were interpolated from interpreted seismic-reflections beneath Lake Okeechobee and the St. Lucie Canal (Collier Consulting, Inc., 2007). These maps were then used to assist in mapping the structure of upper contacts of the Ocala Limestone and Arcadia Formation for this report. To construct the structure maps for the Ocala Limestone and the Arcadia Formation, the reported depth values along the seismic-reflection profiles (Collier Consulting, Inc., 2007) were converted to altitude, incorporated into a dataset of geologic contact altitudes from wells outside the lake, and interpolated.

Hydrogeologic Framework

The Floridan aquifer system in central south Florida is a thick sequence of predominantly carbonate rocks that includes, in ascending order, the upper part of the Cedar Keys Formation of Paleocene age, the Oldsmar Formation of early Eocene age, the Avon Park Formation of middle Eocene age, the Ocala Limestone of late Eocene age, the Suwannee Limestone of Oligocene age (Miller, 1986), and a basal part of the Arcadia Formation of the Hawthorn Group (Parker and others, 1955; Shaw and Trost, 1984; Reese, 2004; fig. 2). The Hawthorn Group contains the Arcadia and Peace River Formations (Scott, 1988) and ranges in age from possibly late Oligocene to early Pliocene (Wingard and others, 1994; Guertin and others, 2000; Cunningham and others, 2001a, 2003). Overlying the Hawthorn Group and extending to the surface are the Tamiami Formation of Pliocene age, various formations of Pleistocene age, and undifferentiated sediments of Holocene age. The upper contacts of the Avon Park Formation, the Ocala Limestone, the Suwannee Limestone, and the Arcadia Formation were mapped or indicated on stratigraphic and hydrogeologic sections in this study (sheets 1–6). All of these formations are present throughout the study area except for the Ocala and Suwannee Limestones. These two formations are thickest in the western part of the study area and are absent in the eastern part (Shaw and Trost, 1984; Miller, 1986; Arthur and others, 2008). Arthur and others (2008) indicate the Suwannee Limestone is absent east of the western parts of Highlands and Glades Counties.



1 **Pleistocene-age formations in southeastern Florida**–Pamlico Sand, Miami Limestone, Anastasia Formation, Fort Thompson Formation, Key Largo Limestone

2 **Geologic unit missing in eastern parts of study area**

3 **Thicknesses are from the southeastern Florida part of the study area**

Figure 2. Chart showing correlation of hydrogeologic units as defined in this study with stratigraphic units and their lithologies. Modified from Reese and Richardson (2008).

In addition to the indicated formation contacts, two marker horizons, the informal upper contacts of the lower Avon Park Formation and lower Arcadia Formation, were identified in this study, primarily on the basis of borehole geophysical data and correlation between wells (fig. 2; sheets 1–6). The upper contact of the lower Avon Park Formation was previously referred to as the middle Avon Park marker horizon, or MAP, in southern and central Florida (Reese and Richardson, 2008), and it is sometimes associated with a thin interval (10 to 30 ft thick) of low GR activity compared to background levels. The marker horizon at the upper contact of the lower Arcadia Formation is identified by a distinct increase in GR log activity caused by an abrupt increase in phosphorite content. This lower Arcadia Formation marker horizon corresponds to the base of a previously defined “lower Hawthorn marker unit” mapped in Lee, Hendry, and Collier Counties (Reese, 2000), Palm Beach County (Reese and Memberg, 2000), and Martin and St. Lucie Counties (Reese, 2004). Lithology in the upper Arcadia Formation above this marker horizon is characterized by lime mudstone and claystone.

The hydrologic unit superjacent to the Floridan aquifer system is the intermediate confining unit in the eastern part of the study area, or intermediate aquifer system in the western part of the study area (figs. 1 and 2). The intermediate confining unit or intermediate aquifer system confines the Upper Floridan aquifer and separates it from the surficial aquifer system. In Hendry and Collier Counties, the intermediate aquifer system includes the sandstone aquifer, principally in the Peace River Formation, and the mid-Hawthorn aquifer in the uppermost part of the Arcadia Formation (fig. 2; Smith and Adams, 1988; Reese and Richardson, 2008). The intermediate confining unit and intermediate aquifer system include most of the Hawthorn Group and, in some areas, part of the Tamiami Formation.

The upper part of the Floridan aquifer system is divided into three major permeable zones and two semiconfining units, and listed in descending order, they are the Upper Floridan aquifer, middle semiconfining unit 1, Avon Park permeable zone, middle semiconfining unit 2, and upper permeable zone of the Lower Floridan aquifer. The Upper Floridan aquifer commonly includes a basal part of the Arcadia Formation (Shaw and Trost, 1984; Reese and Memberg, 2000; Reese, 2004), which in this report is included in the lower Arcadia Formation (fig. 2). The base of the Avon Park permeable zone is commonly near or just above the marker horizon at the upper contact of the lower Avon Park Formation, and the upper boundary of the Avon Park permeable zone can extend hundreds of feet above this marker horizon. The upper boundary of the upper permeable zone of the Lower Floridan aquifer is below the marker horizon at the upper contact of the lower Avon Park Formation in most areas.

The upper boundary of the Upper Floridan aquifer is always below the upper contact of the lower Arcadia Formation and commonly coincides with or occurs immediately above the upper contact of the Ocala limestone. The lower boundary extends down into the upper part of the Avon Park Formation in most of the eastern half of the study area. An assessment of geologic or hydrogeologic unit thickness is best conducted using isopach maps if sufficient data are available to construct them. A cursory assessment was conducted using the stratigraphic and hydrogeologic sections. The Upper Floridan aquifer ranges in thickness from 25 ft in well BREX-1 (sheet 1) to 480 ft in well BGTP-1 (sheet 5) and is generally thickest around the southern end of Lake Okeechobee. Flowmeter, packer test, and aquifer performance-test data indicate that much of the Ocala Limestone and the upper part of the Avon Park Formation are not very transmissive in areas to the southwest, west, and northwest of Lake Okeechobee and are not included in the Upper Floridan aquifer (well L2-TW, sheet 3; LAB-TW, sheet 2; BREX-1, sheet 1; and ROMP29A and OKF-105, sheet 6).

The middle semiconfining unit 1 separating the Upper Floridan aquifer and Avon Park permeable zone varies from 100 ft thick in well MF-40 (sheet 1) to 860 ft thick in well OKF-105 (sheet 6). Middle semiconfining unit 1 generally thins to the east of Lake Okeechobee near the Atlantic coast.

The Avon Park permeable zone is present in all cross-section wells deep enough to penetrate it. Lateral hydraulic connectivity within this permeable zone, however, is uncertain in some areas. Thickness of the Avon Park permeable zone, based on the sections, ranges from 25 ft in well L2-TW (sheet 3) to 420 feet in well PSL-DMW (sheet 1). The Avon Park permeable zone is generally thinnest at the southern end of Lake Okeechobee and thickens to the northwest of Lake Okeechobee (well ROMP29A, sheet 6). Well-to-well hydraulic connectivity within the rocks designated as Avon Park permeable zone is uncertain on the eastern side of Lake Okeechobee and near the Atlantic coast. In some areas near the Atlantic coast, the Avon Park permeable zone is hydraulically connected with the Upper Floridan aquifer, for example, at the MF-40 site (sheet 1). Aquifer testing at this site indicates the upper part of the Avon Park permeable zone is hydraulically connected to the Upper Floridan aquifer (Sunderland, 2008).

A thick section of permeable, fractured limestone above the Avon Park permeable zone in the Avon Park Formation is present in some wells in the study area (BREX-1, OKF-100, and W-17052; sheets 1, 5). This section, which is hundreds of feet thick, may or may not be hydraulically connected to the Avon Park permeable zone, and the development of fractures may be highly localized. The occurrence of highly fractured limestone in wells BREX-1 and OKF-100 is indicated by borehole video, formation microresistivity images, and caliper and sonic data (Missimer Groundwater Science, 2007; U.S. Army Corps of Engineers, 2002). A 250-ft section of fractured limestone above the Avon Park permeable zone is indicated in well W-17052 by caliper (sheet 5) and sonic data curves, high drilling rates, and the loss of large volumes of cement during casing installation (Geraghty and Miller, Inc., 1991). Fracturing in the upper part of the Avon Park Formation is also indicated in well MF-40 (sheet 1; Sunderland, 2008).

The middle semiconfining unit 2 separating the Avon Park permeable zone and upper permeable zone of the Lower Floridan aquifer ranges in thickness from 60 ft in well W-17052 near the southeastern shore of Lake Okeechobee (sheet 5) to 750 ft in well W-16182 near the Atlantic coast (sheet 3). Generally this unit is thinnest in wells near Lake Okeechobee. The thickness of the upper permeable zone of the Lower Floridan aquifer ranges from about 30 ft in well W-15880 (sheet 1) to 220 feet in FPL-IW2 (sheet 3).

All aquifers and major permeable zones in the Floridan aquifer system contain brackish to saline groundwater in most of the study area. The Upper Floridan aquifer contains fresh groundwater only in the northern parts of Okeechobee and Glades Counties and in most of Highlands County (Sprinkle, 1989).

Geologic Features

Geologic features identified in this study could affect recovery of freshwater injected into potential storage zones in the Upper Floridan aquifer and Avon Park permeable zone that contain brackish to saline groundwater. Maps showing the configuration of the upper contacts of the Ocala Limestone and Arcadia Formation illustrate local features that may influence decisions on ASR placement and well construction activities (sheets 7 and 8). Three hydrogeologic factors that may control recovery are confinement of storage zones, distribution of the permeability within storage zones, and the structural setting (Reese, 2002). Fracturing, faulting, and associated vertical dissolution and karst collapse could reduce the vertical confinement of selected storage zones. These features could allow injected freshwater to move upward, making it less likely to be recovered, or allow for saline water to move upward into the storage zone during recovery and mix with the injected water. Fracturing within storage zones that increases the transmissivity of the storage zone could lead to the loss of injected freshwater due to increased dispersive mixing. Buoyancy forces could cause the movement of freshwater away from injected wells located in structural lows or in areas of higher dip.

Upper Contact of the Ocala Limestone

The altitude of the upper contact of the Ocala Limestone ranges from 351 ft below NGVD 29 in the northwestern part of the study area to 1,177 ft below NGVD 29 in the southern part, following the regional dip to the south and southeast into the south Florida basin (Miller, 1986; sheet 7). The Ocala Limestone thins to the south and east, and in southeastern Palm Beach and northeastern Broward Counties, this formation is absent. Beyond the extent of the Ocala Limestone, mapped contours represent the upper contact of the Avon Park Formation (sheet 7). The upper contact of the Ocala Limestone is an unconformity, and the absence of this formation in this area could be the result of complete erosion of the unit (Miller, 1986).

Prominent surface depressions in the mapped upper contact of the Ocala Limestone, showing as much as 200 to 300 ft of relief or offset, occur along the southwestern and northeastern sides of Lake Okeechobee (sheet 7). In one of the depressions along the west-southwestern edge of the lake, the altitude is almost 1,000 ft below NGVD 29 at well W-5436. Other features of this mapped surface include (1) an elongate structural low extending from near the center of Lake Okeechobee, dipping through the southeastern corner of the lake, and continuing into southeastern Palm Beach County, (2) a narrow structural high extending and dipping to the southeast along the Kissimmee River from north of Lake Istokpoga in Highlands County into Okeechobee County, and continuing into the northern part of Lake Okeechobee, and (3) a broad structural high in the west-central part of Lake Okeechobee defined to the west by the low at the southwestern corner of the lake (sheet 7).

Upper Contact of the Arcadia Formation

Some geologic features shown on the map of the upper contact of the Ocala Formation are also visible on the map of the upper contact of the Arcadia Formation, as well as additional features (sheet 8). Altitude for the upper contact of the Arcadia Formation ranges from 92 ft below NGVD 29 in the northwestern part of the mapped area to 797 ft below NGVD 29 in the southeastern part along the Atlantic coast. Geologic features shown on this map include (1) depressions along the southwestern and northeastern sides of Lake Okeechobee (with less relief than on the mapped upper contact of the Ocala Limestone), (2) a structural or erosional low in the southeastern part of Lake Okeechobee extending to the southeast, and (3) a structural or erosional high along the Kissimmee River extending southeastward into the northern part of Lake Okeechobee. This latter feature extends further to the southeast beneath Lake Okeechobee than it does on the mapped upper contact of the Ocala Limestone. Some of the paleotopographic relief associated with the upper contact of the Arcadia Formation is likely the result of erosion, and several lows shown on this map that are not present on the mapped upper contact of the Ocala Limestone may be, at least in part, due to erosion. These paleo-depressions include (1) a low in the west-central part of Lake Okeechobee based on seismic-reflection data, (2) a low that extends to the northwest from the northwestern side of Lake Okeechobee through central Highlands County and Lake Istokpoga, and (3) a narrow elongate low that extends from the southwestern corner of Lake Okeechobee to the southwest into northwestern Hendry County.

The low in the west-central part of Lake Okeechobee appears to connect with the three other lows extending from the northwest, southwest, and southeast of Lake Okeechobee. This low has been previously identified as a paleo-river channel incised into the upper part of the Arcadia Formation (Collier Consulting, Inc., 2007). Incision into the Arcadia Formation was identified in the western parts of seismic-reflection profiles 1 and 2 in this area (sheet 8), and this erosional low is interpreted to be filled in with deltaic, siliciclastic deposits that are part of the Peace River Formation. This paleo-river channel identified in the west-central part of Lake Okeechobee is likely a northern, upstream extension of a quartz-sand-filled channel mapped to the south in Hendry, Palm Beach, and Broward Counties (Cunningham and others, 1998).

Summary and Conclusions

This report presents a refined hydrogeologic framework of the Floridan aquifer system and identifies geologic features that may affect placement of aquifer storage and recovery (ASR) wells in the areas of interest to the Comprehensive Everglades Restoration Plan to use ASR as a water-management tool around Lake Okeechobee. New data used in this report were collected after a preliminary hydrogeologic framework study, and they include data from additional wells drilled and water-based seismic-reflection profiles collected within Lake Okeechobee and a nearby canal. This report presents (1) six stratigraphic and hydrogeologic sections of the upper part of the Floridan aquifer system and the overlying intermediate confining unit or intermediate aquifer system, and (2) maps of the altitude of upper contacts of the Ocala

Limestone and the Arcadia Formation. The upper contact of the Ocala Limestone is commonly near the upper boundary of the Floridan aquifer system, and the upper contact of the Arcadia Formation is in the overlying intermediate confining unit or aquifer system.

Three major permeable zones within the Floridan aquifer system—the Upper Floridan aquifer, Avon Park permeable zone, and uppermost major permeable zone of the Lower Floridan aquifer—are shown on the stratigraphic and hydrogeologic sections and for the most part, were found to be continuous in the study area. The middle confining unit of the Floridan aquifer system is divided into two middle semiconfining units separated by the Avon Park permeable zone. Delineation of the Avon Park permeable zone and upper permeable zone of the Lower Floridan aquifer follows a stratigraphic marker horizon used to define the upper contact of the lower Avon Park Formation. Hydraulic connectivity within the Avon Park permeable zone is uncertain between some areas, such as between wells on the east side of Lake Okeechobee and wells farther to the east near the Atlantic coast. In some eastern areas near the Atlantic coast, the Avon Park permeable zone is hydraulically connected with the Upper Floridan aquifer.

The altitude of the upper contacts of the Ocala Limestone and Arcadia Formation were mapped using well data and seismic-reflection data from beneath Lake Okeechobee. Pronounced depressions, with relief up to 300 feet occur along the northeastern and southwestern sides of Lake Okeechobee. Other elongate paleotopographic highs and lows were also mapped. The origin of some geologic features could be related to karst collapse structures, which are commonly observed along the seismic-reflection profiles in Lake Okeechobee, or possibly be associated with regional tectonic movement.

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Appendixes

Appendixes 1–2 are available for download at *http://dx.doi.org/10.3133/sim3288* in the following formats:

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