Virginia Key, FL Deep Injection Well Site: Overview of Well Design, Geology, Hydrogeology, and Drilling Operations to 10,000 Feet

Joint SEGS and FAPG Event

March 31 – April 1, 2017

Guidebook Number 71

The Southeastern Geological Society (SEGS) Publication

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Stantec

A Field Trip of the Southeastern Geological Society and Florida Association of Professional Geologists – Section of AIPG

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Introduction and Acknowledgements

The Southeastern Geological Society (SEGS) is a non-profit organization that advocates the practice of geology, conducts educational field trips, encourages professional networking by these events, and more recently, has expanded our field trips to include other technical disciplines and non-geologists to broad the understanding of the practice of geology. This trip is a great example of the interdisciplinary needs of a large scale infrastructure project whereby geologists and various engineers come together to improve the regional community and management of natural resources. We are proud to be partnered with the Florida Association of Professional Geologists (FAPG) to make this trip happen and look forward to greater interaction and sharing of knowledge, resources, and ideas for the future growth of the natural resources industry. I would like to point out key persons and organizations that were critical to the execution of this trip:

- Stantec, Inc. in particular Ed Rectenwald, P.G. Principal Hydrogeologist on this project. Support was gracious provided by him and related staff at Stantec to pull this trip together and provide technical material and presenters.
- Miami Dade Water and Sewer Department for hosting the event and Friday night venue for presentations. In particular, Virginia Walsh, P.G., for her support and planning assistance.
- Anne Murray, P.G., President of FAPG for planning support and logistics.
- Our Technical Speakers: Virginia Walsh (Miami-Dade), Jason Mills (CDM), Gerrit Bulman (CH2M), Ed Rectenwald (Stantec), Kevin Cunningham (USGS).
- And last but not least: **Younquist Brothers Drilling** for providing access to their drilling rig and being our lunch sponsor.

Thank you to all attendees for your support and please consider being an SEGS member or learning about SEGS by visiting www.segs.org

All that is needed is interest to be a member and to keep on learning.

Clint Noble, P.G.
SEGS President
Gannett Fleming Inc.
904 613 2261
cnoble@gfnet.com

POST OFFICE BOX 1636, TALLAHASSEE, FL 32302

THE SOUTHEASTERN GEOLOGICAL SOCIETY AND FLORIDA ASSOCIATION OF PROFESSIONAL GEOLOGISTS JOINT FIELD TRIP ANNOUNCEMENT
March 31 – April 1, 2017

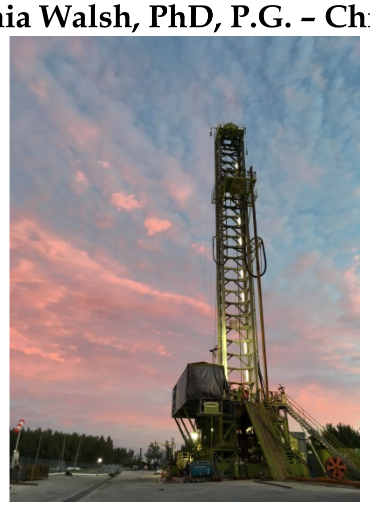
Virginia Key Deep Well Site, Virginia Key, Florida

Central District Wastewater Treatment Plant
3989 Rickenbacker Causeway
Miami FL 33189

March 31 – Friday Night Meeting, Technical Presentation, and Social: 3071 SW 38th Ave, Miami, FL 33146

April 1 – Saturday Field Trip at Drill Site: Virginia Key, 3989 Rickenbacker Causeway, Miami, FL 33189

Courtesy of the Miami-Dade Water and Sewer Department
Lead by Virginia Walsh, PhD, P.G. – Chief of Hydrogeology



ALL (SEGS/FAPG) participants must register and submit payment via the SEGS website: www.segs.org, for this trip. Please submit registration, trip forms, and payment by 5:00 PM Thursday, March 30, 2017. Note that registration is open to ALL FAPG and SEGS members and their guests. You do NOT have to be a geologist to attend this exciting event, feel free to invite friends, family, business associates, and colleagues! Any and all properly registered attendees are welcome! All required forms for review and signature are available at the SEGS website.

The Southeastern Geological Society (SEGS) and the Florida Association of Professional Geologists (FAPG) will be jointly hosting a field trip to examine the geology, drilling operations, and hydrogeology of the deep injection well currently near drilling completion at Virginia Key. We have been gracious to have been given the opportunity to visit the Site by the Miami-Dade Water and Sewer Department coordinated through Virginia Walsh, PhD, P.G.

Safety:

All attendees are required to bring the following safety equipment: hard hat, sturdy closed-toe footwear (preferably boots), safety glasses, gloves, and long pants and sleeved shirt (no tank tops or flip flops). In addition, attendees may wish to bring digging tools, rock hammers, and bags to collect specimens. There is no age limit for this trip, so attendee's under the age of 18 are allowed if they are accompanied by an adult/guardian. Please review the attached safety guidelines. Site specific safety training will be given by site personnel the morning of the trip and you will be required to sign the liability forms attached as part of registration in advance.

Timeline and Logistics:

Friday March 31 Meeting: We will be meeting at 6:00 PM at the Miami-Dade County Water and Sewer Department building located at 3071 SW 38th Ave, Miami, FL 33146 (305-665-7477). Parking is located at in the garage located immediately west and adjacent to this address. Attendees can walk into the building and check in with security. Everyone should meet at the entrance lobby and people will be escorted to the meeting room. PLEASE plan in advance to manage rush hour traffic in Miami. Light refreshments will be served and the agenda is as follows:

1. FAPG and SEGS Brief Business Meeting and Legislative Update
2. Technical Presentation titled "Cenozoic and Late Mesozoic Geology and Hydrogeology of a 10,000 foot Exploratory Well, Virginia Key, Florida" by Virginia Walsh, Ph.D., P.G. and Ed Rectenwald, P.G.
3. After the presentation, there will be an opportunity to socialize. Those who are interested can gather up with your friends/colleagues and meet at one of the many nearby restaurants / bars for food, good company, and networking.

Note that site directions and pictures are on the SEGS website under Events tab.

Saturday April 1 Field Trip: At 9:00 AM we will meet in the parking lot of the Central District Waste Water Treatment Plant located on Virginia Key with the address: 3989 Rickenbacker Causeway Miami FL 33189. The agenda for the morning is as follows:

- Overview of the geology, hydrogeology and deep well drilling operations by onsite geologists (Ed Rectenwald, P.G., Principal Geologist with MWH/Stantec, USGS field personnel, and the Youngquist Brothers, Inc., the drilling company onsite). Attendees will get to see the **deepest geologic cores collected in the State** and obtain a tour of a drilling rig and operations that was able to pull this from 10,000 feet!
- The project team will provide discussion and specimens of the geologic formations and hydrogeologic characteristics encountered down to 10,000 ft below land surface, geophysical logging, County and USGS seismic acquisition project, and tour and explanation of E-Rig and drilling components. Questions and discussion in the field will be encouraged for one of the largest and valuable infrastructure improvement and environmental projects in the State of Florida utilizing top notch engineers and geologists.
- Field refreshments (water, Gatorade) will be provided. At about 1:00PM, we will break for lunch together as a group. Field drinks and boxed lunches (sandwiches) will be provided. This will be a great time to socialize with members and share information. After lunch the field trip will end.
- For those who choose, there are great outdoor activities in the area that can be considered for interested groups Saturday afternoon:
  - Virginia Key North Point Trails
  - Virginia Key Outdoor Center – Kayaks and Canoes (https://www.vkoc.net)
  - Miami Seaquarium
  - Vizcaya Museum & Gardens
- The following link provides an great article describing the nature and scope of this important project to Miami community: http://www.miamidade.gov/releases/2016-06-17-wasd-completes-exploratory-well.asp

Trip Registration Instructions – for ALL Attendees – GO to www.segs.org

The cost of this event is $50 (or $25 for students). The fee includes Friday night presentation/refreshments, lunch and drinks in the field Saturday, trip guidebook (hardcopy to be provided to all registrants) and geologic handouts. Please access www.segs.org and go to the Events tab. Use the PayPal function to pay for the trip. Trip information and related forms are also on the website. The trip is limited in size, therefore, **register as soon as possible online, attendees will be allowed on a first come first served basis.** Your registration is NOT considered complete until payment is received AND all required forms (on website) are submitted via email to Clint Noble (cnoble@gfnet.com) and Anne Murray (amurray@martin.fl.us). Members will be notified when registration is closed. The following forms are required for registration all on the SEGS website:

1. FAPG-AIPG Liability/indemnity form
2. SEGS liability/indemnity form
3. Registration form
4. Trip Guidelines form review/sign
5. Payment on SEGS website using Paypal.

Note that directions and site pictures are also provided on the SEGS website.

Attendees are responsible for their own lodging accommodations; some more affordable area lodging is listed here for your use – note that SEGS-FAPG has NOT blocked any rooms:

- Fortune House Hotel http://www.fortunehousehotel.com/
- Hotel Urbano http://www.hotelurbanomiami.com/default-en.html
- Extended Stay https://www.extendedstayamerica.com/hotels/fl/miami/downtown-brickell-cruise-port-

We look forward to seeing you on this trip! **A very special thanks to Ed Rectenwald, Anne Murray (President of FAPG), and Virginia Walsh for providing planning efforts and coordination to make this event happen!**

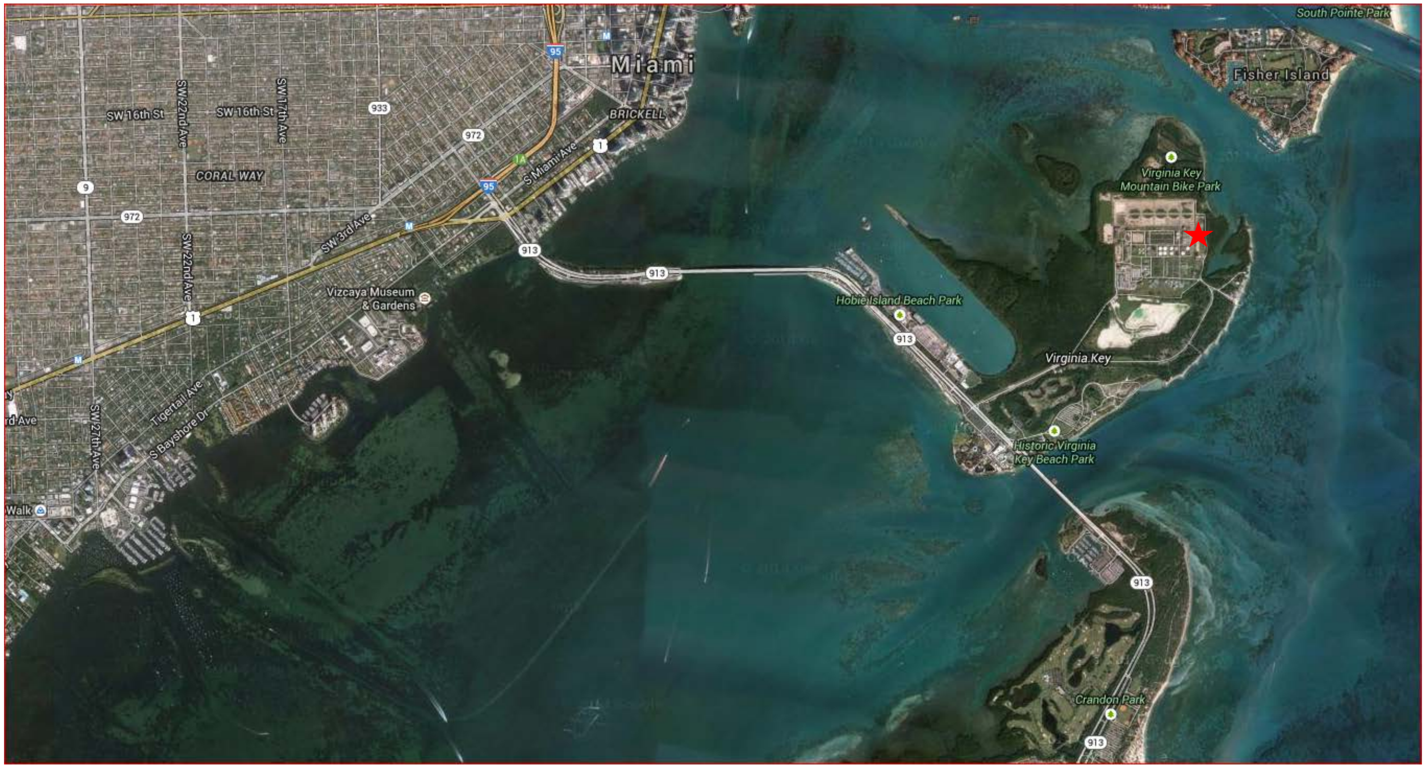
Please contact me via cell phone with any questions or concerns.

Regards,

Clint Noble, P.G.
President – Southeastern Geological Society
904-613-2261 (cell)
cnoble@gfnet.com

Directions and Pictures of the Virginia Key Deep Well Site

FAPG-SEGS Joint Field Trip April 1 2017



Take I-95 South and exit to Rickenbacker Causeway across to Virginia Key. Make first left after traffic light on Virginia Key (Mast Academy) - you'll see signs for Central District Treatment Plant (across from Miami Seaquarium). You'll see the guard house - if someone is there just tell them you are going to the wastewater treatment plant for Water and Sewer. They won't charge you. Follow signs for **Youngquist Brothers Construction Site (YBI)**. You will drive towards to the Virginia Key Outdoor Center (VKOC) – do not go in through the main gate. Drive past the kayak rentals, and you'll see a drill rig - cant miss it sticking up! You'll see two giant golf balls looking structures – there's a dirt road you'll turn left on to and you'll go in through the drill site construction gate towards them.

Pull into the construction site, and drive down past the rig to the construction trailers and park there. Hard Hat and safety vest will be provided. Please wear closed toe shoes or sneakers – no sandals or ballerina shoes!

Follow the red line to get to site - see next page!

As you are driving towards to the site, look at the large pipe coming out of the ground (labeled **Ocean Outfall Pipe** on next map and pictured here). We'll be talking about that pipe at the site.

For those of you who like to map addresses:

Central District Wastewater Treatment Plant
3989 Rickenbacker Causeway
Miami FL 33189

If you end up at a security gate and they won't let you in – you went to the wrong entrance!!

Virginia Walsh cell is 786-251-1849.


Consruction entrance to drive through
Drill Site
Ocean Outfall Pipe
Landfill
Virginia Key
Sewage Plant Rd
Stay to the right!
Mast Academy
Guardhouse
913
Miami Seaquarium
© 2015 Google
Google earth
1995
25°44'30.25" N 80°09'23.82" W elev 45 ft eye alt 11904 ft

Friday Night March 31, 2017 Meeting Agenda

1. Clint Noble - Introduction to field trip and SEGS
2. Anne Murray - Introduction to FAPG and pressing industry issues
3. Virginia Walsh – Miami-Dade WASD Welcome and Introduction
4. Jason Mills (CDM) - Hydrogeologic Evaluation for Potential UFA Wellfield Development at South Miami Heights
5. Gerrit Bulman (CH2M) - The End of the Rainbow: An Overview of the Ocean Outfall Legislation Program Deep Injection Well Plan
6. Ed Rectenwald (Stantec) – Project Overview / Hydrogeology
7. Kevin Cunningham (USGS): Overview of Cretaceous to Neogene Geologic and Hydrogeologic Framework Study in the Miami-Dade County Area
8. Break / Networking

VIRGINIA KEY DEEP WELL SITE

Central District Wastewater Treatment Plant

Overview of the Central District Industrial Injection Well System Design, geology, hydrogeology and drilling operations.

Stantec, INC.
April 1st, 2017

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Executive Summary

Miami-Dade County Water and Sewer Department (MDWASD) owns and operates the Central District Wastewater Treatment Plant (CDWWTP) located on Virginia Key, Florida. The CDWWTP, as shown in **Figure 1,** has a permitted capacity of 143 million gallons per day (MGD) with an annual average daily flow of 116.8 MGD for 2014. The pure-oxygen activated treatment system effluent currently receives primary and secondary disinfection prior to disposal through the ocean outfall pipeline.

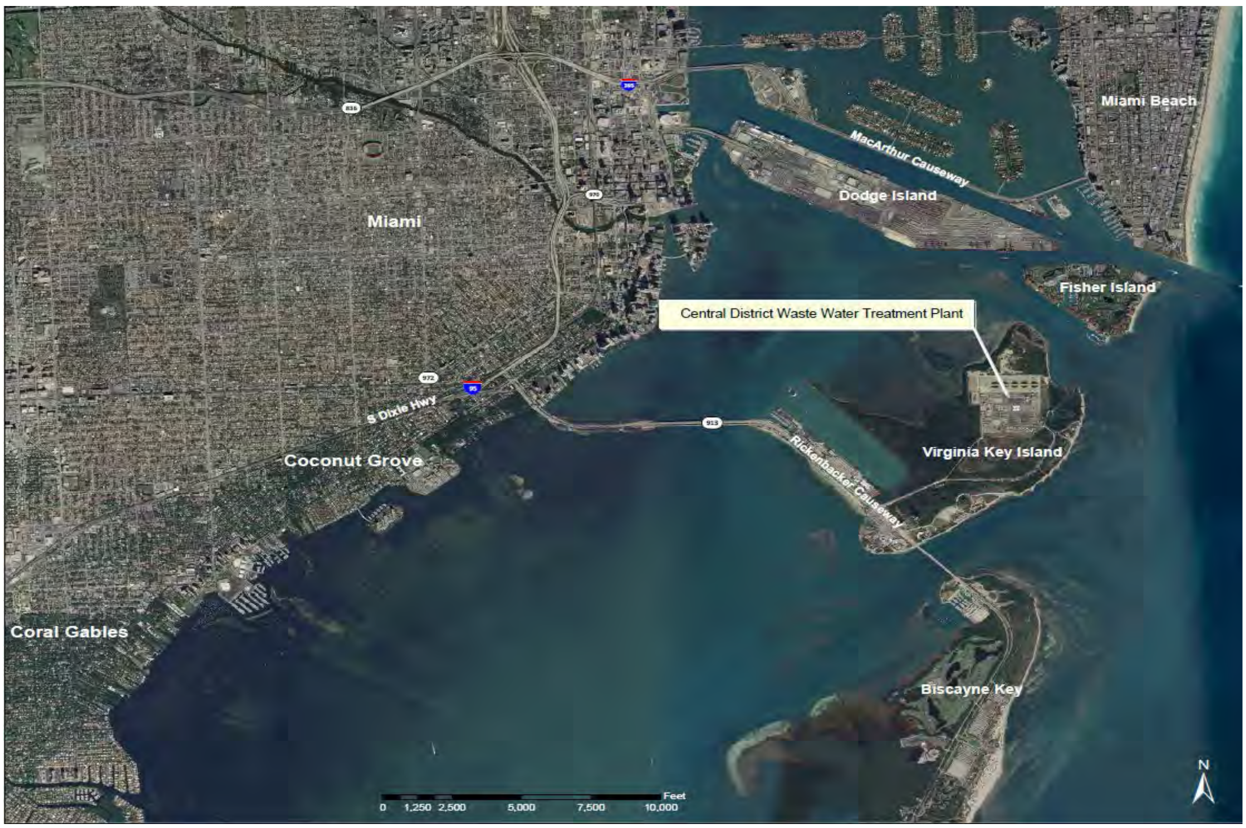

Figure 1. Central District Waste Water Treatment Plant (CDWWTP) Location

There are two independent process trains at the CDWWTP (Plant 1 and 2). Plant 1 treats lower-chloride wastewater from the mainland and Plant 2 treats higher chloride wastewater from Miami Beach, Virginia Key, and Key Biscayne. The Plant 1 process train influent passes through aerated grit chambers to the pure oxygen treatment tanks. The mixed liquor from these tanks passes to the final settling tank where the activated sludge settles out and the overflow goes to the effluent pumping station. Chlorine is added to the Plant 1 effluent as it flows to the effluent pumping station. The Plant 2 treatment train is identical to, but separate from the Plant 1 train. The two effluent flows are combined in the pumping station. From the pumping station, the majority of the effluent flows by gravity through the ocean outfall pipe that ultimately discharges

18,800 feet (3.56 miles) from the shore. A small volume of effluent is further treated for reuse. Sludge from the oxygenation tanks is either returned to the tanks or wasted to the gravity sludge thickeners. Sludge from the North District Wastewater Treatment Plant (NDWWTP) is transported to the CDWWTP and processed through the thickeners. Concentrated sludge is pumped to the sludge digesters and is dewatered using centrifuges prior to disposal or land application.

Per Florida Statutes Chapter 403 Section 086(9)(b), the discharge of domestic wastewater through the ocean outfalls must meet advanced wastewater treatment (AWT) and management requirements no later than December 31, 2018. This requirement can be met by reducing the outfall baseline loadings of total nitrogen and total phosphorus, which would be equivalent to that which would be achieved by the AWT if the requirements were fully implemented beginning December 31, 2018, and continued through December 31, 2025. MDWASD will be able to reduce nutrient loading to meet the criteria by removing the industrial non-hazardous waste stream from the centrate process, the gas scrubbers, and the treated effluent and injecting this industrial waste into a deep injection well. In addition to the MDWASD industrial non-hazardous waste stream, leachate resulting from groundwater remediation at the adjacent south property (former Virginia Key Landfill) will also be disposed of in the deep injection well. The injection well will be located on the eastern boundary of the CDWWTP as shown in **Figure 2**.

Figure 2. Central District Industrial Injection Well System Location

The first injection well (CDIIW-1) was initially permitted as a UIC Class V Exploratory Well (Class V, Group 9) on October 30, 2013, to evaluate the Oldsmar Formation Boulder Zone for wastewater disposal, the Upper Floridan aquifer for the feasibility of future beneficial reuse activities, and the Upper Cretaceous formations to identify additional potentially suitable wastewater disposal zones below the Floridan Aquifer System. Upon completion of drilling and testing, and prior to any operational injection testing, MDWASD submitted a new UIC well construction permit application to reclassify the permitted Class V injection well as a UIC Class I industrial injection well and to include a second injection well, CDIIW-2.

The CDWWTP industrial injection wells (CDIIW-1 and CDIIW-2) are designed and being constructed in accordance with Chapter 62-528 of the Florida Administrative Code (F.A.C.). The injection wells are alternatively designed with a nominal 36-inch diameter API-5L Grade B Longitudinal Seam Submerged-Arc Welded (LSAW) steel final casing to an approximate depth of approximately 2,780 feet below land surface (bls) on CDIIW-1 and 2,610 feet bls on CDIIW-2. A nominal 24-inch diameter fiberglass reinforced plastic (FRP) injection tubing was installed inside the 36-inch diameter final steel casing with a triple seal packer. The annular space between the final steel casing and the FRP tubing is filled with cement to land surface as an alternate design to a fluid-filled annulus.

In addition to CDIIW-1 and CDIIW-2, a Floridan aquifer dual-zone monitoring well (CDIDZMW-1) was constructed to monitor groundwater quality and hydraulic head in two monitoring zones. The Upper Monitor Zone (UMZ) was constructed to provide groundwater monitoring immediately above the base of the Underground Sources of Drinking Water (USDW), defined as waters with Total Dissolved Solids (TDS) greater than 10,000 milligrams per liter (mg/L). A Lower Monitor Zone (LMZ) was constructed above the principal confining units for the purpose of early detection of wastewater migration from the injection zone (Boulder Zone), should it occur. CDIDZMW-1 was positioned approximately 146 feet from CDIIW-1 and CDIIW-2, as shown in **Figure 3**.

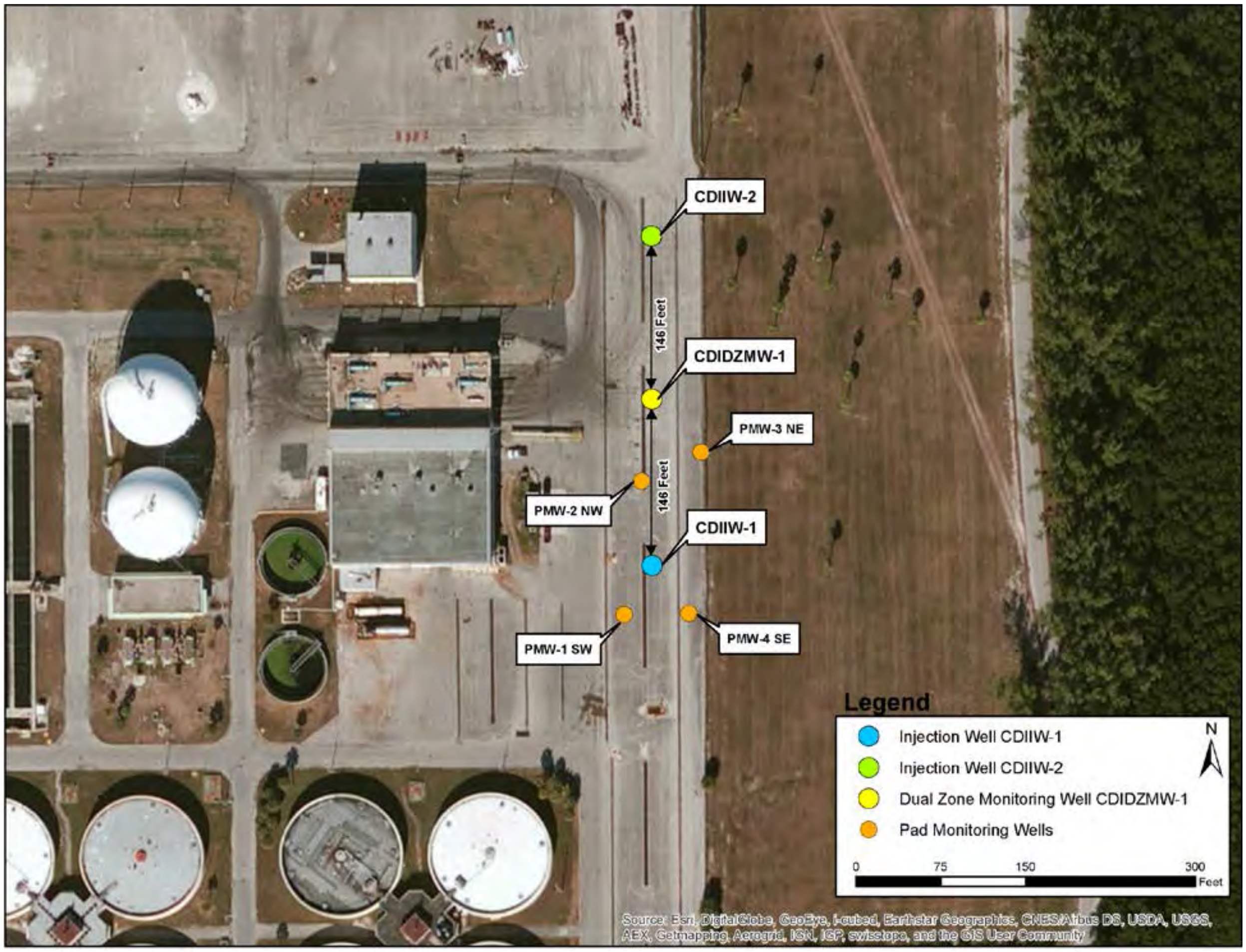

Figure 3. Central District Industrial Injection Well System Layout

Injection Well Hydraulic Design Criteria

The CDWWTP injection wells (CDIIW-1 and CDIIW-2) have been designed for the disposal of industrial wastewater produced from sludge dewatering centrifuges, scrubber blowdown water, and treated effluent from the CDWWTP, and non-hazardous groundwater from the groundwater remediation system associated with the former Virginia Key Landfill (**Figure 4**). The maximum estimated flow produced from the centrifuges is 1 MGD, scrubber blowdown is 8.6 MGD (Scrubber No. 1 produces 3.2 MGD and Scrubber No. 2 produces 5.4 MGD), and the treated effluent is 14.1 MGD. The landfill groundwater recovery system will collect non-hazardous ammonia impacted groundwater from shallow extraction wells located on the perimeter of the former landfill area. Based on similar groundwater remediation systems installed in coastal Miami-Dade County, the extracted groundwater flows are not anticipated to exceed 2 MGD from the landfill. Therefore, the anticipated injection flow is expected to be no greater than 19.9 MGD per injection well.

The injection wells were constructed with a nominal 24-inch diameter Future Pipe Industries, Inc. Red Box 1250 FRP injection tubing, cemented inside of the 36-inch diameter final steel casing. In accordance with fluid velocity limitations for the alternative injection well design (10 feet per second [ft/sec]) through the injection tubing (23.78-inch inside diameter [ID]), the maximum design disposal capacity is 13,842 gallons per minute (gpm), (approximately 19.9 MGD), per well, for a total disposal capacity of 39.8 MGD.

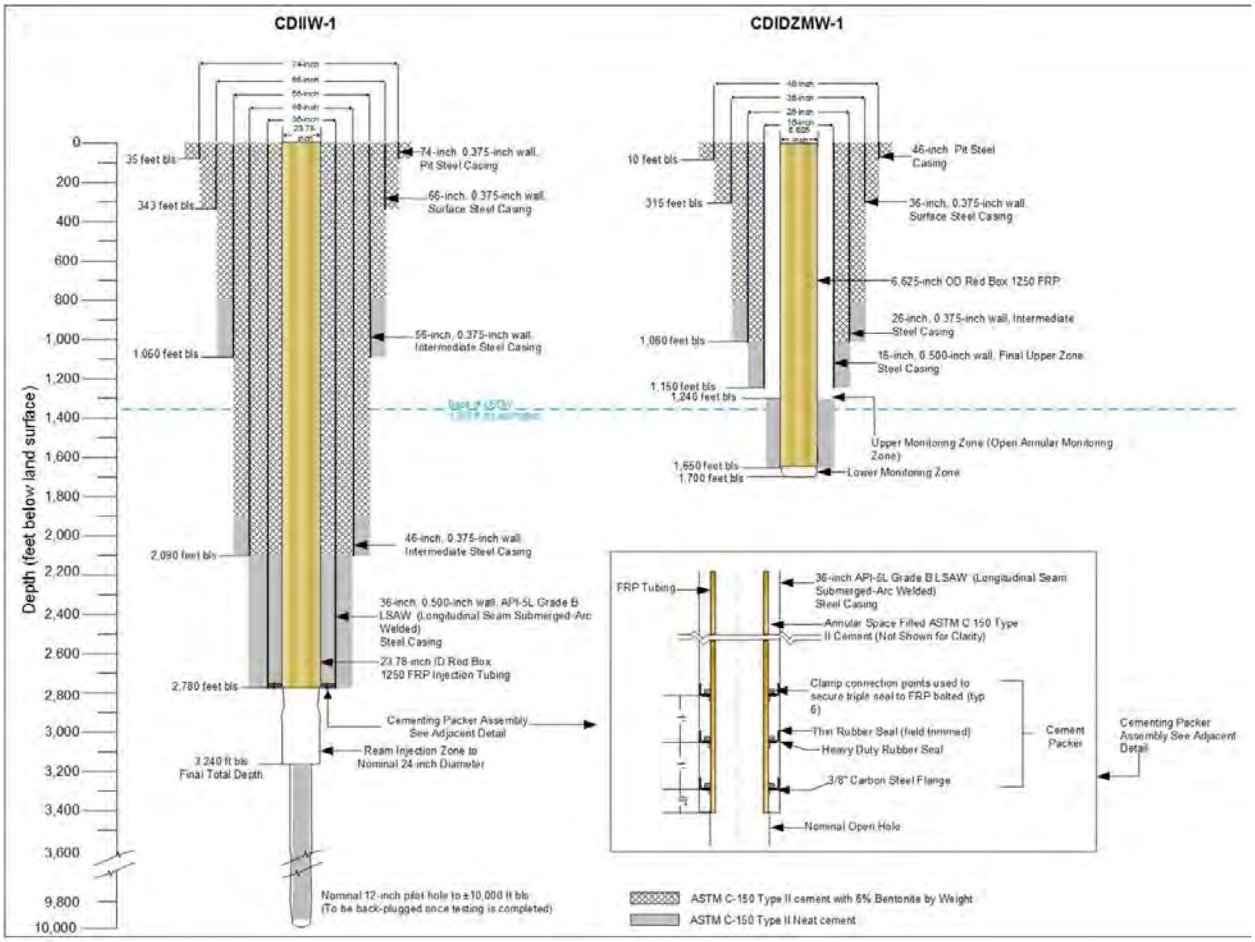

Figure 4. Injection Well and Dual Zone Monitoring Well Design

Well CDIIW-1 Design

As shown in **Figure 4**, CDIIW-1 was designed as a multi-cased well with an open-hole to a total depth of approximately 3,240 feet bls. Well CDIIW-1 was constructed with five different size steel casings (74-inch, 66-inch, 56-inch, 46-inch, and 36-inch-diameter) each installed to isolate and protect the groundwater quality and production zones encountered as the well is drilled to depth. All steel casings installed during the construction of the well were fully cemented to land surface. The final casing depth was 2,780 feet bls for the 36-inch steel casing. The well was completed with an open borehole to an estimated depth of 3,240 feet bls below the 36-inch steel casing. The injection zone is located in the Oldsmar Formation or Boulder Zone of the Lower Floridan aquifer (LFA).

The base of the USDW (groundwater having a total dissolved solids concentration of less than 10,000 mg/L) has been identified at a depth of 1,360 feet bls during construction of Well CDIIW-1 at the CDWWTP site. The 56-inch diameter first intermediate steel casing was installed to a depth of 1,060 feet bls and the 46-inch diameter second intermediate steel casing was installed below the base of the USDW to a depth of 2,090 feet bls. The 36-inch diameter final steel casing was installed to 2,780 feet bls.

The injection well was constructed with a 24-inch diameter Future Pipe Industries, Inc. Red Box 1250 FRP injection tubing cemented inside of the 36-inch diameter, API-5L Grade B LSAW steel 0.500-inch wall, seamless final steel casing. This injection tubing design provides ease of operation and maintenance for the County since it is inert to the corrosive effects of the landfill leachate.

Well CDIIW-2 Design

Well CDIIW-2 was also designed as a multi-cased well with an open-hole total. The design is identical to Well CDIIW-1 except the installation depths for the casings vary slightly.

Dual Zone Monitor Well CDIDZMW-1 Design

The CDWWTP injection well system includes a dual-zone monitoring well (CDIDZMW-1) for continuous monitoring of the hydraulic head within two completed monitoring zones (UMZ and LMZ). The UMZ will be located just above the base of the USDW and the LMZ will be located just above the principal confining strata in the lowermost permeable unit below the base of the USDW based on current water quality conditions. CDIDZMW-1 will also be used for collection of groundwater samples for laboratory analysis during injection well operation. As previously shown on **Figure 4**, the UMZ and LMZ are located within the intervals from approximately 1,150 feet to 1,240 feet bls and 1,650 feet to 1,700 feet bls, respectively.

CDIDZMW-1 was designed with pumps and piping to convey purging and sampling water produced from the monitoring zones.

Operational testing and monitoring data collected from CDIDZMW-1 monitoring zones will include permit specified groundwater quality analyses and the hydraulic head (elevation in feet) in both monitor zones. Upon FDEP's approval to commence operational testing, this data will be electronically measured and recorded for submittal with monthly operating reports.

Testing During Construction

For hydrogeological testing and analysis below the USDW from an approximate depth of 1,360 feet bls, a 12.25-inch diameter pilot-hole was drilled and tested to an estimated depth of 3,500 feet bls. Cores and packer testing were conducted to evaluate the subsurface hydrogeology. This information provided valuable information to properly design the injection wells regarding the final casing seat depths and total borehole depths. The testing and coring schedule conducted on CDIIW-1 is shown in **Figure 5.**

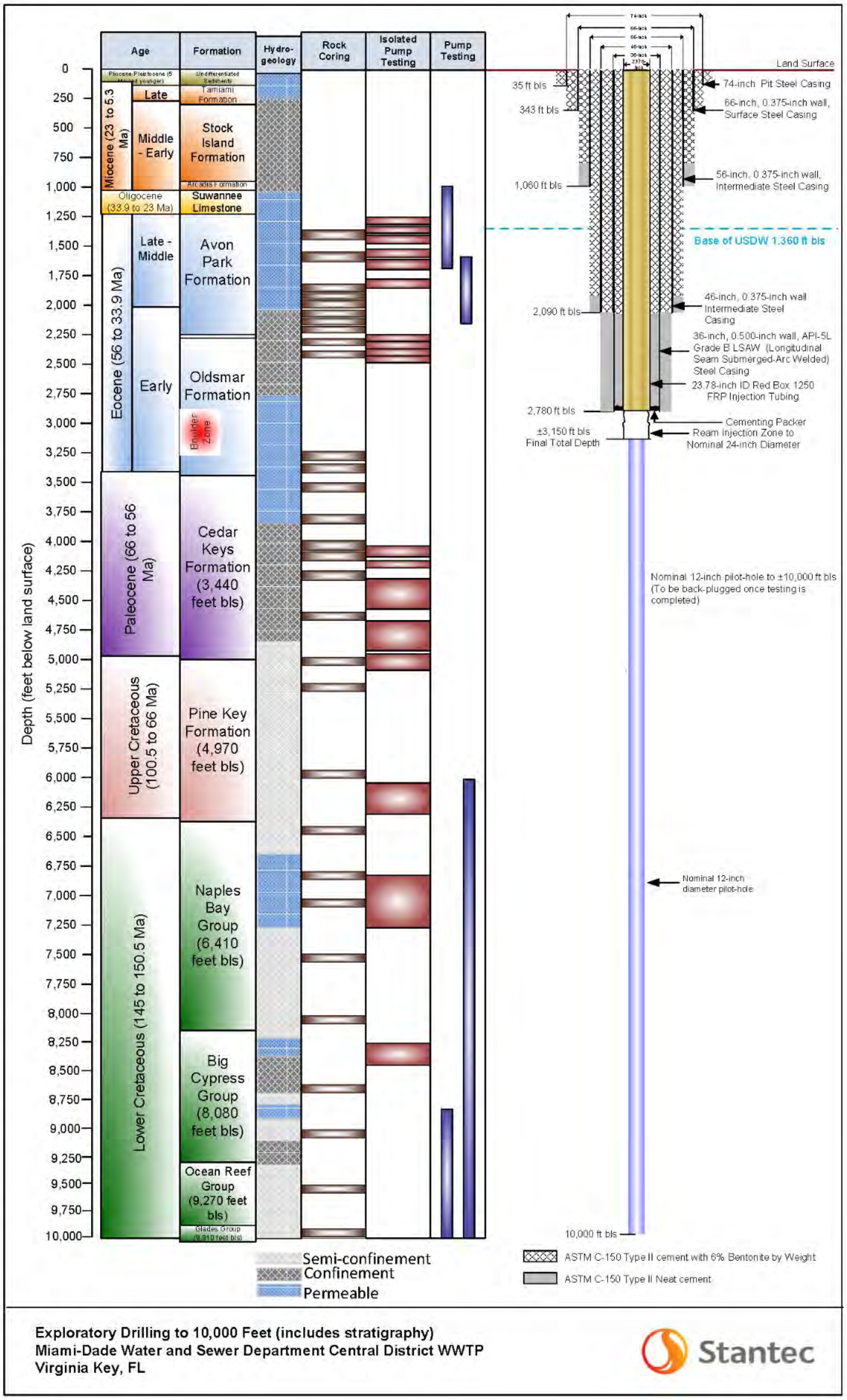

Figure 5. Testing and Coring During CDIIW-1 Construction

Final Injection Testing and Operational Testing

Following the construction and injection testing of the CDWWTP Injection Well System, written authorization for final injection testing will be requested from the FDEP. The source water for the injection test is expected to be secondary treated effluent after successful completion of mechanical integrity and radioactive tracer survey testing.

Operational data including wellhead pressure, flow rates and injection volumes for Wells CDIIW-1 and CDIIW-2 will be recorded continuously and the injectate will be sampled and analyzed for the water quality parameters on a monthly basis. Wellhead pressures and water levels in each monitoring zone of the Well CDIDZMW-1 will also be recorded continuously and each monitor zone will be sampled and analyzed for the required water quality parameters on a monthly basis. As required for the Class I Injection Well Construction Permit operational testing phase, an initial non-hazardous waste stream analysis will be collected from the CDWWTP waste streams and the adjacent Virginia Key Landfill for the following water quality parameters prior to operation:

- Primary Drinking Water Standards; excluding asbestos, dioxin, butachlor, acrylamide, and epichlorohydrine
- Secondary Drinking Water Standards

Geology and Hydrogeology

The geology of Miami-Dade County has been described in reports by the Miami Geological Society (Winston, 1994), the Florida Geological Survey (Oglesby, 1994), and by various authors and consultants. Information on the regional geology and hydrology are included to provide a framework for understanding the local hydrologic conditions encountered while drilling Well CDIIW-1.

The State of Florida lies on the Florida Platform on the southeastern edge of the North American continent. The platform extends 400 miles north to south and nearly 400 miles east to west (at its widest point). Over half of the platform is presently under water, leaving a narrower peninsula of land extending from the mainland. The major subsurface structural element in the region is the South Florida Shelf (Applin and Applin, 1965). They described the shelf as a relatively flat area in the Comanche Rocks (Cretaceous) which "trends S 45° E, extends nearly 200 miles across the peninsula from Charlotte County on the Gulf Coast to Key Largo, Monroe County, on the Atlantic Coast". A nearly 5,300-foot thick sequence of middle Mesozoic to recent carbonate rocks forms the Florida Platform in central Florida (Spechler and Kroening, 2006).

White (1970) divided the Florida peninsula into three geomorphic zones; the southern or distal zone, the central or mid-peninsular zone, and the northern or proximal zone. The Well CDIIW-1 lies within the distal zone. Miami-Dade County is composed mainly by the Everglades in the North, Northwest, West and Central parts, while the Atlantic Coastal Ridge can be found running along the Eastern shore of the county from Broward County on the north all the way to Homestead in the south. The beaches and barrier islands along the east and south coasts belong to the coastal marshes and mangroves region. The Well CDIIW-1 is located along this last region, in Virginia Key, which is part of the Miami Limestone formation. The Well CDIIW-1 is at an altitude of approximately 11.99 feet above North American Vertical Datum (NAVD) 88 (**Figure 6**).

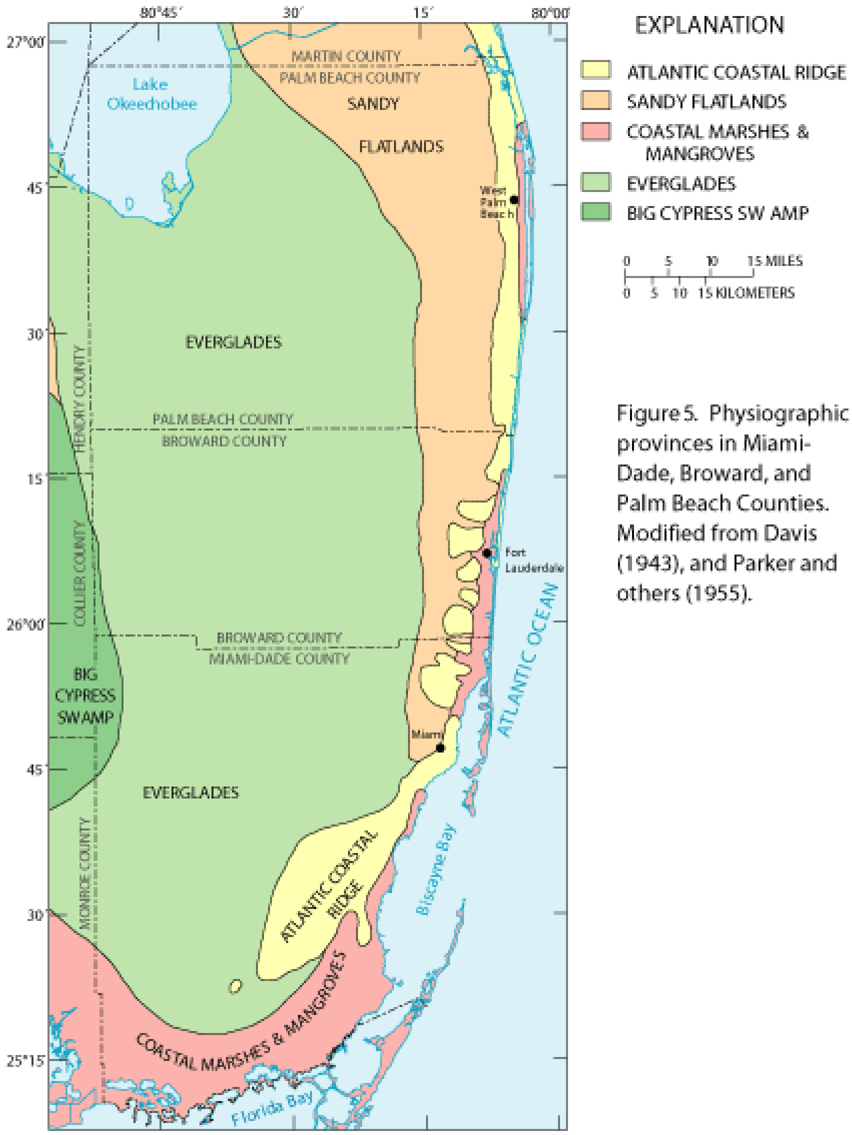

Figure 6. Physiographic provinces in Miami Dade, Broward and Palm Beach Counties

STRATIGRAPHY

Well CDIIW-1 ranges in age from Holocene to Lower Cretaceous. Lithologic descriptions are based on formation samples collected from Well CDIIW-1 and existing literature. A general description of the lithostratigraphy and its relationship to the hydrostratigraphy of the site is provided below. Stratigraphic units are described in descending order. All geologic formation picks are still in draft and are subject to change.

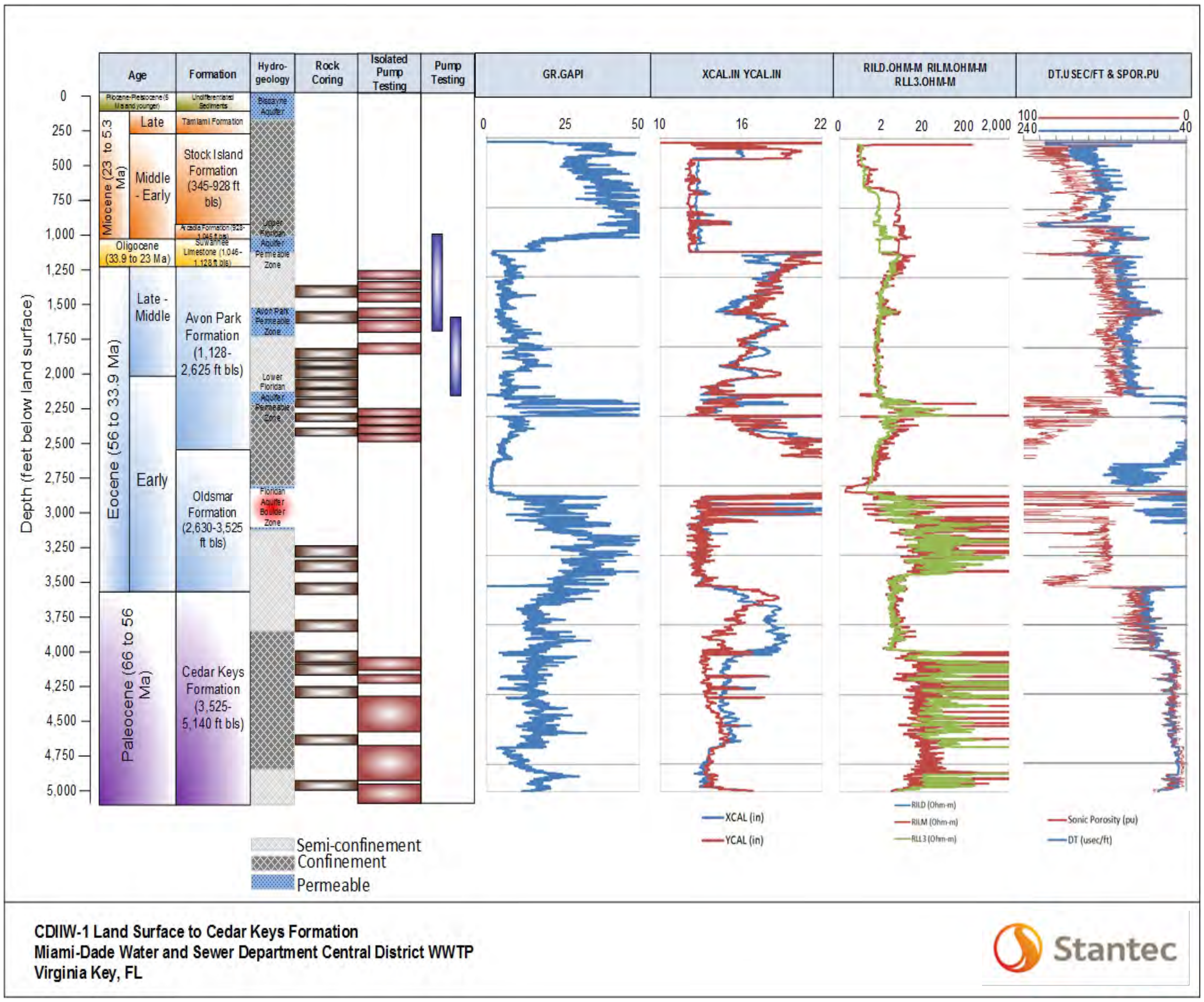

Figure 7. CDIIW-1 Testing Land Surface to Cedar Keys Formation

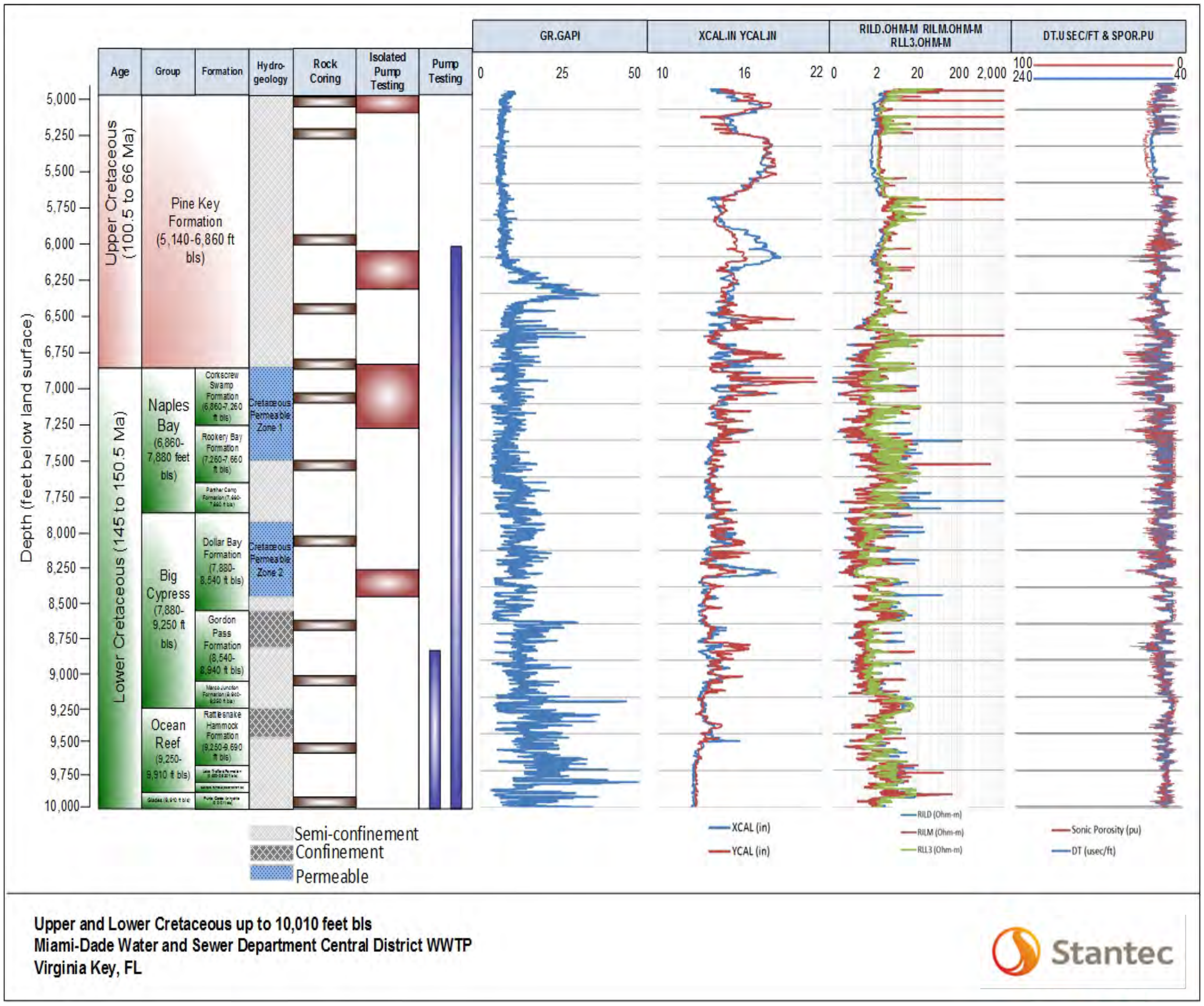

Figure 8. CDIIW-1 Testing Upper and Lower Cretaceous

Stock Island Formation

Present from the base of the surface casing, located at 345 feet bls, to approximately 928 feet bls. The formation is 583 feet thick and it is comprised of pale olive silty sand to an approximate depth of 620 feet bls, where it transitions into a thin interval of poorly indurated limestone with calcium carbonate mud between 620 feet and 690 feet bls. Sandy clays are encountered from 690 feet to approximately 928 feet bls.

Hawthorn Group

Dall and Harris (1892) first used the term "Hawthorn beds" for phosphatic sediments being quarried for fertilizer near the town of Hawthorne in Alachua County, Florida. The unit has been extensively studied, mapped and discussed by Florida geologists since the early 1900's because of its economic importance.

The Hawthorn Group at the site is comprised only of the Arcadia Formation, with a thickness of 118 feet, and consists of predominantly sandy phosphatic clay and silt grading to limestone and dolostone at its base. The Arcadia Formation was encountered from approximately 928 feet bls to 1,046 feet bls and is indicated on the geophysical logs by a sharp increase in gamma ray activity. The lithology from 928 feet to 980 feet bls consists of a phosphatic clay. The lithology from 980 feet to 1,045 feet bls represents a transitional zone of phosphatic clay to yellowish gray micritic limestone. This is accompanied by a moderate attenuation of gamma activity.

Suwannee Limestone

The Suwannee Limestone underlies the Arcadia Formation from a depth of 1,045 feet to approximately 1,128 feet bls, with a thickness of 83 feet, and consists of yellowish gray to pale yellowish brown friable limestone and interbedded layers of clay. The formation consists of good to moderate porosity packstone, and interbedded lower porosity wackestone. The geophysical characteristic in the Suwannee Limestone includes attenuated gamma ray activity because of a reduced presence of phosphate.

The contact between the Hawthorn group and the Oligocene aged Suwannee Limestone may be an unconformity, but it is only marked by a gradational color change in lithology and absence of phosphate in the Suwannee. The contact is best seen by the abrupt increase in gamma ray activity in the lower section of the phosphatic Hawthorn Group. Gamma ray attenuation has been used in numerous studies in central Florida to determine this contact.

Avon Park Formation

The Avon Park Formation is present from 1,128 feet to 2,625 feet bls, with a thickness of 1,497 feet, and consists primarily of very pale orange to yellowish brown friable limestone and interbedded layers of dolomitic limestone.

The top of the Avon Park Formation can be identified at 1,128 feet bls by a transition into fossiliferous limestone, abundant *Cushmania americana* (formerly known as *Dictyoconus americanus*) and the appearance of the index fossil *Spirolina coryensis* at approximately 1,140 feet bls. The fossil content slowly tapers with depth to approximately 1,660 feet bls with the bulk of this interval being comprised of limestone in varying stages of dolomitization interfingered with microcrystalline calcite. The fossil content increases again at approximately 2,380 feet bls to 2,625 feet bls. There are multiple lithology changes between 1,660 feet and 2,625 feet bls. Broadly characterized, the interval between 1,660 and 2,160 feet bls is comprised of alternating layers of wackestone, mudstone and more competent grainstone. The lithology reflects progressively well indurated limestone, dolostone and fragmented crystalline dolomite to 2,160 feet bls. The lithology substantially changes from the alternating beds of wackestone, mudstone and more competent grainstone to microcrystalline and coarsely crystalline dolostones from 2,160 feet to approximately 2,380 feet bls. This is identified on the geophysical logs by an increased gamma activity characteristic of hard crystalline dolomite and dolostone. Another considerable change in lithology occurs from 2,380 feet to 2,630 feet bls, where the formation consists of alternating fossiliferous layers of packstone, wackestone and mudstone. The geophysical characteristic in this interval includes attenuated gamma ray activity.

Figure 9. Core No. 10 (2,405 – 2,417 feet bls) obtained from CDIIW.

Oldsmar Formation

The Oldsmar Formation is present from 2,630 feet to 3,525 feet bls, with a thickness of 895 feet, and consists primarily of very pale orange limestone and dolomitic limestone interbedded with brown to gray dolostone. The lithology reflects well indurated limestone, dolostone and fragmented crystalline dolomite. The top of the Oldsmar Formation can be hard to identify because of the lack of diagnostic microfossils. This unit is identified on geophysical logs by increased borehole diameters on the caliper log, due to a slight increase in permeability and a decrease in resistivity. The boulder zone was identified at 2,848 feet to 3,150 feet bls approximately with the occurrence of fractured dolostone, as shown in the picture below.

Figure 10. Core No. 12 (3,245.5 – 3,255.6 feet bls) showing fracture and dissolution features.

Cedar Keys Formation

The Cedar Keys Formation is mainly composed of microcrystalline dolomite with various beds of anhydrite in its middle portion and its thickness is approximately 1,615 feet. The top of the formation is designated at 3,525 by a change in lithology. The formation can be divided into 6 different units. Unit A and B consists mainly of dolomite, while Unit C is mainly anhydrite with microcrystalline dolomite. Unit D is composed mostly of dolomite with a few anhydrite beds, and Unit E and F are similar to Unit D in composition. Unit C, D and E can be established by regionally persistent anhydrites. Unit F is present only in South Florida, and establishing its depth can be tricky, since its thickness is irregular and it is interbedded with the top of the Pine Key Formation (Winston 1994). The base of the formation is placed at 5,140 feet bls by the change from the lowermost thick dolomite bed above to chalky limestone below. In geophysical logs, the Cedar Keys Formation is distinguished by a sharp increase in resistivity in its middle and lower units. This sharp increase is due to various anhydrite beds, which are not apparent in a PE/Bulk Density log, but easily distinguishable in rock cuttings.

Figure 11. Core No. 18 (4,254 – 4,264 feet bls) showing Anhydrite, obtained at CDIIW-1.

Pine Key Formation

The Pine Key Formation is mainly composed of white chalk and chalky limestone and its thickness is 1,720 feet. The top of the formation is designated at 5,140 feet bls by a change from a thick dolomite to a chalky limestone. The base of the formation is placed at 6,860 feet bls by the appearance of a thin anhydrite bed and a brown sucrosic dolomite. In geophysical logs, resistivity decreases and smoothens significantly in the absence of anhydrite, while caliper log shows an increase in the diameter of the borehole, indicating a softer, less competent material. The Gamma ray activity decreases as well in the upper and middle part of the formation, only to increase slightly at the lower part, accompanied by mudstones and traces of organic material. Neutron/Density porosity logs indicate the presence of limestone, which is also the main constituent in rock cuttings.

Figure 12. Core No. 24 (6,856 to 6,868 feet bls) obtained at CDIIW-1. This core might have cut through the base of the Pine Key Formation and into the top of the Corkscrew Swamp Formation, as seen in the change in lithology from top to bottom on the picture.

Corkscrew Swamp Formation

The name of this formation is derived from Corkscrew Swamp, located north of the type well (Humble #1 Collier Corp). It is mainly composed of dolomitic limestone with a few thin anhydrite and dolostone beds and it is present from 6,860 feet to 7,260 feet bls, with a thickness of 400 feet. The top of this formation can be distinguished by the appearance of a thin anhydrite bed and a brown sucrosic dolomite. The base of the formation is determined by a change from a dense limestone to a thick regionally persistent anhydrite. On resistivity logs, spikes in resistivity are seen where rock cuttings show anhydrite beds. In the PE/Bulk Density log, anhydrite beds are easily distinguishable, while in the caliper log, a reduction in borehole diameter indicates a more competent formation. Gamma ray activity remains low.

Rookery Bay Formation

Rookery Bay Formation got its name from a bay southwest of the type well (Humble #1 Collier Corp). The lithology consists mostly of thick and thin anhydrite beds interbedded with thin beds of limestone and dolomite, with a thickness of approximately 400 feet. The top of the Rookery Bay Formation is identified at 7,260 feet bls and consists of a micritic limestone on top to a persistent anhydrite below, while its base is placed at 7,660 feet bls from the change of a thin pelletal micritic limestone above to regionally persistent anhydrite below. The base of this formation was designated by the regional persistence in resistivity logs of the anhydrite bed. In geophysical logs, the resistivity of the formation increases slightly from the previous formation, and shows many spikes where anhydrite beds are found. Anhydrite beds are easily visible in rock cuttings as well as in the PE/Bulk Density logs, while caliper log shows a narrow borehole indicating competent rock formations. Gamma ray activity remains low.

Panther Camp Formation

The Panther Camp Formation consists mainly of dolomitic limestone with several thick anhydrite beds. The formation is approximately 220 feet thick. The top of the formation is designated at 7,660 feet bls and it's noted by a change from a thin pelletal micritic limestone to a persistent anhydrite. The base is placed at 7,880 feet bls by a change from porous pelletal limestone to another persistent anhydrite. In e-logs, both the top and bottom of the formation are easily distinguishable on the resistivity log. PE/Bulk Density log and rock cuttings indicate abundant anhydrite beds, while caliper log continues to show competent rocks. Gamma ray activity remains low.

Dollar Bay Formation

The Dollar Bay Formation consists of four different units of sediment deposition in a back-reef environment. Cycles begin and end with Anhydrite, while porous limestone and dolomite are found in between. Unit C is the thickest cycle, and has shown to be petroliferous in other localities. The top of the Dollar Bay Formation is designated at 7,880 feet bls by a change from a porous pelletal micritic limestone to a persistent anhydrite. The base of the formation was placed at 8,540 feet bls by a change from a dense limestone to a thin anhydrite below. The approximate thickness of the formation is 660 feet. In geophysical logs, the resistivity decreases slightly throughout the formation, but is higher at the formation boundaries. Anhydrite beds are not as abundant on both rock cuttings and PE/Bulk Density logs. Gamma ray activity remains low.

Gordon Pass Formation

The Gordon Pass Formation was named after a barrier beach lagoon west of the type well (Humble # 1 Collier Corp.). The upper part of the formation is made up of several beds of anhydrite interbedded with dense limestone, while the lower part of the formation consists of numerous beds of dense chalky limestone interspersed with anhydrite beds. The thickness of the formation is approximately 400 feet. The top of the formation is identified at 8,540 feet bls with the change from a dense limestone above to a thin anhydrite below. Its base is designated at 8,940 feet bls with a change from a dense limestone overlaying a thin anhydrite. In geophysical logs, the resistivity log increases significantly on the top of the formation, and decreases through the lower part. The presence of anhydrite in the upper part is easily visible in the PE/Bulk Density logs as well as in rock cuttings. Caliper log continues showing a competent rock formation, while the Gamma ray log increases in the lower section of the formation.

Marco Junction Formation

The Marco Junction Formation was named after a road junction south of the type well (Humble #1 Collier Corp.). This formation consists mostly of limestone with few dolomite and anhydrite beds. The approximate thickness of the formation is 310 feet. The top of the formation is designated at 8,940 feet bls by a change from a thin limestone to a thick anhydrite bed below. This contact was the most persistent on this part of the electric log. The base of the formation was found at 9,250 feet bls by a change from a dense limestone on top to a thick anhydrite below (Winston, 1976). In geophysical logs, resistivity remains relatively low, with only some high peaks. In the PE/Bulk Density log and rock cuttings, anhydrite is found where the resistivity peaks are located. The caliper log shows a slightly wider borehole, indicating softer rock.

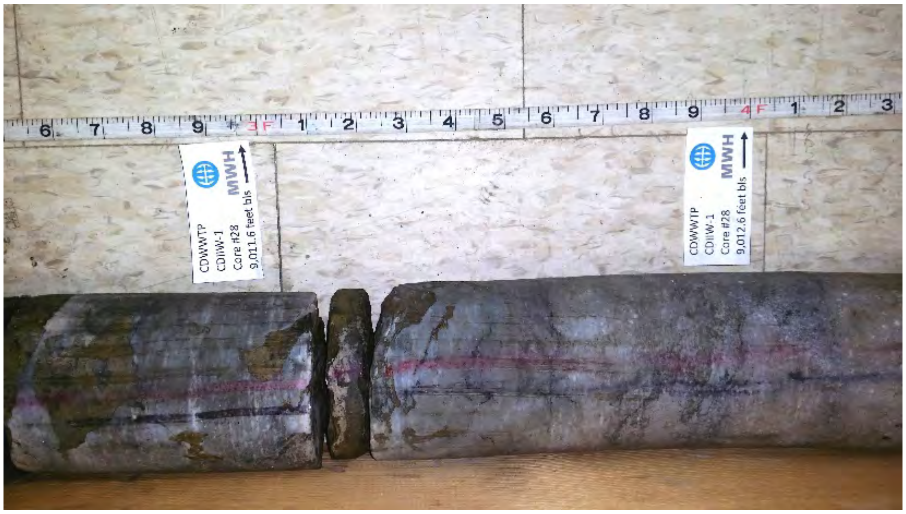

Figure 13. Core No. 28 (9,008.6 – 9,020.6 feet bls) obtained at CDIIW-1, showing some Anhydrite interbedded with limestone.

Rattlesnake Hammock Formation

The Rattlesnake Hammock Formation was named after an area north of the well type (Humble #1 Collier Corp.). This formation consists of an upper and lower part. The upper part is made up predominantly of anhydrite with dense limestone and dolomite beds, while in the lower part limestone is dominant, while anhydrite is rare. The approximate thickness of the formation is 440 feet. The top of the formation is found at 9,250 feet bls by a change from a dense limestone to a thick regionally persistent anhydrite below. The base is designated at 9,690 feet bls by the change from a thick, dense limestone on top to an anhydrite bed below. In geophysical logs, the top of the formation is characterized by a sharp peak in Gamma ray activity, while the upper part of the formation is marked by an increase in resistivity and abundant anhydrite on the PE/Bulk Density logs and rock cuttings. The caliper log continues to show very competent rock with no washout zones.

Lake Trafford Formation

The Lake Trafford Formation is mostly composed of light colored micritic limestone with some interbedded anhydrite. The approximate thickness of the formation is 140 feet. The top of the formation is designated at 9,690 feet bls and consists of a thick limestone above to a thick anhydrite below. The base is placed at 9,830 feet bls and it is noted by a change in lithology. Neutron/Density Porosity logs show abundant limestone.

Sunniland Formation

The Sunniland Formation is known for its oil producing capabilities. The formation is composed mainly of thick black limestones with a couple of anhydrite beds, with a thickness of 80 feet. The top of the formation is designated at 9,830 feet bls by a change in lithology. The base of the formation is placed at 9,910 feet bls by a sharp change from carbonates rocks to anhydrite. Neutron/Density Porosity logs show abundant limestone

Punta Gorda Formation

The Punta Gorda Formation is mainly composed of Anhydrite. The top of the formation is designated at 9,910 feet bls by a sharp change from carbonate rocks to anhydrite. The base of the formation was not reached by pilot hole drilling activities. In geophysical logs, resistivity increases, and anhydrite is evident in rock cuttings as well as in the PE/Bulk Density logs.

HYDROGEOLOGY

The hydrogeology observed in well CDIIW-1 can be divided into two categories, the upper section or Tertiary/Quaternary Aquifer Permeable Zones, and the lower section or Cretaceous Permeable Zones. A general overview of the hydrogeology of CDIIW-1 is shown in the figure 7 and 8.

According to Miller (1986), the Lower Floridan aquifer contains water with total dissolved solids (TDS) concentrations that are more than 10,000 milligrams per liter (mg/L). The Upper Floridan aquifer contains water with TDS concentrations that are generally less than 10,000 mg/L. The base of the USDW (Underground Source of Drinking Water), which is determined by the FDEP (Federal Department of Environmental Protection) to be the lowermost formation with TDS concentrations lower than 10,000 mg/L, was found around 1,360 ft. bls.

An aquifer is a saturated permeable geologic unit that can store and transmit significant quantities of water under ordinary hydraulic gradients (Freeze and Cherry, 1979). Confining zones are areas that have comparatively low hydraulic conductivity. Confining units limit the vertical transmission of water that occurs within or between aquifers. Although similar in depth to the stratigraphic units, the hydrogeological properties of the subsurface can differ or remain constant within each stratigraphic unit.

Biscayne Aquifer

The Biscayne Aquifer is the only surficial aquifer in South Florida, and it is present from the surface to about 130-150 ft. bls. Since the aquifer is not capped by any formation, but rather ends at the top of the water table, this aquifer is classified as an unconfined aquifer. Due to the unconfined and coastal nature of this aquifer, it is highly susceptible to contamination by chemical run offs and saltwater intrusion due to groundwater over pumping. Considering this aquifer is the only source of drinking water to most of South Florida, important steps are taken to protect the water quality of this surficial aquifer. The Biscayne Aquifer is characterized by highly permeable limestones found from 30 ft. bls to 150 ft. bls, capped by 30 feet of sands and clays on top, and low permeable limestone and silty sand at its base. The Intermediate Confining Unit rests below the Biscayne Aquifer, preventing water migration from deeper, saltier aquifers. During pilot-hole drilling of this section, mud was used as the drilling fluid, making the collection of formation water samples not possible.

Upper Floridan Aquifer Permeable Zone

The upper Floridan Aquifer Permeable Zone is part of a confined aquifer that is present below the sandy clay of the Intermediate confining unit, found from 1,000 to 1,090 ft. bls. This highly permeable zone is only about 90 feet thick. The lithology is characterized by soft, highly permeable and porous limestone with abundant fossils. This interval is characterized by an increase in sonic porosity. The groundwater found in this Zone of the Floridan Aquifer contains TDS concentration of around 400 mg/L.

Avon Park Permeable Zone

The Avon Park Permeable Zone is found from 1,575 to 1,725 ft. bls, about 150 feet thick, and it's below the USDW Transition Zone. The lithology of this section is mainly very pale orange limestone and dolomitic limestone, with moderate porosity and permeability and abundant benthic foraminifera (principally *Dictyoconus Sp*), and few vugs and echinoid tests. The groundwater found in Avon Park Permeable Zone ranges in TDS concentration from 6,000 to 25,000 mg/L, placing this formation below the USDW Transition Zone.

Lower Floridan Aquifer Permeable Zone

The lower Floridan Aquifer Permeable Zone is part of a confined aquifer and it is present from 2,125 to 2,200 ft. bls, with a thickness of approximately 75 feet. Lithologically speaking, this interval is characterized by light orange to gray and brown limestones and dolomitic limestones, with high to moderate porosity and permeability. In geophysical logs, this interval in characterized by a slight increase in borehole diameter and a sudden increase in resistivity, sonic porosity and gamma ray activity below the interval. The groundwater found in this zone of the Floridan Aquifer has a TDS concentration between 24,000 to 27,000 mg/L, well below the USDW Transition Zone.

Boulder Zone/Injection Zone (Floridan Aquifer)

The Boulder Zone/Injection Zone of the Floridan Aquifer is an area characterized by light and dark yellowish brown, hard dolostones with low porosity and permeability. Sucrosic recrystallization and chicken wire structures are abundant. Large caverns and washout zones are present in this interval, found from 2,875 to 3,150 ft. bls for a total thickness of 275 feet. In XY caliper geophysical logs, this interval is characterized by large increases in borehole diameter, as well as loss of circulation on the drill bit due to caving of the formation. The resistivity, sonic porosity and gamma ray activity greatly increases as well, but the cavernous nature of this zone is best visible in Video Survey logs. The groundwater found in the Boulder Zone of the Floridan Aquifer contains TDS concentrations ranging from 22,000 to 38,000 mg/L.

Conclusions

Upon successful completion of the final injection test, the presence of favorable geologic conditions, a highly transmissive injection zone with native water greater than 10,000 mg/L TDS, suitable confining sequence, and suitable monitor zones will permit the use of the injection well for disposal of the blended wastestream in accordance with existing state and federal underground injection control regulations.