Special Publication SJ2009-SP3

ASSESSMENT OF THE FEASIBILITY OF SHALLOW WELL DEMINERALIZATION CONCENTRATE DISPOSAL IN COASTAL AREAS OF THE ST. JOHNS RIVER WATER MANAGEMENT DISTRICT: LITERATURE REVIEW

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ASSESSMENT OF THE FEASIBILITY OF SHALLOW WELL DEMINERALIZATION CONCENTRATE DISPOSAL IN COASTAL AREAS OF THE ST. JOHNS RIVER WATER MANAGEMENT DISTRICT: LITERATURE REVIEW

St. Johns River Water Management District

Palatka, Florida

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EXECUTIVE SUMMARY

St. Johns River Water Management District (the District) is exploring options for membrane demineralization concentrate management to promote the development of environmentally responsible alternative water supply. This report compiles hydrogeologic and water quality data from the surficial aquifer system (SAS) of Flagler, Brevard, and Indian River counties to assess the feasibility of shallow Class V well concentrate disposal. Class V, Group 4 wells inject water into or above an Underground Source of Drinking Water (USDW), and the injected water quality must be better than or comparable to that of the receiving aquifer. Data from the District's water quality monitoring network, published U.S. Geological Survey (USGS) and Florida Geological Survey (FGS) reports, District consumptive use permits, and consultant reports reveal a predominantly fresh to brackish water (for the purposes of this assessment, brackish groundwater is classified as having salinities between 1,000 mg/L and 10,000 mg/L TDS) SAS in the study areas. The exception may be along the ocean-side of the barrier islands, particularly in Flagler and southern Indian River counties, where seawater has intruded laterally. These areas offer the greatest potential for Class V well application. For comparison, the hydrogeology and construction of existing Class V disposal well systems at Highland Beach, Florida, and in the Florida Keys are examined in this report. These case studies and a brief discussion of the regulation of Class V injection wells provide guidelines for shallow disposal well siting, testing, and construction in suitable areas of the District. An exploratory drilling program could better delineate the brackish-saline water interface both laterally and vertically along the barrier islands to identify possible locations for pilot Class V injection well systems.

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ACRONYMS AND ABBREVIATIONS

the District or SJRWMD	St. Johns River Water Management District
SAS	surficial aquifer system
USDW	Underground Source of Drinking Water
USGS	U.S. Geological Survey
FGS	Florida Geological Survey
RO	reverse osmosis
NF	nanofiltration
ED	electrodialysis
EDR	electrodialysis reversal
TDS	total dissolved solids
EPA	U.S. Environmental Protection Agency
FAS	Floridan aquifer system
ICWW	Intracoastal Waterway
FDEP	Florida Department of Environmental Protection
UIC	Underground Injection Control
F.A.C.	Florida Administrative Code
USDW	Underground Source of Drinking Water
mg/L	milligrams per liter
UFA	Upper Floridan aquifer
LFA	Lower Floridan aquifer
DWS	Drinking Water Standards
ASR	aquifer storage and recovery
bls	below land surface
FPUA	Fort Pierce Utilities Authority
FKAA	Florida Keys Aqueduct Authority
WTP	water treatment plant
PVC	polyvinyl chloride
gpm	gallons per minute
ft^2/d	square feet per day
mgd	million gallons per day
IAS	intermediate aquifer system

INTRODUCTION

The St. Johns River Water Management District (the District or SJRWMD) is currently examining ways to meet projected 2025 industrial, agriculture, and municipal water demands. One technology identified in the *District Water Supply Plan 2005* (SJRWMD 2006) as a promising water supply alternative is membrane demineralization technology. Demineralization membrane technology involves using reverse osmosis (RO), nanofiltration (NF), electrodialysis (ED), or electrodialysis reversal (EDR) to remove total dissolved solids (TDS) from brackish (for the purposes of this assessment, brackish groundwater is classified as having salinities between 1,000 mg/L and 10,000 mg/L TDS) or saline sources. The resulting finished water meets U.S. Environmental Protection Agency (EPA) primary and secondary drinking water standards. While the surficial aquifer system (SAS), the Floridan aquifer system (FAS), and the ocean offer various sources for brackish and saline source water, options for concentrate management—a by-product of demineralization technology—remain a primary concern for stakeholders. Regulatory approvals for constructing and operating membrane water treatment facilities are dependent on an environmentally acceptable concentrate disposal plan.

The District has begun exploring several options for concentrate management including ocean outfall, surface discharge to the Indian River, and subsurface discharge (Reiss Environmental 2003, L.S. Sims and Associates 2003, and CH2M HILL 2006). Subsurface concentrate disposal methods employed in Florida include:

- Deep well injection (Class I wells)
- Coastal shallow Class V disposal wells

The coastal shallow injection well alternative offers distinct cost advantages over the Class I deep injection well, which typically involves drilling to significantly greater depths. A typical Class I well requires 180 days to construct, whereas a Class V well may require only 60 days to construct. Additionally, where Intracoastal Waterway (ICWW), lagoon, and barrier island areas are laterally intruded by seawater, the coastal shallow disposal well minimizes the risks of adversely impacting potential underground sources of drinking water in the FAS. The application of the shallow well disposal method in Highland Beach, Florida, and in the Florida Keys attests to its effectiveness.

This technical memorandum provides a feasibility-level analysis of shallow well disposal to support the District's evaluation of concentrate management alternatives. The hydrogeology of selected coastal study areas within the

District will be compared with the hydrogeology of operational Class V well sites based on a review of existing published studies and available data.
As shown in Figure 1, the study areas considered in this review include the coastal areas of Indian River County, Brevard County, and Flagler County. Indian River County represents the southern extent of the District and may exhibit hydrogeologic conditions closest to those observed at Highland Beach in Palm Beach County. Coastal areas in Brevard and Flagler counties were identified as priority water resource caution areas in previous studies (SJRWMD 2006, CH2M HILL 2006).

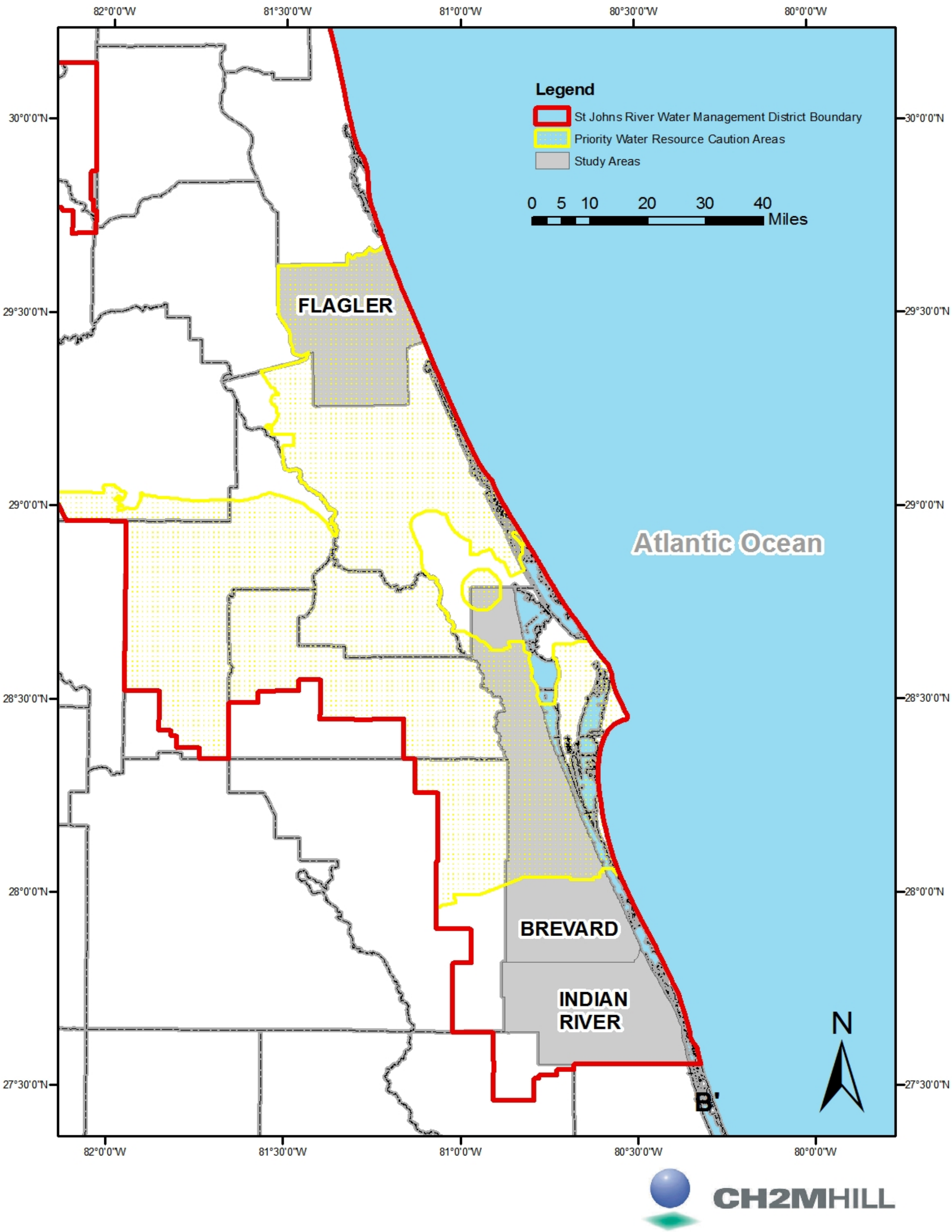

Figure 1. Study areas for this evaluation

REGULATORY REVIEW

Current regulations in Florida prohibit the migration of wastewater into zones of potential drinking water, including surface and underground water sources. Consequently, permitting efforts typically focus on demonstrating that the zone of discharge is confined or that different zones or potential water sources are not affected. The Florida Department of Environmental Protection (FDEP) Underground Injection Control (UIC) program oversees the regulation of injection wells as mandated by the Code of Federal Regulations (CFR 40) and Chapter 62-528 of the Florida Administrative Code (*F.A.C.*). Part V of the *F.A.C.*, Chapter 62-528 outlines the definitions, construction standards, testing, and monitoring of Class V wells. As opposed to Class I wells, which by definition inject below the lowermost Underground Source of Drinking Water (USDW), Class V wells inject into or above a USDW. Groundwater with a TDS concentration of 10,000 milligrams per liter (mg/L) or greater can be classified as either G-III (in unconfined aquifers) or G-IV (in confined aquifers), according to Rule 62-520.410 of the *F.A.C.*

In a simplified conceptual hydrogeologic model, the lowermost USDW in Florida is the Upper Floridan aquifer (UFA), below which lies the generally saline groundwater in the Middle Floridan confining unit and Lower Floridan aquifer (LFA). The brackish UFA is confined by the intermediate confining unit in most areas of the central and southern peninsula of Florida. Above the intermediate confining unit, or in the absence of a confining unit, above the UFA lies the SAS. To comply with the regulation that Class I wells must inject below the lowermost USDW, most Class I wells are constructed in the LFA (deep injection wells). Class V wells are generally constructed at much shallower depths. While the shallower wells have lower construction costs and shorter construction times than deeper Class I wells, permitting certain types of Class V wells can be challenging, particularly with respect to complying with stringent water quality criteria.

The criteria upon which injection water quality is evaluated are dictated by the purpose of the well. Class V wells are subdivided into nine groups based on application as follows:

- Group 1 - Air conditioning return flow wells;
- Group 2 - Recharge or saltwater intrusion barrier wells;
- Group 3 - Domestic septic system wells;
- Group 4 - Industrial and commercial desalination process concentrate disposal wells;
- Group 5 - Mining wells used to return spent brine to the same formation;
- Group 6 - Stormwater drainage wells;
- Group 7 - Aquifer storage and recovery (ASR) wells;

- Group 8 - Motor vehicle waste disposal wells; and
- Group 9 - Geothermal and swimming pool drainage wells.

Membrane demineralization concentrate injection wells are classified as Group 4 waste disposal wells, provided the concentrate adheres to the Primary and Secondary Drinking Water Standards (DWS) outlined in Chapter 62-550, *F.A.C.* Exceptions to this strict adherence to primary and secondary drinking water standards are allowed under Rule 62-522.300 (2):

(2) Zones of discharge shall be allowed for projects or facilities that allow direct contact with groundwater listed in paragraphs (a) through (c) below, which provide beneficial discharges through wells to ground water as described in the cited rules.

(a) Projects designed to recharge aquifers with surface water of comparable quality, or projects designed to transfer water across or between aquifers of comparable quality for the purpose of storage or conservation;

Paragraphs (b) and (c) grant exceptions for ASR wells and for environmental remediation injection wells. Although paragraph (a) refers to aquifer recharge projects, the intent of the rule may be relevant to Class V, Group 4 wells—to limit injection to water of quality comparable to that in the receiving zone. The primary intent of each rule cited above is to protect USDWs within aquifers containing G-I, G-II, and F-I groundwater, whether from migration of groundwater of significantly different water quality between aquifers or from injected water that could adversely impact a USDW. As a result, the FDEP Technical Advisory Committee, established by Rule 62-528.100, may elect to approve well construction permits only following a thorough, site-specific hydrogeologic investigation. The applicant is charged with the often onerous task of demonstrating that a proposed well will not cause a significant degradation in groundwater quality in the receiving zone. Thus, as a general guideline, applicants proposing to inject concentrate into a USDW with better water quality than the concentrate are less likely to be successful in obtaining a permit. The quality of the injected water should either meet the primary and secondary DWS or have a better water quality (that is, a lower TDS) than the receiving zone in order to mitigate potential environmental problems and to minimize the regulatory review effort.

The construction standards for Class V wells are based on the intended use for each well, and designs must be individually approved by FDEP. If FDEP determines that the proposed design of a Class V well may allow fluid to migrate into a USDW to the extent of causing a violation of DWS, Class I well construction standards may be applied. Regardless of whether Class V or Class I criteria apply, the injection well must be constructed in such a manner that the integrity of confining units is maintained. One way to accomplish this is by installing cemented, telescoping casing. The minimum requirement for casing and cementing is described in Chapter 62-532, *F.A.C.* Drilling cuttings must be collected during construction to identify the site-specific geologic conditions and related permeability of penetrated units.

Monitoring requirements are site-specific. They are determined by the quality of the injected fluid, the water quality of the receiving zone, and the proximity and hydraulic interconnection of the receiving zone to a USDW. The water quality parameters and frequency of monitoring are similarly contingent upon the intended use of the well and site-specific conditions.

Upon completion of the well construction and testing and demonstration by the user that the Class V well will not adversely impact a USDW, FDEP will issue a non-renewable and non-expiring authorization to use the well.

CASE STUDIES

Permitting Class V wells that inject directly into a USDW can be challenging. A feasibility assessment to evaluate using a Class V well to discharge at 1,500 feet below land surface (bls) into the FAS was conducted by CH2M HILL for Fort Pierce Utilities Authority (FPUA) (Skehan and Kwiatkowski 2000).

At typical recovery rates of 85 to 90 percent, the FPUA RO membrane water treatment plant (WTP) would produce concentrate that was similar in quality to the formation water in the proposed receiving zone. However, fluoride and radionuclides exceeded the concentrations of the formation water and those allowed by the DWS. The fluoride concentration of the membrane by-product was estimated to be 2.86 mg/L. This concentration exceeded the secondary DWS (2.0 mg/L), but met the primary DWS (4.0 mg/L). Thus, only a secondary DWS exemption would have been required—a fairly routine FDEP approval. The projected radionuclide concentrations violated *both* the primary and secondary water quality standards. Moreover, the projected radionuclide concentrations were based on a small sampling of Floridan aquifer source water that could exhibit significant variability geographically and over time. FDEP indicated that variability in radionuclide data would have to be clearly understood to obtain a permit. Consequently, FPUA decided to avoid an uncertain permitting process and to pursue a deeper (3,200 feet bls) Class I deep injection well system.

In contrast the Florida Keys Aqueduct Authority (FKAA) Marathon RO facility and the Town of Highland Beach both operate shallow Class V wells. These wells were permitted because the receiving zone is not a USDW.

HIGHLAND BEACH

In 2003, FDEP permitted the construction of two shallow, Class V, Group 4 injection wells to dispose of non-hazardous RO concentrate and non-contact air conditioning return flow at the Town of Highland Beach WTP. The permit required two monitor wells to assure that concentrate would not be allowed to migrate downward toward the intermediate confining unit and underlying UFA or upward into an overlying freshwater lens (CH2M HILL 2004).

By 2004 all four wells were completed. Pilot-hole drilling revealed a thin freshwater lens immediately bls and a transition to 10,000 mg/L TDS water between 12 feet and 17 feet bls. Outer casing was installed to provide protection of the shallow freshwater lens during drilling. The injection wells were completed entirely within the poorly consolidated sandy limestone of the Anastasia Formation (part of the SAS). The inner (final) 15-inch inside diameter corrosion-resistant polyvinyl chloride (PVC) casings were installed to 104 feet bls, and the open hole receiving zones were drilled to 184 feet bls. This left more than 80 feet of separation between the top of the injection zone and the overlying USDW, and 56 feet between the total depth of the injection wells and the top of the intermediate confining unit at 240 feet bls (Figure 2). The UFA USDW was identified at 1,030 feet bls.

The shallow monitor well was constructed with 4-inch-diameter PVC casing to a depth of 30 feet bls and an open interval to 35 feet bls. The deep monitor well was similarly constructed with a 4-inch-diameter PVC final casing; however, an intermediate 12-inch-diameter casing was installed to the top of the Hawthorn Group. The open hole interval was drilled from 351 feet to 376 feet bls. Background water quality sampling was performed on both monitor wells to establish baselines against which future water quality sampling could be compared to observe potential changes indicative of concentrate migration upward or downward.

As expected, the native water quality was similar for both shallow injection wells. The concentration of TDS was 32,000 mg/L, and the chloride concentrations were between 14,000 mg/L and 16,000 mg/L. This water quality confirmed that the injection zones were not located within a USDW, and the data were consistent with the anticipated lateral seawater intrusion along the coast.

Injection testing was conducted using raw Floridan aquifer source water. At an injection rate of 750 gallons per minute (gpm), the specific injectivity (comparable to approximately 80 percent of specific capacity) was estimated at 62 gpm/ft. This corresponds to a transmissivity of 20,000 square feet per day (ft^2/d) or greater. Upon completion of construction and testing, the permitted capacity of the Class V injection well system was 1.03 million gallons per day (mgd) (peak hourly flow) for a concentrate reject with a TDS of approximately 21,000 mg/L.

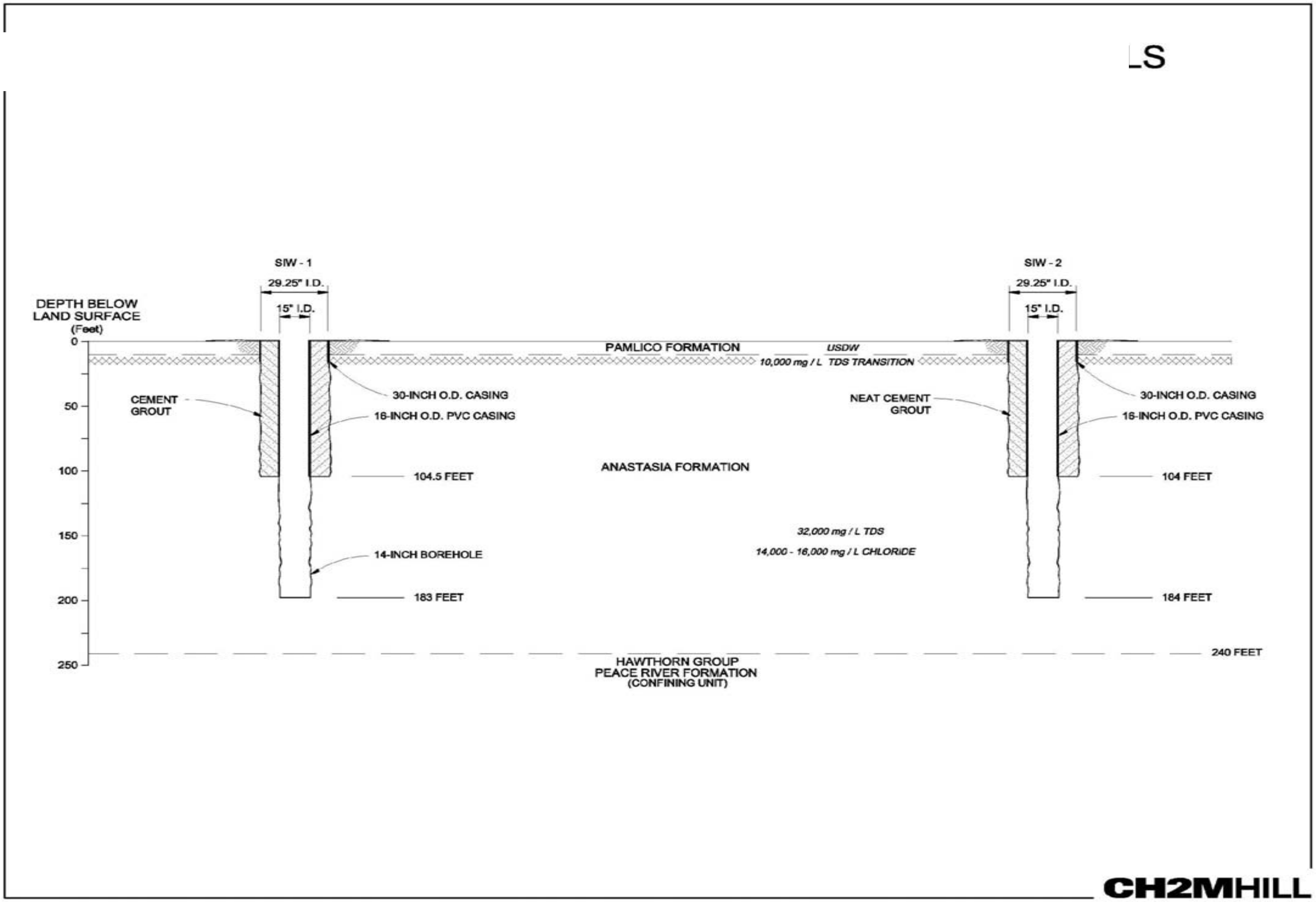

Figure 2. Highland Beach Class V well diagrams

FLORIDA KEYS AQUEDUCT AUTHORITY

FKAA permitted and constructed a shallow Class V, Group 4, injection well in 1996 to dispose of RO concentrate reject from the emergency membrane WTP, Marathon RO Plant, in the Middle Keys.

The injection well was sited approximately 455 feet from the plant supply well, which was constructed to a depth of 60 feet bls. As shown in Figure 3, the injection well was constructed entirely within the Key Largo Limestone, a hard, fossiliferous limestone characterized by dissolution cavities and a corresponding high permeability. Sampling from the surficial aquifer throughout the area revealed water quality similar to that of seawater.

Consequently, there were no structural, geologic, or water quality issues that would require an intermediate or outer casing. A 14-inch-diameter, corrosion-resistant PVC casing was cemented in place to 110 feet bls, and the open hole injection zone was drilled to 150 feet bls. The underlying intermediate confining unit was not encountered during drilling, but existing data indicate that the top of the Hawthorn Group occurs below depths of 600 feet (Scott 2001).

The primary regulatory concern was that the injected concentrate could impact the source water for the adjacent supply well. To investigate this concern and to determine the specific capacity of the injection well, a pumping test was conducted at 2,500 gpm for 6 hours. The specific capacity of the injection well was estimated at 1,785 gpm/ft, and the water level in the supply well was not affected by the pumping test. The transmissivity estimated using a simplified Cooper-Jacob analytical solution for unconfined aquifers is 480,000 ft^2/d.

Water quality analyses from the injection well yielded a TDS concentration of approximately 26,600 mg/L and a chloride concentration of 15,000 mg/L. The TDS concentration of the RO by-product was estimated at 50,000 mg/L. Migration of concentrate into a USDW was not a concern, given the significant lateral and vertical separation from the nearest USDW.

The Marathon RO Plant has an Industrial Wastewater Facility Permit with annual average underground injection allocation of 2.33 mgd.

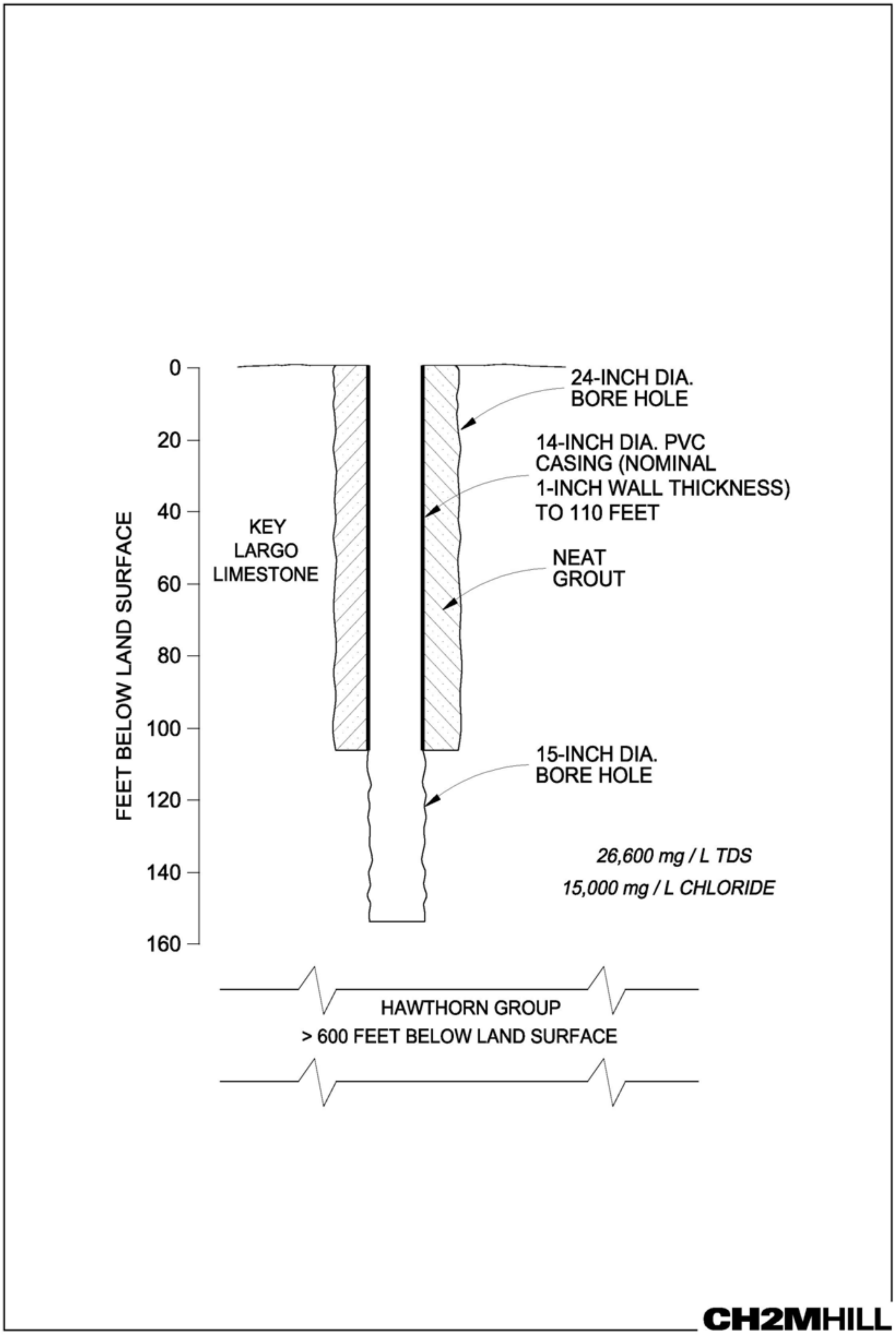

Figure 3. Florida Keys Aqueduct Authority well diagram

HYDROGEOLOGY OF COASTAL STUDY AREAS

The SAS in the study areas was evaluated by reviewing available data and existing published reports prepared by the District, USGS, FGS, and private consulting firms. In addition, lithologic and geophysical logs provided by FGS and SJRWMD were used to construct hydrogeologic cross sections of the generalized hydrostratigraphy and water quality underlying the coastal areas of Flagler, Brevard, and Indian River counties.

Following is a discussion of the findings from the data and literature review. Figures 4 and 5 provide a general location map for the cross sections presented in Figures 6 and 7, discussed below.

GEOLOGY

The geological setting of the coastal areas of Flagler, Brevard, and Indian River counties exists within a thick sequence of carbonate rock capped by a relatively thin siliciclastic, sedimentary sequence. Sediments within the sequence of carbonate rock range in age from middle Jurassic to Holocene. The aquifer systems underlying the study area are contained within sediments ranging in age from late Paleocene (55 million years old) to Holocene (Recent). From deepest to shallowest, these aquifer systems are the FAS, the intermediate aquifer system (IAS), and the SAS. Geologic units comprising the SAS in the study area are generally represented by the Holocene and Pleistocene deposits and the Tamiami Formation of Pliocene age. These units are briefly discussed below.

Holocene/Pleistocene Series

Undifferentiated Deposits. Undifferentiated sediments of Pleistocene and Recent age deposits blanket all of Flagler, Brevard, and Indian River counties (see Figures 6 and 7). These deposits occur from the land surface to depths of approximately 20 feet in the southern part of Flagler County to more than 100 feet beneath the coastal ridges of the barrier island and Indian River lagoon areas. The Pleistocene and Recent deposits consist primarily of coquina with varying amounts of fine to medium quartz sand and organic material (Anastasia Formation) along the barrier islands, and just a few miles west of the Indian River lagoon, these deposits contain greater percentage of quartz sands with lesser amounts of coquina (Fort Thompson Formation).

Pliocene Series

Tamiami Formation. The Pleistocene and Recent sediments are underlain by the Pliocene deposits of the Tamiami Formation, which consists primarily of interbedded argillaceous to arenaceous, slightly phosphatic, bioclastic coquinoid limestone with quartz sand and silt beds (Toth 1988).

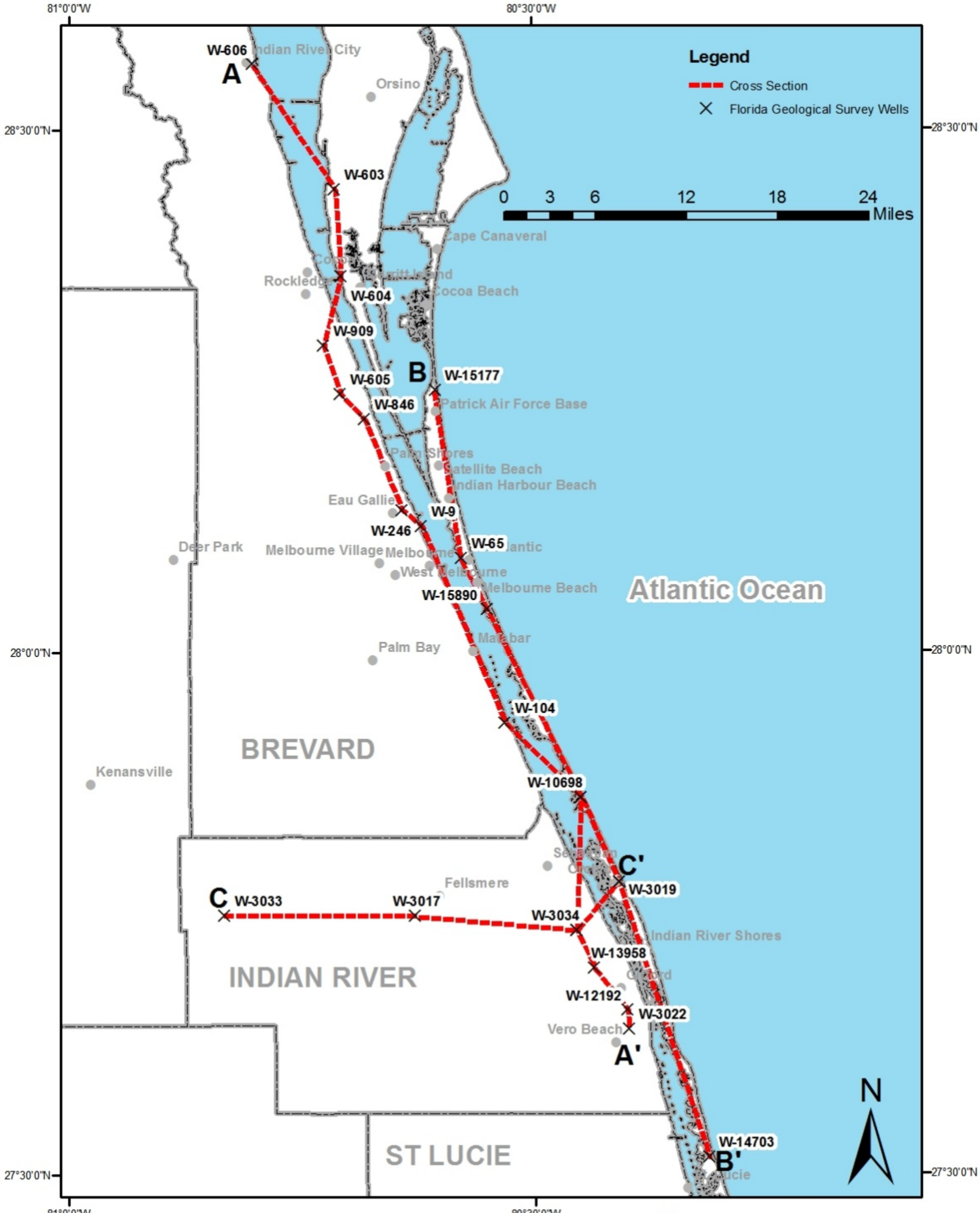

Figure 4. Hydrogeologic cross sections location map (Brevard and Indian River counties)

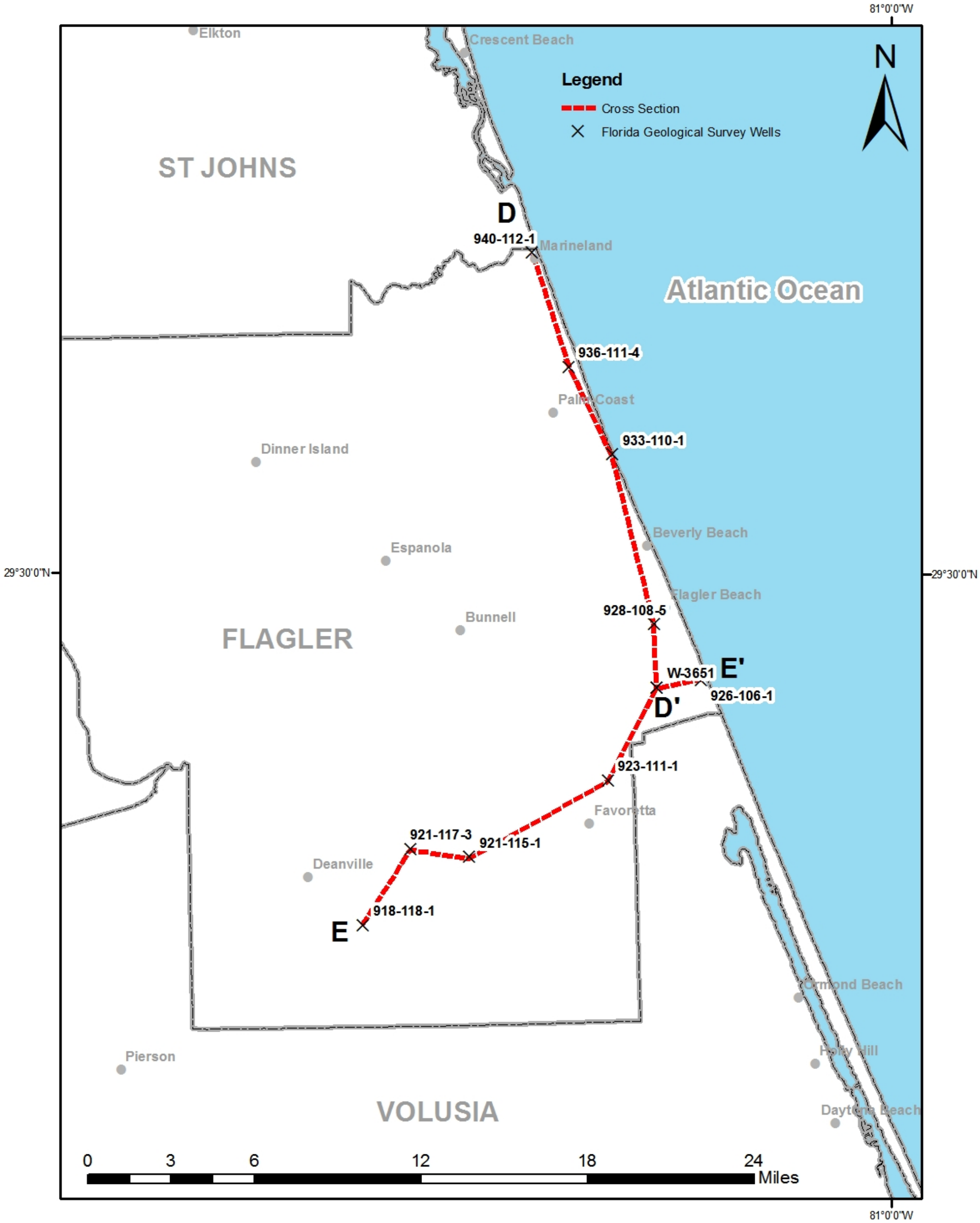

Figure 5. Hydrogeologic cross sections location map (Flagler County)

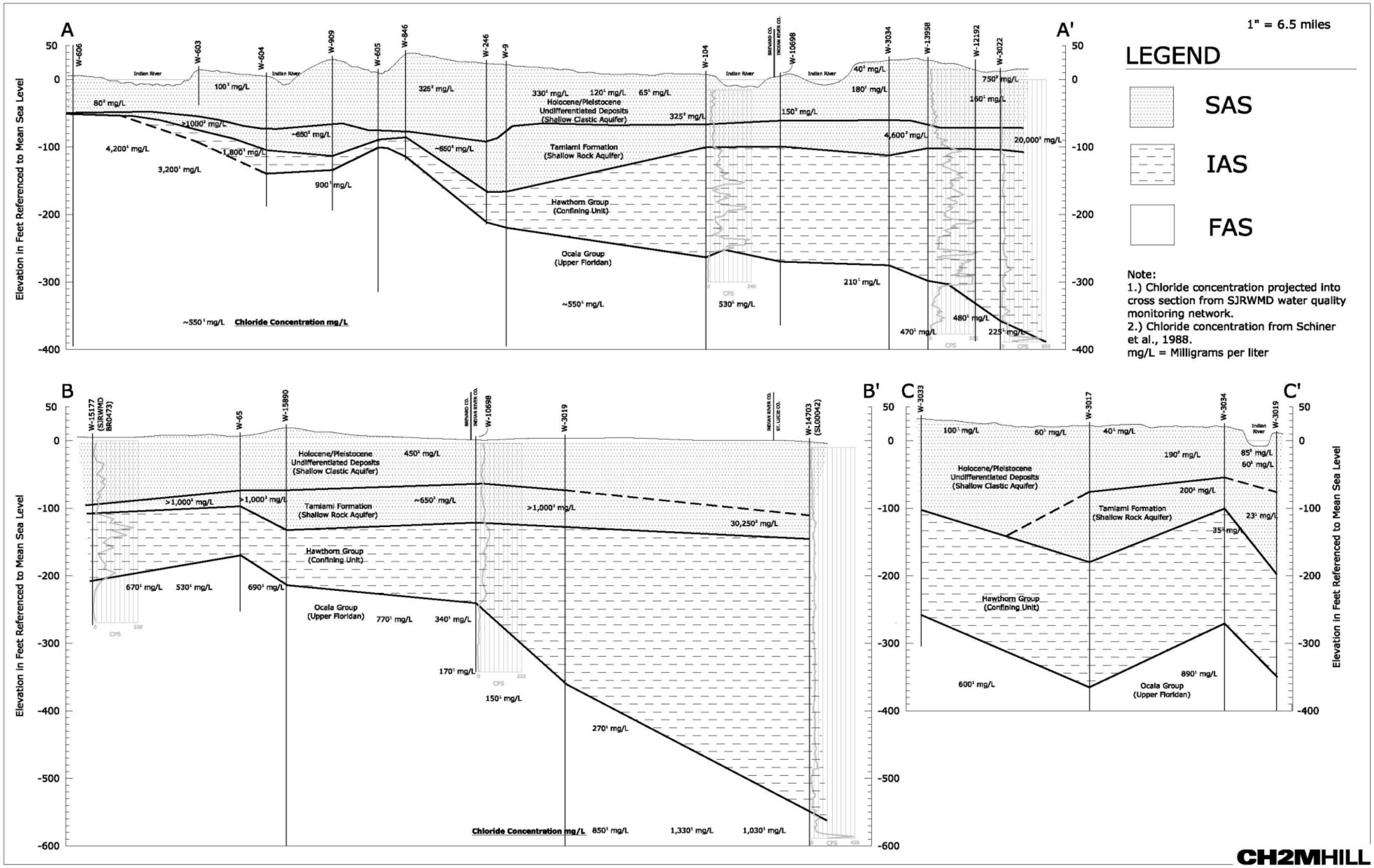

Figure 6. Hydrogeologic cross sections in Brevard and Indian River counties

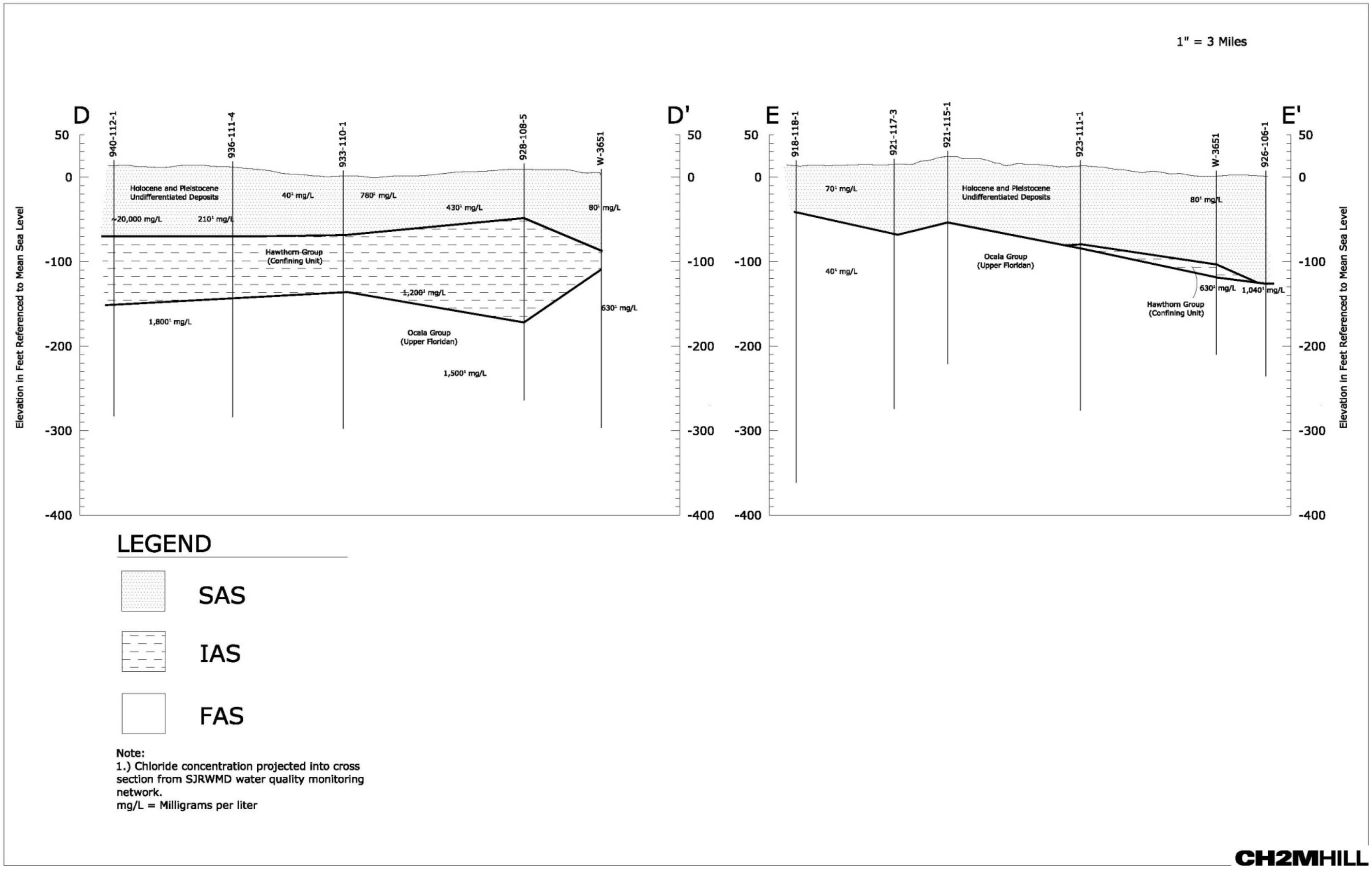

Figure 7. Hydrogeologic cross sections in Flagler County

The thickness of the Tamiami Formation ranges from 60 feet beneath the barrier island up to 100 feet beneath the Indian River lagoon areas (Toth 1988, Schiner 1988). The top of the formation ranges from approximately 50 feet bls to approximately 110 feet bls, with increasing depth toward the coast. These limestone units form the shallow rock aquifer of the SAS.

Miocene Series

Hawthorn Group. The Hawthorn Group occurs below the Tamiami Formation and is present throughout most of the study area with the exception of the northern Brevard County and southern Flagler County (see Figures 6 and 7). The thickness of the Hawthorn Group varies considerably throughout the study area, reaching up to 300 feet thick toward the south and southeast in Indian River County. Lithologically, the Hawthorn Group consists primarily of olive-gray and phosphatic clays and silts with interbedded sandy limestone of Miocene age. The carbonate beds are characterized by sandy, hard, recrystallized, phosphatic limestone with some brown dolomite (Toth 1988). Generally, all but the lowermost strata of the Hawthorn Group compose the confining unit separating the SAS from the FAS.

SURFICIAL AQUIFER SYSTEM

The SAS occurs from the water table, near land surface, and extends to total depths ranging between 100 feet and 200 feet bls within the study areas. Based on lithologic characteristics, the SAS can be subdivided into two hydrogeologic units: a shallow clastic aquifer zone comprised of undifferentiated sediments from Pleistocene to Holocene age and an underlying shallow rock aquifer zone consisting of Tamiami Formation limestone (Toth 1988). The SAS is underlain by the IAS, which consists of interbedded carbonates, siliciclastics, and clay in the Hawthorn Formation. The clays and silts of the Hawthorn Group, where present, form a semi-confining layer that restricts the exchange of water between the underlying FAS and the SAS. The UFA is characterized by a potentiometric surface that generally lies above land surface below the IAS. Published maps for the UFA in Indian River and Brevard counties show equipotential contours between 20 and 40 feet, and approximately 10 feet above land surface in Flagler County (Schiner et al. 1988, Bush and Johnston 1988).

Water levels in the SAS occur a few feet bls and fluctuate in response to seasonal changes in precipitation, evapotranspiration, and pumping (Schiner et al. 1988). The direction of groundwater flow in Brevard and Indian River counties is to the northeast, but in the southern part of Indian River County, groundwater generally flows to the southeast (Toth 1988).

The sources for the SAS include direct recharge from precipitation, surface water body infiltration, and lateral intrusion from seawater. A component of SAS water may also be derived from vertical migration of FAS water through corroded FAS well casings and through less confining areas of the IAS, where the Hawthorn Formation is particularly thin or absent (Schiner et al. 1988).

Hydraulic Properties

Units of lower permeability occur within the SAS and cause transmissivities to vary within the study areas. The transmissivity of the SAS in Indian River County ranges from 2,400 ft^2/d in Vero Beach to 11,000 ft^2/d in Sebastian Highlands. In Brevard County, reported transmissivity values range from 1,737 ft^2/d in the northern part of the county to approximately 1,654 ft^2/d in the southern part the county (Toth 1988).

The specific capacity of wells penetrating the SAS in eastern Indian River County ranges from 9 gpm/ft in Vero Beach to 70 gpm/ft. Specific capacity results as low as 1.05 gpm/ft and 2.17 gpm/ft have been reported from SAS wells located in Palm Coast, Florida (CH2M HILL 1981).

Water Quality

SJRWMD maintains water quality data from a network of monitoring wells, some of which are located within the study area. Data obtained from the District (Boniol 2007) were used in conjunction with published water quality data (Schiner et al. 1988) to evaluate chloride concentrations within the SAS. These data were compiled and plotted on cross sections as shown in Figures 6 and 7.

Figure 6 shows that chloride concentrations in the SAS are generally below 1,000 mg/L in the coastal areas of Brevard and Indian River counties, with the exception of water in the shallow rock aquifer within Round Island West Park near the St. Lucie County line (30,250 mg/L) and immediately next to the Indian River in Vero Beach (20,000 mg/L), where lateral intrusion of seawater presumably occurs because of over-pumping of a nearby SAS wellfield (Schiner et al. 1988, and Toth 1988). The top of the shallow rock aquifer in the Round Island West Park occurs at a depth of approximately 110 feet, with a thickness of approximately 40 feet, as presented on cross section B (W-14703) in Figure 6. The top of the shallow rock aquifer in Vero Beach occurs at a depth of 70 feet bls, and its thickness at this location is approximately 40 feet. A map of SAS water quality in Indian River and Brevard counties is presented in Figure 8.

As indicated in Figure 7, the water quality in the SAS of Flagler County is primarily fresh to slightly brackish. Locally, however, east of the ICWW, lateral seawater intrusion may dominate, as evidenced by the saline water quality of wells drilled to 60 feet at Marineland in the northeast corner of the county. The extent of saline water in the SAS south of Marineland along the coast is not known. However, by inference, the paucity of SAS wells immediately adjacent to the beach suggests that water quality may be generally unsuitable for potable supply or irrigation. A map of SAS water quality in Flagler County is presented in Figure 9.

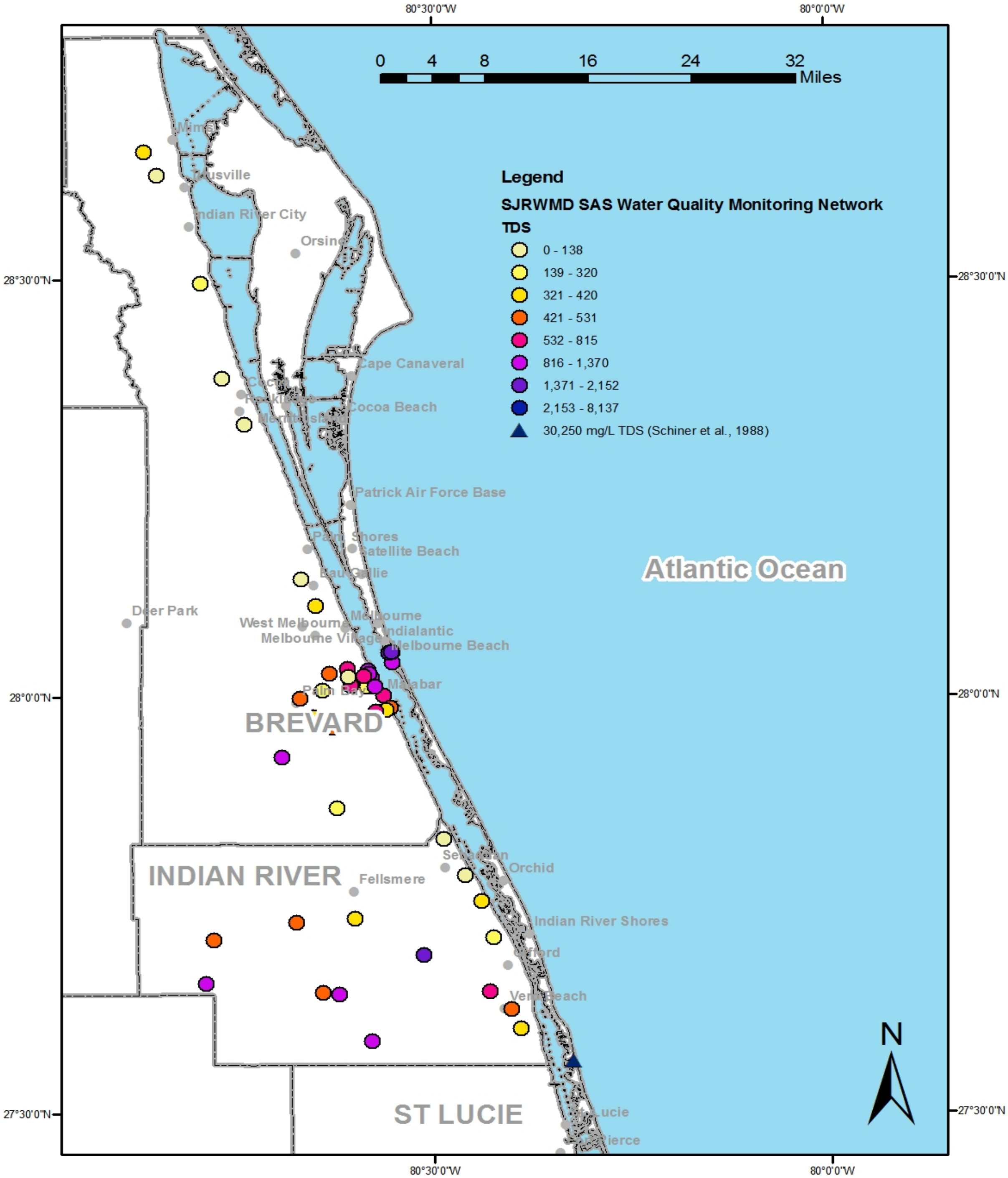

Figure 8. Map of total dissolved solids in the surficial aquifer system in Indian River and Brevard counties

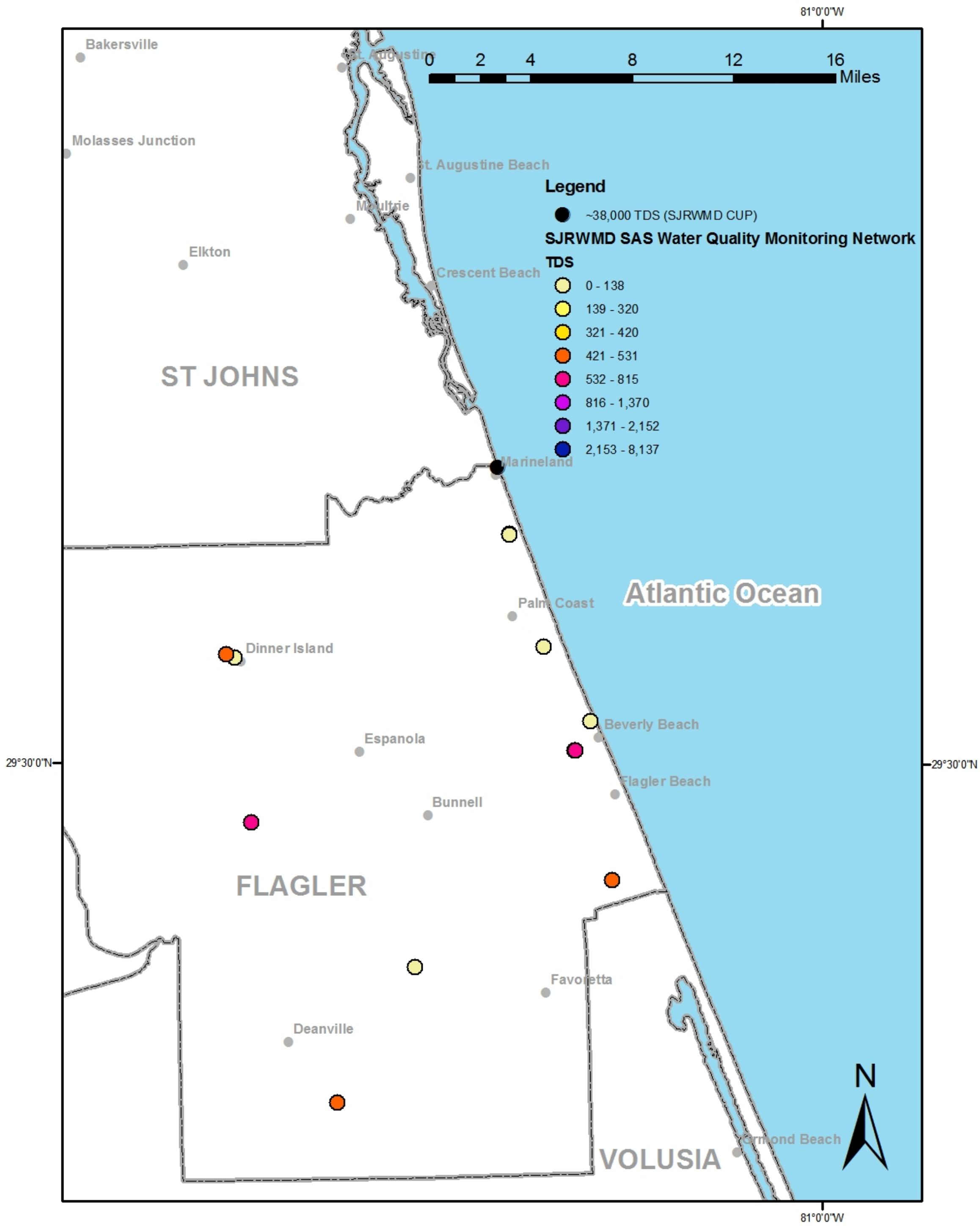

Figure 9. Map of total dissolved solids in the surficial aquifer system in Flagler County

FEASIBILITY OF CLASS V WELL INJECTION

The cost of installing and operating a Class V injection well system depends on a number of factors, including permitting, pretreatment of injected concentrate, construction of the well and aboveground facility, and monitoring. The construction investment alone depends on the depth of the receiving zone, geology, required capacity, regulatory testing, injection pressure (pump) requirements, site characteristics, and conveyance. Although the cost of installing a shallow well disposal system may be high relative to local surface discharge, the cost will typically be significantly less than a deep injection well system constructed with a tubing and packer design. As the relative cost of the investment decreases proportionally to the capacity requirements of the membrane WTP, a shallow injection well system may be both an economically and environmentally favorable alternative for larger plants.

Large seawater demineralization plants may be in the future of SJRWMD, as discussed in the *District Water Supply Plan 2005*. For the District to promote the feasibility of seawater demineralization, the issue of concentrate management must be addressed concurrently. Among the five sites identified in the *District Water Supply Plan 2005* (SJRWMD 2006), two sites lie within the coastal areas reviewed in this Class V well feasibility study: the Indian River Power Plant and the Cape Canaveral Power Plant (SJRWMD 2006, Beck 2002).

As discussed in previous sections, Class V well, Group 4, injection is a practical, cost-effective, and environmentally prudent option where the receiving groundwater is above 10,000 mg/L TDS and where there is little risk of impacting an overlying or underlying USDW.

Figure 10 provides a graphical representation of aquifer suitability to shallow well concentrate disposal. In the case of Highland Beach, the receiving groundwater was non-potable (G-IV), with a higher TDS concentration than the by-product. The presence of the overlying fresh groundwater —a USDW— and the moderate transmissivity were causes of concern during the permitting process. Therefore, upper and lower monitor wells were required. At Marathon, the injected concentrate at the Marathon RO Plant was essentially seawater demineralization by-product, but the high transmissivity and absence of a USDW were conducive to a relatively easy permitting process, without subsequent monitoring. For comparison, the average ranges for TDS and transmissivity in the study areas are represented in Figure 10. Although a few wells on the barrier island in central Brevard County and east of the Vero Beach wellfield are characterized by higher TDS concentrations, the majority values for SAS wells lie below 2,000 mg/L TDS. With little site-specific transmissivity data, the range of values presented on the chart is 2,000 to 11,000 ft^2/d (Schiner et al. 1988). The TDS concentration for the SAS well near Round Island West Park would plot near the Highland Beach point. No transmissivity data are readily available for this well.

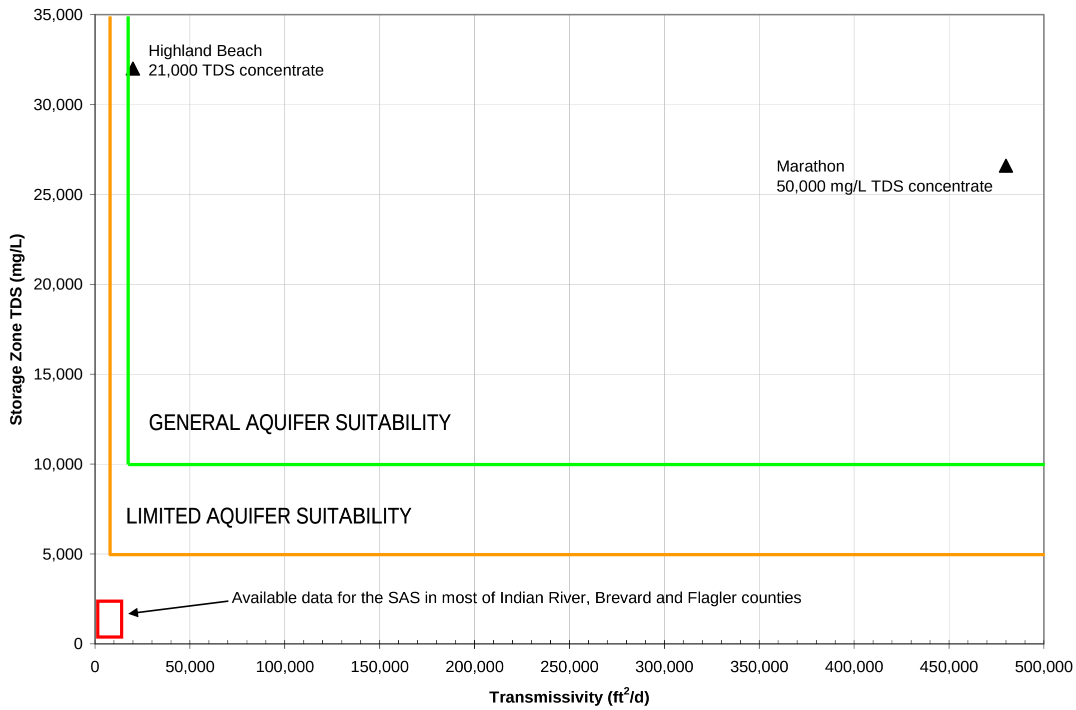

Figure 10. Aquifer suitability to shallow well concentrate disposal

In areas of the SAS characterized by lower TDS concentrations and transmissivity, seawater demineralization concentrate disposal may be more difficult to permit; however, Class V well concentrate disposal remains an alternative. Utilities operating in areas less suitable for seawater demineralization concentrate disposal may wish to continue developing brackish water sources. For example, demineralization concentrate concentrations between 1,000 mg/L and 10,000 mg/L correspond to source water TDS concentrations of 500 mg/L to 3,000 mg/L, with a 70 percent recovery. Permitting Class V injection wells in zones of the SAS with TDS concentrations greater than 1,000 mg/L and less than 10,000 mg/L may require site-specific investigations and DWS exemptions, but may still offer broader utilization of cost-effective underground disposal.

Existing SAS water quality data supports further investigation of the brackish-saline water interface in the southern study areas. Most SAS production wells in the coastal and barrier island areas of Indian River and Brevard County are constructed to 20 to 40 feet below land surface, and, as shown in Figure 11, water quality at these shallow depths does not appear to be correlated to depth in the aquifer. A graph of the relationship between the TDS concentrations and chloride concentrations for SAS groundwater in the study area has been provided in Figure 12. This figure can be used to compare chloride values to the TDS values discussed in previous sections and presented in Figures 8 and 9. Note that no reported water quality in the monitor wells reaches the

10,000 mg/L TDS threshold; the highest TDS concentration from the SJRWMD water quality monitoring network is just over 8,000 mg/L, from a well on the barrier island in central Brevard County.

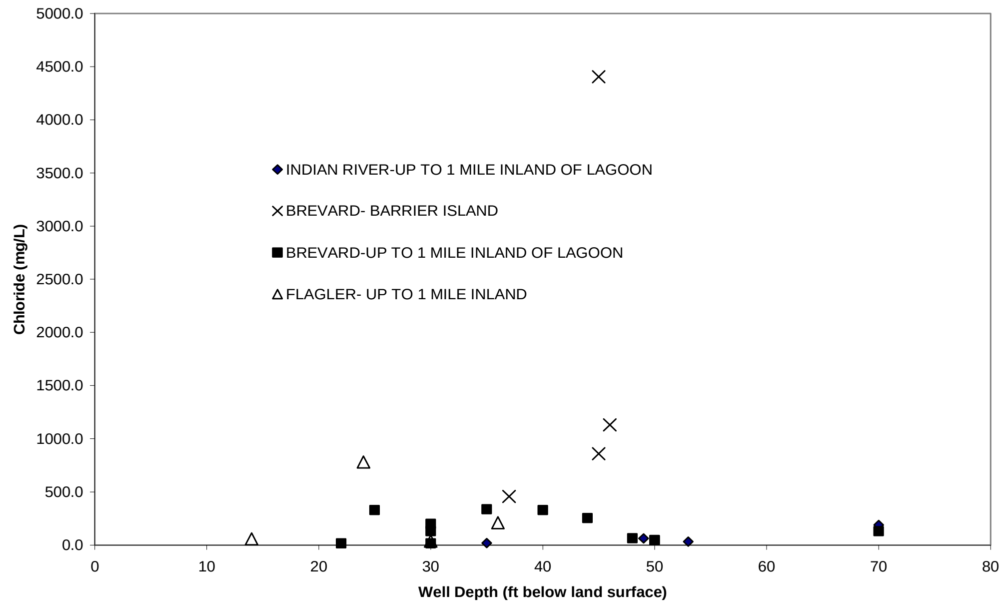

Figure 11. SAS water quality as a function of well depth

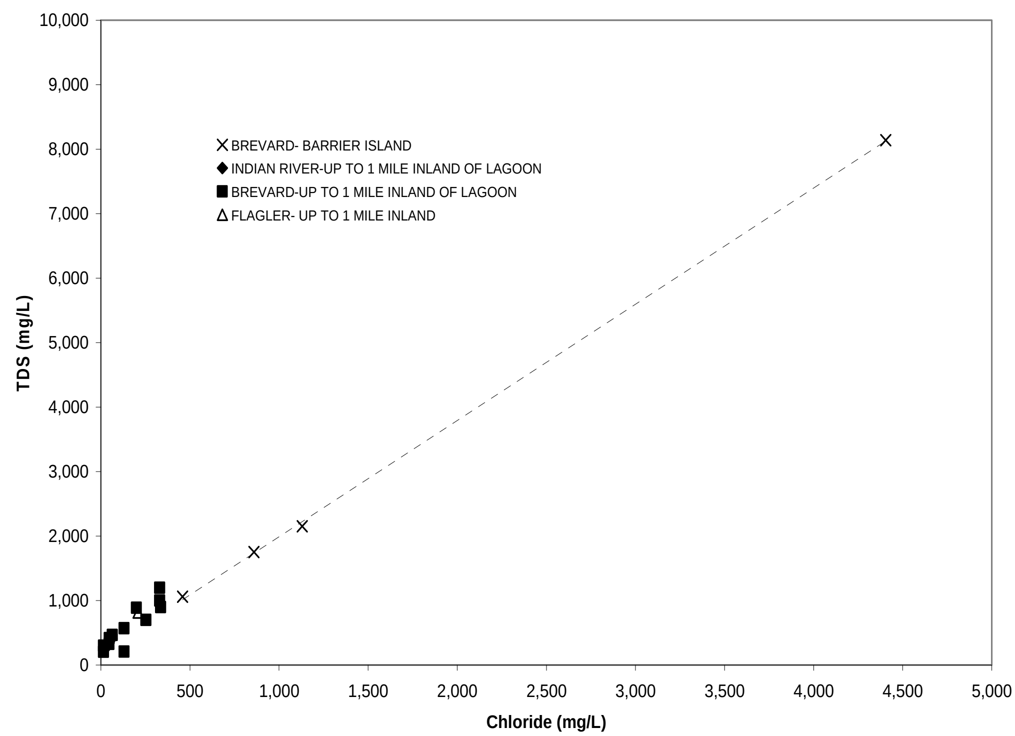

Figure 12. Total dissolved solids as a function of chloride

The Shallow Rock Aquifer in the Tamiami Formation extends from approximately 70 feet below mean sea level (BMSL) to more than 100 feet BMSL near the coast. Little data exists from this interval, particularly on the barrier islands, where the potential for lateral seawater intrusion is greatest. In fact, the general trend is toward shallower wells depths in the southern parts of the study area (southern Brevard and Indian River counties). This relationship is illustrated in Figure 13, in which the depth of permitted production wells has been plotted against latitude. The wells may be shallower in the south as a result of a shallower brackish-saline interface, and deeper exploratory wells in the southern barrier island areas of Indian River and Brevard counties may reveal this water quality transition. The depth of the well with saline water reported by Schiner et al. (1988) in the Round Island area, for example, is 147 feet bls.

The presence of an upward hydraulic gradient from the UFA and a thick intermediate confining unit underlying the SAS, both of which provide hydrogeologic separation between a potential injection zone in the SAS and the underlying UFA USDW, are favorable for development of Class V injection wells. To the north, in Brevard and Flagler counties, the confining unit is thin or absent, and conditions are less favorable for development of Class V injection wells.

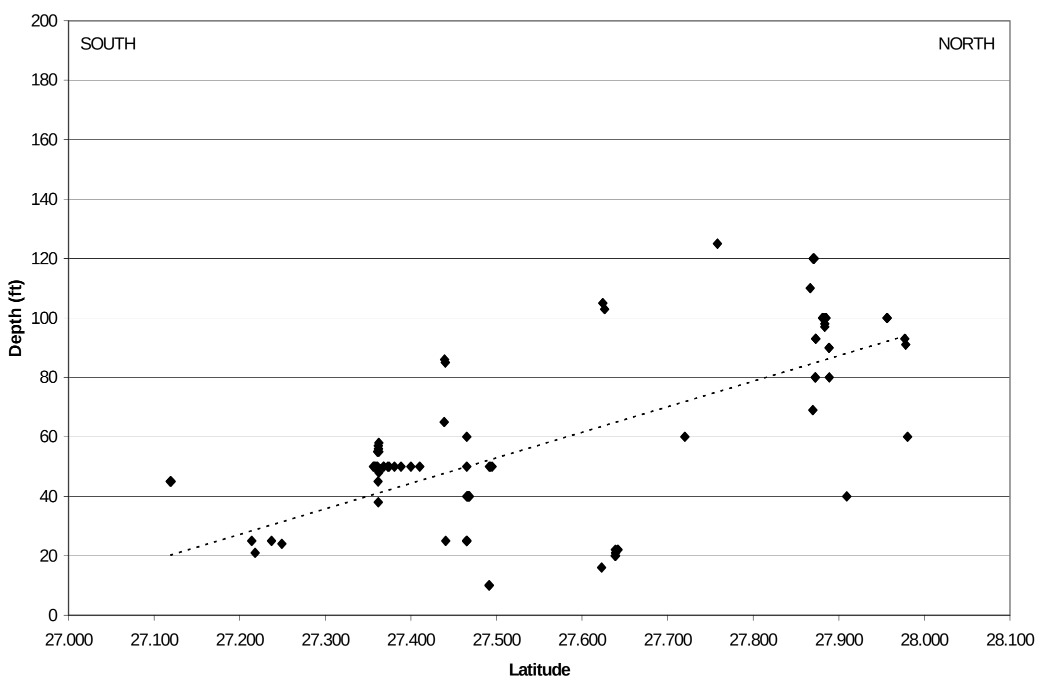

Figure 13. Consumptive use permit SAS well depths in the Barrier Island and near coastal area of Indian River County

Site-specific investigations in Flagler County east of the ICWW may reveal suitable areas for Class V well injection. As described in Section 4.2.2, lateral seawater intrusion has been documented at Marineland, where withdrawal of 7.2 mgd of saline groundwater has been permitted (SJRWMD 2001). The barrier island is narrow in Flagler County between two constant-head boundaries, the ocean and the ICWW. Areas where saline intrusion has already occurred on the barrier island, particularly on or near the ocean beach, may be suitable for concentrate disposal. The water quality of the demineralization concentrate from a brackish water source would likely have a lower TDS than the receiving zone seawater. Nonetheless, the spatial extent of a suitable receiving aquifer is critical to the long-term success of an underground concentrate disposal system, as discussed below.

Pending successful location of a seawater intrusion zone, the biggest limitation to Class V feasibility in the study area is the potentially small areal extent of any non-USDW aquifer. An exploratory program would not only have to identify the 10,000 mg/L TDS brackish-saline water interface on the barrier island, but would also have to demonstrate that the zone was laterally continuous. Over time, injected concentrate will, theoretically, create a reservoir that grows concentrically outward from the point of injection. As displayed in Figure 14, for example, the radius of this concentrate reservoir could extend outward for more than 1 mile following several years of injection at a rate of 2.5 mgd. If the geographic extent of the saline water appears to be less than that of the proposed concentrate reservoir, FDEP may apply Rule 62-520.465, *F.A.C.*, *Dimensions of Zones of Discharge for Class G-II Groundwater*, which states that the zone of discharge must be confined to the owner's property boundary. Exceptions to this rule would likely involve a lengthy environmental and hydrogeologic investigation with a questionable outcome.

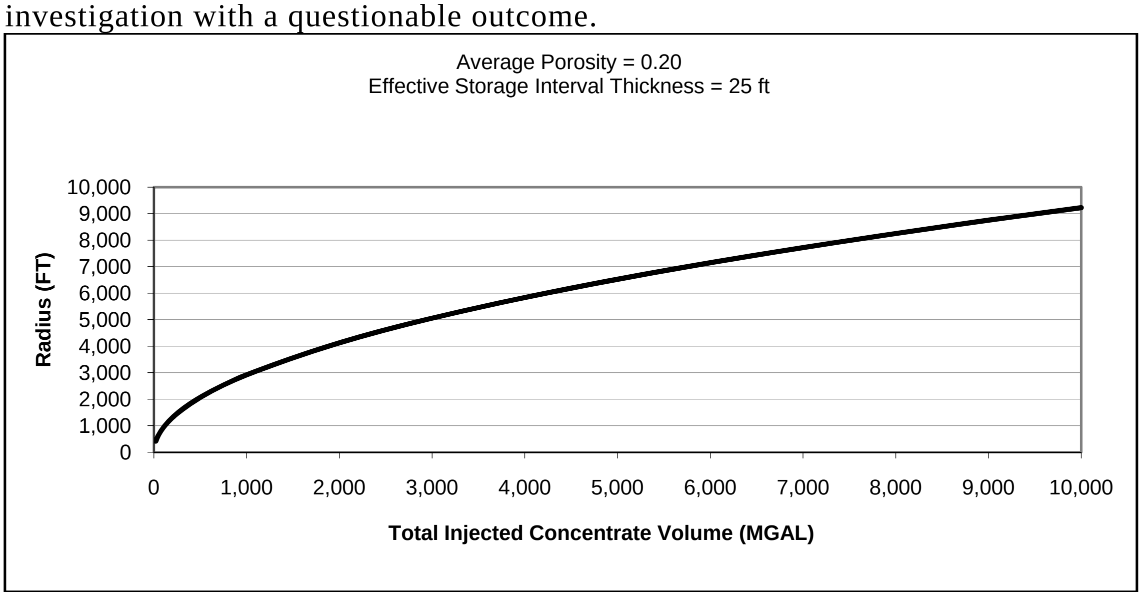

Figure 14. Theoretical radius of injected concentrate reservoir as a function of total injection volume

If the only limitation to a shallow and highly transmissive receiving zone along an ocean beach is the landward spatial extent of the non-USDW aquifer, directional drilling may be considered on an experimental basis. Horizontal directional drilling technology has been widely adopted by the utility and environmental sectors, but has not yet been applied to concentrate injection wells. Aquifer testing and modeling could be used during well siting to determine whether horizontal directional drilling under the ocean, for example, would add the injection capacity or lateral separation from the brackish-saline water interface to make the investment worthwhile. Moreover, the risk could be considerable for such experimental technology, given the challenges associated with constructing a horizontal directionally drilled well with a casing diameter large enough to offer the needed capacity and redeveloping the well.

Conventional horizontal directional drilling beneath the ICWW or Indian River lagoon may be employed to install pipelines that convey concentrate from membrane plants to barrier island disposal wells. However, discharge beneath the Indian River may require a costly effort to demonstrate, with reasonable assurances that the injected concentrate would not migrate vertically into the river or laterally into G-II groundwater inland or beneath the adjacent barrier island.

RECOMMENDATIONS

Available data suggest that the majority of the coastal areas of Indian River, Brevard, and Flagler counties are underlain by a fresh to brackish water SAS and, therefore, are not favorable for development of Class V injection wells. However, the limited data evaluated in this report indicate that some saline water intrusion occurs along the ocean sides of barrier islands, and these areas offer potential sites for shallow well disposal of high TDS concentrate.

One documented site on the barrier island in Flagler County, for example, exhibits shallow seawater intrusion. Given the sparse data for the barrier island in the county, this site may be indicative of widespread seawater intrusion. Similarly, the eastern side of some barrier island areas, particularly in southern Brevard and Indian River counties, may offer local opportunities for concentrate disposal. Note that the data available for the areas examined here are limited. Therefore, potential SAS shallow well disposal sites may not be identified in this literature review.

Available water quality data for the IAS is even less abundant. Further research on this aquifer is outside of the scope this review, but an evaluation of existing geophysical logs may be worthwhile. Recent investigations in the Hawthorn Group in Palm Beach County have revealed very discrete (1 to 3 feet) high transmissivity horizons in an otherwise confining unit (CH2M HILL 2007).

A small-scale exploratory drilling program to define the water quality profile from land surface to the top of the UFA could also be beneficial, particularly in the barrier island areas of central and southern Brevard County and Indian River County. This program could consist of drilling several 4-inch-diameter wells, collecting successive water quality samples through the surficial and intermediate aquifer systems, and conducting geophysical logging to the total depths of the wells. The results would help to identify the relationship between upward migrating UFA water, freshwater in the SAS, and the general location of lateral saline water intrusion in the barrier island areas. Such an investigation could provide site-specific conclusions about the feasibility of Class V injection. Shallow test wells along the barrier island in Flagler County could help delineate the spatial extent of the saline intrusion currently observed at one site. From a hydrogeologic perspective, this area may offer the greatest potential for Class V injection.

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