SOUTH FLORIDA WATER MANAGEMENT DISTRICT

BISCAYNE BAY COASTAL WETLANDS
Aquifer Salinity Investigation

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Executive Summary

To investigate aquifer salinity in the Biscayne Bay Coastal Wetlands, 22 monitor wells were installed at 13 sites in the aquifer study area along the western edge of Biscayne National Park. The South Florida Water Management District (SFWMD or District) used these monitor wells to document groundwater levels and delineate the saline water interface to study the hydrogeologic characteristics and groundwater quality within the upper portion of the Biscayne aquifer around the Biscayne Bay Coastal Wetlands.

Modifications to natural flow patterns have been made in the Biscayne Bay watershed to accommodate growth and control flooding. These changes have affected the volume and timing of fresh water discharged to the Biscayne Bay Coastal Wetlands. A proposed redistribution of freshwater flow across a broad front is expected to replace lost overland flow and partially compensate for the reduction in groundwater seepage. A better understanding of the hydrogeologic framework of the surficial aquifer in the bay's coastal wetlands is needed for this restoration effort, to support modeling efforts, and for ongoing water resource management initiatives. Hydrogeologic data obtained through this aquifer salinity investigation will be used to develop a representation of groundwater flow within the Biscayne aquifer from the Everglades and urban areas through the coastal wetlands to Biscayne Bay.

This investigation was conducted within the upper part of the Biscayne aquifer. The Biscayne aquifer is one of the most permeable aquifers in the United States. The geologic formations in this study include the Miami Limestone and uppermost part of the Fort Thompson Formation. In the SFWMD Lower East Coast Subregional Model, these formations correspond to Layer 1 and the upper portion of Layer 2, respectively.

This report summarizes field and groundwater quality data obtained from the 22 monitor wells installed in 2004 and 2007. Sixteen of the monitor wells were installed across a broad geographical area along the western edge of Biscayne National Park by the U.S. Army Corps of Engineers in August 2004. In April 2007, the SFWMD provided oversight for the drilling of four boreholes and construction of six monitor wells near the Military Canal Stormwater Treatment Detention Area, east of the Homestead Air Reserve Base. Data from these boreholes and wells were reviewed and are included in this report.

The U.S. Geological Survey conducted geophysical logging in the deepest boring for each well pair before well construction. The well logs showed four well pairs that appear to monitor interconnected cavities and void spaces (preferential flow paths) and two well pairs that appear to monitor diffuse-carbonate flow zones. Preferential flow paths exhibit very high hydraulic conductivity, which may be continuous between wells in the study area and over relatively large portions of the Biscayne aquifer.

A vertical salinity gradient was identified with the use of fluid conductivity and bulk conductivity/resistivity logs. These data showed a sharp transition from fresh water to slightly saline to moderately or very saline groundwater conditions. Salinity transitions were identified at elevations from -26 to -35 feet National Geodetic Vertical Datum of 1929 (NGVD 1929), approximately 0.6 to 1 mile west of the shoreline.

After well completion, specific conductivity measurements were collected from each of the 22 monitor wells during well development. Specific conductance data were examined for three depth horizons: -9 to -20 feet NGVD 1929 (shallow wells), -23 to -31 feet NGVD 1929 (medium wells), and -35 to -50 feet NGVD 1929 (deep wells). There appears to be sufficient data density south of the Military Canal to draw conclusions about the geometry of the freshwater/ saltwater interface.

Groundwater quality classification and geophysical logging support the freshwater/saltwater interface described in previous investigations. Fresh groundwater near the coast occurs in a wedge-shaped body flowing toward a discharge point along the shoreline. The freshwater wedge overlies saline water. However, a better understanding of the preferential flow paths and their relationship to saltwater movement is needed. The freshwater/saltwater interface shown in previous studies at the base of the Biscayne aquifer is further west in the southern portion of the study area, compared to the northern portion. Limited data in this investigation also suggest a further western extent of saltwater impacts in the southern portion of the study area.

Table of Contents

Executive Summary i

Table of Contents iii

List of Tables iii

List of Figures iv

Section 1: Introduction 1

- Hydrogeologic Framework 2
- Field Methods 3
  - USACE Wells 3
  - SFWMD Wells 5
- Investigation Findings 6
  - Stratigraphy and Lithology of Monitor Intervals 6
  - Groundwater Classification Based on Specific Conductance Measurements 6
  - Vertical Salinity Gradient Based on Geophysical Logging 7

Section 2: Conclusions 11

Section 3: Tables and Figures 13

Section 4: References 33

List of Tables

Table 1. Construction and water quality data for Biscayne Bay Coastal Wetlands wells 14

Table 2. Geophysical logs for Biscayne Bay Coastal Wetlands wells. 16

Table 3. Shallow monitor wells (-9 to -20 feet NGVD 1929) screened in Layer 1 of the LECsR Model 17

Table 4. Medium monitor wells (-23 to -31 feet NGVD 1929) screened in Layer 1 of the LECsR Model 18

Table 5. Deep monitor wells (-35 to -50 feet NGVD 1929) screened in Layer 2 of the LECsR Model 19

List of Figures

Figure 1. Site location. 20
Figure 2. Well location map.......... 21
Figure 3. LECsR Model Layer 1 - shallow monitor wells 22
Figure 4. LECsR Model Layer 1 - medium monitor wells.......... 23
Figure 5. LECsR Model Layer 2 - deep monitor wells.......... 24
Figure 6. BBCW7-GW1/GW2 geophysical logs and well diagrams 25
Figure 7. BBCW9-GW1/GW2 geophysical logs and well diagrams 26
Figure 8. BBCW8-GW1/GW2 geophysical logs and well diagrams 27
Figure 9. BBCWSTA-MW4A geophysical logs and well diagrams 28
Figure 10. BBCWSTA-MW4B geophysical logs and well diagrams. 29
Figure 11. BBCWSTA-MW5A/MW5B geophysical logs and well diagrams.......... 30
Figure 12. BBCWSTA-MW6A/MW6B geophysical logs and well diagrams.......... 31

1
Introduction

BACKGROUND

Modifications to natural flow patterns have been made in the Biscayne Bay watershed to accommodate growth and control flooding. These changes have affected the volume and timing of fresh water discharged to the Biscayne Bay Coastal Wetlands. A proposed redistribution of freshwater flow across a broad front is expected to replace lost overland flow and partially compensate for the reduction in groundwater seepage. A better understanding of the hydrogeologic framework of the surficial aquifer in the bay's coastal wetlands is needed for this restoration effort, to support modeling efforts, and for ongoing water resource management initiatives. Hydrogeologic data obtained through this aquifer salinity investigation will be used to develop a representation of groundwater flow within the Biscayne aquifer from the Everglades and urban areas through the coastal wetlands to Biscayne Bay.

To investigate aquifer salinity in the Biscayne Bay Coastal Wetlands, monitor wells were installed at sites in the aquifer study area along the western edge of Biscayne National Park. The South Florida Water Management District (SFWMD or District) used these monitor wells to document groundwater levels and delineate the saline water interface to study the hydrogeologic characteristics and groundwater quality within the upper portion of the Biscayne aquifer around the Biscayne Bay Coastal Wetlands.

This report summarizes field and groundwater quality data obtained from the 22 monitor wells installed at 13 sites in 2004 and 2007. Sixteen of the monitor wells were installed across a broad geographical area along the western edge of Biscayne National Park by the U.S. Army Corps of Engineers (USACE) in August 2004. In April 2007, four boreholes were drilled and six monitor wells constructed near the Military Canal Stormwater Treatment Detention Area, east of the Homestead Air Reserve Base, with oversight provided by the SFWMD. Of the 22 monitor wells installed, 18 were paired with monitor intervals in upper and lower zones. Data from these boreholes and wells were reviewed and are included in this report. **Figure 2** shows well locations and **Table 1** presents well construction summaries.

HYDROGEOLOGIC FRAMEWORK

This investigation was conducted within the upper part of the Biscayne aquifer and includes the Miami Limestone and uppermost part of the Fort Thompson Formation. The Biscayne aquifer is one of the most permeable aquifers in the United States and includes the Miami Limestone, Fort Thompson Formation, Anastasia Formation, and the Key Largo Limestone. The SFWMD Lower East Coast Subregional Model (LECsR Model) (Giddings *et al.* 2006) divides the surficial aquifer system in Miami-Dade County into three layers. The wells and boreholes examined in this study allowed characterization of portions of both units of the Miami Limestone, which together comprise Layer 1 and the uppermost unit of the three Fort Thompson Formation units, which comprise Layer 2. None of the wells installed in this study reach the base of the Biscayne aquifer, generally 60 to 140 feet below sea level in the study area (Fish and Steward 1991). **Figures 3** and **4** show hydraulic conductivity estimates from the LECsR Model for Layer 1, and **Figure 5** shows hydraulic conductivity estimates for the LECsR Model Layer 2. These figures indicate a regional increase in hydraulic conductivity from north to south in LECsR Model Layers 1 and 2.

The Miami Limestone is described in the study as consisting of two units, an upper unit of oolith, pellet, miliolid grainstone, and packstone, approximately 15 to 20 feet thick, and a lower unit of miliolid, peneroplid, bryozoan, pellet grainstone, and packstone, approximately 15 to 20 feet thick (Enos and Perkins, 1977, Plate I). The uppermost unit of the Fort Thompson Formation is described primarily as arenaceous packstone and quartz sandstone, approximately 20 to 40 feet thick.

The Cunningham *et al.* (2004 and 2006) studies of the Lake-Belt Area in north-central Miami-Dade County, approximately 10 miles northwest of this study area, further subdivides the Miami Limestone and Fort Thompson Formation into depositional sequences called High Frequency Depositional Cycles (HFCs). Each HFC contains multiple depositional facies that correspond to groundwater flow classes. The flow class with the greatest potential for groundwater flow, Pore Class I, is characterized by interconnected cavities and void spaces (preferential flow paths), which are readily identifiable with the use of borehole video and geophysical logging methods. The diffuse-carbonate groundwater flow class, Pore Class II, also has potential for high groundwater flow and is characterized by voids and inter-granular porosity. Two flow classes described in Cunningham's studies with lower flow potential are the Pore Class III and peat/muck/marl, which are leaky, with low permeability marl. Each of these flow classes is contained in lithologic layers, which can be correlated between wells in Cunningham's study area and are thought to have significant geographic extent.

Reich *et al*. (2006) studied surface and groundwater flow characteristics from the onshore environment west of Biscayne Bay into Biscayne Bay. A series of boreholes/monitor wells were installed in a northwest/southeast transect across Biscayne Bay from Black Point (western shoreline) to Pacific Reef (approximately 5 miles east of Elliot Key). Core data indicated that the Miami Limestone and underlying Fort Thompson lie beneath the marine sediments within Biscayne Bay. Reich's study identifies layers representative of subareal exposure, which separate the upper and lower units of the Miami Limestone and the Miami Limestone and the underlying Fort Thompson Formation. Exposure of limestone to weathering during periods of low sea level can contribute to the solution and formation of cavities and voids, increasing the capacity for groundwater flow.

Many studies have described the interaction of groundwater and marine surface waters in Miami-Dade County and documented the inland migration of the freshwater/saltwater interface, including Parker *et al*. (1945), Kohout (1960), Kohout (1964), Langevin (2001), and Renken *et al*. (2005). Fresh groundwater occurs above the denser saline groundwater. The depth of the freshwater/saltwater interface progressively deepens further inland from the shoreline, so that in the cross-section view there is a generalized increase in the vertical extent of the freshwater lens as the distance west of the shoreline increases. Sonenshein (1997) estimated the inland extent of the saltwater interface at the base of the Biscayne aquifer in 1984 and 1995 by using groundwater chloride data, borehole geophysical data, and surface geophysical data, as shown in **Figures 3**, **4**, and **5**. In plain view, the distance of the freshwater/saltwater interface from the shoreline increases from the northern portion of the BBCW study area (less than 1 mile) to the southern portion (approximately 6 to 8 miles).

FIELD METHODS

USACE Wells

The USACE contracted Challenge Engineering and Testing, Inc. (CETI), of Mobile, Alabama, to install 16 monitor wells at eight land sites and two marine sites along the western portion of Biscayne National Park.

Before monitoring well installation, CETI collected continuous soil and/or rock samples at the deep borehole using split spoons to competent rock and a wire-line core barrel thereafter. Lithologic descriptions and estimated formation tops were included in the report prepared by CETI (2006).

CETI installed monitor wells at these sites between August 5 and August 31, 2004. **Figure 2** shows the locations of the monitor well sites. One deep borehole was drilled at each site to depths ranging from approximately 45 to 95 below land surface (bls). Monitor wells were installed to depths ranging from approximately 17 feet to 49 feet bls. Twelve wells were installed as paired wells (identified as GW1 [lower] and GW2 [upper]) at six sites: BBCW3, BBCW6, BBCW7, BBCW8, BBCW9, and BBCW10. Single wells (identified as GW1) were installed at four sites: BBCW1, BBCW2, BBCW4, and BBCW5.

Geophysical logging was conducted in the deepest boring for each well pair by the U.S. Geological Survey (USGS) for three wells: BBCW7-GW1, BBCW8-GW1, and BBCW9-GW1. Logging included use of a digital borehole imager and geophysical logs for porosity, flow meter, gamma ray, caliper, fluid temperature, and bulk conductivity and resistivity. **Table 2** presents a list of logs run in each borehole and **Figures 6**, **7**, and **8** show the logs respectively.

Monitor wells were installed at each station by drilling/reaming each borehole to the desired completion depth. Two deep soil borings, BBCW7-GW1 and BBW9-GW1, drilled to approximately 95 and 71 feet bls, were filled to depths of approximately 46 and 31 feet bls, respectively, with gravel pack followed by bentonite seal before well installation. Monitor wells were constructed of 2-inch diameter Schedule 40 polyvinyl chloride (PVC) risers and 2.5-foot PVC well screens. Well screens at stations BBCW1 through BBCW6 were of a 0.01-inch slot size and at Stations BBCW7 through BBCW10 were of a 0.06-slot size. A 6/10 silica sand filter pack was used with the 0.01-inch slot screens and a 0.125 to 0.250-inch gravel filter pack with the other screens. Filter packs were from 4 to 11 feet thick. A 2-foot bentonite seal was placed over each filter pack and each well grouted to surface with neat cement. Six-inch Schedule 80 PVC surface casings were installed over the marine wells and attached to stainless steel platforms. The land-based wells were completed with either a flush-mount manhole or a 6-inch Schedule 80 PVC riser. Flush-mounted wells were located along canal right-of-ways and wells with protective risers were located in remote scrub areas. All land-based wells had a 2-foot square cement pad. Wells were subsequently developed with compressed air and pumping. CETI performed slug tests in each well after they were developed.

A State of Florida licensed surveyor subsequently surveyed the well locations with a Global Positioning Satellite Receiver System (GPS) and associated post-processing software. The final computed horizontal coordinates to Florida East – 1983 North American Datum (NAD 1983) State Plane Coordinates were provided. The top of casing and ground elevations were measured relative to the 1929 National Geodetic Vertical Datum (NGVD 1929).

The SFWMD redeveloped each groundwater monitor well in April and May of 2006. Wells were developed with a centrifugal pump until stabilization of the following groundwater parameters occurred: temperature, specific conductance, and pH. Groundwater parameter measurements were conducted with a YSI 610XL, calibrated at a minimum of once per day.

SFWMD Wells

The SFWMD contracted GFA International (GFA) to install six monitor wells in 2007 at three sites near Military Canal. These wells are approximately 0.5 to 1 mile west of Biscayne Bay. The purpose of the well installation was to measure seepage rates from an adjacent stormwater treatment detention area into the underlying aquifer. Data from four boreholes, BBCW-4A, BBCW-4A-new, BBCW-5, and BBCW-6, and six monitor wells, BBCWSTA-MW4A, -MW4B, -MW5A, -MW5B, -MW6A, and -MW6B, are included in this study.

GFA installed these monitor wells between January 29 and April 26, 2007. **Figure 1** shows the location of these wells. Boreholes were drilled to depths ranging from approximately 43 to 63 feet bls. Continuous coring was conducted using a wire-line core barrel before installing the wells. Lithologic descriptions were conducted by the District. Upon completion, the USGS conducted geophysical logging in BBCWSTA-MW4A, -MW4B, -MW5A, and -MW6A. Logging included use of a digital borehole imager and geophysical logs for porosity, flow meter, gamma ray, caliper, fluid temperature, and bulk conductivity and resistivity. A list of logs run in each borehole is shown in **Table 2** and logs are shown in **Figures 9**, **10**, **11**, and **12**, respectively.

Monitor wells were installed at each site by drilling/reaming a borehole to the base of the planned filter pack interval. Boreholes deeper than approximately 1-foot below the planned screened interval were back-plugged with grout before reaming. Monitor wells were constructed with 2-inch diameter Schedule 40 PVC risers and 2-foot PVC well screens. Well screens were of a 0.06-inch slot size and a 0.125- to 0.250-inch gravel filter pack was placed around it in the annular space. Filter packs were from 4 to 11 foot thick. A 2-foot bentonite seal was placed over each filter pack and the remaining annular space was grouted to land surface with neat cement. GFA completed each well with a flush-mounted manhole and a 2-foot square cement pad reinforced with rebar.

A State of Florida licensed surveyor subsequently surveyed the well locations with a GPS and associated post-processing software. The horizontal coordinates are in Florida East – NAD 1983 State Plane Coordinates. The top of casing and ground elevations were measured relative to NGVD 1929 and North American Vertical Datum1988 (NAVD 1988).

The SFWMD developed each groundwater monitor well in April 2007. Wells were developed with compressed air and pumped for approximately 30 to 40 minutes. The District collected the following groundwater parameters during well development with a calibrated YSI 600XL probe: temperature, specific conductance, and pH. The wells were considered developed once the parameters were within five percent of each other for three consecutive readings. In addition, the SFWMD on-site geologist ensured that the water appeared free of suspended solids.

INVESTIGATION FINDINGS

Stratigraphy and Lithology of Monitor Intervals

Based on borehole descriptions and estimated formation tops in the CETI report, well filter pack intervals for 13 wells appear to be installed within, or are straddling the base of the Miami Limestone, included as Layer 1 of the LECsR Model (LECsR Model Layer 1). Based on the elevation of the monitor intervals, these wells are further classified as shallow wells (-9 to -20 feet NGVD 1929) and medium wells (-23 to -31 feet NGVD 1929). **Figure 3** shows the shallow wells and **Figure 4** shows the medium wells. **Tables 3** and **4** list the construction and water quality data for the shallow and medium wells, respectively. Filter pack intervals for nine wells appear to be installed within the upper part of the Fort Thompson Formation (Model Layer 2). These wells are classified as deep wells (-35 to -50 feet NGVD 1929) and are shown in **Table 5** and **Figure 5**. Also shown is the freshwater/saltwater interface at the base of the Biscayne aquifer in 1995 (Renken *et al*. 2005).

Digital borehole image logs and geophysical well logs were reviewed to estimate the groundwater flow classes. Based on this examination, well pairs BBCW7-GW1/GW2, BBCW8-GW1/GW2, BBCW9-GW1/GW2, and BBCWSTA-MW5A/MW5B appear to monitor Pore Class I type flow, characterized by interconnected cavities and void spaces. Well pairs BCWSTA-MW4A/MW4B and BBCWSTA-MW6A/MW6B appear to monitor Pore Class II type flow, characterized by voids and inter-granular porosity. Only a caliper log is available for this evaluation for the BBCW8 well pair, but it indicates that both the shallow and the deep wells could be complete in Pore Class I type flow zones. The geophysical log data indicates that these wells are completed in zones with high hydraulic conductivity and have the potential for high groundwater flow. Log and well construction data are shown in **Figures 6** through **12**.

Groundwater Classification Based on Specific Conductance Measurements

The District collected specific conductance data from the USACE wells in April and May 2006 and from the SFWMD wells in April 2007. Specific conductance measurements ranged from 552 microsiemens per centimeter (μS/cm) to 52,180 μS/cm, as shown in **Tables 1**, **3**, **4**, and **5**. Specific conductance data was examined for three depth horizons based on the well screen completion interval: -9 to -20 feet NGVD 1929 (shallow wells - **Table 3** and **Figure 3**), -23 to -31 feet NGVD 1929 (medium wells - **Table 4** and **Figure 4**), and -35 to -50 feet NGVD 1929 (deep wells - shown in **Table 5** and **Figure 5**). Kasenow (1997) places groundwater into six classifications based on specific conductance: fresh (<1,500 μS/cm), slightly saline (1,500 to 4,600 μS/cm), moderately saline (1,500 to 15,000 µS/cm [4,600 to 15,000 µS/cm is used in this report for clarification]), very saline (15,000 to 54,000 µS/cm), seawater (54,000 µS/cm), and brine (>54,000 µS/cm). Based on Kasenow's classification, six wells in this study area are ranked as very saline, two wells are ranked as moderately saline, four wells are ranked as slightly saline, and 10 wells are ranked as fresh. **Table 1** shows specific conductance, groundwater classification, and well construction information for each well ranked by distance (west) from the shoreline.

Four well pairs, BBCWSTA-MW4A/B, BBCWSTA-MW5A/B, BBCWSTA-MW6A/B, and BBCW9-GW1/GW2, and the single well BBCW2-GW1, were installed in close proximity to a canal or wetland. Surface water salinities may influence salinity in these wells; however, collection of surface water salinity data was not included in this investigation. Specific conductivity measurements yielded the following:

- All of the marine wells (BBCW10-GW1/GW2 and BBCW8-GW1/GW2) were very saline.
- One onshore shallow well (BBCW7-GW2), 0.2 miles west of the shoreline, was slightly saline. The rest of the onshore shallow wells, from 0.4 to 2.5 miles west of shoreline, were fresh.
- Three onshore medium wells were slightly saline, and two onshore medium wells were fresh.
- Two onshore deep wells were very saline, two were moderately saline, and three were fresh.

Vertical Salinity Gradient Based on Geophysical Logging

A vertical salinity gradient was identified in selected wells with the use of fluid conductivity and bulk conductivity/resistivity logs (**Figures 6 through 12**) run before well construction. The calibrated fluid conductivity logs provided an accurate conductivity reading of groundwater entering the borehole after pumping, subject to density stratification and/or flow across preferential flow zones within the borehole. Of the five fluid conductivity logs run, BBCW7-GW1 was not calibrated due to equipment malfunction. Bulk conductivity/resistivity logs measure formation characteristics and therefore do not provide conductivity of pore fluid alone, but are useful for identification of relative changes in pore fluid salinity.

The logged boreholes were located 0.2 to 1.0 miles west of the shoreline. Fluid conductivity logs show a relatively constant or gradual increase in conductivity with depth culminating in a sharp increase in fluid conductivity, typically 5 to 10 times the initial value, over 1 to 3 feet near the base of each well. A water quality transition from relatively fresh to relatively saline water is estimated based on the sharp increase, referred to as the salinity transition in this report. Specific conductivity measurements during well development indicate that wells completed above the transition zone exhibited specific conductivity values in the fresh to slightly saline groundwater classification (Kasenow, 1997). One well, BBCW7-GW1, completed to approximately 6 feet below the salinity transition zone, yielded moderately saline development water. The wells are discussed in order of proximity to Biscayne Bay as follows.

- BBCW7 is the closest land-based well pair to Biscayne Bay, approximately 0.2 miles west of the shoreline. The fluid conductivity log for BBCW7-GW1 (**Figure 6**) indicates a salinity transition at an elevation of approximately -33 feet NGVD 1929.
- The fluid conductivity log for BBCW9-GW1 (**Figure 7**), approximately 0.4 miles west of shoreline, indicates a salinity transition at an elevation of approximately -30 feet NGVD 1929.
- The fluid conductivity log for BBCWSTA-MW5A (**Figure 11**), approximately 0.6 miles west of shoreline, indicates a salinity transition at an elevation of approximately -32 feet NGVD 1929.
- The fluid conductivity log of BBCWSTA-MW6A (**Figure 12**), approximately 0.62 miles west of shoreline, indicates a salinity transition at an elevation of approximately -34 feet NGVD 1929.
- The fluid conductivity logs for BBCWSTA-MW4A (**Figure 9**) and BBCWSTA-MW4B (**Figure 10**), approximately 1 mile west of shoreline, indicate salinity transitions from fresh at shallow depths to elevations of -31 and -26 feet NGVD 1929, respectively.

As previously mentioned, the screened intervals from these wells are completed in Pore Class I or II groundwater flow classes. Both of these classes typically have a high hydraulic conductivity and have the potential for high groundwater flow.

Salinity Conversion

Millero (1982) presents a formula allowing the calculation of salinity in practical salinity units (PSUs) from specific conductance data. This conversion is another way of comparing water with different ion concentrations to seawater. Millero's formula is presented as follows.

$$S = 0.008 - 0.1692(Rt)^{0.5} + 25.3851(Rt) + 14.0941(Rt)^{1.5} - 7.0261(Rt)^{2} + 2.7081(Rt)^{2.5} + DeltaS$$

Rt = Measured Conductivity/53793.9 (note: 53793.9 = conductivity of seawater at 25 °C)

$$DeltaS = t - [15/1 + 0.0162(t-15)]\left[\left(0.0005 - 0.0056(Rt)^{0.5}\right) - 0.0066(Rt) - 0.0375(Rt)^{1.5} + 0.0636(Rt)^{2} - 0.0144(Rt)^{2}\right.$$

t = temperature in degrees Centigrade

The use of the specific conductance data collected during well development in Millero's formula yields salinities from 0.26 to 35.23 PSUs. For reference, seawater is 35 PSUs. These salinity data are presented in **Tables 1**, **3**, **4** and **5**.

2

Conclusions

Digital borehole image logs and geophysical well logs indicate the filter pack intervals for paired wells at BBCW7, BBCW-8, BBCW9, and BCWSTA5 were installed across preferential flow path within either the Miami Limestone (LECsR Model Layer 1) or Fort Thompson Formation (LECsR Model Layer 2). Although these flow zones are difficult to correlate directly, preferential flow paths may be continuous between wells in the study area and over relatively large portions of the Biscayne aquifer.

Fluid or bulk conductivity logging was conducted in five boreholes installed along the Military Canal, approximately 0.6 to 1 mile west of the shoreline. A sharp increase observed in fluid and bulk conductivity logs with depth correlates with a salinity transition from fresh or slightly saline to moderately or very saline groundwater conditions based on development water (groundwater quality) classifications. Salinity transitions were identified at elevations from -26 to -35 feet NGVD 1929.

In the southern portion of the study area, from Military Canal south, there appear to be sufficient data to draw conclusions about the geometry of the freshwater/saltwater interface. Development water classification and geophysical logging support the description of the freshwater/saltwater interface described in previous investigations. Fresh groundwater near the coast occurs in a wedge-shaped body flowing toward a discharge point along the shoreline. The freshwater wedge overlies saline water.

- Three of the four medium-depth onshore wells installed along the Military and C-103 Canals, approximately 0.6 to 1 mile west of the shoreline, exhibited slightly saline development water; however, all of the shallow wells in that area exhibited fresh water. These medium-depth wells are representative of the base of LECsR Model Layer 1 and mark the westernmost extent of saline water into Layer 1 identified in this study.
- The westernmost extent of very saline water was observed in deep onshore wells, representative of the upper portions LECsR Model Layer 2, from 2 to 3.2 miles west of the shoreline; however, all of the onshore shallow and medium wells produced fresh or slightly saline water.

- Previous investigations have mapped the western extent of saline water at the base of the Biscayne aquifer to the west of wells that exhibited saline water in this report, reflective of the westward deepening of the freshwater/saltwater interface.

The data collected in this limited investigation suggest a further western extent of saltwater impacts in the southern portion of the study area compared to the northern portion. This may be due to a combination of many factors, including a regional increase in hydraulic conductivity from north to south across the study area, or variations in anthropogenic influences, such as groundwater withdrawal for consumptive use and/or restriction of natural overland surface flow.

3
Tables and Figures

Table 1. Construction and water quality data for Biscayne Bay Coastal Wetlands wells.

Site ID	Specific Conductance (µS/cm) Well Re-development	Water Classification (Kasenow 1977)	Practical Salinity Units (PSU) (Millero 1982)	Ground Elevation - ft (NGVD 1929)	Elevation at Top of Filter Pack - ft (NGVD 1929)	Elevation at Bottom of Filter Pack - ft (NGVD 1929)	Length of Filter Pack - ft	Elevation at Bottom of Well Screen - ft (NGVD 1929)	Well Screen Length - ft	Screen Slot Size (inch)	Sand Pack at Screen Interval
BBCW10-GW1	48,110	Very Saline	32.23	-5.82	-36.61	-47.20	10.59	-40.11	2.5	0.06	1/4" by 1/8"
BBCW10-GW2	52,180	Very Saline	35.23	-5.76	-13.84	-24.40	10.56	-17.34	2.5	0.06	1/4" by 1/8"
BBCW8-GW1	45,960	Very Saline	30.27	-3.5	-37.12	-48.50	11.38	-40.62	2.5	0.06	1/4" by 1/8"
BBCW8-GW2	43,990	Very Saline	28.82	-3.5	-13.47	-18.00	4.53	-16.97	2.5	0.06	1/4" by 1/8"
BBCW7-GW1	8,382	Moderately Saline	4.68	6.1	-35.06	-39.90	4.83	-38.56	2.5	0.06	1/4" by 1/8"
BBCW7-GW2	3,666	Slightly Saline	1.94	6.1	-7.84	-13.90	6.06	-11.34	2.5	0.06	1/4" by 1/8"
BBCW9-GW1	2,826	Slightly Saline	1.43	4.0	-21.95	-27.00	5.05	-25.45	2.5	0.06	1/4" by 1/8"
BBCW9-GW2	1,261	Fresh	0.62	4.0	-12.09	-20.00	7.81	-15.59	2.5	0.06	1/4" by 1/8"
BBCW2-GW1	11,040	Moderately Saline	6.32	2.4	-38.31	-42.60	4.29	-40.81	2.5	0.01	6/10
BBCWSTA-MW5A	1,393	Fresh	0.69	4.39	-26.61	-30.61	4	-30.28	2.0	0.06	1/4" by 1/8"
BBCWSTA-MW5B	971	Fresh	0.54	4.50	-13.50	-17.50	4	-17.17	2.0	0.06	1/4" by 1/8"
BBCWSTA-MW6A	2,287	Slightly Saline	1.20	4.85	-23.15	-27.15	4	-26.82	2.0	0.06	1/4" by 1/8"
BBCWSTA-MW6B	1,059	Fresh	0.56	4.90	-5.41	-9.41	4	-8.77	2.0	0.06	1/4" by 1/8"
BBCWSTA-MW4A	1,904	Slightly Saline	0.97	4.88	-22.12	-26.12	4	-25.79	2.0	0.06	1/4" by 1/8"

Table 1. Construction and water quality data for Biscayne Bay Coastal Wetlands wells (Continued).

Site ID	Specific Conductance (µS/cm) Well Re-develop-ment	Water Classifica-tion (Kasenow 1977)	Practical Salinity Units (PSU) (Millero 1982)	Ground Elevation - ft (NGVD 1929)	Elevation at Top of Filter Pack - ft (NGVD 1929)	Elevation at Bottom of Filter Pack - ft (NGVD 1929)	Length of Filter Pack - ft	Elevation at Bottom of Well Screen - ft (NGVD 1929)	Well Screen Length - ft	Screen Slot Size (inch)	Sand Pack at Screen Interval
BBCWSTA-MW4B	1,306	Fresh	0.65	5.11	-10.69	-14.69	4	-14.36	2.0	0.06	1/4" by 1/8"
BBCW1-GW1	1,200	Fresh	0.61	5.6	-32.69	-39.40	6.71	-36.19	2.5	0.01	6/10
BBCW4-GW1	17,960	Very Saline	10.37	2.8	-28.15	-42.20	4.05	-31.65	2.5	0.01	6/10
BBCW3-GW1	903	Fresh	0.45	4.1	-36.45	-40.90	4.45	-39.95	2.5	0.01	6/10
BBCW5-GW1	17960	Very Saline	10.53	2.8	-34.62	-42.20	7.58	-38.12	2.5	0.01	6/10
BBCW6-GW1	552	Fresh	0.26	3.1	-35.43	-44.90	9.47	-38.93	2.5	0.01	6/10
BBCW6-GW2	559	Fresh	0.27	2.9	-13.14	-23.60	10.46	-16.64	2.5	0.01	6/10

Table 2. Geophysical logs for Biscayne Bay Coastal Wetlands wells.

Site ID	Log Run
BBCW7-GW1	Digital borehole image; gamma ray; caliper; heat pulse flow meter (not calibrated); fluid temperature, resistivity, and conductivity (not calibrated); bulk conductivity and resistivity; sonic porosity
BBCW8-GW1	Caliper
BBCW9-GW1	Digital borehole image; gamma ray; heat pulse flow meter; bulk conductivity and resistivity; sonic porosity
BBCWSTA-MW4A	Digital borehole image; caliper; fluid temperature, resistivity, and conductivity
BBCWSTA-MW4B	Digital borehole image; caliper; fluid temperature, resistivity, and conductivity
BBCWSTA-MW5A	Digital borehole image; caliper; fluid temperature, resistivity, and conductivity
BBCWSTA-MW6A	Digital borehole image; caliper; fluid temperature, resistivity, and conductivity

Table 3. Shallow monitor wells (-9 to -20 feet NGVD 1929) screened in Layer 1 of the LECsR Model.

Site ID	Approx. Distance from Shoreline	Specific Conductance (µS/cm) Well Re-development	Water Classification (Kasenow 1977)	Practical Salinity Units (PSU) (Millero 1982)	Elevation at Top of Filter Pack - ft (NGVD 1929)	Elevation at Bottom of Filter Pack - ft (NGVD 1929)	Length of Filter Pack - ft	Elevation at Bottom of Well Screen - ft (NGVD 1929)	Screen Length - ft	Screen Slot Size (inch)	Sand Pack at Screen Interval
BBCW8-GW2	-0.2	43,990	Very Saline	28.82	-13.47	-18.00	4.53	-16.97	2.0	0.06	1/4" by 1/8"
BBCW7-GW2	0.2	3,666	Slightly Saline	1.94	-7.84	-13.90	6.06	-11.34	2.0	0.06	1/4" by 1/8"
BBCW9-GW2	0.4	1,261	Fresh	0.62	-12.09	-20.00	7.81	-15.59	2.0	0.06	1/4" by 1/8"
BBCWSTA-MW5B	0.62	971	Fresh	0.54	-13.50	-17.50	4	-15.84	2.0	0.06	1/4" by 1/8"
BBCWSTA-MW6B	0.62	1,059	Fresh	0.56	-5.41	-9.41	4	-8.77	2.0	0.06	1/4" by 1/8"
BBCWSTA-MW4B	1.00	1,306	Fresh	0.65	-10.69	-14.69	4	-14.36	2.0	0.06	1/4" by 1/8"
BBCW3-GW2	2.5	685	Fresh	0.34	-14.14	-19.90	5.76	-17.64	2.0	0.01	6/10

Table 4. Medium monitor wells (-23 to -31 feet NGVD 1929) screened in Layer 1 of the LECsR Model.

Site ID	Approx. Distance from Shoreline	Specific Conductance (µS/cm) Well Re-development	Water Classification (Kasenow 1977)	Practical Salinity Units (PSU) (Millero 1982)	Elevation at Top of Filter Pack - ft (NGVD 1929)	Elevation at Bottom of Filter Pack - ft (NGVD 1929)	Length of Filter Pack - ft	Elevation at Bottom of Well Screen - ft (1929 NGVD)	Screen Length - ft	Screen Slot Size (inch)	Sand Pack at Screen Interval
BBCW10-GW2	-0.6	52180	Very Saline	35.23	-13.84	-24.40	10.56	-17.34	2.0	0.06	1/4" by 1/8"
BBCW9-GW1	0.4	2826	Slightly Saline	1.43	-21.95	-27.00	5.05	-25.45	2.0	0.06	1/4" by 1/8"
BBCWSTA-MW5A	0.62	1393	Fresh	0.69	-26.61	-30.61	4	-31.19	2.0	0.06	1/4" by 1/8"
BBCWSTA-MW6A	0.62	2287	Slightly Saline	1.20	-23.15	-27.15	4	-26.82	2.0	0.06	1/4" by 1/8"
BBCWSTA-MW4A	1.00	1904	Slightly Saline	0.97	-22.12	-26.12	4	-25.79	2.0	0.06	1/4" by 1/8"
BBCW6-GW2	6.8	559	Fresh	0.27	-13.14	-23.60	10.46	-16.64	2.0	0.01	6/10

Table 5. Deep monitor wells (-35 to -50 feet NGVD 1929) screened in Layer 2 of the LECsR Model.

Site ID	Approx. Distance from Shoreline	Specific Conductance (µS/cm) Well Re-develop-ment	Water Classification (Kasenow 1977)	Practical Salinity Units (PSU) (Millero 1982)	Elevation at Top of Filter Pack - ft (NGVD 1929)	Elevation at Bottom of Filter Pack - ft (NGVD 1929)	Length of Filter Pack - ft	Elevation at Bottom of Well Screen - ft (NGVD 1929)	Screen Length - ft	Screen Slot Size (inch)	Sand Pack at Screen Interval
BBCW10-GW1	-0.6	48,110	Very Saline	32.23	-36.61	-47.20	10.59	-40.11	2.0	0.06	1/4" by 1/8"
BBCW8-GW1	-0.2	45,960	Very Saline	30.27	-37.12	-48.50	11.38	-40.62	2.0	0.06	1/4" by 1/8"
BBCW7-GW1	0.2	8,382	Moderately Saline	4.68	-35.06	-39.90	4.83	-38.56	2.0	0.06	1/4" by 1/8"
BBCW2-GW1	0.6	11,040	Moderately Saline	6.32	-38.31	-42.60	4.29	-40.81	2.0	0.01	6/10
BBCW1-GW1	1.2	1,200	Fresh	0.61	-32.69	-39.40	6.71	-36.19	2.0	0.01	6/10
BBCW4-GW1	2.0	17,960	Very Saline	10.37	-28.15	-42.20	4.05	-31.65	2.0	0.01	6/10
BBCW3-GW1	2.5	903	Fresh	0.45	-36.45	-40.90	4.45	-39.95	2.0	0.01	6/10
BBCW5-GW1	3.2	17,960	Very Saline	10.53	-34.62	-42.20	7.58	-38.12	2.0	0.01	6/10
BBCW6-GW1	6.8	552	Fresh	0.26	-35.43	-44.90	9.47	-38.93	2.0	0.01	6/10

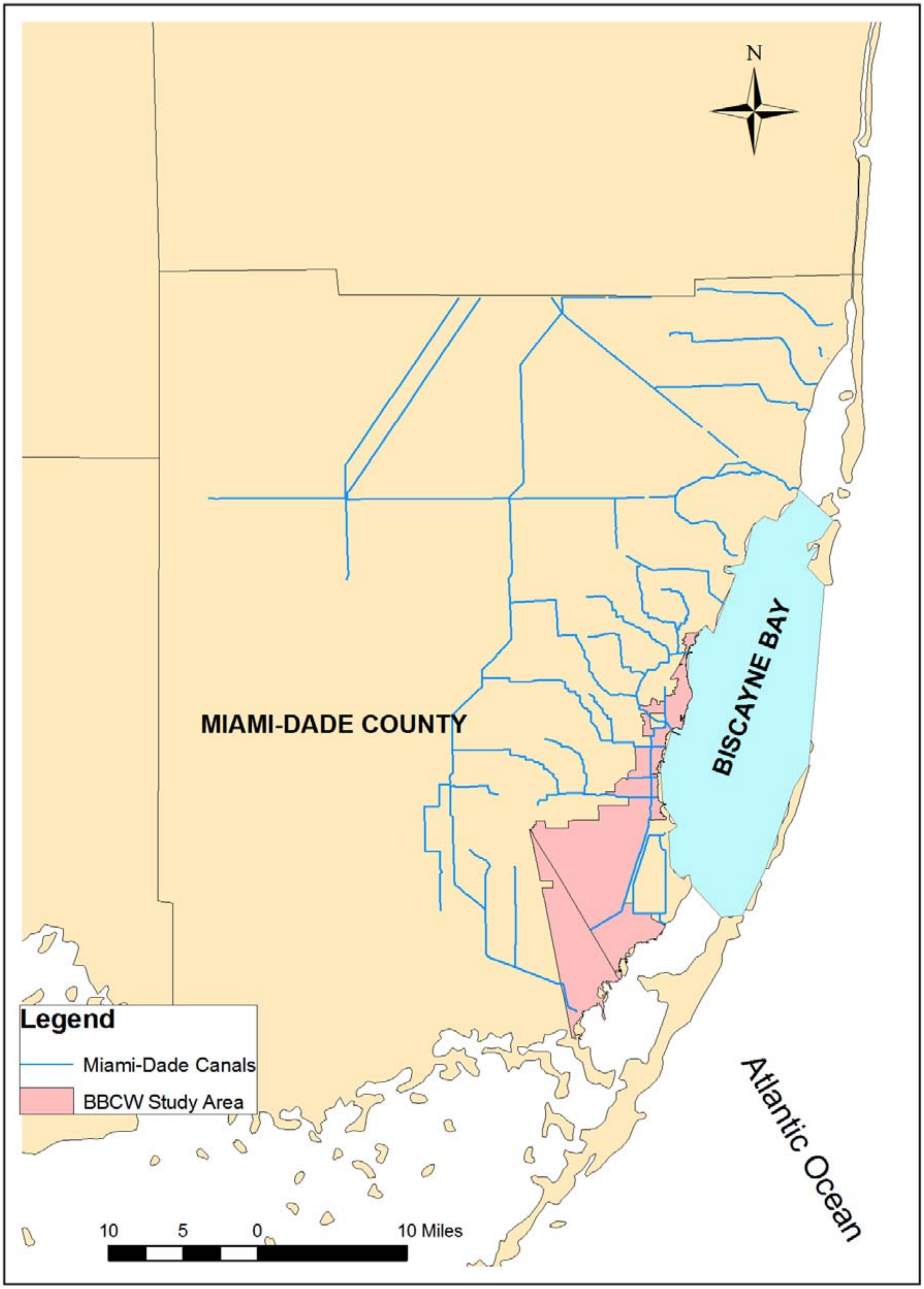

Figure 1. Site location.

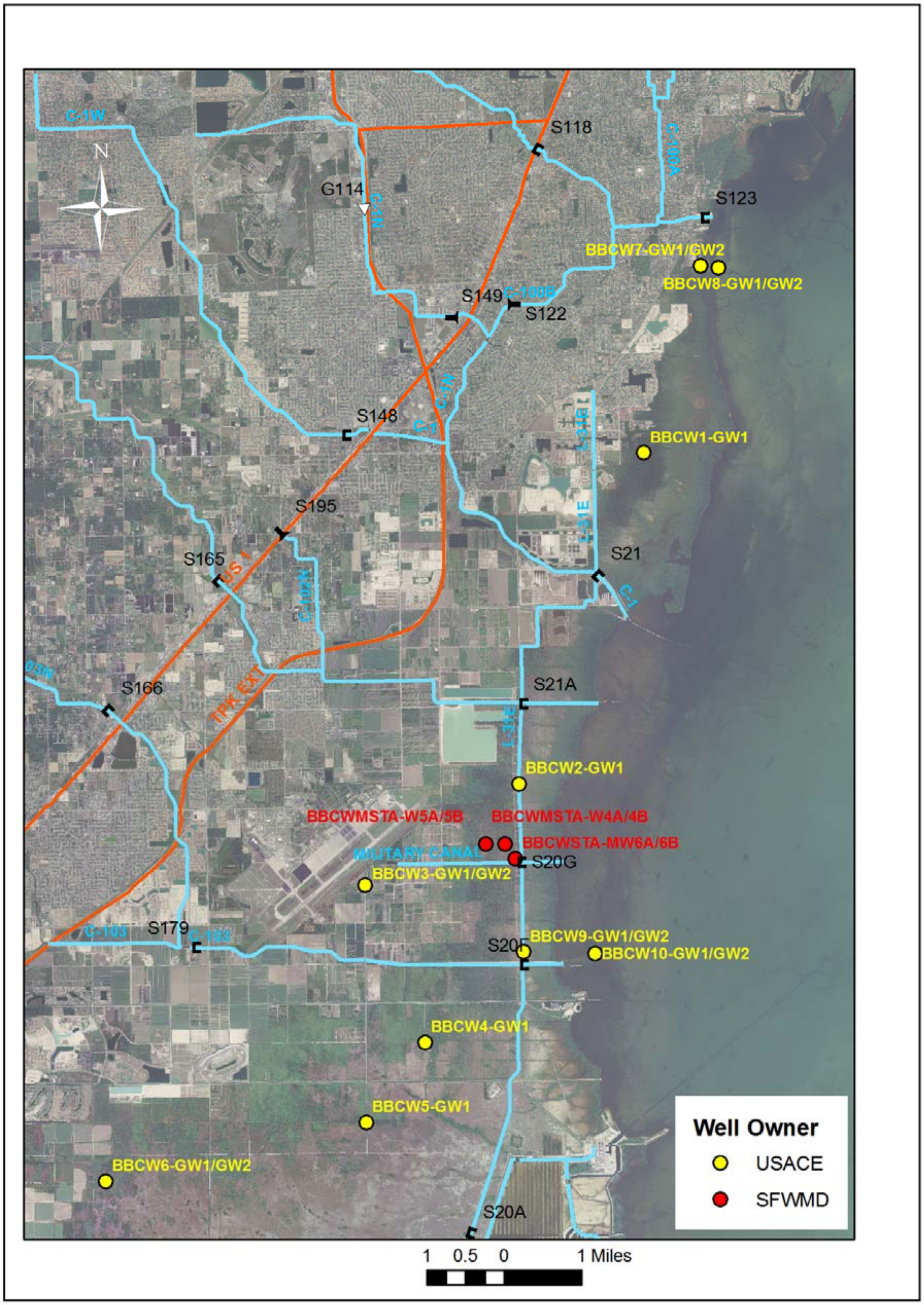

Figure 2. Well location map.

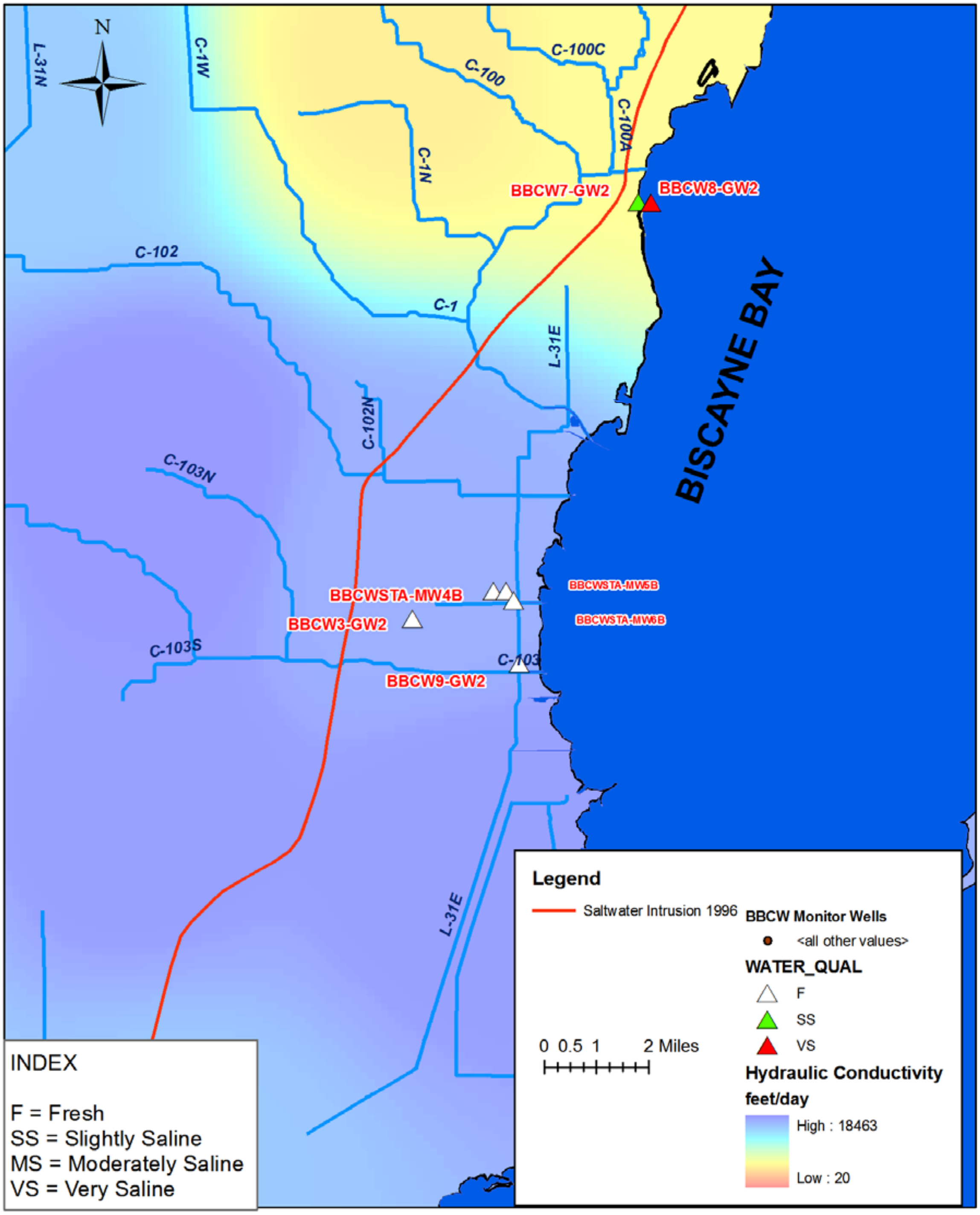

Figure 3. LECsR Model Layer 1 - shallow monitor wells (-9 to –20 feet NGVD 1929).

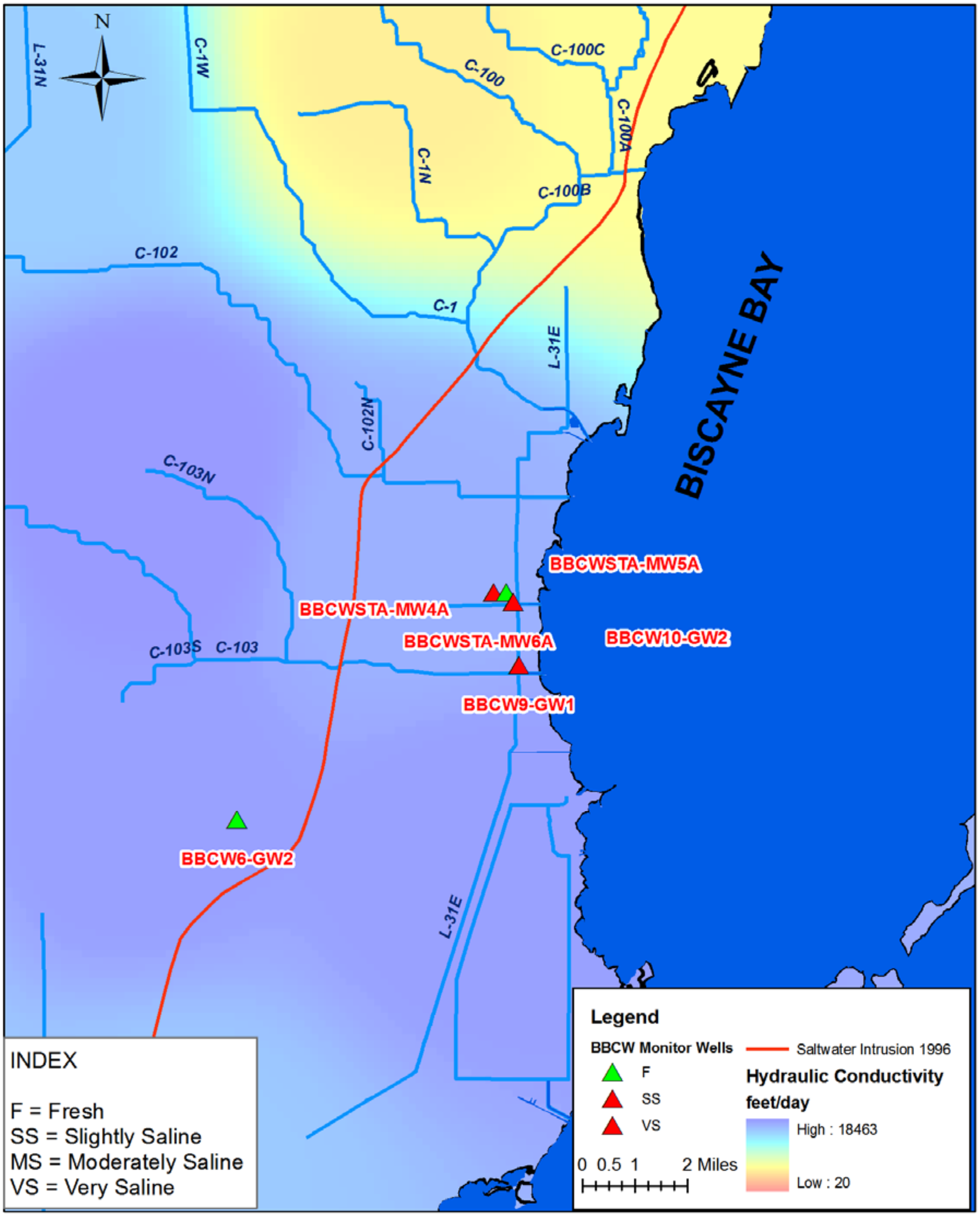

Figure 4. LECsR Model Layer 1 - medium monitor wells (-23 to –31 feet NGVD 1929).

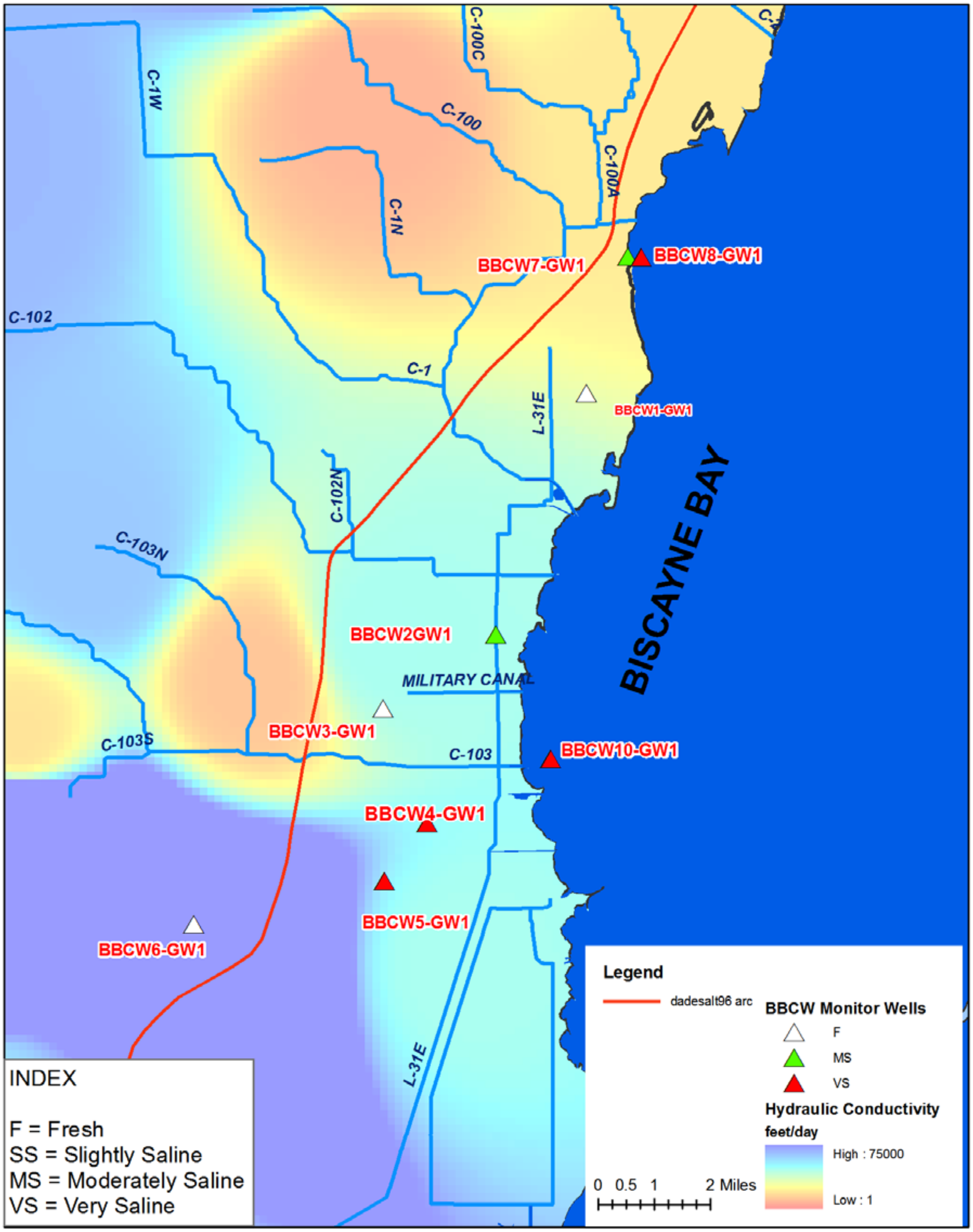

Figure 5. LECsR Model Layer 2 - deep monitor wells (-35 to –50 feet NGVD 1929).

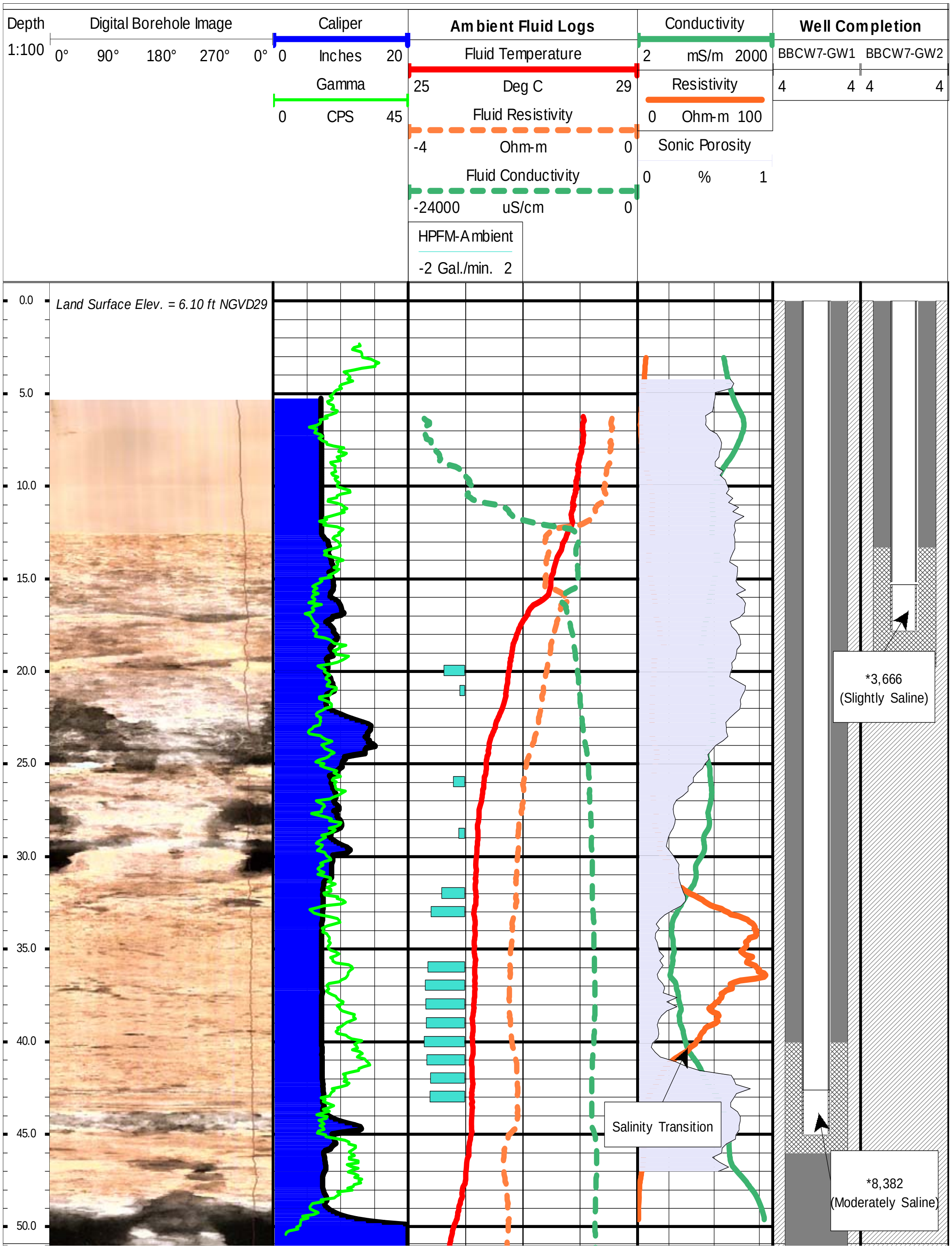

Figure 6. BBCW7-GW1/GW2 geophysical logs and well diagrams.

* in µS/cm², Kasenow (1997) groundwater classification
Note: ambient fluid logs for BBCW-GW1 were not calibrated
Source: Geophysical log data from USGS

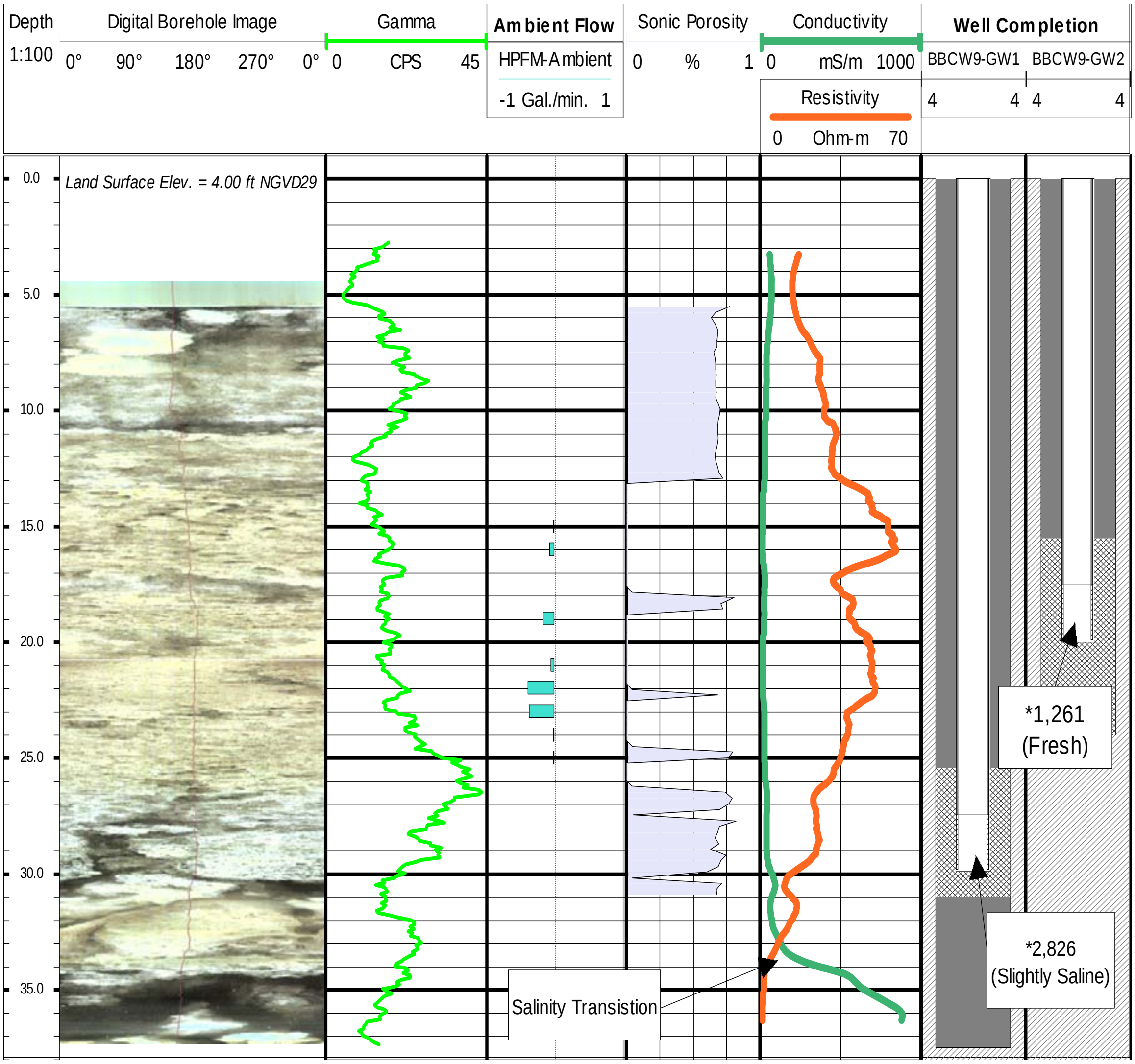

Figure 7. BBCW9-GW1/GW2 geophysical logs and well diagrams.

* in µS/cm², Kasenow (1997) groundwater classification
Source: Geophysical log data from USGS

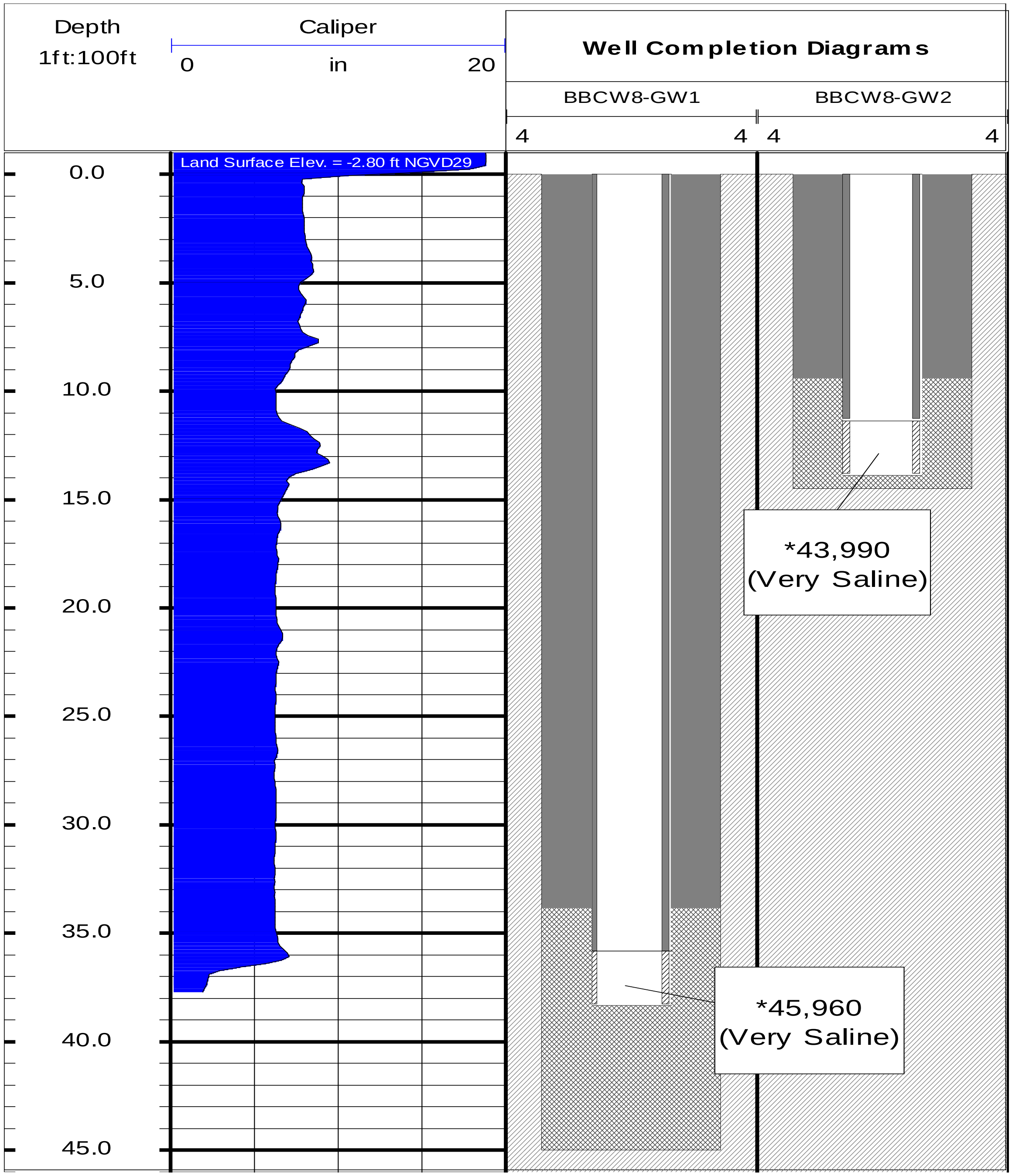

Figure 8. BBCW8-GW1/GW2 geophysical logs and well diagrams.

* in µS/cm^2, Kasenow (1997) groundwater classification
Source: Geophysical log data from USGS

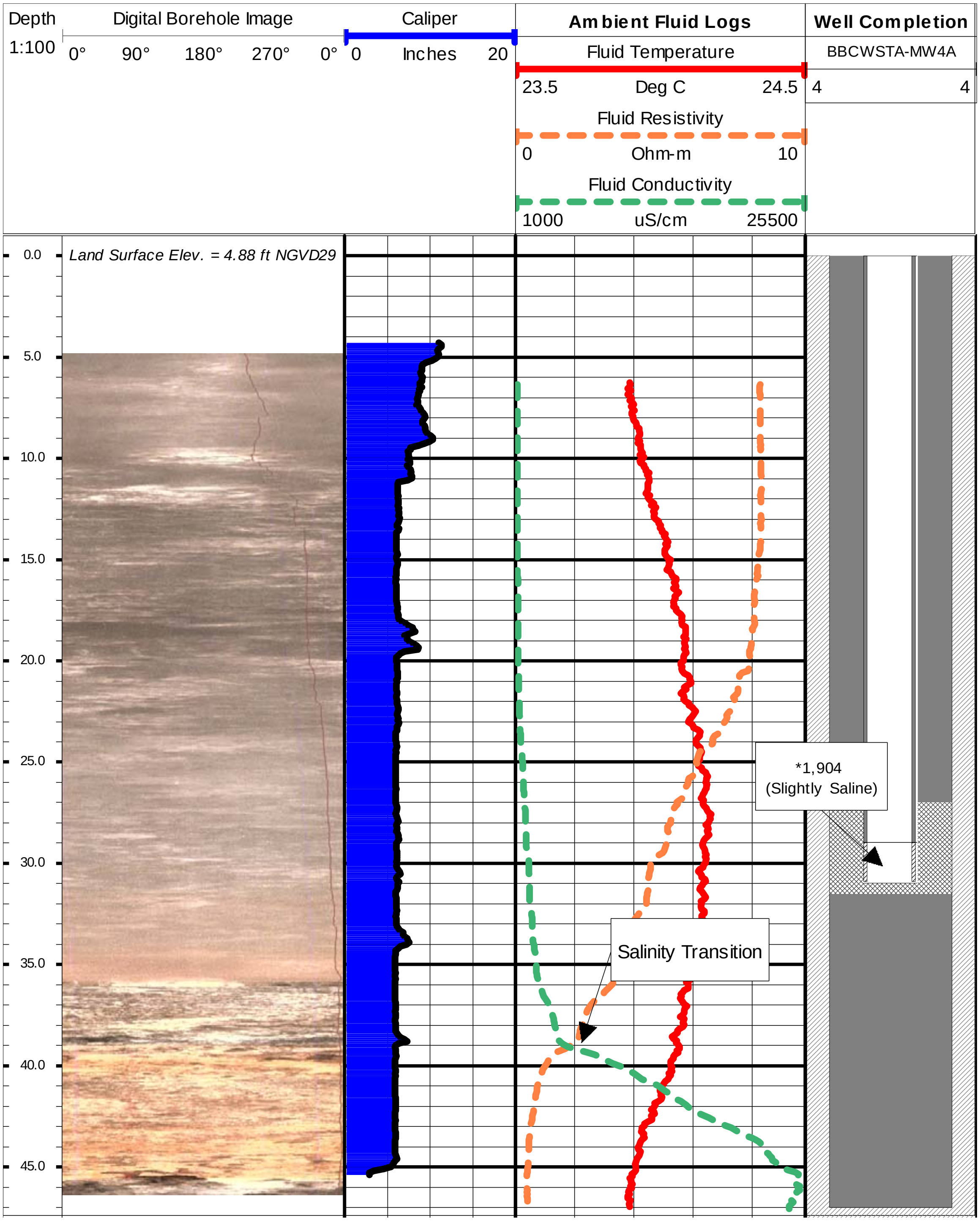

Figure 9. BBCWSTA-MW4A geophysical logs and well diagrams.

* in µS/cm², Kasenow (1997) groundwater classification
Source: Geophysical log data from USGS

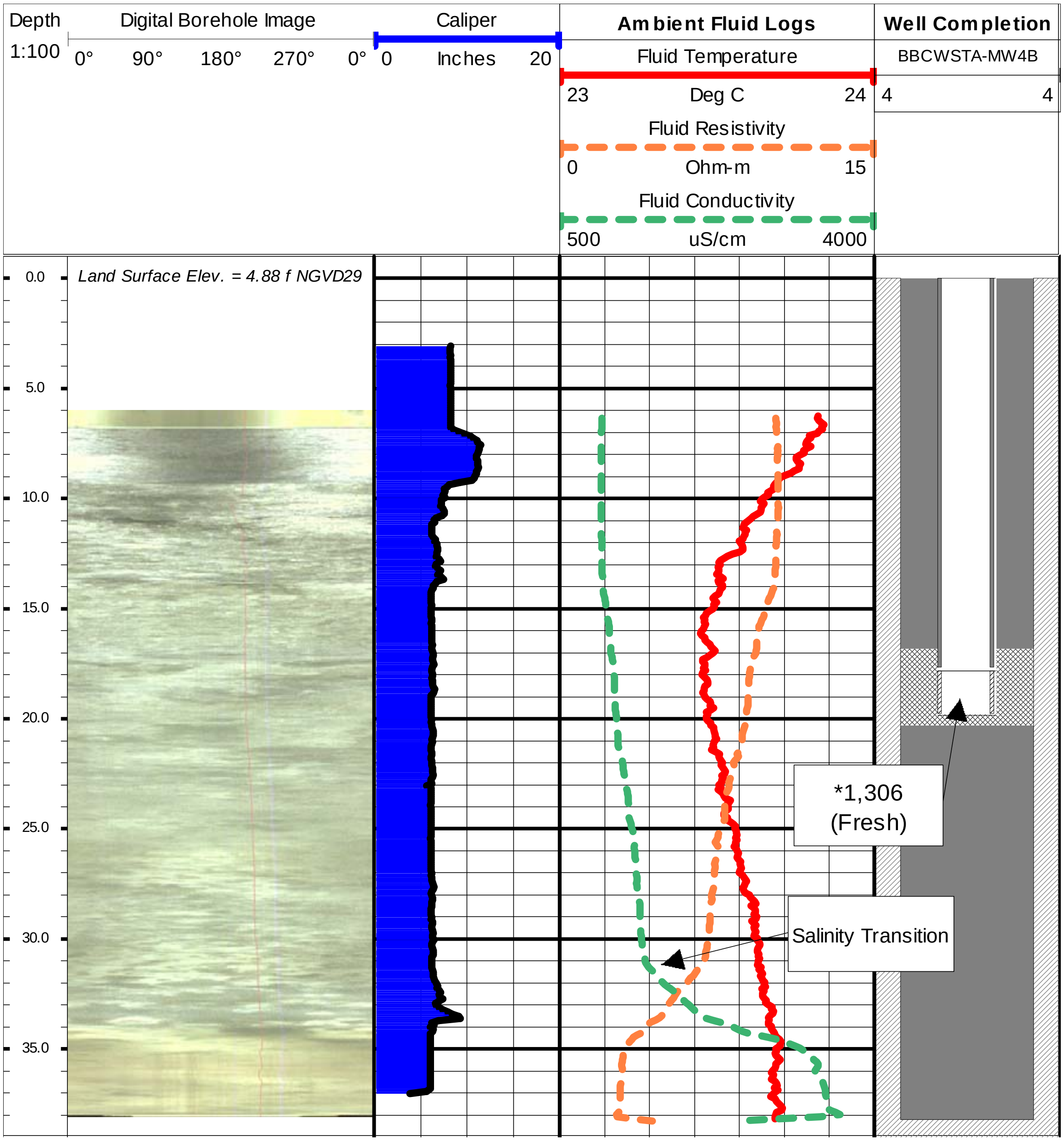

Figure 10. BBCWSTA-MW4B geophysical logs and well diagrams.

* in µS/cm[2], Kasenow (1997) groundwater classification
Source: Geophysical log data from USGS

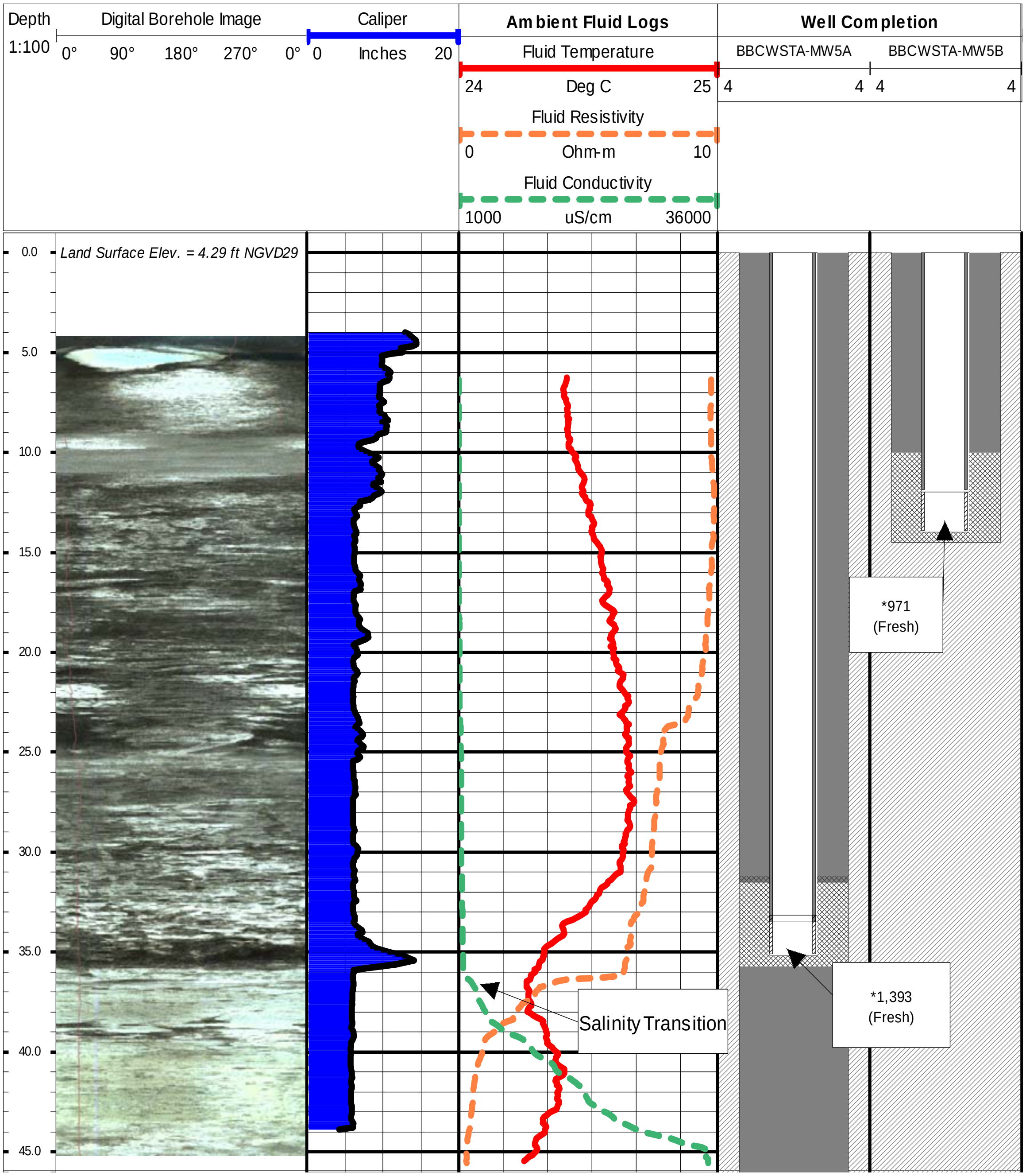

Figure 11. BBCWSTA-MW5A/MW5B geophysical logs and well diagrams.

* in µS/cm², Kasenow (1997) groundwater classification
Source: Geophysical log data from USGS

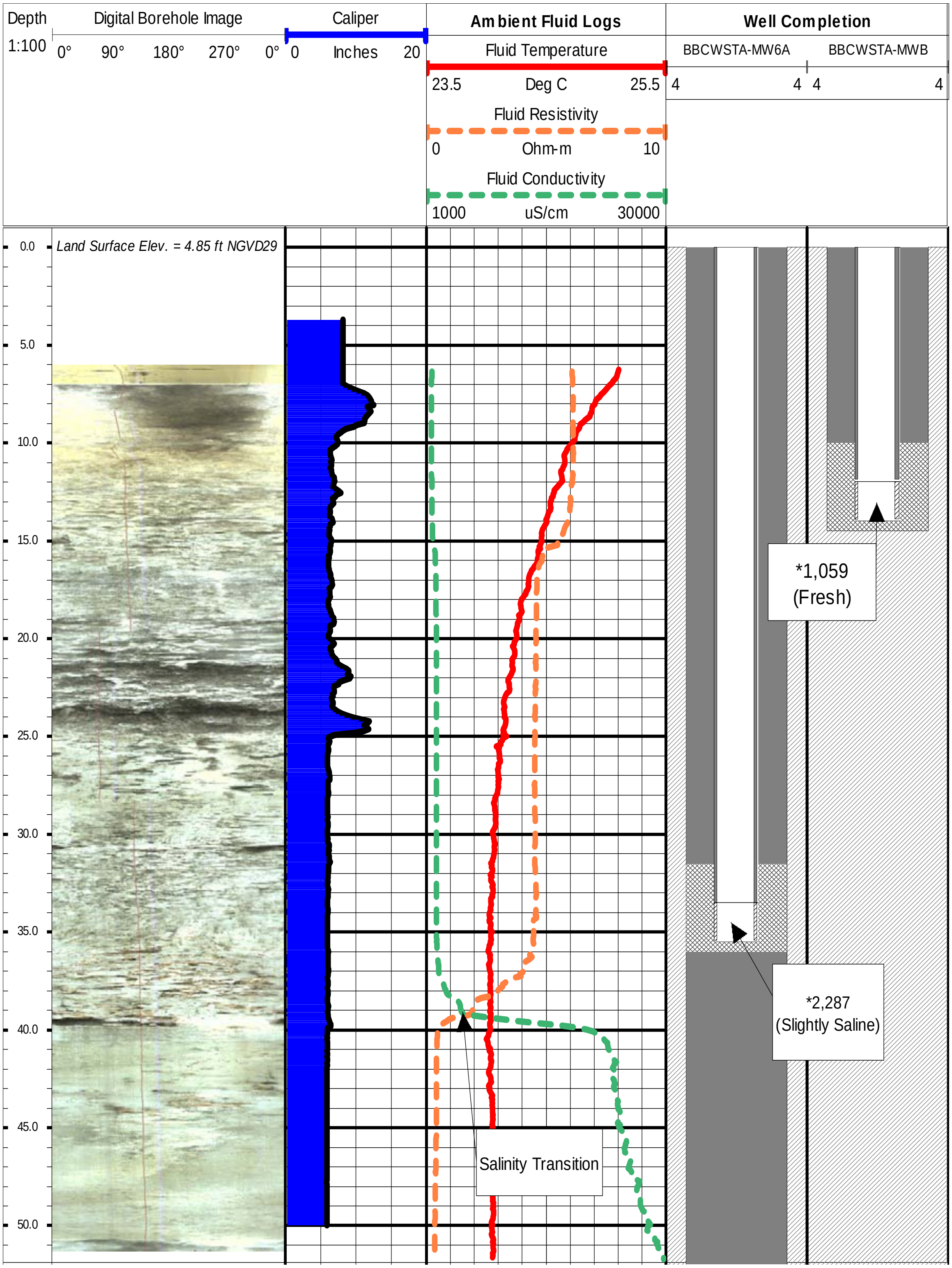

Figure 12. BBCWSTA-MW6A/MW6B geophysical logs and well diagrams.

* in µS/cm², Kasenow (1997) groundwater classification
Source: Geophysical log data from USGS

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