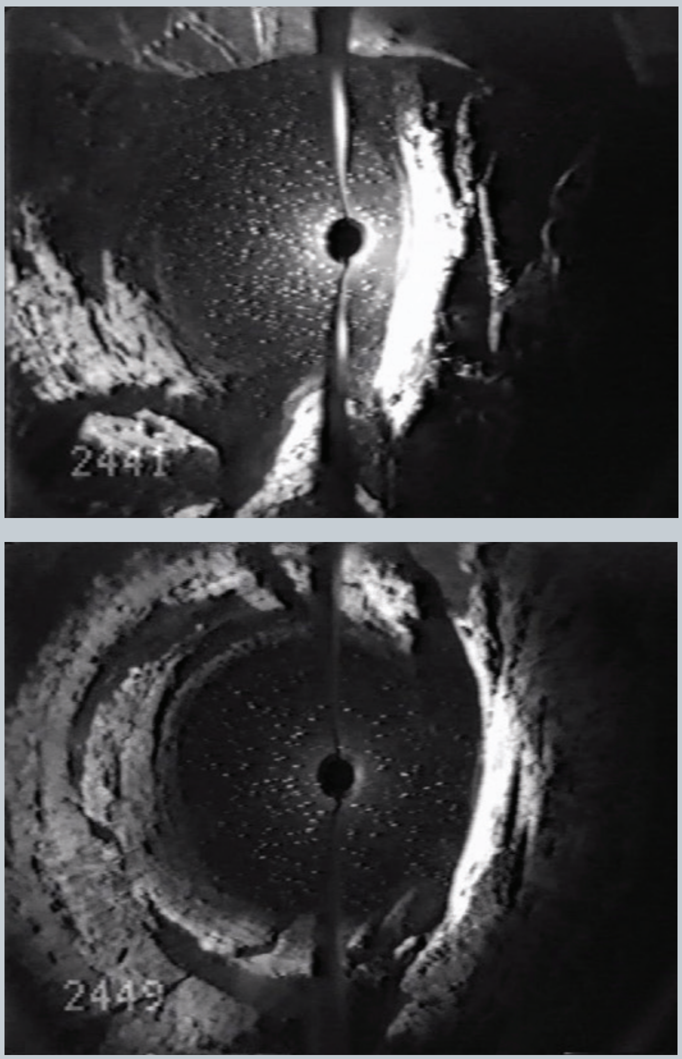
Prepared in cooperation with the Miami-Dade Water and Sewer Department

Hydrogeologic Characterization of Part of the Lower Floridan Aquifer at the South District Wastewater Treatment Plant, Miami-Dade County, Florida



Open-File Report 2019–1034

U.S. Department of the Interior
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Cover. Borehole video images showing vertical fractures, potentially solution enlarged, that extend through approximately 8 feet of the dolomite unit at the top of the Oldsmar Formation in well IW-10. Further details provided in figure 5, herein.

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DAVID BERNHARDT, Secretary

U.S. Geological Survey
James F. Reilly II, Director

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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
inch (in.)	2.540	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Flow rate	
gallon per minute (gal/min)	0.06309	liter per second (L/s)
gallon per day (gal/d)	0.003785	cubic meter per day (m^3/d)
	Transmissivity	
foot squared per day (ft^2/d)	0.09290	meter squared per day (m^2/d)
gallon per day per foot ([gal/d]/ft)	0.2070	liter per second per meter ([L/s]/m)

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as
°C = (°F – 32) / 1.8.

Datum

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

Hydrogeologic Characterization of Part of the Lower Floridan Aquifer at the South District Wastewater Treatment Plant, Miami-Dade County, Florida

By Kevin L. DeFosset and Kevin J. Cunningham

Abstract

The South District Wastewater Treatment Plant in southeastern Miami-Dade County, Florida, includes a Class I treated wastewater injection well system. The detection of ammonia in monitoring zones above the injection zone in the Lower Floridan aquifer has elicited a need to understand the nature of confinement within the Lower Floridan aquifer as it pertains to the vertical migration of injectate out of the injection zone upward into the Underground Source of Drinking Water in the upper part of the Floridan aquifer system. Geologic and geophysical data, borehole video imagery, and aquifer performance data were used to refine and clarify the geologic and hydrogeologic frameworks of part of the Lower Floridan aquifer at the treatment plant. The data provide evidence for zones of enhanced dissolution permeability, extensive secondary porosity, fractures, karst collapse structures, and faults that could provide vertical cross-formational fluid pathways that transect the Lower Floridan aquifer.

Introduction

At the South District Wastewater Treatment Plant (referred to as the South District “Boulder Zone” Well Field by Cunningham [2015]) in southeastern Miami-Dade County (fig. 1), treated municipal wastewater is disposed of by injection into the Lower Floridan aquifer (fig. 2). The facility includes a treated wastewater injection well system with 17 Class I injection wells and 17 associated monitor wells completed between 1977 and 1995 (fig. 1). The monitor wells were constructed with dual monitor zones to observe the water quality both above and below the base of the Underground Source of Drinking Water (U.S. Environmental Protection Agency, 2018) that lies within the upper part of the Floridan aquifer system (fig. 2) and about 1,070 feet (ft) above the treated wastewater injection zone. The Underground Source of Drinking Water is a critical brackish water resource for alternative water-supply projects in Miami-Dade County.

The primary injection zone for treated wastewater is the highly permeable Boulder Zone, a hydrogeologic unit in the lower part of the Lower Floridan aquifer (fig. 2; Miller, 1986, 1990). Additionally, for 10 of the injection wells, the injection zone extends approximately 300 to 400 ft above the Boulder Zone to the top of a dolomite unit capping the Oldsmar Formation, which is the upper part of the uppermost major permeable zone of the Lower Floridan aquifer at the South District Wastewater Treatment Plant (fig. 2). Beginning in 1994, ammonia attributed to upward migrating treated wastewater injectate has been detected in nine monitor wells above the disposal zone (Dausman and others, 2009; Walsh and Price, 2010).

To evaluate the migration of injected fluids vertically upward out of the injection zone at the South District Wastewater Treatment Plant, it is important to understand the delineation and characteristics of the geologic and hydrogeologic units from the top of the Lower Floridan aquifer to the upper part of the Boulder Zone. The geologic and hydrogeologic frameworks presented in Miller (1986), Meyer (1989), Reese and Richardson (2008), Reese and Cunningham (2014), Cunningham (2015), Williams and Kuniansky (2015), and Cunningham and others (2018a, b) indicate that these studies differ in their respective delineations of the geologic and hydrogeologic units of the Lower Floridan aquifer. Hydraulic or aquifer performance testing can provide a quantitative evaluation of characteristics that influence vertical fluid movement. However, the paucity of different types of tests used on the subject interval in the study area provides inconsistent results, possibly caused either by the different types of tests, the natural heterogeneity in hydraulic properties, or both. In 2014, the U.S. Geological Survey, in cooperation with the Miami-Dade Water and Sewer Department, initiated a study to characterize the Cretaceous and Cenozoic hydrogeologic framework of southeastern Florida.

The purpose of this report is to refine and clarify the geologic and hydrogeologic framework of part of the Lower Floridan aquifer at the South District Wastewater Treatment Plant in southeastern Miami-Dade County (fig. 1) using the geologic and hydrogeologic conceptualizations of the Lower Floridan aquifer presented by Cunningham and

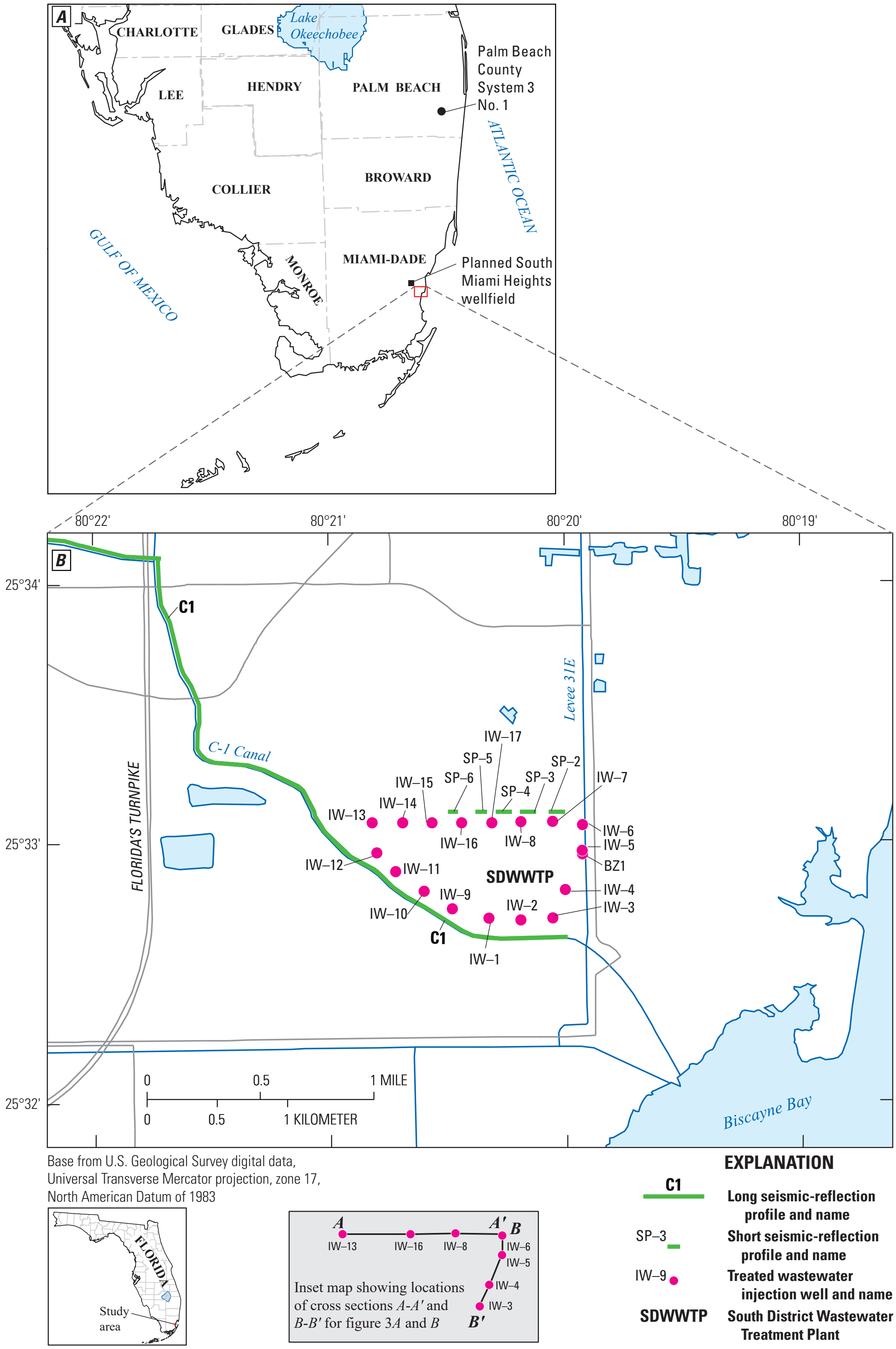


Figure 1. South District Wastewater Treatment Plant where injection wells IW-1 through IW-17 and monitor well BZ-1 are located and the location of seismic-reflection survey profiles in the study area (modified from Cunningham, 2015).

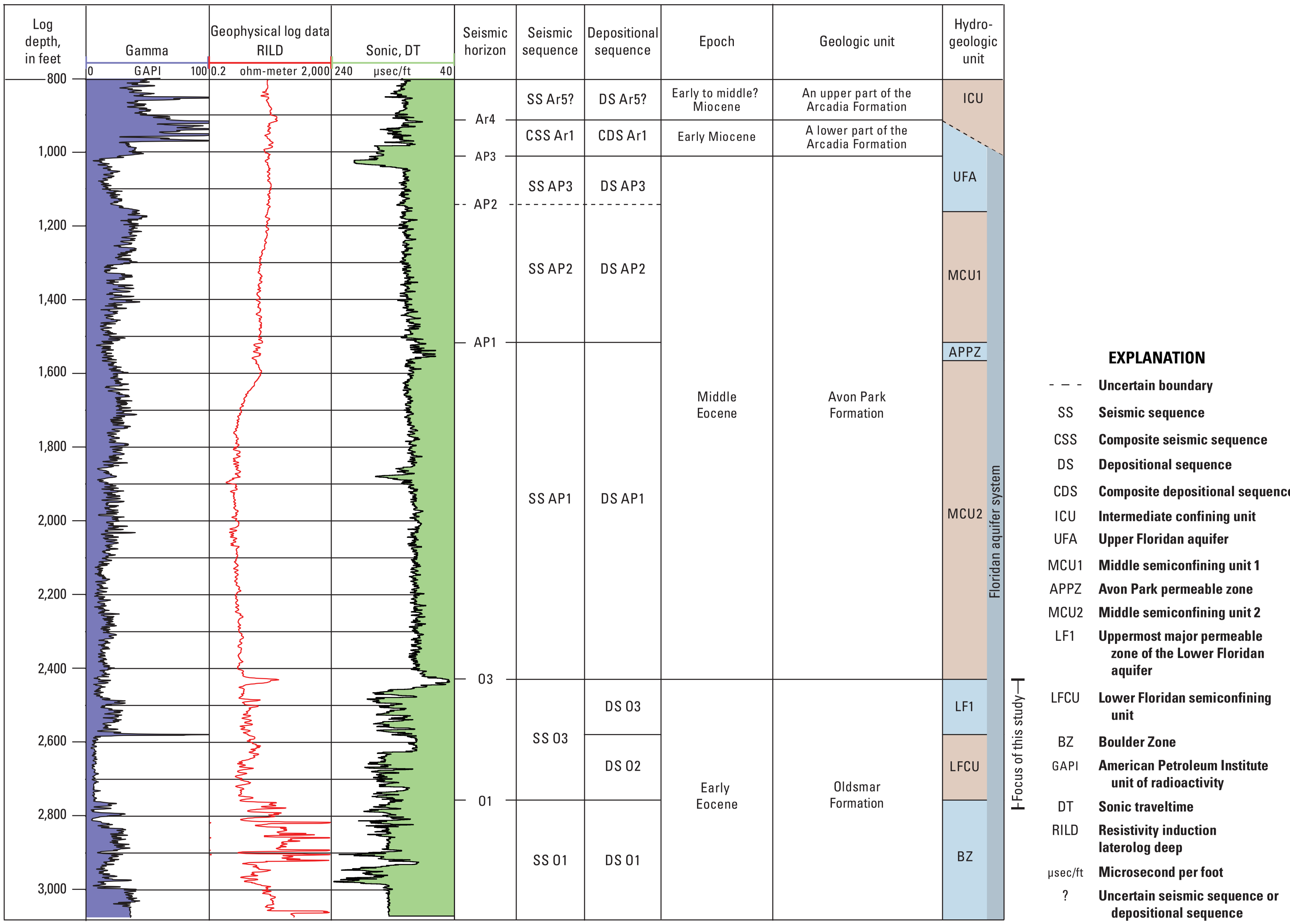


Figure 2. Relations between geophysical well logs for injection well IW-12, located in the western part of the South District Wastewater Treatment Plant (fig. 1), and seismic horizons and sequences, depositional sequences, geologic units, and hydrogeologic units within the Floridan aquifer system in the study area.

others (2018a, b). An approximately 300- to 400-ft interval from the top of the Lower Floridan aquifer to the upper part of the Boulder Zone was evaluated using geologic and geophysical data, borehole video imagery, and aquifer test data. The resulting characterization of this part of the Lower Floridan aquifer should aid quantitative evaluations of the transport of injectate at the treatment plant as well as water resource managers concerned with the sustainability of the potential uses of the Floridan aquifer system.

Methods

The characterization of the Lower Floridan aquifer at the South District Wastewater Treatment Plant is based on an analysis of data that represent the interval of interest: (1) lithologic descriptions of injection well borehole cuttings and core samples (Singh and Sproul, 1980; CH2M Hill, 1981), (2) seismic-reflection data (Cunningham, 2015; Cunningham and others, 2018a, b) and borehole geophysical data, (3) borehole video imagery, and (4) aquifer test data (BC&E/CH2M Hill, 1977; CH2M Hill, 1980; Singh and others, 1980, 1983). Integrated use of these data provided multiple lines of evidence for establishing geologic and hydrogeologic unit boundaries, as well as attributes that characterize the hydraulics of the hydrogeologic units. No new datasets were generated or analyzed for this report.

Although the quality of the lithologic descriptions varies among injection wells, the descriptions were useful for identification of the depths of major vertical shifts in lithology that represent lithostratigraphic unit boundaries. In cases where geophysical borehole fluid log data indicate there is a prominent vertical shift in hydraulic character across a lithostratigraphic boundary, a coincident hydrogeologic unit boundary was assigned. Data from six core samples collected from monitor well BZ-1 (fig. 1) were used as representative rock from the Lower Floridan aquifer. The cores range in length from 6 to 14 ft (CH2M Hill, 1981).

A suite of borehole geophysical data was used to assist in the delineation of lithologic and hydraulic characteristics that define the lithostratigraphic and hydrogeologic units of the Lower Floridan aquifer. Because a vertical datum was not consistently recorded for the borehole geophysical logs, unit boundary depths are stated as log depths. Borehole geophysical data from caliper, gamma-ray, resistivity, and fluid-temperature logging are available at the Miami-Dade Water and Sewer Department for each injection well. Borehole geophysical data from sonic and fluid-resistivity logging are also available at the Miami-Dade Water and Sewer Department for injection wells IW-10 through IW-17 (fig. 1).

Cunningham (2015) provided interpretations of seismic-reflection data acquired on the north side of the well field and on the seismic line C-1 along the C-1 canal adjacent to the south side of the well field (fig. 1). Seismic sequence 3 of Cunningham (2015) is referred to as “seismic sequence O3” of Cunningham and others (2018a, b) herein. Seismic sequence O3 is representative of the depositional sequences O2 and O3, which correlate with the Lower Floridan semiconfining unit and the uppermost major permeable zone of the Lower Floridan aquifer, respectively, at the treatment plant (fig. 2).

Borehole video imagery was used to observe lithologic changes and the presence and type of visible porosity, especially vuggy porosity (Lucia, 1983) created by dissolution or fractures. The borehole video images were of adequate quality to observe hydrogeologic characteristics of the borehole wall only in injection wells IW-8, IW-10, IW-11, IW-13, IW-16, and IW-17 (fig. 1).

Aquifer test results from the wells IW-5, BZ-1, and IW-6 (fig. 1; BC&E/CH2M Hill, 1977; CH2M Hill, 1980; Singh and others, 1980, 1983) were used to provide a quantitative and qualitative hydraulic characterization of the Lower Floridan aquifer at the treatment plant. The aquifer tests conducted at these three wells were completed during the initial exploratory drilling at the site (BC&E/CH2M Hill, 1977; CH2M Hill, 1980; Singh and others, 1980, 1983). The test results are important because they provide the only hydraulic analysis for evaluating confinement between the top of the Boulder Zone and the top of the Lower Floridan aquifer. The authors did not independently analyze the data from these tests but have applied the results reported in BC&E/CH2M Hill (1977), CH2M Hill, (1980), and Singh and others (1980, 1983). Although many factors influence the data collected during aquifer tests, a thorough discussion of these factors is beyond the scope this report. Generic information on aquifer test design and the collection, analysis, and interpretation of test data can be found in Driscoll (1986). Reported depths at the subject wells are used here, because the aquifer performance test reports do not specify a vertical datum.

Geologic Framework

The Lower Floridan aquifer in southeastern Florida includes dolomite and dolomitic limestone in the upper part of the Paleocene Cedar Keys Formation and limestone and dolomite of the Early Eocene Oldsmar Formation (Miller, 1986). This report focuses on the approximately 300- to 400-ft interval of the Oldsmar Formation that extends from the upper part of the thick Boulder Zone, composed mainly of dolomite, to the top of a comparatively thin dolomite unit that forms the uppermost part of the Oldsmar Formation (fig. 2). Site-specific lithologic characteristics are based on descriptions of injection well borehole cuttings and monitor well BZ-1 core samples (CH2M Hill, 1981). Dolomite and limestone units of the Oldsmar Formation dip slightly to the northeast (fig. 3). At this site, Winston (1995) presents interpretations of normal faults with down throw of hanging walls on the east side. Cunningham (2015) describes a seismic profile acquired along the C-1 canal just south of the southern boundary of the treatment plant (fig. 1). The C-1 canal seismic profile shows faults and karst collapse structures are present in the upper part of the Oldsmar Formation.

Cunningham and others (2018a, b) recognize three depositional sequences (O1, O2, and O3) within the succession of shallow-marine carbonate platform rocks of the Oldsmar Formation in eastern Broward County and northeastern Miami-Dade County. Lithologic descriptions coupled with borehole geophysical data and borehole video images were used to determine the unconformable boundaries of these three depositional sequences at the treatment plant (fig. 4).

The uppermost part of depositional sequence O1 forms the lowermost part of the study interval for this report (fig. 2) and corresponds to the vuggy, highly fractured, dolomite, dolomitic limestone, and limestone of the Boulder Zone (fig. 2). The upper boundary of depositional sequence O1 is identified in the borehole geophysical log data by the simultaneous, substantial (1) increases in gamma radiation and resistivity and (2) decrease in sonic interval transit time relative to the overlying depositional sequence O2 (figs. 2–4). Although the highly fractured dolomite that composes most of this depositional sequence is commonly referred to by its hydrogeologic unit designation, the Boulder Zone, Winston (1994) named an equivalent geologic unit the Delray Dolomite, which he delineated in the Palm Beach County System 3 No. 1 well (fig. 1*A*). The upper bounding surface of depositional sequence O1 has not been identified with certainty using seismic-reflection data acquired on the north side of the treatment plant well field and to the south along the C-1 canal (fig. 1; Cunningham, 2015). However, 3–D seismic-reflection data in Cunningham and others (2018a, b) indicate the upper bounding surface has a highly irregular, rugged paleotopography produced by epigenic karst. The upper boundary at the 17 injection wells and BZ-1 well has an average log depth of 2,784 ft, ranging over 52 ft from 2,758 to 2,810 ft.

Depositional sequence O2, generally described as chalky limestone at the study site (CH2M Hill, 1981), has an average thickness of 195 ft. The predominance of limestone and lack of dolomite described (CH2M Hill, 1981), along with low gamma radiation, distinguish this depositional sequence from the lithologies and geophysical log responses of the underlying and overlying depositional sequences (figs. 2–4). Depositional sequence O2 is also characterized by an enlarged borehole diameter, as measured by the caliper tool (fig. 4), which is likely indicative of a limestone having relatively less interparticle cement than the underlying and overlying limestone. Drilling through poorly cemented limestone could result in borehole wall washout that would explain the enlarged borehole throughout much of depositional sequence O2. The upper bounding surface of depositional sequence O2 is placed at the top of a short vertical interval characterized by an abrupt and substantial increase in gamma radiation (figs. 2–4). The high gamma radiation is possibly associated with glauconite, phosphorite, or both. These minerals are attributed to drowning unconformities (Cunningham and others, 2018b), which are created by drowning of a carbonate platform and subsequent onlap of other sediments (carbonate or siliciclastic) (Schlager and Camber, 1986). The upper bounding surface at the 17 injection wells and BZ-1 well is at an average log depth of 2,587 log ft, ranging over 43 ft from 2,571 to 2,614 ft. Fractures were not observed in the borehole videos of this interval, and vuggy megaporosity (Choquette and Pray, 1970; Lucia, 1983) was also poorly developed (fig. 4). However, Cunningham and others (2018a) show that columniform karst-collapse structures and associated faults fully penetrate depositional sequence O2 at a planned South Miami Heights wellfield about 2.5 miles northwest of the South District Wastewater Treatment Plant (fig. 1).

Depositional sequence O3 at this field site is composed of multiple several-foot-scale cycles that mostly shallow-upward (compare to Cunningham and others, 2018b) and are composed of interbedded limestone and dolomite. The sequence has an average thickness of 142 ft (figs. 2–4; CH2M Hill, 1981). Interbedded carbonate rocks containing a varying amount of dolomite are indicated by fluctuating measurements in gamma radiation that is typical of this depositional sequence (figs. 2–4). Depositional sequence O3 is capped by a dolomite unit (figs. 3 and 4) that ranges in thickness from 10 to 22 ft. The upper surface of this dolomite unit has an average log depth of 2,446 ft at the 17 injection wells and the BZ-1 well, ranging over 48 ft from 2,423 to 2,471 ft. The dense dolomite unit correlates to elevated gamma radiation and high resistivity, which can be used as geophysical markers for the top of both depositional sequence O3 and the Oldsmar Formation (figs. 2–4; Cunningham and others, 2018a, b). The upper boundary of depositional sequence O3 is a major unconformity, characterized using seismic-reflection profiles as a highly irregular, epigenic karst surface (Cunningham, 2015; Cunningham and others, 2018a, b). Subaerial exposure and the associated epigenic karst processes, resulted in the early development of vuggy porosity by enhanced dissolution and fracturing (figs. 4 and 5), which is characteristic of the dolomite in the upper part of depositional sequence O3 (Cunningham and others, 2018a, b).

Hydrogeologic Framework

In southeastern Florida, the Lower Floridan aquifer is composed of two permeable zones, the uppermost major permeable zone of the Lower Floridan aquifer and the Boulder Zone, separated by a semiconfining unit (fig. 2; Reese and Richardson, 2008; Reese and Cunningham, 2014; Cunningham, 2015; Cunningham and others, 2018a, b). The regional hydrogeologic framework by Williams and Kuniansky (2015) was not applied to this local hydrogeologic characterization. Permeable zones defined by water entering or exiting the borehole can be discerned by prominent changes in measurements of borehole fluid temperature, resistivity, and

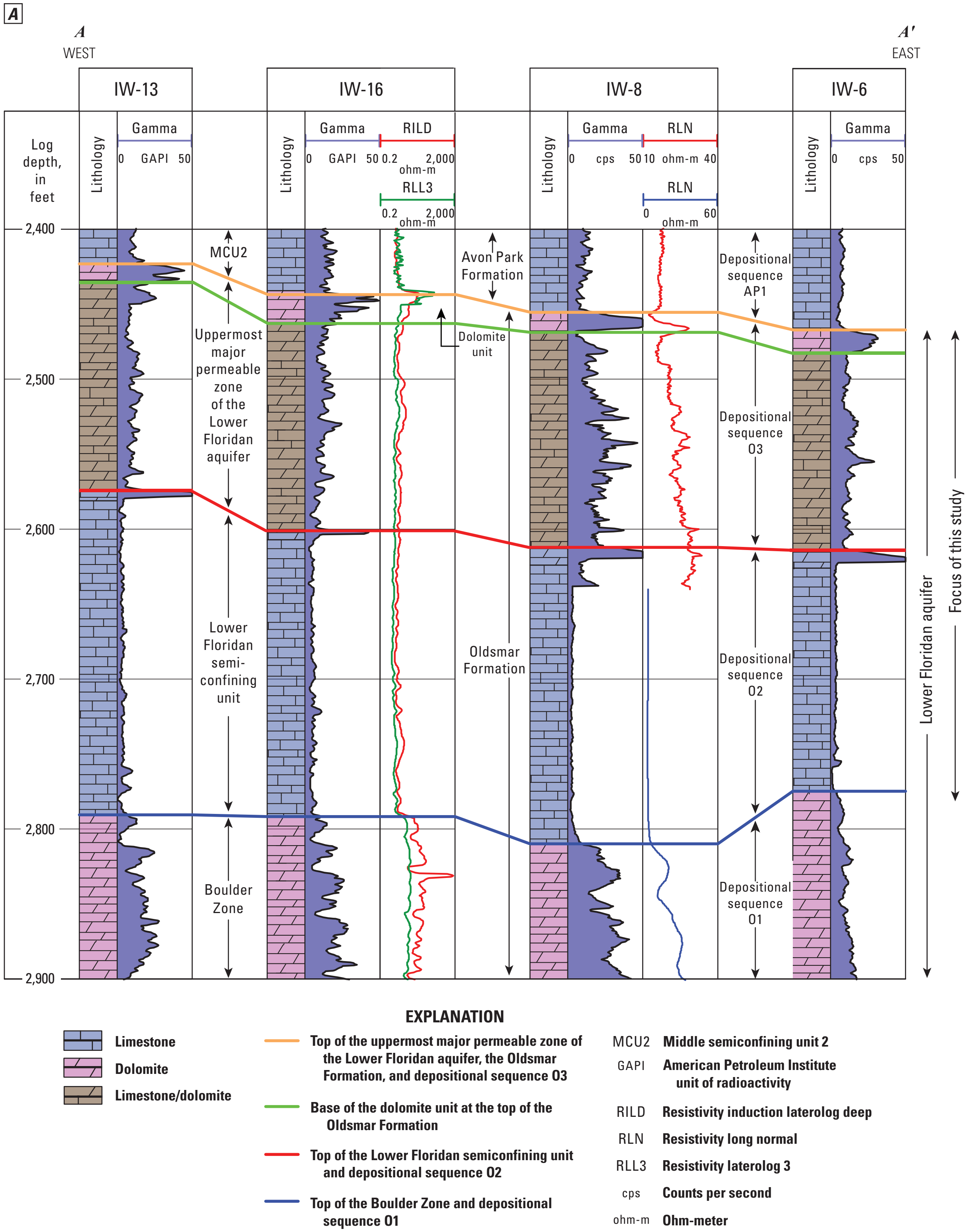


Figure 3. Correlation of hydrogeologic and geologic units, depositional sequences, and well logs within the Lower Floridan aquifer and lower part of the middle semiconfining unit 2 at the South District Wastewater Treatment Plant. *A*, *A–A′* west to east cross section along the northern part of the site (fig. 1). *B*, *B–B′* north to south cross section along the eastern part of the site (fig. 1, inset).

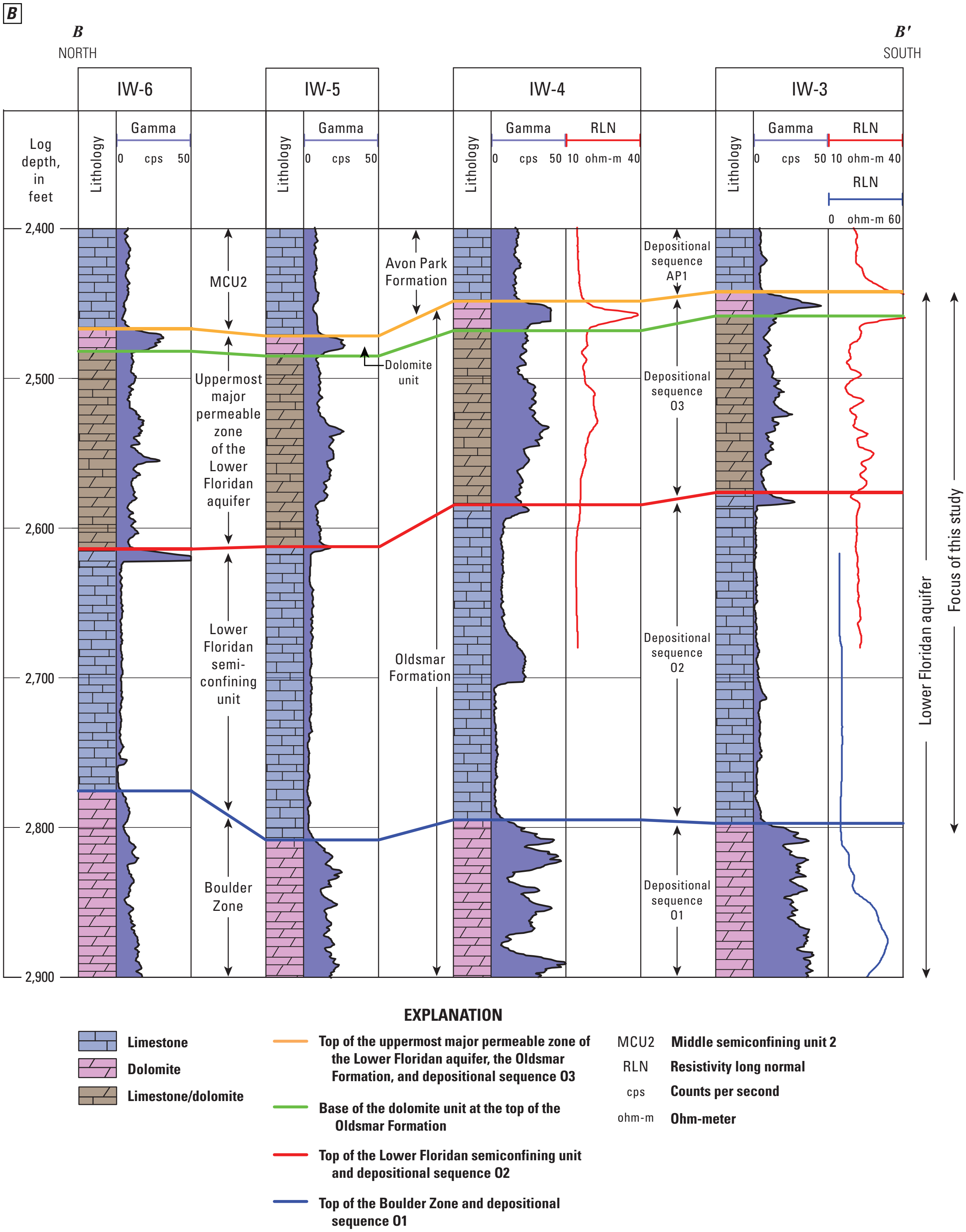


Figure 3. Correlation of hydrogeologic and geologic units, depositional sequences, and well logs within the Lower Floridan aquifer and lower part of the middle semiconfining unit 2 at the South District Wastewater Treatment Plant. *A*, *A–A′* west to east cross section along the northern part of the site (fig. 1). *B*, *B–B′* north to south cross section along the eastern part of the site (fig. 1, inset).—Continued

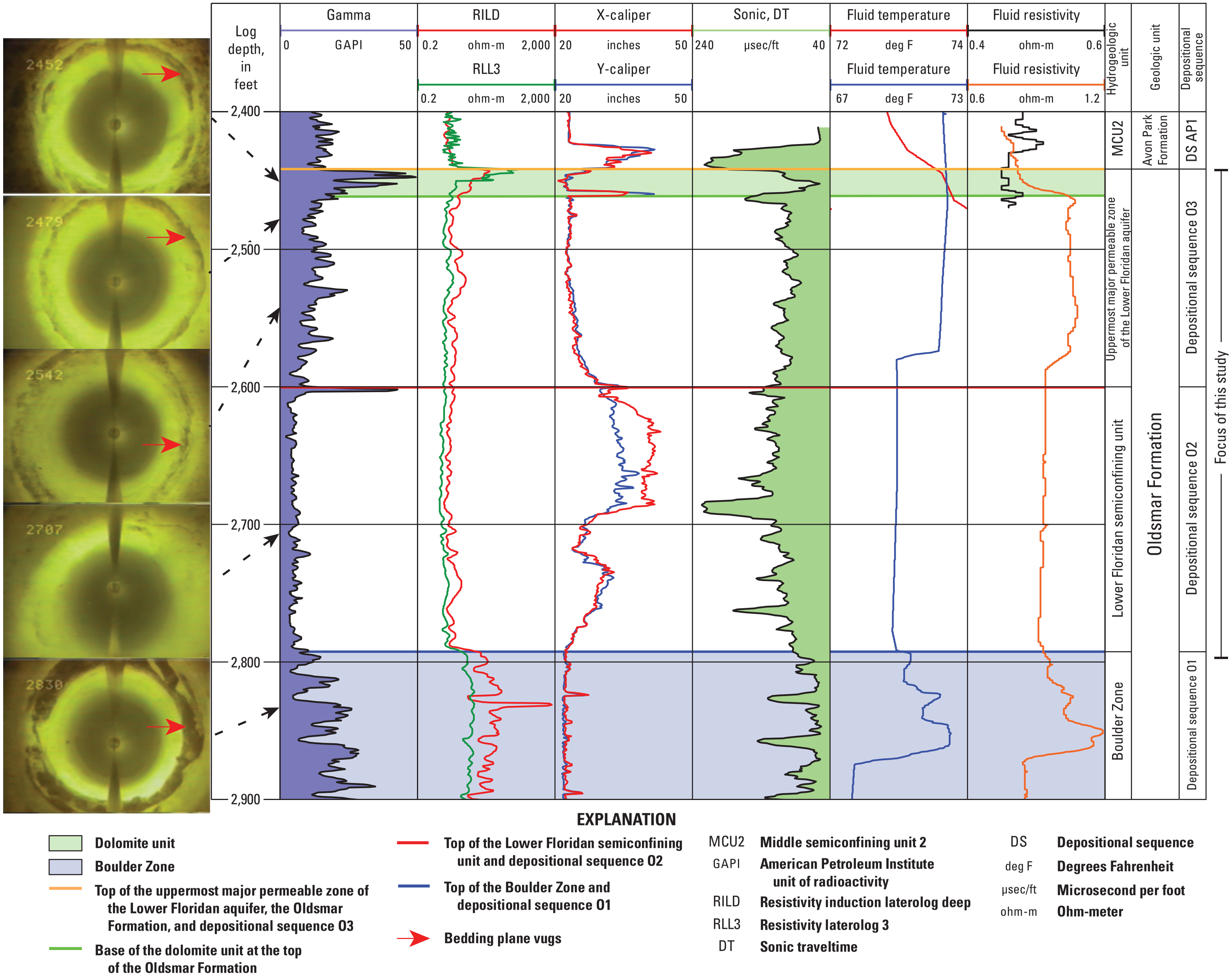


Figure 4. Relations between borehole geophysical data, hydrogeologic units, geologic units, and depositional sequences of the Lower Floridan aquifer in injection well IW-16 (fig. 1). IW-16 borehole video images acquired at the depths of 2830, 2542, 2479, and 2452 feet show examples of vuggy porosity (marked by red arrows), which are probably along bedding planes. The IW-16 borehole video image acquired at a depth of 2,707 feet within the depositional sequence 02 shows relatively poorly developed vuggy porosity compared to the other four images.

flow velocity recorded during well logging. Fluid temperature and fluid resistivity data were found to have been collected over the appropriate depth interval for use in this study at most of the injection well sites. These data were useful in determining hydrogeologic boundaries within the Lower Floridan aquifer at the South District Wastewater Treatment Plant.

The uppermost major permeable zone of the Lower Floridan aquifer was first described by Reese and Richardson (2008) as part of the Avon Park Formation. A revised description of the hydrogeologic units by Cunningham and others (2018b) considers the top of the dolomite unit at the top of the Oldsmar Formation and depositional sequence O3 to be synonymous with the top of the uppermost major permeable zone of the Lower Floridan aquifer (fig. 2). At the South District Wastewater Treatment Plant, the uppermost major permeable zone of the Lower Floridan aquifer includes the dolomite unit as well as the interbedded limestone and dolomite that compose depositional sequence O3 (figs. 2–4). With an average thickness of 142 ft, the upper boundary of the uppermost major permeable zone of the Lower Floridan aquifer has an average log depth of 2,446 ft and the lower boundary has an average log depth of 2,587 ft. These boundaries generally coincide with a water-producing zone that was identified during the drilling of the test-injection well (IW-5) at the study site (BC&E/CH2M Hill, 1977). The “2,500-Foot Zone” was delineated between the reported depths of 2,476 and 2,536 ft (BC&E/CH2M Hill, 1977; Singh and Sproul, 1980). The permeability attributed to the uppermost major permeable zone of the Lower Floridan aquifer is represented by touching-vug porosity (Lucia, 1983) and fractures, which are identifiable in borehole videos (figs. 4 and 5). These porosity features accommodate both horizontal and vertical fluid flow. Borehole video images from one injection well, IW-10, show vertical fractures that extend through the entire thickness of the dolomite unit at the uppermost part of depositional sequence O3, providing a discrete pathway for fluid bypass of this unit (fig. 5). Although vertical fractures were only observed in one of the five borehole videos used in this study, it is reasonable to expect that similar features exist elsewhere at the study site, especially considering evidence from seismic profiles from the nearby planned South Miami Heights wellfield (fig. 1) and Broward County (Cunningham and others, 2018a, b).

Fluid temperature data collected at 10 injection wells (IW-4, IW-6, IW-8, IW-10, IW-11, IW-12, IW-13, IW-14, IW-15, IW-16) indicated a distinct decrease or increase in borehole fluid temperature within either the upper dolomite unit or the underlying interbedded limestone and dolomite (figs. 4 and 6). Additionally, at two of these wells (IW-14, IW-16), there is an associated upward decrease in the borehole fluid resistivity values within the upper dolomite unit (figs. 4 and 6). This fluid temperature change and fluid resistivity decrease is interpreted to indicate that either cooler or warmer and more saline formation water is entering the borehole at multiple points within this hydrogeologic unit, demonstrating an enhanced permeability of the rocks in the uppermost major permeable zone of the Lower Floridan aquifer.

The Lower Floridan semiconfining unit is 195 ft thick, on average, above the top of the Boulder Zone (figs. 2–4 and 6). This unit corresponds to the chalky limestone (CH2M Hill, 1981) that composes depositional sequence O2 (figs. 2–4). Solution enlarged voids in this unit are absent or poorly developed (fig. 4). The relative lack of permeability attributed to this unit is represented by a borehole fluid temperature data trend that either maintains a consistent value throughout the vertical extent of the unit or presents a gradual cooling of borehole fluid with increasing depth that is characteristic of the local geothermal gradient. Sharp deviations in the fluid temperature data that can indicate zones of enhanced permeability are largely absent. The fluid temperature data character indicates either the temperature of water entering the Boulder Zone and moving vertically upward across the Lower Floridan semiconfining unit (figs. 4 and 6) or the ambient temperature of the pore fluid in the rock surrounding the borehole. It should be noted that the columniform karst-collapse structures and associated faults identified in seismic data 2.5 miles to the northwest (Cunningham and others, 2018a) and referred to in the previous section show a higher potential for cross-formational vertical fluid migration than the surrounding host rock.

The Boulder Zone is a thick, mainly dolomitic, highly fractured, highly permeable zone at the base of the Lower Floridan aquifer (figs. 2–4 and 6). Although an evaluation of this unit is beyond the scope of this report, the highly permeable nature of this unit has been demonstrated for decades across southern Florida by serving as the primary disposal zone for treated wastewater and reverse osmosis concentrate. The top of the Boulder Zone at the South District Wastewater Treatment Plant has an average log depth of 2,784 ft.

Aquifer Performance Test Results

In the northeastern part of the South District Wastewater Treatment Plant, single-well packer tests, a single-well constant-rate and step-drawdown test, and a multi-well constant-rate and step-drawdown test were performed during initial development of the site (BC&E/CH2M Hill, 1977; CH2M Hill, 1980; Singh and others, 1980, 1983). Injection well IW-5 (fig. 1) packer tests were performed to determine the effectiveness of confinement between the top of the Boulder Zone at a log depth of 2,808 ft and the base of the Upper Floridan aquifer at a reported depth of 1,690 ft (Singh and others, 1980). Single-well (well IW-5) and multi-well (pumping well IW-5 and monitor wells BZ-1 and IW-6) constant-rate and step-drawdown pump tests were performed to provide estimates of the hydraulic characteristics of the Boulder Zone, but additionally provided qualitative information about the vertical hydraulic connection between the Boulder Zone and shallower parts of the Floridan aquifer system (Singh and others, 1980, 1983).

Paired straddle and single-well packer tests were conducted above the Boulder Zone to a reported depth

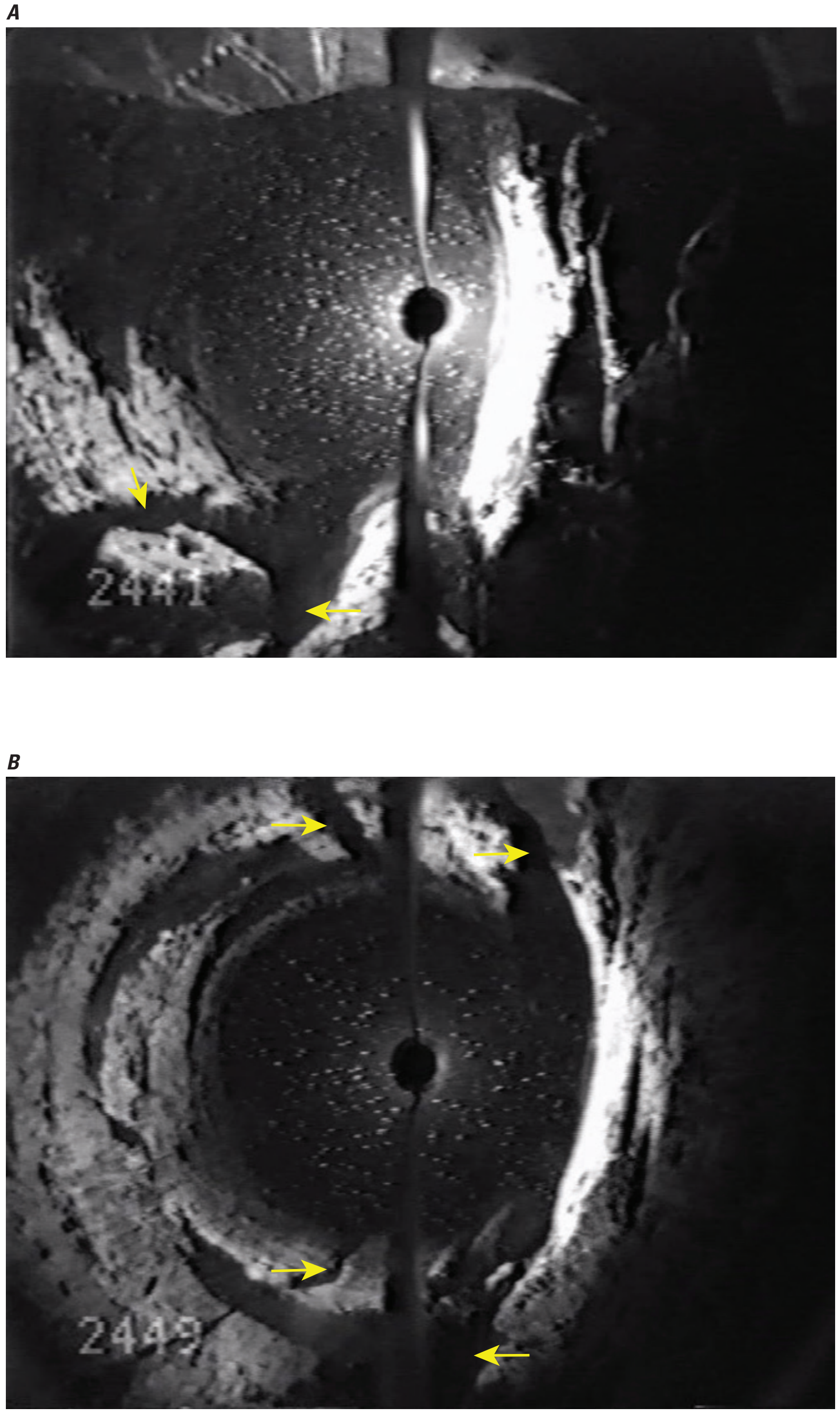
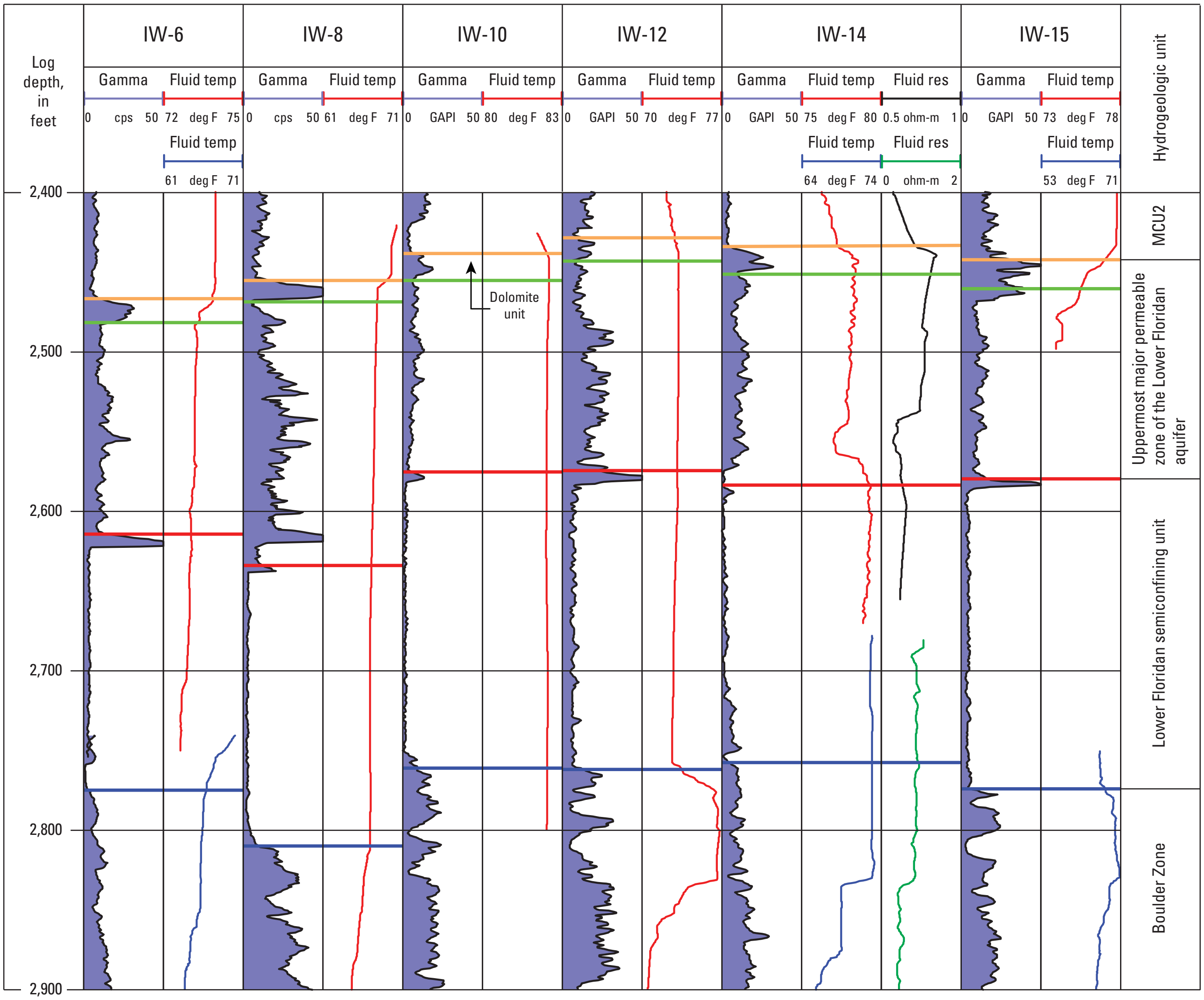


Figure 5. Vertical fractures (potentially solution enlarged), indicated by yellow arrows, that extend through approximately 8 feet (ft) of the dolomite unit at the top of the Oldsmar Formation in IW-10 (fig. 1). Intervening video images show similar fractures. *A*, The upper extent of the vertical fractures at a log depth of 2,441 ft in IW-10. *B*, The lower extent of the vertical fractures at a depth of 2,449 ft in IW-10.



EXPLANATION

- Top of the uppermost major permeable zone of the Lower Floridan aquifer, the Oldsmar Formation, and depositional sequence O3
- Base of the dolomite unit at the top of the Oldsmar Formation
- Top of the Lower Floridan semiconfining unit and depositional sequence O2
- Top of the Boulder Zone and depositional sequence O1

MCU2 **Middle semiconfining unit 2**
GAPI **American Petroleum Institute unit of radioactivity**
temp **Temperature**
deg F **Degrees Fahrenheit**
res **Resistivity**
cps **Counts per second**
ohm-m **Ohm-meter**

Figure 6. Diagram showing injection well borehole gamma-ray, fluid temperature, and fluid resistivity geophysical logs at six injection well sites at the South District Wastewater Treatment Plant. Substantial deflections in the fluid temperature and fluid resistivity data are interpreted to represent water entering the borehole at permeable zones within the uppermost major permeable zone of the Lower Floridan aquifer.

of 2,759 ft during the drilling of injection well IW-5 prior to completion in the Boulder Zone (Singh and others, 1980). An isolated zone was tested with straddle packers, then the interval underlying the straddle packers was tested from the base of the straddle packers down to the bottom of the borehole at 2,759 ft (Singh and others, 1980). Seven packer tests were performed within the Lower Floridan aquifer over intervals spanning 22 to 352 ft with reported transmissivities ranging from 63 gallons per day per foot (8 feet squared per day) to 350 gallons per day per foot (47 feet squared per day, table 1). BC&E/CH2M Hill (1977) and Singh and others (1980) provide details regarding the protocol for completing the progression of packer tests and the analysis of test data.

Upon completion of injection well IW-5 in the Boulder Zone, constant-rate (6,200 gallons per minute [gal/min], 7 hours) and step-drawdown (2,800, 4,300, and 7,600 gal/min; 70 minutes) aquifer tests were performed (Singh and others, 1983). The IW-5 well was pumped from approximately 100 ft below the top of the 20-inch (in.) casing. During pumping, water level was monitored within the 20-in. casing in the temporary open annulus between the 20- and 30-in. casings above a reported depth of 2,473 ft (top of cement) and in the annulus between the 30- and 40-in. casing at a reported approximate depth equivalent to that of the Upper Floridan aquifer (BC&E/CH2M Hill, 1977). Because the response at both the annuli observation points during pumping and recovery was minimal to nonexistent, it was concluded that the tests provided a qualitative confirmation of confinement separating fluid movement between the Boulder Zone and shallower depths within the Floridan aquifer system, as similarly demonstrated by the packer test data (Singh and others, 1980). Singh and others (1980) provide additional details on this single well pumping test.

Constant-rate (5,950 gal/min, 5.5 hours) and step-drawdown (2,077, 3,855, and 5,875 gal/min; 100 minutes) pumping tests conducted in 1979 were designed with a pumping well (IW-5) and two monitor wells (BZ-1, IW-6) (Singh and others, 1983). Located 107 ft south of IW-5, BZ-1 was monitored in the Boulder Zone at a reported depth interval of 2,689 to 3,110 ft and at the top of the Lower Floridan aquifer at a reported depth interval of 2,455 to 2,465 ft. Located 693 ft north of IW-5, IW-6 was monitored in the Boulder Zone at a reported depth interval of 2,740 to 3,112 ft and above the Lower Floridan aquifer in the reported depth interval of 1,790 to 2,295 ft. Singh and others (1983) provides plan and cross-sectional views that illustrate the test design. Minimal drawdown, adjusted for background fluctuations, was recorded in IW-6, but measured drawdown, adjusted for background fluctuations, in shallow and deep monitored zones of BZ-1 was similar in magnitude (table 2). It is suggested that the drawdown data are qualitatively consistent with vertical hydraulic interconnection between the uppermost major permeable zone of the Lower Floridan aquifer and the Boulder Zone (BC&E/ CH2M Hill, 1977; CH2M Hill, 1980, 1981). CH2M Hill (1980) and Singh and others (1983) provide details on background water levels, water-level recording, pumping rate measurement, and test data analysis.

The single-well and multi-well aquifer tests were designed to describe the hydraulic characteristics of the aquifer in the northeastern part of the treatment plant. Although the test results provide a general perspective on the hydraulic characteristics of the Lower Floridan aquifer, the results are limited in spatial representation at the site and are inconsistent and largely qualitative. Consequently, the test results provide an inconclusive characterization of the confinement between the Boulder Zone and the top of the Lower Floridan aquifer at the South District Wastewater Treatment Plant. Single-well aquifer tests, whose results here describe effective confinement, can be used to determine the aquifer hydraulic properties near a borehole. However, multi-well aquifer tests, whose results here describe poor confinement, use monitor wells to determine the hydraulic properties of an aquifer beyond the immediate vicinity of a pumping well. It is reasonable that these tests could provide seemingly contradictory results, because the tests assess different volumes and parts of the heterogeneous and anisotropic aquifer. Thus, it is important to consider the geologic and geophysical data for this site, which provide a conceptualization of the porosity and permeability system analyzed by the two types of aquifer tests.

Table 1. Summary of IW-5 packer tests performed in 1977 (modified from BC&E/CH2M Hill, 1977, table 4–1).

[Dates shown as month, day, year]

Date	Packer test type	Test interval (reported depth, in feet)	Height of test interval (feet)	Transmissivity (gallons per day per foot)	Transmissivity (feet squared per day)	Discharge (gallons per minute)
8/25/1977	Single	2,737–2,759	22	63	8	50
8/25/1977	Straddle	2,697–2,727	30	92	12	4
8/26/1977	Single	2,407–2,759	352	350	47	61
8/27/1977	Straddle	2,543–2,573	30	143	19	55
8/27/1977	Single	2,583–2,759	176	326	44	33
8/28/1977	Single	2,692–2,759	67	264	35	12
8/28/1977	Straddle	2,652–2,682	30	96	13	20

Table 2. Summary of step-drawdown and constant-rate aquifer pump test measurements performed in 1979 (modified from CH2M Hill, 1980, tables 1–3).

Flow rate (gallons per minute)	Well name (reported test interval depth, in feet)				
	IW-5[a] (2,746–3,200)	BZ-1[b] (2,689–3,110)	BZ-1[b] (2,455–2,465)	IW-6[c] (2,740–3,112)	IW-6[c] (1,790–2,295)
	Drawdown (feet)				
Step-drawdown test					
2,077	4.33	0.008	0.010	Too small to measure accurately	0.000
3,855	11.41	0.017	0.020		0.000
5,875	23.63	0.043	0.039		0.000
Constant-rate test					
5,950	23.57	0.048	0.04	0.016	0.000

[a]Pumping well.

[b]Monitor well 107 feet from IW-5.

[c]Monitor well 693 feet from IW-5.

Summary

- The Lower Floridan aquifer is composed of the dolomite and limestone of the Oldsmar Formation. The Oldsmar Formation comprises three unconformity-bound depositional sequences that are recognized in ascending order as depositional sequences O1, O2, and O3.
- Depositional sequence O1 correlates to the hydrogeologic unit known as the Boulder Zone, which is the primary disposal zone for treated wastewater at the South District Wastewater Treatment Plant. A thorough, quantitative characterization of this sequence was beyond the scope of this report.
- Depositional sequence O2 correlates to the Lower Floridan semiconfining unit at the treatment plant. It averages 195 feet in thickness, and mainly poorly cemented limestone composes the depositional sequence. Observations from borehole video images revealed poorly developed vuggy megaporosity and no fractures. However, numerous columniform karst-collapse structures and associated faults identified in seismic profiles at a distance of about 2.5 miles northwest of the treatment plant suggest that similar structures and faults could penetrate this depositional sequence at the South District Wastewater Treatment Plant and serve as vertical pathways for fluids injected into the Boulder Zone.
- Depositional sequence O3 correlates to the uppermost major permeable zone of the Lower Floridan aquifer at the South District Wastewater Treatment Plant. The top of this depositional sequence also correlates to the top of the Lower Floridan aquifer and the Oldsmar Formation. The sequence is 142 feet thick, on average, and composed of alternating limestone and dolomite.
- The upper boundary of depositional sequence O3 is a major unconformity, characterized as a highly irregular, epigenic karst surface. Observations from borehole video images indicate solution-enlarged, touching-vug porosity and fractures are common. Within this unit, borehole fluid-temperature and fluid-resistivity log data indicate the presence of permeable zones where water is entering the borehole.
- At the South District Wastewater Treatment Plant, single-well packer tests, a single-well aquifer test, and a multi-well aquifer test were inconclusive in describing the nature of confinement between the Boulder Zone and the top of the Lower Floridan aquifer, because the tests were spatially limited and produced inconsistent, largely qualitative results. However, because these tests assessed different parts of the aquifer, it is possible the inconsistent results well reflect the heterogeneous and anisotropic nature of this karst aquifer.

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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

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