Cycle Testing Summary Report

Hillsboro Canal Aquifer Recharge, Storage, and Recovery System

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FOREWORD

The Hillsboro aquifer recharge, storage, and recovery (ASR) project is the result of an 18-year effort led by the South Florida Water Management District (SFWMD) to design, permit, construct, and test the potential of ASR as a component of the Comprehensive Everglades Restoration Plan (CERP). This body of work represents the efforts of a multiagency, multidisciplinary team of hydrogeologists, engineers, and environmental scientists who developed plans, responded to reviews and critiques, formulated strategies, and conducted experiments to answer technical questions about the role of ASR in CERP.

The ASR system was built to capture excess water from the Hillsboro Canal, store it in the Upper Floridan aquifer, and later recover the water to the Hillsboro Canal to demonstrate the effectiveness of ASR technology in western Boca Raton.

The SFWMD performed cycle testing of the Hillsboro ASR system in response to unusually wet conditions during 2016 and 2017. This report presents the findings of the most recent cycle test and compares them to previous evaluations of the system. Additionally, this report documents the many steps that have occurred since the inception of the project and is intended to assist future work in the field of ASR.

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In addition to agency staff, the project was designed, constructed, operated, and monitored by the following firms:

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GlobeTec Construction
Post Buckley Schuh & Jernigan, Inc.
Diversified Drilling Corporation

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ACRONYMS AND ABBREVIATIONS

µg/L	micrograms per liter
µmhos/cm	micromhos per centimeter
ASR	aquifer recharge, storage, and recovery
bls	below land surface
CERP	Comprehensive Everglades Restoration Plan
cfu/100 mL	colony forming units per 100 milliliters
CROGEE	Committee on the Restoration of the Greater Everglades Ecosystem
FAS	Floridan aquifer system
gpm	gallons per minute
mg/L	milligrams per liter
mgd	million gallons per day
mV	millivolt
NPDES	National Pollutant Discharge Elimination System
NTU	nephelometric turbidity units
ORP	oxidation reduction potential
PCU	platinum-cobalt color unit
PMP	Project Management Plan
ppb	parts per billion
PPDR	Pilot Project Design Report
psi	pounds per square inch
SAS	surficial aquifer system
SFWMD	South Florida Water Management District
TDS	total dissolved solids
UFA	Upper Floridan aquifer
USACE	United States Army Corps of Engineers
UV	ultraviolet

INTRODUCTION

The South Florida Water Management District (SFWMD) constructed the Hillsboro aquifer recharge, storage, and recovery (ASR) facility as a demonstration project for the Comprehensive Everglades Restoration Plan (CERP) to ascertain the effectiveness of ASR technology as a component of ecosystem restoration efforts. The system is adjacent to Water Conservation Areas 1 and 2A, along the Hillsboro Canal, in western Boca Raton (**Figure 1**).

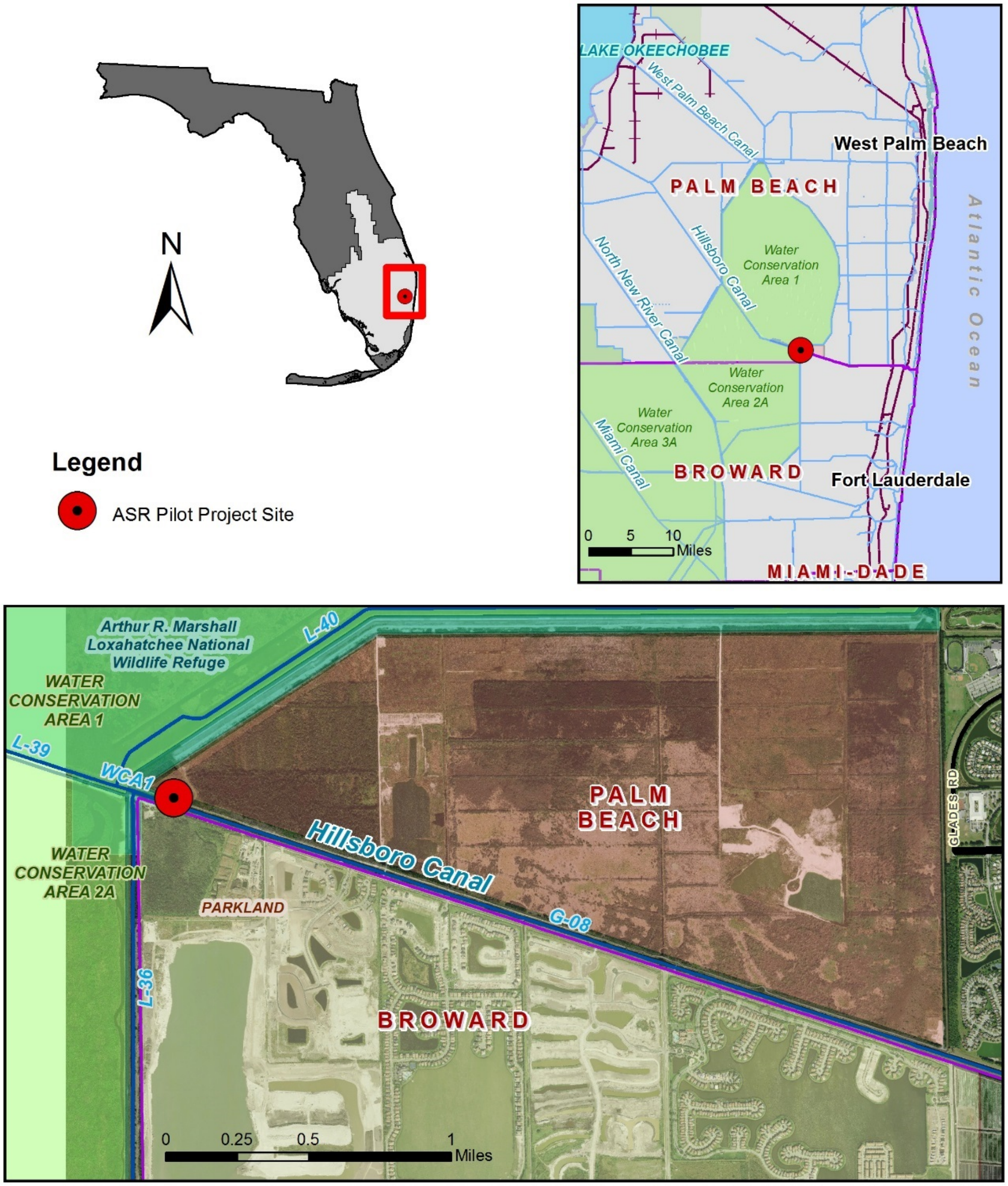

Figure 1. Location of the Hillsboro ASR pilot project site.

The Hillsboro ASR system consists of a 24-inch diameter ASR well completed in the Upper Floridan aquifer (UFA) and connections to the Hillsboro Canal via an intake/discharge structure, recharge pump, mechanical screen filter, and ultraviolet (UV) disinfection mechanism (**Figure 2**). The system is designed to recharge and recover water at a rate of 3,500 gallons per minute (gpm), equivalent to approximately 5 million gallons per day (mgd), 8 cubic feet per second, or 16 acre-feet per day.

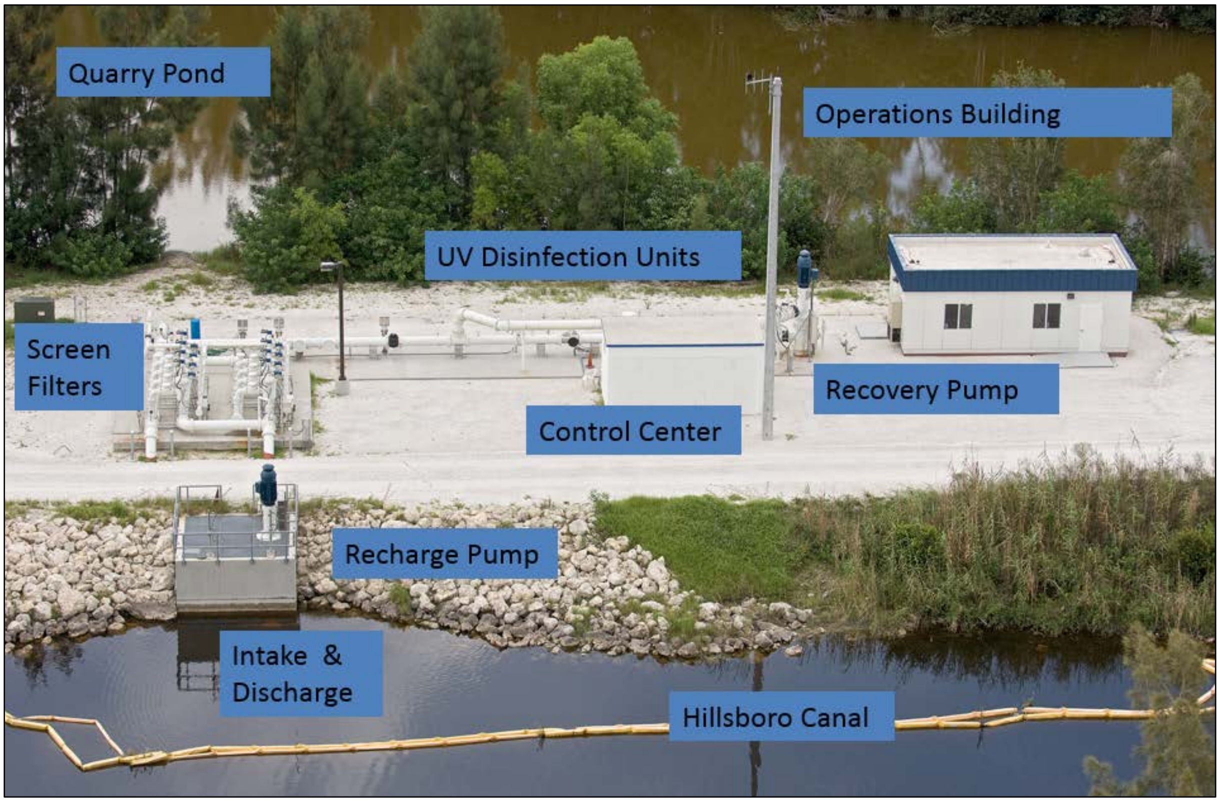

Figure 2. Aerial view of the constructed Hillsboro ASR system.

This report summarizes the results of cycle testing at the Hillsboro ASR facility from February through August 2017 (Cycle 4) and presents those results relative to previous evaluations of the system. From 2010 through 2012, the system was subjected to three brief test cycles.

Part 1 of this report summarizes early work performed as part of the plan, design, exploration, and construction of the Hillsboro ASR facility. Part 2 summarizes the hydrogeologic characteristics at the ASR site and the previous cycle tests. Part 3 presents the results of Cycle 4 relative to earlier evaluations. A chronology of the project since its inception is presented below.

Summary Project Chronology

1999	CERP ASR Issue Team report
2000	Exploratory ASR well construction
2001	Pilot Project Management Plan (PMP)
2002	National Academy of Science review of PMP
2003	Design studies
2004	Pilot Project Design Report/Environmental Impact Statement
2005	Underground Injection Control Construction Permit Issued by the Florida Department of Environmental Protection
2006	Surface facility construction initiated
2007	Monitoring well construction
2009	Surface facility construction complete
2010	Cycle testing initiated
2012	Three cycle tests completed
2013	CERP ASR Pilot Project Technical Data Report published
2017	Cycle 4 completed

PART 1: PROJECT HISTORY

ASR in the Comprehensive Everglades Restoration

The use of ASR technology to support CERP was first envisioned in 1996 as part of the Governor's Commission for a Sustainable South Florida. The commission recommended, "ASR technology should be investigated to determine its feasibility on a regional scale." Due to the limited understanding of the effects of regional ASR implementation, the South Florida Ecosystem Restoration Working Group formed the ASR Issue Team in September 1998 to conduct an independent scientific review of the conceptual implementation of ASR as part of CERP. The team was to develop an action plan and identify projects needed to address the hydraulic, hydrogeologic, and geochemical uncertainties associated with ASR facilities. The ASR Issue Team's final report was published in July 1999 and recommended studying the following seven topics:

1. Characterization of source waters that could be pumped into the ASR wells.
2. Characterization of regional hydrogeology of the Floridan aquifer system (FAS).
3. Analysis of critical pressure for rock fracturing.
4. Analysis of local and regional changes in groundwater flow patterns.
5. Analysis of water quality changes during storage in the FAS.
6. Effects of ASR on mercury bioaccumulation for ecosystem restoration projects.
7. Relationships among ASR storage interval, recovery rate, and recharge volume.

The United States Army Corps of Engineers (USACE) and SFWMD published the Central and Southern Florida Project Comprehensive Review Study in 1999, presenting a framework for Everglades restoration, preservation, and protection while providing for other water-related needs of the region such as municipal, industrial, and agricultural water supply and flood protection. The study, now known as CERP, is a cooperative effort containing 68 components, including structural and operational changes to the existing infrastructure of canals and water control features that were built throughout South Florida in the 1940s and 1950s. CERP implementation is designed to improve the quality, quantity, timing, and distribution of water flows; restore and enhance natural systems; and improve fish and wildlife habitats to promote recovery of native flora and fauna, including threatened and endangered species.

Of the 68 project components recommended in CERP, 7 components involve using ASR wells. CERP anticipated construction of up to 30 ASR wells at the Hillsboro site that would be integrated into a reservoir impoundment referred to as the Site 1 Impoundment, which subsequently was renamed the Fran Reich Reservoir. Additionally, CERP recommended construction of ASR pilot projects along the Hillsboro Canal, Caloosahatchee River, and Lake Okeechobee to address uncertainties of ASR technology prior to regional implementation.

Project Management Plan and CROGEE Review

The SFWMD and USACE prepared a PMP to address questions raised by the ASR Issue Team and to implement the Hillsboro ASR pilot project. The PMP included the goals, objectives, tasks, scope, schedule, and budget for the pilot project. The National Academy of Sciences Committee on the Restoration of the Greater Everglades Ecosystem (CROGEE) reviewed the PMP and published the review in 2001 (National Research Council 2001). Based on the CROGEE review, the CERP ASR scope was broadened to include systemwide effects of using ASR technology throughout South Florida, which resulted in the CERP ASR Regional Study (USACE and SFWMD 2015).

Exploratory Well Construction

While the PMP was being prepared, reviewed, and finalized, well construction activities were initiated at the Hillsboro ASR site. The ASR well and associated monitoring wells were constructed in 1999 and 2000 by Diversified Drilling Corporation. A dual-zone and a single-zone FAS monitoring well were constructed under a single contract, at a cost of $650,000. The ASR well was constructed at a cost of $980,000. The ASR well comprises a 24-inch diameter steel casing, cemented to a depth of 1,015 feet below land surface (bls), and an open borehole completed to 1,225 feet bls (**Figure 3**). An additional single-zone FAS well and a surficial aquifer system (SAS) monitor well subsequently were constructed at a cost of $451,000. The total cost of construction for all the wells was $2,081,000.

Design Studies and the Pilot Project Design Report

The CERP ASR pilot project was designed between 2001 and 2004. The design was based on the hydrogeologic testing and evaluations of the availability, quality, and variability of water within the Hillsboro Canal; groundwater quality assessment and modeling; water treatment (filtration and disinfection); mechanical pumping systems; permitting strategy; testing plans; conceptual schematics; and cost estimates. The results of these evaluations are provided in the Pilot Project Design Report (PPDR; USACE and SFWMD 2004a). The PPDR also included an environmental impact statement, which concluded the Hillsboro ASR project (and other pilot projects) would not cause significant environmental harm (USACE and SFWMD 2004b). The PPDR had an estimated construction cost of $6,119,200 for the Hillsboro ASR facility. The USACE and SFWMD approved and accepted the PPDR, allowing construction of the Hillsboro ASR facility to proceed.

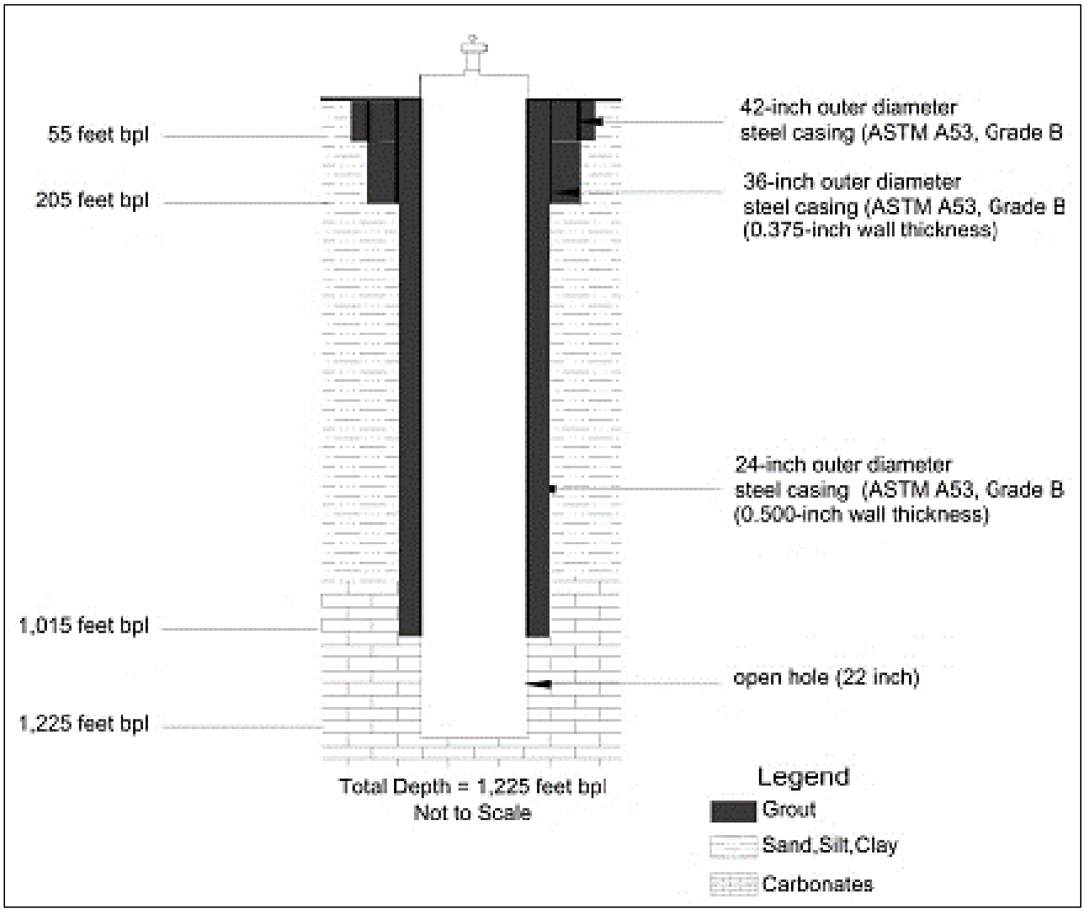

Figure 3. Hillsboro ASR well construction schematic (Note: bpl – below pad level).

ASR System Construction

From 2004 through 2005, design of the Hillsboro ASR facility (**Figure 4**) was finalized, technical specifications and drawings were prepared, and a construction contractor was procured. GlobeTec Construction built the surface facilities of the ASR system between 2006 and 2007 for a contract price of $2,277,598. Major components of the surface facilities contract included installation of the intake/discharge structure, screen filters, UV disinfection units, pumps, piping, valves, and electrical controls and meters (**Figure 4**).

The ASR well system recharges treated (filtered and disinfected) Hillsboro Canal water into the UFA. During recharge, canal water passes through a 1-millimeter slot-sized screen mounted on the underwater intake pipe. The intake screen was designed to prevent entrainment of fish larvae into the ASR system. A three-stage, 250-horsepower vertical turbine pump is used to recharge canal water through the aboveground treatment system and into the ASR well. Recharge water then passes through an 80-micron mechanical screen filter (manufactured by Amiad) to minimize suspended solids pumped into the ASR well, which could clog the open hole. The final step in the recharge process before water enters the ASR well is an in-line UV disinfection system consisting of 2 reaction chambers, each fitted with 12 bulbs (manufactured by Aquionics). Recovery is accomplished using a separate three-stage, 250-horsepower vertical turbine pump mounted on the ASR wellhead, which routes water from the well back through the surface piping to the intake/discharge structure on the bank of the Hillsboro Canal. Recovery also can be accomplished without use of the pump, by allowing stored water to flow naturally under the artesian pressure of the aquifer at a rate of approximately 1,400 gpm (equivalent to 2 mgd).

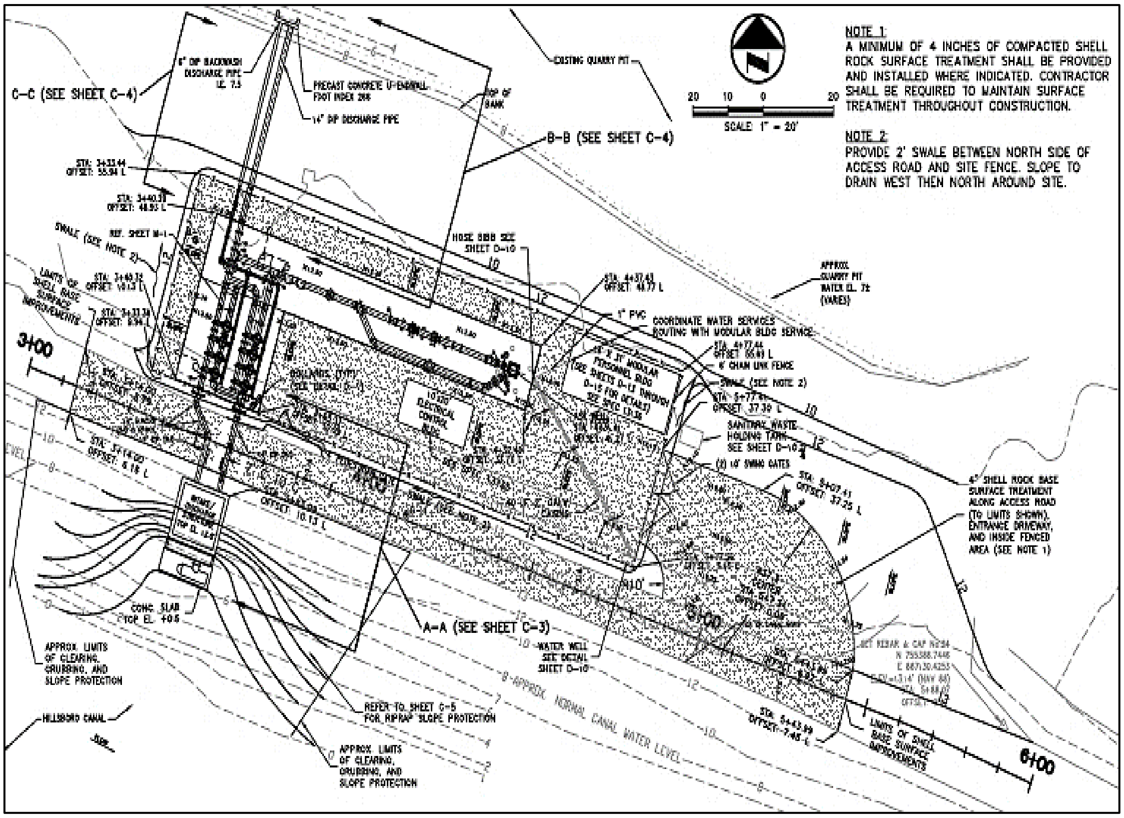

Figure 4. Hillsboro ASR facility site schematic.

Several monitoring wells at the Hillsboro ASR site are completed in various intervals of the FAS and SAS. **Figure 5** shows a cross-section of the aquifers in addition to the ASR well and monitor wells. An aerial view of the orientation of the monitor wells is shown in **Figure 6**. **Table 1** provides a brief description of each monitor well.

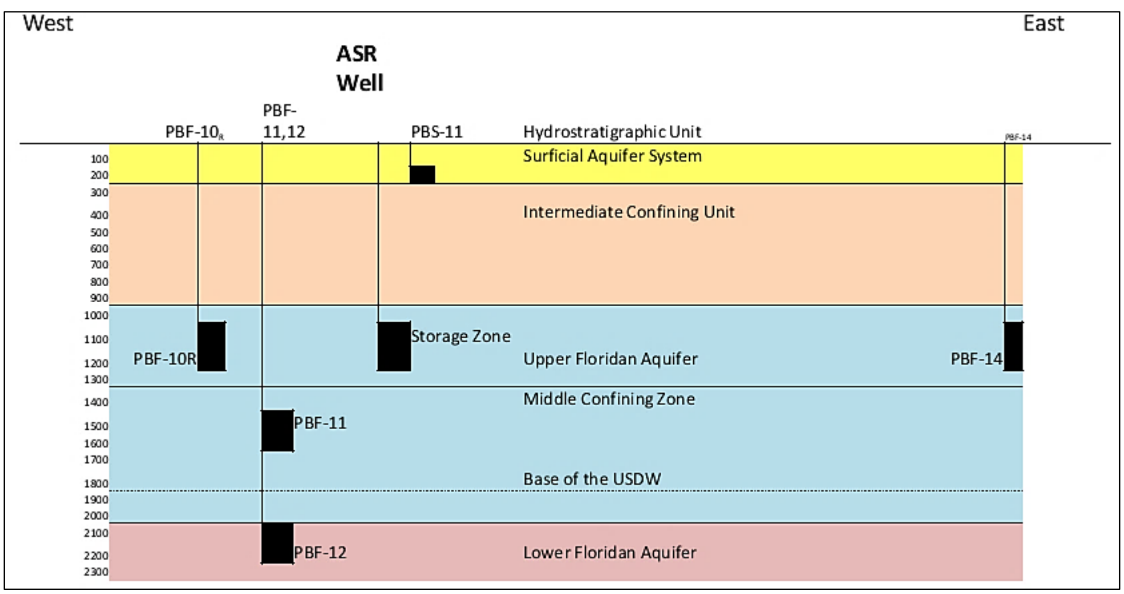

Figure 5. Aquifer cross-section showing the vertical relationship of the monitoring wells and ASR well at the Hillsboro ASR site.

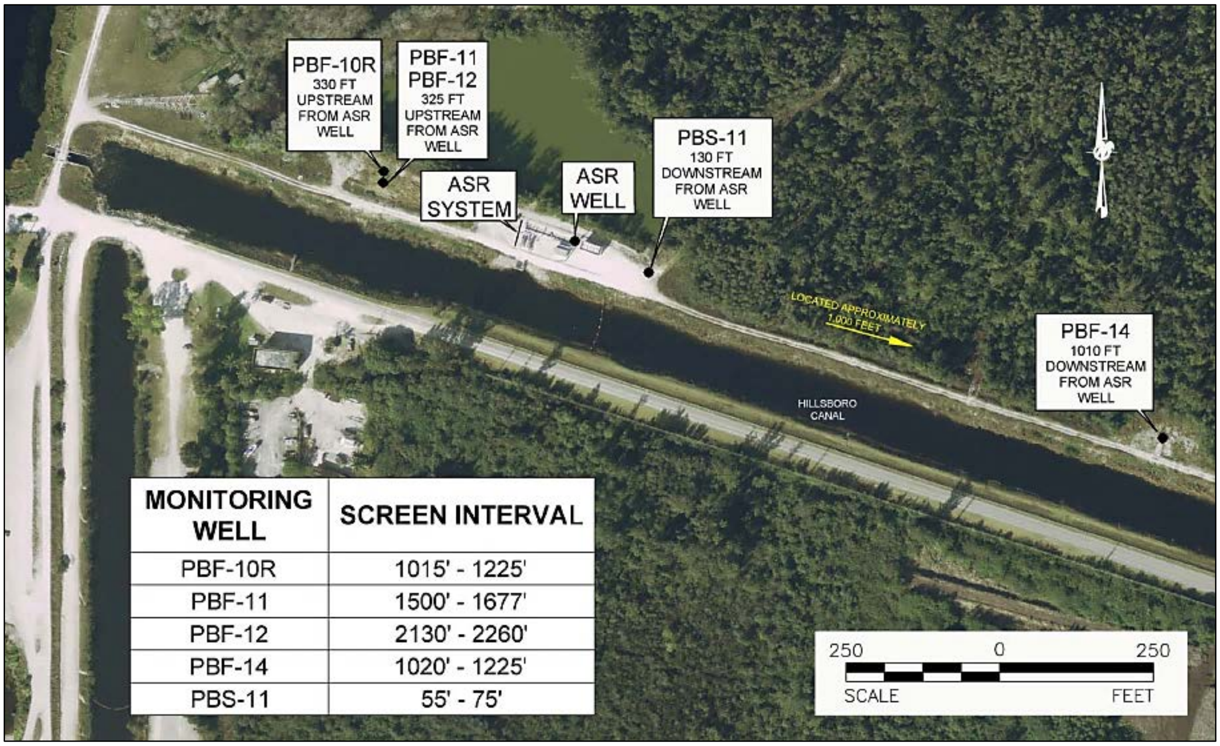

Figure 6. Locations of the monitoring wells and ASR well at the Hillsboro ASR site.

Table 1. Details of the monitoring wells at the Hillsboro ASR site.

Monitoring Well	Description
PBF-10R	Storage zone FAS monitoring well 330 feet from the ASR well, monitoring the interval from 1,015 and 1,225 feet bls
PBF-11	Intermediate-depth FAS monitor well 325 feet from the ASR well, monitoring the interval from 1,500 to 1,677 feet bls
PBF-12	Deep FAS monitor well 325 feet from the ASR well, monitoring the interval from 2,130 to 2,260 feet bls
PBF-14	Storage-zone FAS monitor well 1,010 feet from the ASR well, monitoring the interval from 1,020 to 1,225 feet bls
PBS-11	SAS monitor well approximately 130 feet from the ASR well, with a screened interval from 55 to 75 feet bls

ASR = aquifer recharge, storage and recovery; bls = below land surface; FAS = Floridan aquifer system; SAS = surficial aquifer system.

PART 2: SITE CHARACTERIZATION

Hydrogeology

The hydrogeology at the Hillsboro ASR site was characterized during construction of the ASR and monitoring wells, (**Figure 7**; SFWMD 2001). In summary, the SAS extends from land surface to approximately 200 feet bls. The Hawthorn Formation, consisting of fine-grained clays and limestone, extends from approximately 200 to 900 feet bls. The Hawthorn Formation is the primary confining sequence separating the SAS and FAS. Below 900 feet bls, the FAS is present, consisting of porous shelly limestones and dolomites to the site's total drill depth of 2,350 feet bls. The ASR well is completed with an open-hole interval in the uppermost portion of the FAS, from 1,015 to 1,225 feet bls, which was identified from testing during drilling operations as an appropriate zone for ASR. The geologic units within this depth interval have been defined as the Suwannee Limestone and Avon Park Formations.

Figure 8 presents a compilation of geophysical logs collected during drilling and construction of the ASR well, and a lithologic interpretation provided by the United States Geological Survey (2008). The figure shows the depth intervals of the ASR well and storage-zone monitor wells PBF-10R and PBF-14 between 1,000 and 1,200 feet bls. **Figure 8** also shows that monitor well PBF-11 is completed beneath a semi-confining sequence (designated MC1). The sonic and neutron-density logs between 1,000 and 1,700 feet bls indicate a divergence in the calculated values of porosity. This divergence typically is indicative of secondary (fracture or vuggy) porosity, which may indicate the MC1 interval is "leaky". Additionally, **Figure 8** indicates that monitor well PBF-12 is completed within the dolomitic and fractured Avon Park Permeable Zone.

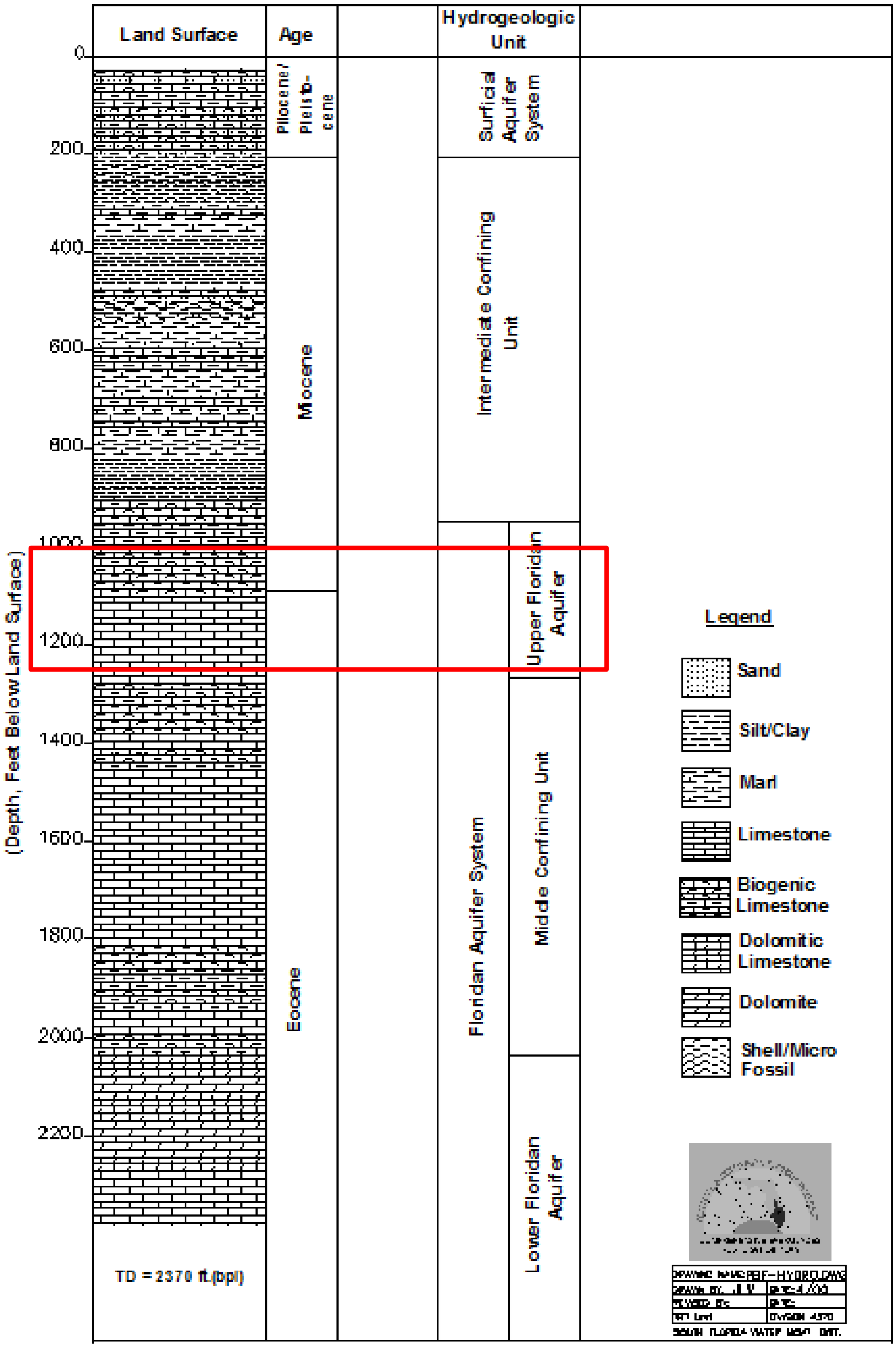

Figure 7. Generalized hydrogeology of the Hillsboro ASR site. (The red box designates the open-hole storage zone portion of the ASR well.)

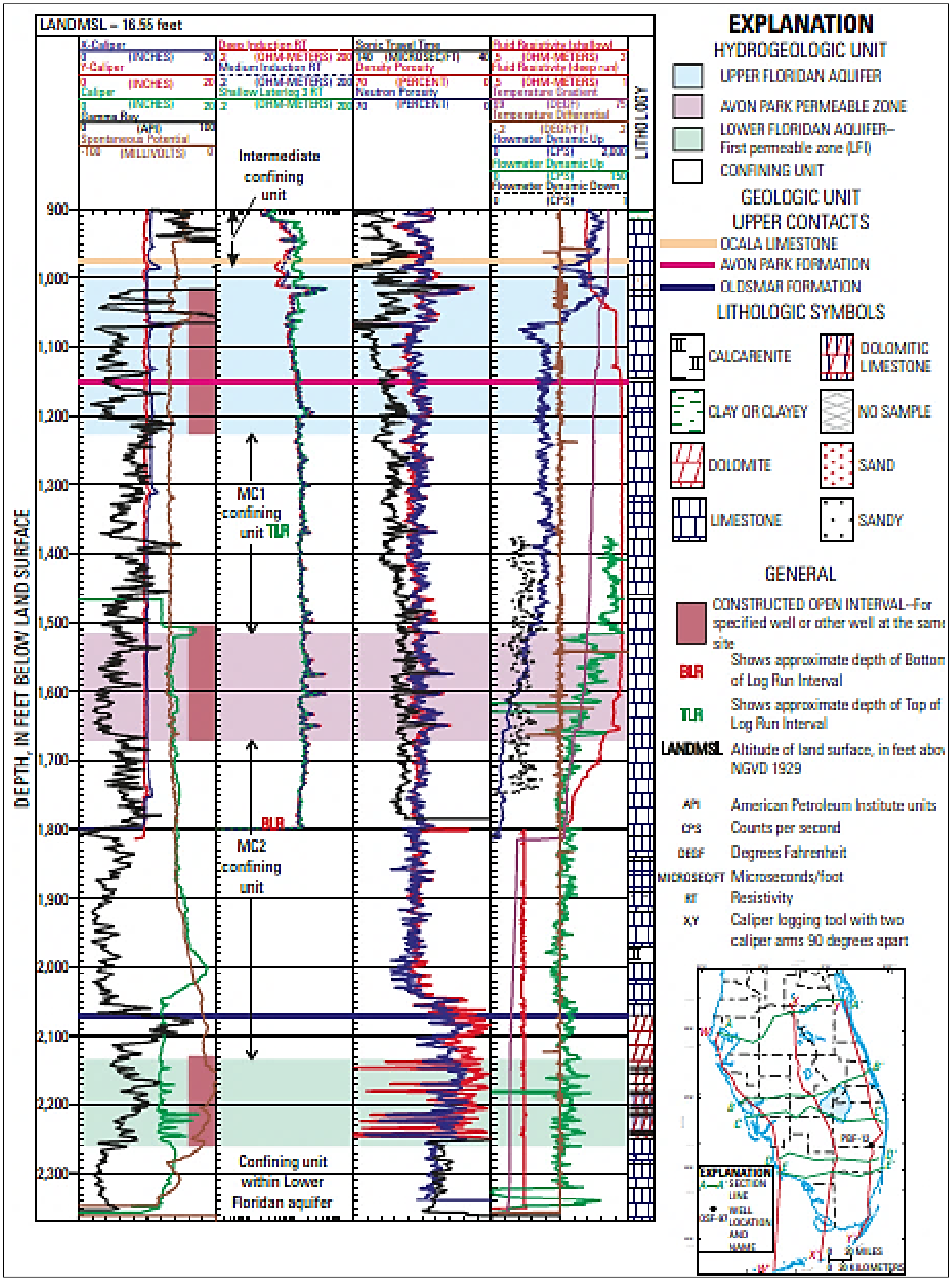

Figure 8. Compilation of geophysical logs from the Hillsboro ASR system (From: United States Geological Survey 2008).

Hydraulic Properties of the Storage Zone

Pumping tests performed on the ASR well yielded hydraulic characteristics for the UFA storage zone at the Hillsboro ASR site. Analysis of the drawdown data yielded similar results at the monitoring wells 330 and 1,010 feet away from the ASR well (**Figures 9** and **10**). The transmissivity of the storage interval was estimated to be 18,700 feet squared per day at the monitor well 330 feet away and 23,900 feet squared per day at the monitor well 1,100 feet away from the ASR well.

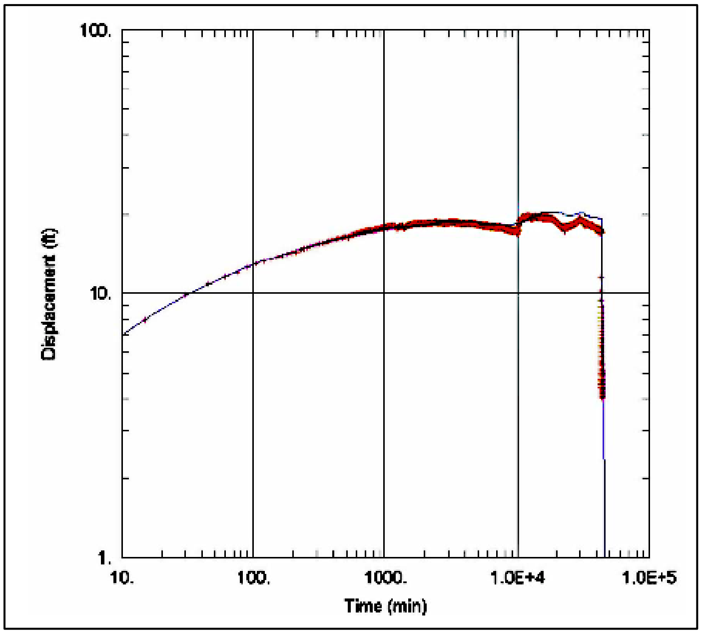

Figure 9. Drawdown response of water levels in monitoring well PBF-10R, located 330 feet away from the ASR well.

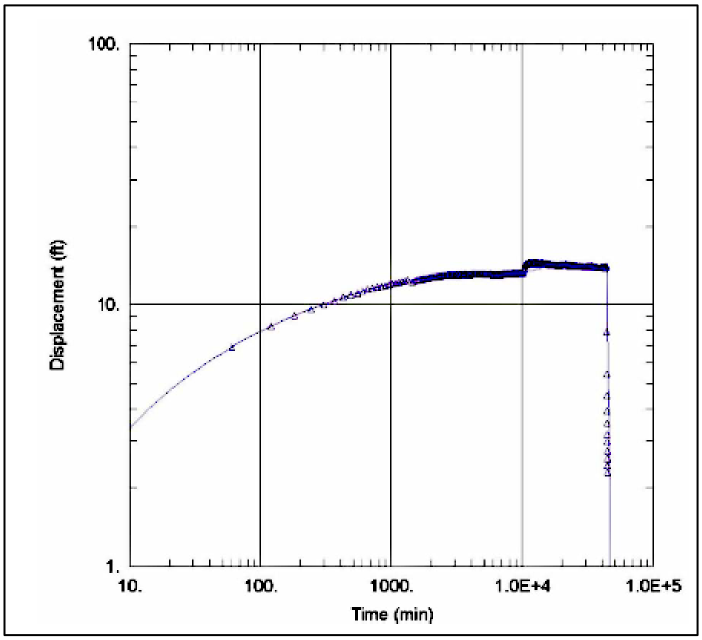

Figure 10. Drawdown response of water levels in monitoring well PBF-14, located 1,010 feet away from the ASR well.

Flow Zones Within the Upper Floridan Aquifer

In 2003, the SFWMD conducted a cross-well nuclear magnetic resonance seismic reflection survey at the Hillsboro ASR site. The investigation resulted in a geophysical refinement of the ASR storage zone (between 1,000 and 1,200 feet bls) into upper and lower flow zones (**Figure 11**; Parra et al. 2003). The survey results suggested that recharge water may preferentially flow into the more permeable lower flow zone (at approximately 1,100 feet bls), rather than the upper flow zone.

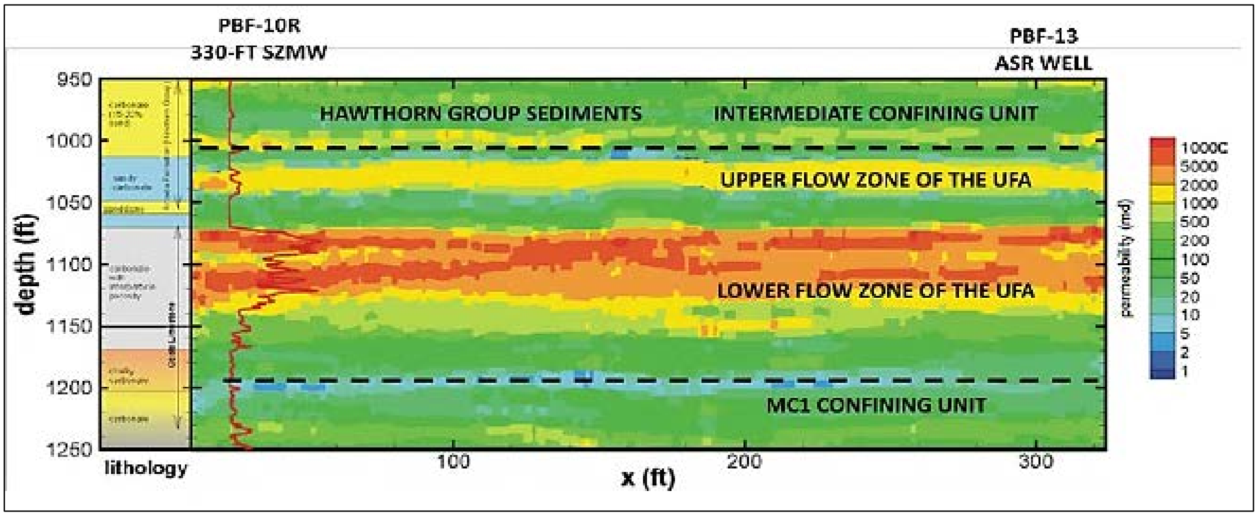

Figure 11. Cross-section of the upper and lower flow zones of the FAS at the Hillsboro ASR site.

Previous Cycle Testing Summary

This section summarizes earlier evaluations of the ASR system to provide historical context for comparison with the results obtained during Cycle 4. The Hillsboro ASR facility was originally constructed and operated under the following permits and authorizations:

- Underground Injection Control Permit: 153872-002-UC
- Comprehensive Everglades Restoration Plan Regulation Act Permit: 01543872-003-GL
- National Pollutant Discharge Elimination System (NPDES) Permits: FL0484890 and FLG071582
- Water Quality Criteria Exemption: 06-0718
- Administrative Order: 153872-005-UC
- Water Use Permit: 50-06823-W

Background (Pre-Cycle) Water Quality Data (2008)

The SFWMD collected water samples from the monitor wells and the Hillsboro Canal (source water) in 2008 as part of a background characterization of the site, prior to any cycle testing. Background data are summarized in **Table 2**.

Table 2. Pre-cycle (2008) background water quality data from the Hillsboro ASR site.

Parameter	Monitoring Location					
	Canal	PBF-10R	PBF-11	PBF-12	PBF-14	PBS-11
Aquifer Interval	Surface Water	UFA Storage Zone	Middle Confining Zone	Lower FAS	UFA Storage Zone	SAS
Color	80	BDL	BDL	BDL	BDL	10
pH		7.51	7.85	7.43	7.60	7.00
Specific conductivity (µmhos/cm)		8,700	4,400	44,000	5,400	4,746
Total dissolved solids (mg/L)	370	4,500	2,500	26,000	3,000	2,600
Chloride (mg/L)	72	2,300	1,200	21,000	1,450	1,200
Sodium (mg/L)	37	1,200	NA	NA	800	NA
Arsenic (µg/L)	BDL	BDL	NA	NA	BDL	NA
Sulfate (mg/L)	11	840	340	1,800	400	210
Total organic carbon (mg/L)	19	8	2.4	NA	2.1	NA

Note: Median analytical values are from five sampling events in 2008.
µg/L = micrograms per liter; µmhos/cm = micromhos per centimeter; BDL = below method detection limit; FAS = Floridan aquifer system; mg/L = milligrams per liter; NA = not analyzed; SAS = surficial aquifer system; UFA = Upper Floridan aquifer.

The background water quality data show a considerable difference in the salinity of the water in the monitoring wells completed within the ASR storage zone (PBF-10R and PBF-14). Water collected from PBF-14 (1,010 feet from the ASR well) exhibited a total dissolved solids (TDS) concentration of 3,000 milligrams per liter (mg/L), whereas water from PBF-10R (330 feet from the ASR well) was more saline, exhibiting a TDS concentration of 4,500 mg/L. Water quality in PBF-10R was similar to the ambient water quality of the storage zone in the ASR well owned by Palm Beach County Water Utilities Department (approximately 5 miles east of the Hillsboro ASR facility), which suggests the higher salinity is more common in the region. One explanation for the fresher water at PBF-14 is vertical upward intrusion of fresher water from the interval below the storage zone. Water from PBF-11, completed 400 feet deeper into the FAS, had a TDS concentration of 2,500 mg/L, which is fresher than water from both monitoring wells completed in the storage zone. This water quality “inversion” has been observed elsewhere in the FAS in Palm Beach and Broward counties (Reese 1994).

Water collected from monitoring well PBF-12 (completed within the Avon Park Permeable Zone) had a TDS concentration of 26,000 mg/L. This well was completed below the base of the underground source of drinking water (USDW), defined as water with TDS concentrations greater than 10,000 mg/L.

Water collected from monitoring well PBS-11 (completed in the SAS) had a salinity similar to water in the UFA. Portions of the SAS in Palm Beach County are known to contain relict seawater (i.e., connate water), and PBS-11 likely is completed in such a zone (Reese and Wacker 2009).

Cycle 1 (2010)

The SFWMD conducted Cycle 1 of the Hillsboro ASR system from January through March 2010. The cycle consisted of recharge, followed by storage, then recovery, with each phase lasting 31 days. Recharge and recovery pumping rates averaged 3,400 gpm, and 152 million gallons of water were pumped into the ASR well. During recharge, the ASR wellhead pressure remained below 60 pounds per square inch (psi). Water quality data from the storage zone monitor wells indicated that canal water mixed and diffused with groundwater 330 and 1,010 feet from the ASR well. The monitor wells completed above and below the storage zone indicated little, if any, water quality changes from the surface water recharged into the storage zone. Recovery was accomplished using the recovery pump on the ASR wellhead. The NPDES permit specified recovery should be terminated (during normal operational modes) when conductivity of the recovered water reached 1,275 micromhos per centimeter (µmhos/cm). Under this permit-based limiting condition, the recovery efficiency for Cycle 1 was approximately 20 percent. Water recovered from the ASR well exhibited an arsenic concentration of 111 parts per billion (ppb) during the first flush of recovery, but concentrations decreased to less than 10 ppb over the remainder of the recovery period. The concentration of arsenic in all the monitor wells remained below 10 ppb during the entire recovery cycle. All surface water recharged into the ASR well was recovered during this cycle; therefore, no fresh water was left in the storage interval to create a buffer for Cycle 2. Allowing fresh water to remain in the aquifer upon completion of a test cycle helps develop a "target storage volume," which increases the recovery efficiency of subsequent cycles performed on an ASR system.

Cycle 2 (2010)

The SFWMD conducted Cycle 2 from April through August 2010. Recharge took place over 81 days, with 375 million gallons (1,135 acre-feet) of water pumped into the UFA at a rate of approximately 3,400 gpm. During recharge, the ASR wellhead pressure increased from approximately 50 psi to more than 70 psi. To decrease the wellhead injection pressure, the SFWMD implemented a schedule of weekly back-flushing for the remainder of the recharge period. During the back-flushing process, the recharge pump was turned off and the ASR well was allowed to backflow freely for approximately 2 hours. Water from the ASR well was routed to the quarry pond adjacent to the site. This process allowed for fine-grained solids to be loosened and removed from the open hole. After 2 hours of back-flushing, the recharge pump was reactivated, and injection pressures were reduced to approximately 50 psi.

There was no storage phase during this cycle. Cycle 2 recovery lasted 21 days, from July 27 to August 17, 2010. Recovery captured 82 million gallons of water before the cycle was terminated based on the specific conductance limit in the NPDES permit. The recovery efficiency of Cycle 2 was 21 percent, nearly identical to that of Cycle 1. A net volume of 300 million gallons (920 acre-feet) of water remained in the aquifer after the recovery period to form a target storage volume for subsequent cycles.

Water quality data from the storage zone monitoring wells indicated canal water mixed and diffused with FAS groundwater 330 and 1,010 feet from the ASR well. Wells completed above and below the storage zone indicated little water quality changes from the water placed within the storage zone. During recharge, arsenic concentrations between 10 and 20 ppb were observed at PBF-10R (330 feet from the ASR well) in early sampling events but were below 10 ppb by the end of the recovery period. Arsenic concentrations at PBF-14 (1,010 feet from the ASR well) were below 10 ppb during the entire cycle. The arsenic concentration in water recovered from the ASR well did not exceed 10 ppb during the recovery period.

Acidization (2011)

Following Cycle 2, the SFWMD subjected the Hillsboro ASR well to an acidization procedure to lower the operating wellhead pressure during recharge phases for future cycle tests. Mactec Inc. performed the acidization in June 2011 under contract to the USACE. During acidization, 3.53 million gallons of low-pH water (between 2.4 and 4.0) were pumped into the ASR well and allowed to react with the carbonate limestone formation. Upon recovery of the acidization fluids, the specific injectivity of the well increased from 40 to 50 gpm per foot (approximately 25 percent).

Cycle 3 (2011 to 2012)

After an idle period of approximately 15 months, the SFWMD conducted Cycle 3 from November 2011 through March 2012. Recharge lasted 118 days, at an average injection rate of 3,300 gpm (4.75 mgd), resulting in 357 million gallons of water being pumped into the FAS. The storage period for this cycle was 78 days. Recovery occurred for 28 days at a rate of 2,430 gpm (3.5 mgd) before the cycle was terminated based on the specific conductance limit in the NPDES permit. Recovery efficiency for Cycle 3 was 41 percent, a substantial increase over the recovery efficiencies of the previous cycles. The increased recovery efficiency likely was due to the development of a target storage volume in the storage zone following Cycle 2. The previous cycle test created a diffused zone of low-salinity water around the ASR well that kept higher-salinity formation water from interacting with the recharged fresh water. **Figure 12** is a graphical presentation of the volumes of water recharged, stored, and recovered during the first three test cycles. During Cycle 3, arsenic concentrations in water recovered from the ASR well and all the storage zone monitoring wells did not exceed 10 ppb. The results of the first three cycle tests were summarized by the USACE and SFWMD (2013). Upon completion of Cycle 3, the Hillsboro ASR system remained inactive for nearly 5 years (2012 to 2017).

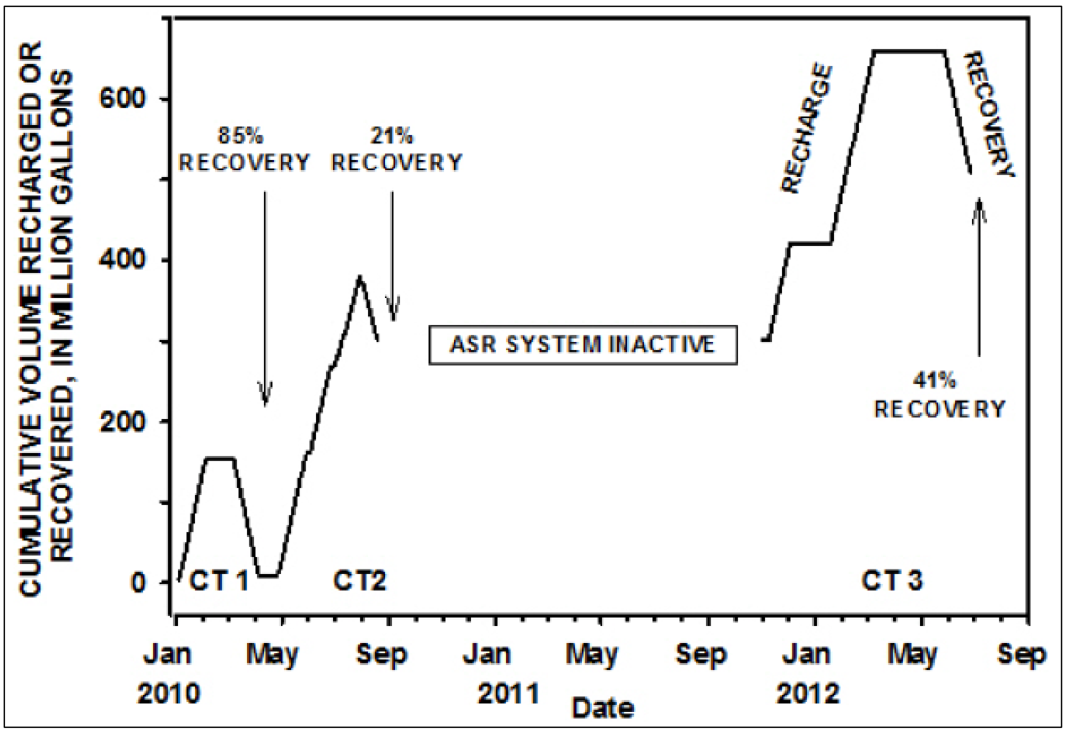

Figure 12. Hillsboro ASR facility cumulative recharge, storage, and recovery volumes (gallons) during the first three test cycles.

PART 3: CYCLE 4 RESULTS

Cycle Testing

Pre-Cycle Water Quality Testing

Prior to the initiation of Cycle 4, the SFWMD collected background water quality samples from the ASR well and the SAS monitoring well (PBS-11) on April 26, 2016 (**Table 3**). The results showed the salinity of water near the ASR well had not decreased substantially from Cycle 3 testing 5 years earlier. This is indicative of the slow rate of groundwater movement within the FAS and the buoyancy of the fresh water left after the end of Cycle 3. The high salinity of water collected from the SAS monitor well is further confirmation that connate water is present in the area.

Table 3. Water quality sampling results from the Hillsboro ASR well and monitoring well PBS-11.

Parameter	ASR Well	PBS-11
Depth Interval	Storage Zone	Surficial Aquifer System
Color	15	5
pH	7.6	7.1
Specific conductivity (µmhos/cm)	778	4,665
Total dissolved solids (mg/L)	548	2,380
Chloride (mg/L)	206	1,100
Sodium (mg/L)	127	718
Arsenic (ppb)	1.7	4.5
Sulfate (mg/L)	39.6	193

µmhos/cm = micromhos per centimeter; ASR = aquifer recharge, storage, and recovery; mg/L = milligrams per liter; ppb = parts per billion.

Recharge Phase

Recharge for Cycle 4 began on February 22, 2017. During the recharge phase, the system pumped water from the Hillsboro Canal into the ASR well at approximately 5 mgd, with average ASR wellhead pressures between 60 and 62 psi. Over 60 days, 323 million gallons (990 acre-feet) of water were pumped into the UFA storage zone; the recharge pump was turned off on April 24, 2017. During recharge, the pumping, filtration, and UV disinfection systems operated as designed; however, the drinking water standard for coliform bacteria occasionally was exceeded when water from the canal exhibited high color and turbidity. During the recharge phase, the SFWMD conducted water quality monitoring at the ASR well and monitoring wells PBF-10R, PBF-14, and PBS-11. Water quality monitoring was not conducted on the deeper FAS monitoring wells completed beneath the storage interval. The results of the water quality sampling are discussed later in this report.

Storage Phase

The Hillsboro ASR system was idle for 30 days after recharge was complete. During this storage phase, water quality sampling took place at monitor wells PBF-10R and PBF-14. The SFWMD collected samples for analysis of color, temperature, pH, turbidity, dissolved oxygen, specific conductivity, chloride, TDS, total coliform bacteria, and arsenic. The results of the water quality sampling are discussed later in this report.

Recovery Phase

On May 25, 2017, the SFWMD began the recovery phase from the ASR well using ambient artesian pressure from the FAS. The wellhead valve was opened, allowing water to flow from the ASR well through the system piping and into the Hillsboro Canal. The ASR wellhead pressure was approximately 16 psi before the wellhead valve was opened. Initial recovery flow rates were approximately 1,600 gpm, but after 6 days, the flow rate decreased to 1,400 gpm. Recovery lasted 89 days and ended when the recovered water exhibited a specific conductance of 1,275 µmhos/cm, in compliance with the NPDES permit (**Figure 13**). A total of 178 million gallons of water was recovered from the ASR system, a recovery efficiency of 60 percent. This recovery efficiency represented a continued increase in the percentage of water recovered from the ASR system, likely the result of the diffused buffer water in the storage zone from previous cycles. During the recovery phase, the SFWMD conducted water quality monitoring on the ASR well and monitor wells PBF-10R, PBF-14, and PBS-11 using the same parameters as in the recharge and storage phases.

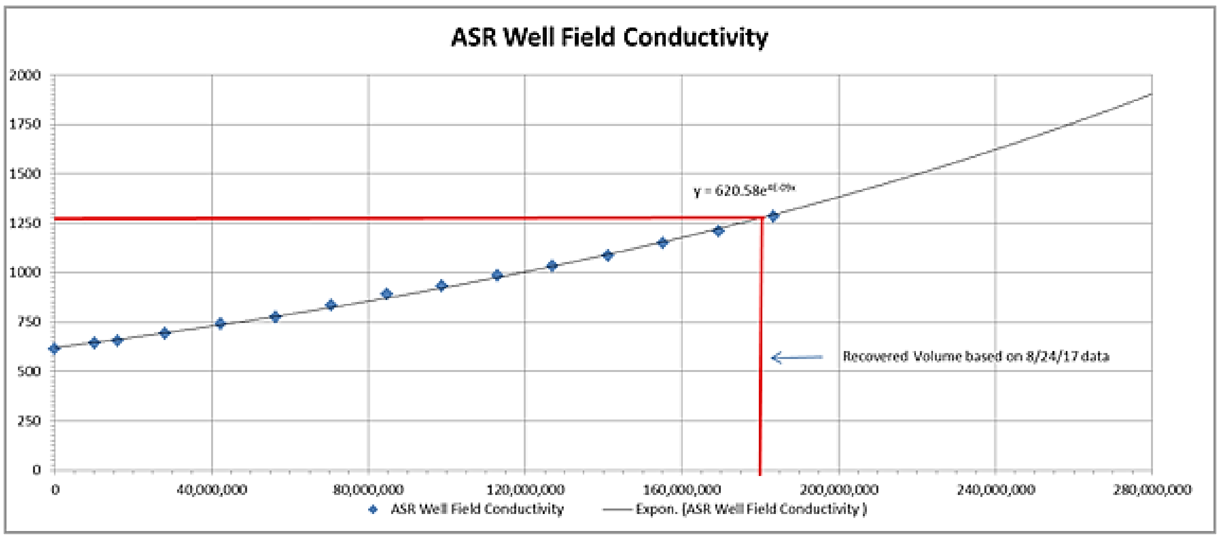

Figure 13. Specific conductivity of the water recovered from the Hillsboro ASR well during Cycle 4.

Hydraulic Responses During Cycle 4

ASR Well

Prior to Cycle 4, the ASR wellhead pressure was 16 psi, which translates to 37 feet of static artesian water level above land surface. Land surface elevation at the Hillsboro ASR site is approximately 13 feet above sea level (NGVD29). The wellhead pressure is representative of natural artesian pressure exhibited in the UFA in the area. When recharge commenced, wellhead pressure in the ASR well increased 34 psi over the pre-recharge level, equivalent to 79 feet of head. Recharge occurred at a rate of 3,900 gpm, which translated to a specific injectivity (capacity) of 50 gpm per foot of head.

By the end of the 60-day recharge period, the ASR wellhead pressure had increased from 50 to 60 psi while recharging at a rate of 3,500 gpm. This pressure increase translated to a 20 percent decline in specific injectivity, suggesting higher friction losses within the well casing and storage zone aquifer. The likely cause of this was scale buildup within the well casing and/or partial clogging of the storage zone from suspended solids or biological growth and encrustation.

Storage Zone Monitoring Wells

The hydraulic response to recharge was observed in water levels at the FAS monitoring wells completed within the storage interval (PBF-10R and PBF-14). The wellhead pressure in PBF-10R (330 feet from the ASR well) increased from 15 to 23 psi (an increase equivalent to approximately 16 feet of head; **Figure 14**). During the storage phase, wellhead pressure decreased to 15.5 psi, similar to pre-recharge levels. During artesian recovery from the ASR well, the pressure in PBF-10R decreased to 13.0 psi, a drawdown that equates to approximately 6 feet of head. When recovery from the ASR well ended, pressure in PBF-10R returned to 15.5 psi.

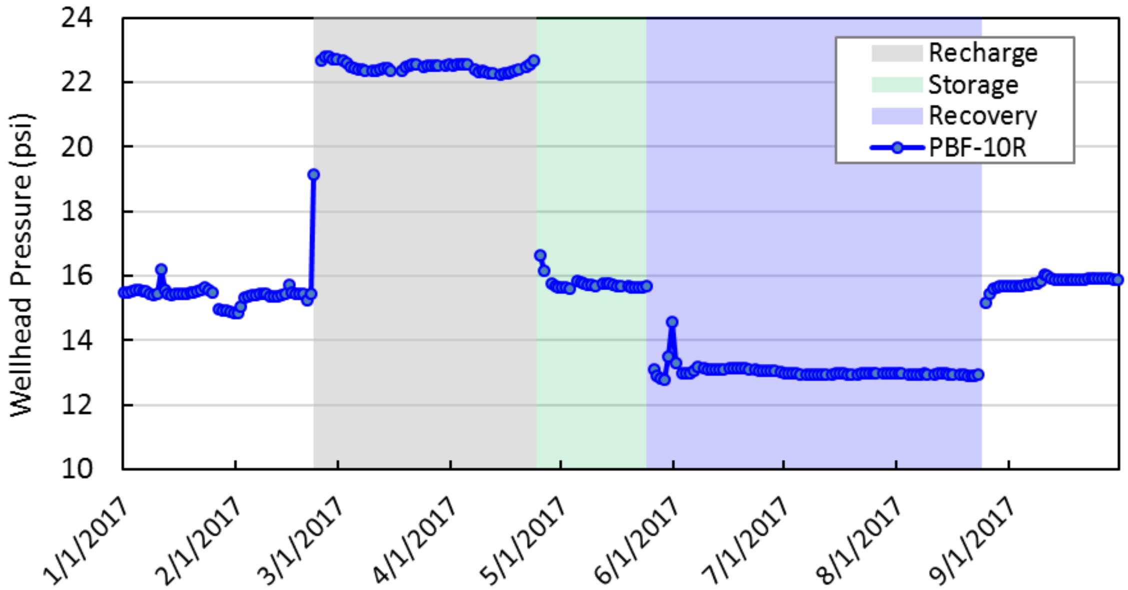

Figure 14. Wellhead pressure (in psi) in storage zone monitoring well PBF-10R in response to recharge, storage, and recovery at the Hillsboro ASR site during Cycle 4.

When recharge in the Hillsboro ASR well began, the pressure in PBF-14 (1,010 feet from the ASR well) increased from 15 to 21 psi, an increase equivalent to approximately 14 feet of head (**Figure 15**). When recharge ended (during storage), the pressure returned to pre-recharge values. When artesian recovery began, the pressure declined to 12 psi, and when recovery ended, the pressure returned to approximately 15 psi.

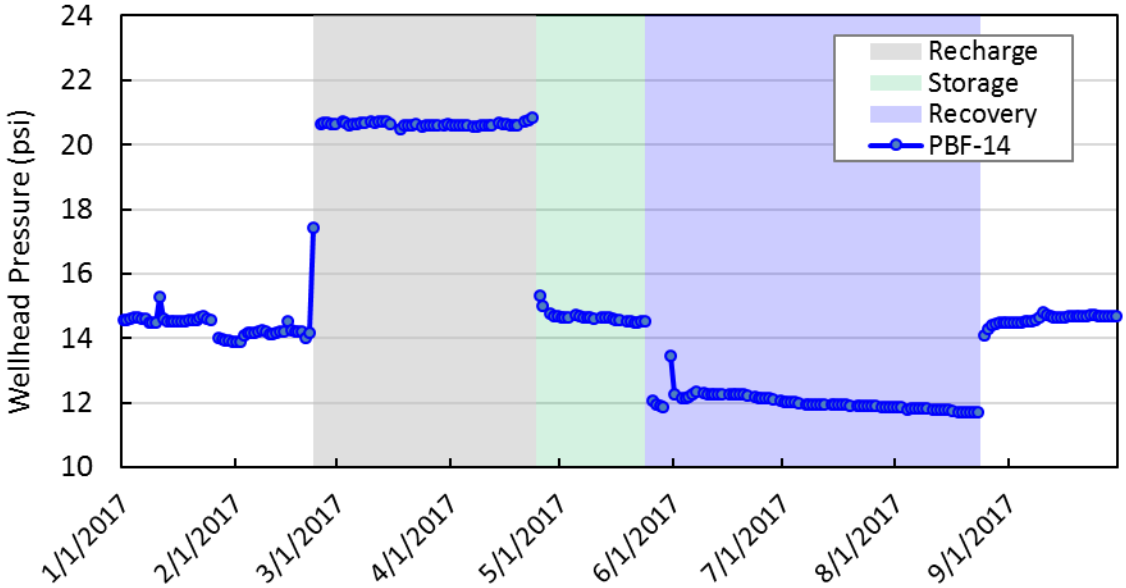

Figure 15. Wellhead pressure (in psi) at storage zone monitoring well PBF-14 in response to recharge, storage, and recovery at the Hillsboro ASR site during Cycle 4.

Monitor Wells Completed Below the Storage Zone

The wellhead pressure in PBF-11 (completed 400 feet below the storage zone) showed a subtle (1 psi) hydraulic response to the recharge, storage, and recovery phases of Cycle 4, indicating some communication (leakance) with the overlying storage zone. The pressure in PBF-11 fluctuated between 16 and 18 psi throughout the testing period (**Figure 16**). Leakance in this zone, which contains fresher water than the overlying storage zone, could explain the difference in salinities observed between the monitor well completed within the overlying storage interval at the site.

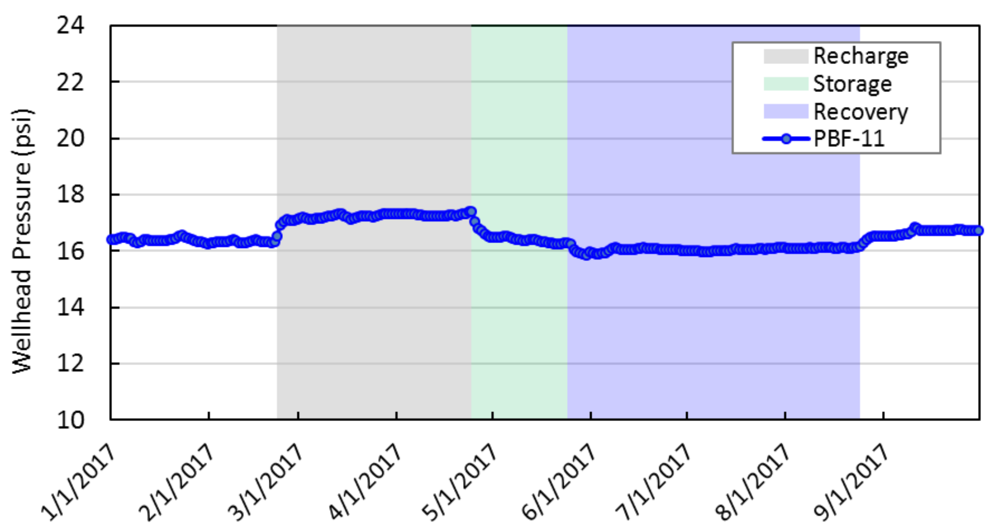

Figure 16. Wellhead pressure (in psi) in monitoring well PBF-11 during operation of the Hillsboro ASR well.

The wellhead pressure at monitoring well PBF-12, completed 1,000 feet below the ASR storage zone, did not show a direct response to the recharge, storage, or recovery phases. Wellhead pressures fluctuated between 11.5 and 12.5 psi throughout Cycle 4 (**Figure 17**).

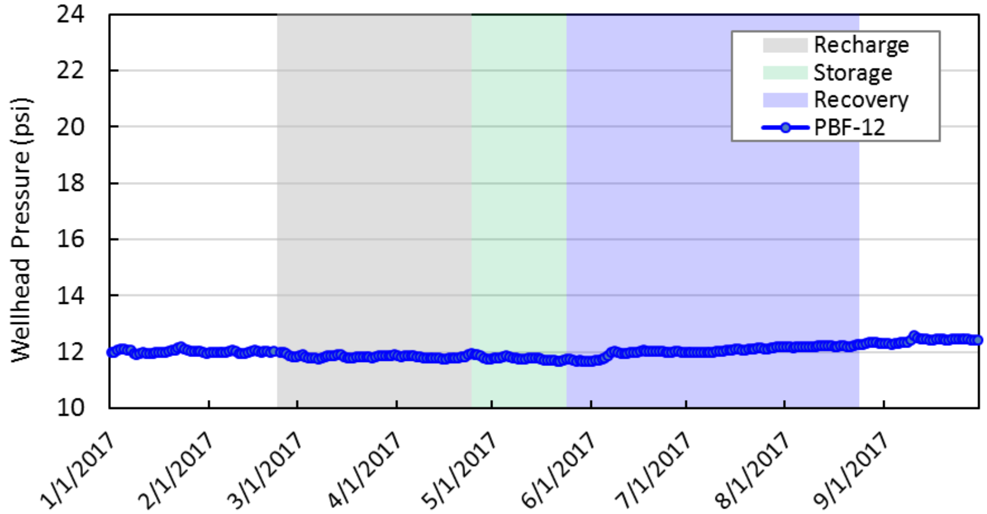

Figure 17. Wellhead pressure (in psi) in monitoring well PBF-12 during operation of the Hillsboro ASR well.

Water Quality During Cycles 1 through 4

The **Appendix** contains the water quality data collected during Cycles 1 through 4 for water recharged, stored, and recovered from the ASR well and collected from monitoring wells PBF-10R and PBF-14. Individual water quality plots are presented in the following subsections. The plots include data from Cycles 1 to 3 to provide context for the interpretation of Cycle 4 data.

Color

During the four test cycles, water from the Hillsboro Canal recharged into the ASR well exhibited color between 50 and 100 platinum-cobalt color units (PCUs), which is common for canal water within South Florida (**Figure 18**). Water recovered from the ASR well typically exhibited a lower color (20 to 40 PCUs), indicating substantial mixing with FAS groundwater. That the color of the water recovered from the ASR well did not decrease to the ambient (natural FAS groundwater) values indicates some canal water remained in the aquifer after recovery ended.

The color of the water collected from the storage zone monitoring wells (PBF-10R and PBF-14) remained very low (less than 5 PCUs) throughout all phases of each test cycle, indicating that by the time recharge water traveled to these monitoring wells through the storage zone strata, substantial filtration and dilution had occurred.

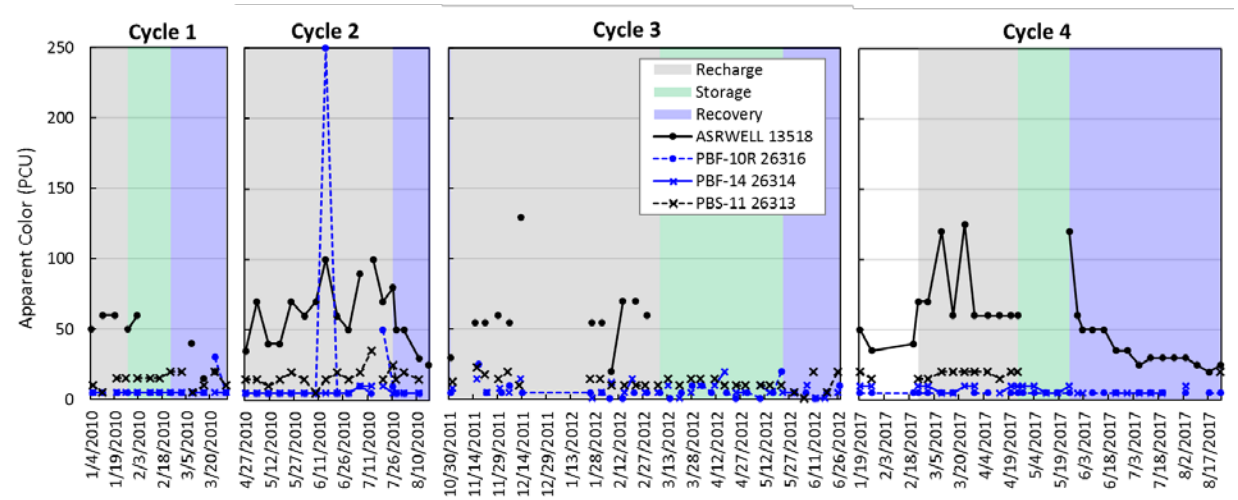

Figure 18. Water color from the Hillsboro ASR well and monitoring wells during the four test cycles.

During the recovery phase of Cycle 4, there was a distinct change in the visual tint of water collected from the ASR well. In **Figure 19**, the bottles on the left were collected when recovery began and the bottles on the right were collected near the end of the recovery period. The water transitions from a dark yellowish tint in the earliest recovered samples to nearly clear during the middle of recovery, then back to a yellowish tint towards the end of the recovery phase.

Figure 19. Weekly water samples collected from the Hillsboro ASR wellhead during the recovery phase of Cycle 4.

Temperature

During the four test cycles, the temperature of canal water recharged into the ASR well varied seasonally. During cooler months, the temperature of the recharge water ranged between 8°C and 22°C; during warmer months, the temperature was between 24°C and 32°C (**Figure 20**). In contrast, groundwater collected from the monitoring wells remained relatively constant (approximately 24°C) year-round, during all phases of recharge, storage, and recovery. Water temperature from the ASR well during each recovery phase of the cycle tests was approximately 24°C, indicating it had equilibrated to the ambient FAS groundwater temperature during storage.

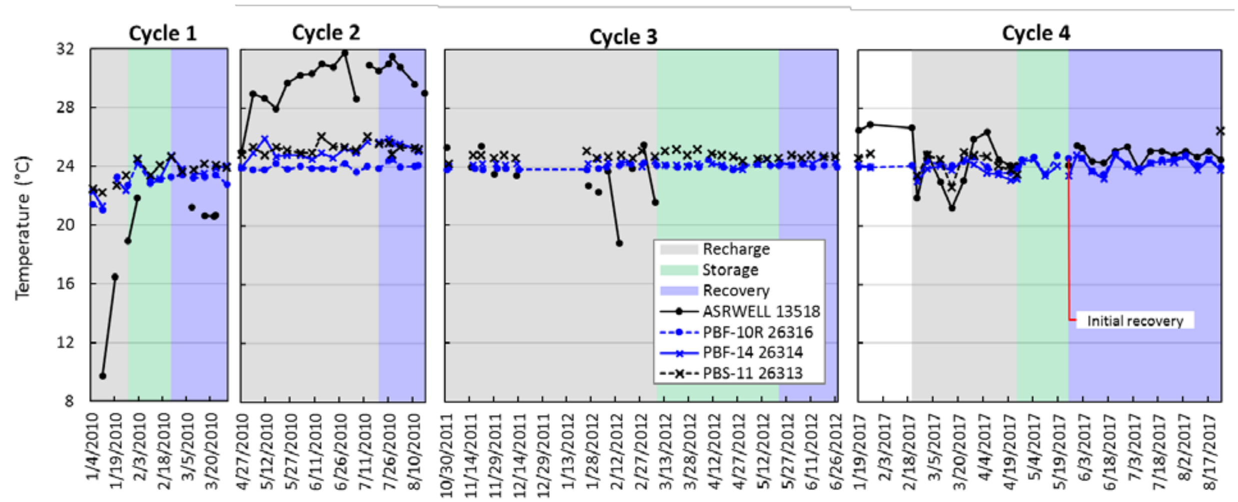

Figure 20. Water temperature from the Hillsboro ASR well and monitoring wells during the four test cycles.

pH

During the four test cycles, water from the Hillsboro Canal recharged into the ASR well exhibited pH values between 7 and 8, with occasional values slightly higher than 8 (**Figure 21**). The pH of water collected from the storage zone monitoring wells (PBF-10R and PBF-14) remained near 7.6 throughout all phases of the test cycles. Water recovered from the ASR well typically exhibited a similar pH, indicating it had equilibrated to the ambient groundwater. Water pH from the SAS monitor well remained around 7 during all the test cycles, with occasional spurious readings.

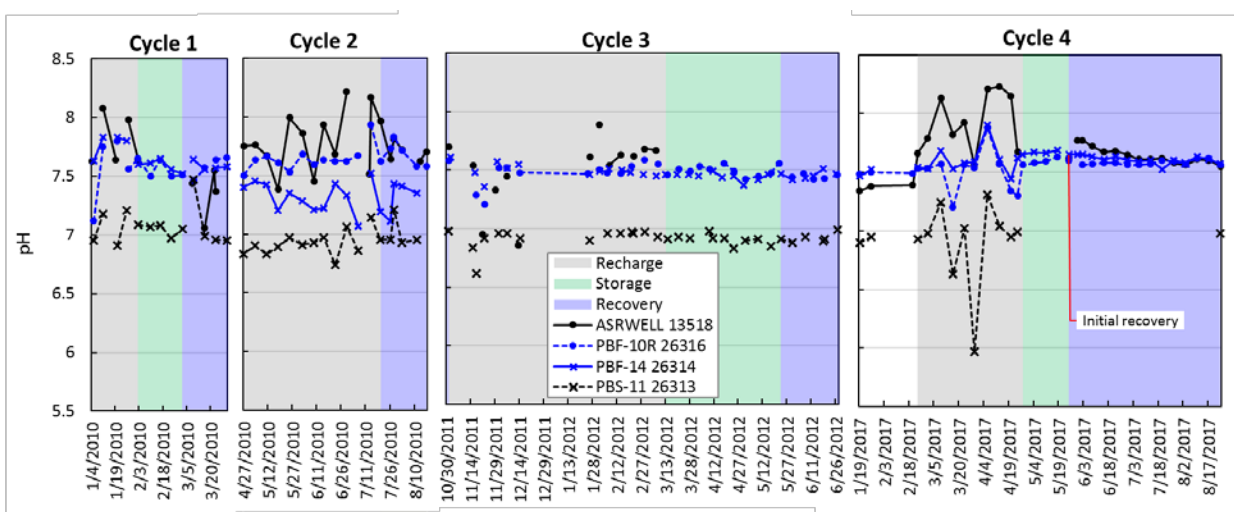

Figure 21. Water pH levels from the Hillsboro ASR well and monitoring wells during the four test cycles.

Turbidity

During the four test cycles, turbidity of the Hillsboro Canal water recharged into the ASR well ranged between 0.5 to 8.0 nephelometric turbidity units (NTU), with occasional readings higher than 8.0 NTU (**Figure 22**). During the recharge phase of Cycles 1 and 2, high turbidity readings were observed at PBF-10R and PBF-14, which may indicate passage of the front of mixed recharged canal water and ambient groundwater. During subsequent cycles, high turbidity readings were continually observed in samples collected from PBF-10R. A subsequent video inspection performed on that monitoring well indicated the open borehole had partially collapsed and become filled with unconsolidated formational debris. The high turbidity readings observed from samples collected from this well likely were the result of fine-grained materials from the collapsed borehole. By the end of the Cycle 4 recovery phase, the turbidity of water collected from the ASR well and all the monitoring wells was less than 1.0 NTU.

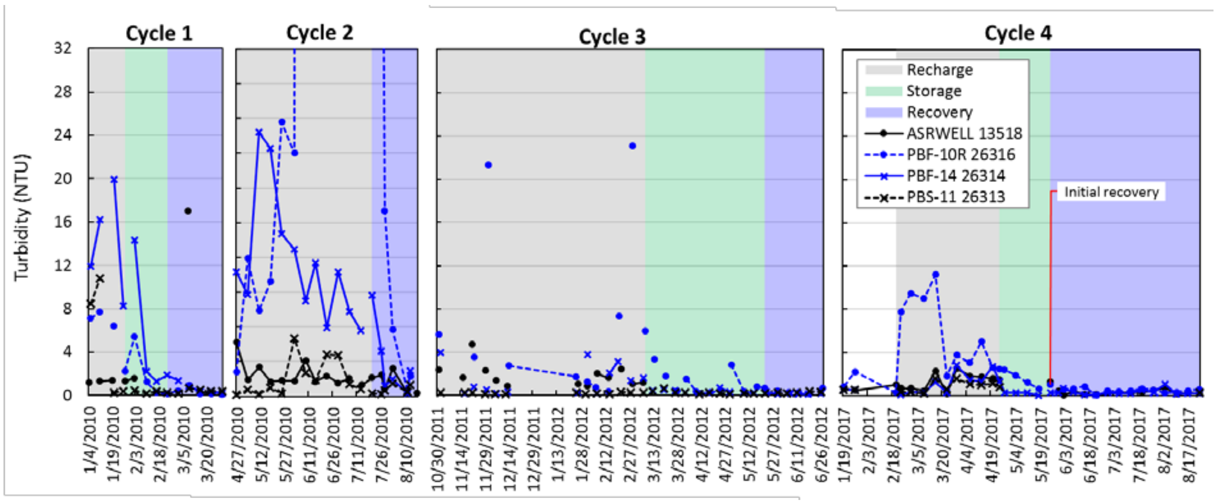

Figure 22. Water turbidity from the Hillsboro ASR well and monitoring wells during the four test cycles.

Dissolved Oxygen

Canal water recharged into the ASR well exhibited dissolved oxygen concentrations typical of surface water (2 to 10 mg/L), often between 4 and 8 mg/L. In contrast, water recovered from the storage zone monitoring wells contained low concentrations of dissolved oxygen (between 0.01 and 0.1 mg/L), typical of groundwater in most deep, confined aquifers (**Figure 23**). Water recovered from the ASR well also exhibited extremely low dissolved oxygen concentrations, indicating oxygen within the stored water had been consumed in biogeochemical reactions within the aquifer.

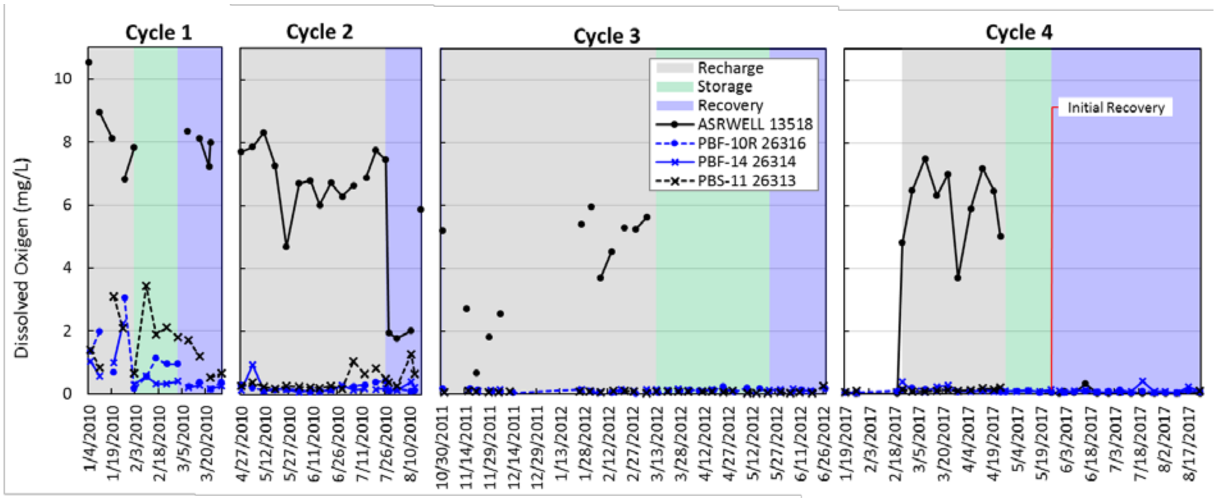

Figure 23. Dissolved oxygen concentrations from the Hillsboro ASR well and monitoring wells during the four test cycles.

Oxidation Reduction Potential

Canal water recharged into the ASR well exhibited positive oxidation reduction potential (ORP), between 20 and 100 millivolts (mV). Water collected from the storage zone monitoring wells (PBF-10R and PBF-14) consistently exhibited strongly negative ORP (between -200 and -260 mV) throughout recharge, storage, and recovery (**Figure 24**). During recharge, the ORP in water collected from the storage zone monitoring wells tended to trend slightly more positive as the oxygenated surface water mixed with ambient groundwater; however, during storage and recovery, the ORP tended to return to pre-recharge, strongly negative concentrations. Water recovered from the ASR well also exhibited strongly negative ORP, indicating it had equilibrated to ambient groundwater during storage. These results suggest oxygen is consumed within the storage zone a relatively short distance (less than 330 feet) from the ASR well.

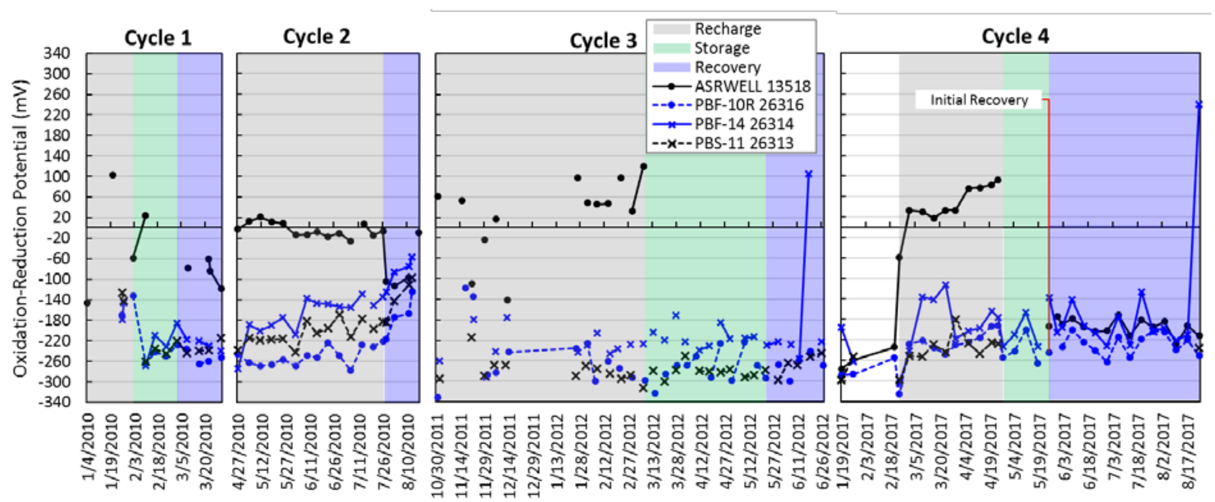

Figure 24. Oxidation reduction potential of water from the Hillsboro ASR well and monitoring wells during the four test cycles.

Specific Conductivity

Specific conductivity is a general measurement of the ionic concentration (or electrical conductance) of water and is considered a reliable indicator of water salinity. As discussed previously, there were substantial differences in the salinity of water collected from storage zone between monitoring wells prior to cycle testing. Fresh canal water recharged into the ASR well typically exhibited specific conductivity readings between 500 and 900 µmhos/cm. During recovery, the specific conductivity of water from the ASR well increased over time to 1,275 µmhos/cm, which was the allowable concentration limit in the NPDES permit.

As Cycles 1 through 4 progressed, the specific conductivity of water from PBF-10R (330 feet from the ASR well) decreased from 8,500 to 4,500 µmhos/cm (**Figure 25**). This trend indicates fresh canal water recharged into the storage zone had traveled the distance to PBF-10R but had not completely flushed the groundwater from the strata prior to ASR activities.

As Cycles 1 through 4 progressed, the specific conductivity of water from PBF-14 (1,010 feet from the ASR well) decreased from 6,000 to 2,000 µmhos/cm (**Figure 25**). At the end of the recovery phase for Cycle 4, the specific conductivity of water collected from PBF-14 was approximately 3,000 µmhos/cm, indicating substantial mixing of fresh canal water and ambient groundwater had occurred 1,000 feet from the ASR well.

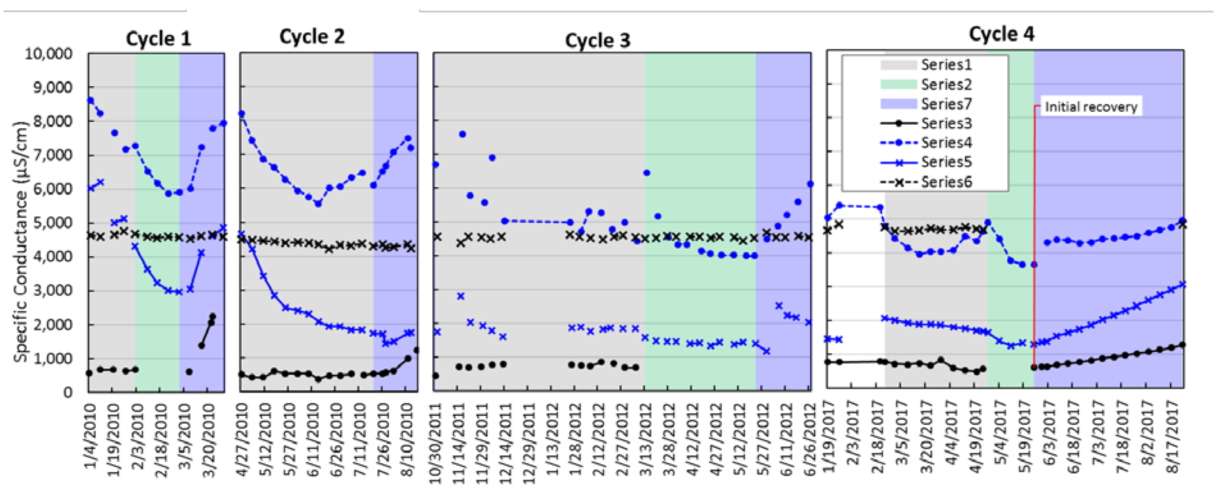

Figure 25. Specific conductivity of water from the Hillsboro ASR well and monitoring wells during the four test cycles.

Chloride

Fresh canal water recharged into the ASR well exhibited a chloride concentration between 80 and 200 mg/L (**Figure 26**). During the recovery phase of Cycle 1, the chloride concentration in water from the ASR well increased to 500 mg/L. During subsequent cycles, the chloride concentration typically increased to approximately 250 mg/L, which is the secondary drinking water quality standard for this constituent.

As recharge began and progressed, the chloride concentration of water from PBF-10R (330 feet from the ASR well) decreased from 2,000 to approximately 1,200 mg/L by the end of Cycle 4.

The chloride concentration of water from PBF-14 (1,010 feet from the ASR well) decreased from 1,500 to less than 500 mg/L during Cycles 2, 3, and 4. At the end of the recovery phase for Cycle 4, the chloride concentration in water collected from PBF-14 was approximately 700 mg/L, indicating substantial mixing of fresh canal water and ambient groundwater had occurred.

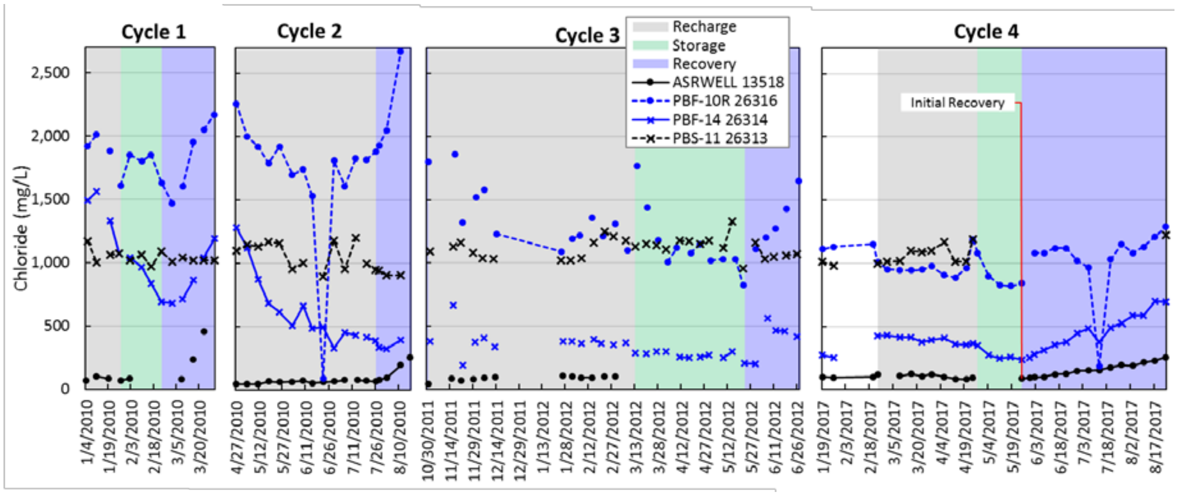

Figure 26. Chloride concentrations in water from the Hillsboro ASR well and monitoring wells during the four test cycles.

Total Dissolved Solids

Fresh canal water recharged into the ASR well exhibited a TDS concentration between 300 and 500 mg/L (**Figure 27**). During the recovery phase of Cycle 1, the TDS concentration in water from the ASR well increased to 1,000 mg/L. During subsequent cycles, the TDS concentration increased to approximately 500 mg/L, which is the secondary drinking water quality standard for this constituent. At the end of the recovery phase for Cycle 4, the TDS concentration of water from the ASR well was slightly less than 600 mg/L.

As recharge began and progressed through all four cycles, TDS concentrations in water from PBF-10R (330 feet from the ASR well) decreased from 5,000 to 3,000 mg/L.

The TDS concentration in water from PBF-14 (1,010 feet from the ASR well) decreased from 3,700 to 1,000 mg/L during Cycles 2 and 3. At the end of the recovery phase for Cycle 4, the TDS concentration in water collected from PBF-14 was approximately 1,800 mg/L, indicating substantial mixing of fresh canal water and ambient groundwater had occurred.

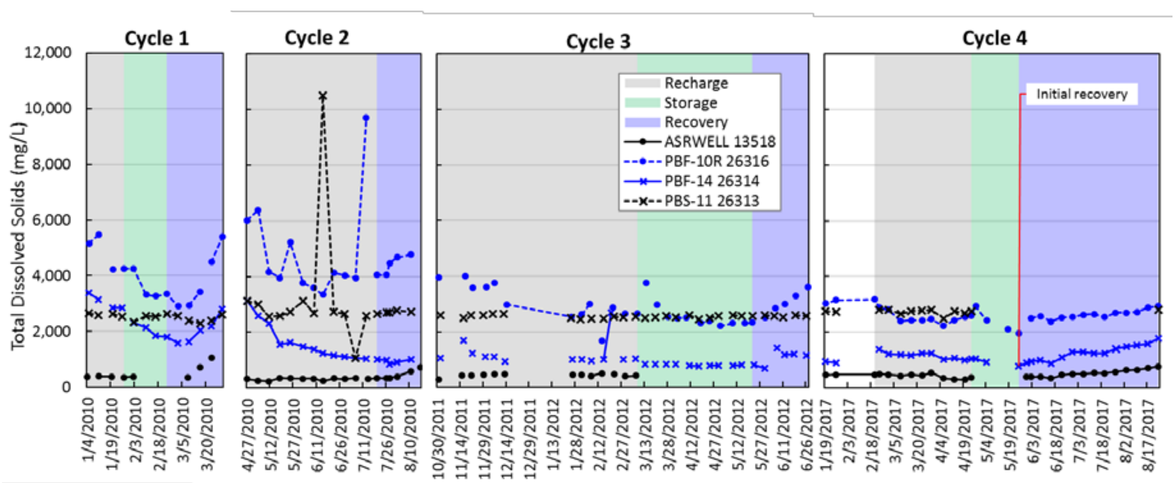

Figure 27. Total dissolved solids concentrations in water from the Hillsboro ASR well and monitoring wells during the four test cycles.

Total Coliform Bacteria

During the recharge phase of Cycle 1, the concentration of total coliform bacteria in water pumped into the ASR well remained below 10 colony forming units per 100 milliliters (cfu/100 mL). Water recovered from the ASR well did not contain detectable quantities of coliform bacteria (**Figure 28**). During the recharge phase of Cycles 2 and 3, total coliform bacteria concentrations began to increase, showing a decay in the effectiveness of the UV disinfection system. Occasional high concentrations of coliform bacteria were observed in the recharge water during the subsequent cycles. However, water recovered from the ASR well and the storage zone monitoring wells (PBF-10R and PBF-14) did not show detectable concentrations of coliform bacteria. This suggests these organisms are inactivated when subjected to anoxic conditions within the FAS during storage.

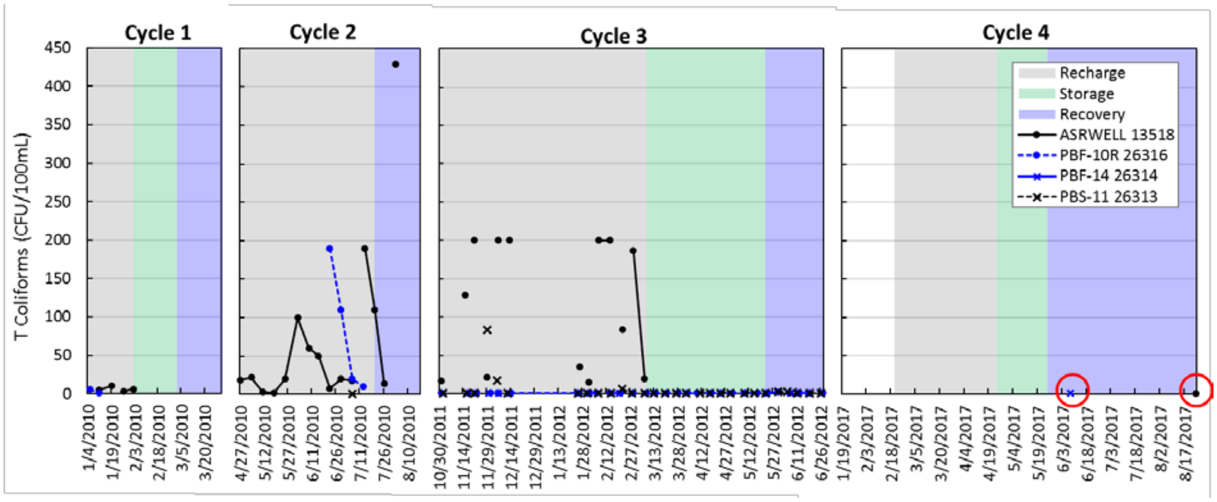

Figure 28. Total coliform bacteria concentrations in water from the Hillsboro ASR well and monitoring wells during the four test cycles.

Arsenic

During the recharge phase of each test cycle, the arsenic concentration in water from the Hillsboro Canal was less than 2 micrograms per liter (µg/L). The federal primary drinking water standard for arsenic is 10 µg/L. During Cycle 1, the arsenic concentration in recovered water was 102 µg/L during the initial flush but decreased to less than 7 µg/L over the remainder of the 31-day recovery period (**Figure 29**). During Cycles 2 and 3, arsenic concentrations in recovered water remained below 8 µg/L. During the recovery phase of Cycle 4, the arsenic concentration was 25 µg/L during the initial first flush but decreased to less than 8 µg/L after 3 weeks. It is likely that the re-introduction of oxygenated surface water into the storage zone following the 5-year inactive period provided a new "pulse" of reaction between the oxygenated surface water and the pyrite within the formation matrix, resulting in remobilization of arsenic near the ASR wellbore during Cycle 4.

Arsenic concentrations from PBF-10R were low during Cycle 1; however, during the storage phase of Cycle 2, arsenic concentrations were almost 20 µg/L. These high concentrations may be related to the high turbidity in water collected from this well, as a result of a partial borehole collapse. During the recovery period and throughout Cycles 3 and 4, arsenic concentrations in water from this well were less than 5 µg/L. Arsenic concentrations in water collected from PBF-14 were less than 2 µg/L during all the test cycles, except for one event when it reached 5 µg/L.

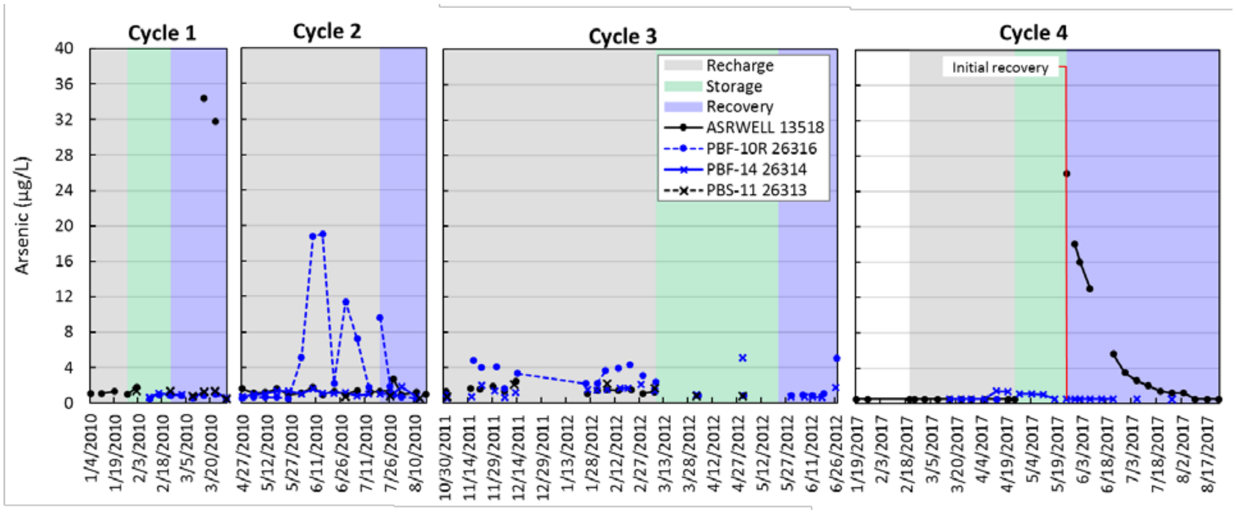

Figure 29. Arsenic concentrations in water from the Hillsboro ASR well and monitoring wells during the four test cycles.

Cycle 4 Essential Findings and Conclusions

- Cycle 4 at the Hillsboro ASR pilot project was successfully conducted from February to August 2017. The test consisted of 60 days of recharge and resulted in storage of approximately 300 million gallons (920 acre-feet) of water within the UFA.
- Recharge rate into the ASR well averaged 3,500 gpm, equivalent to 5 mgd or 8 cubic feet per second. The recharge period was followed by 30 days of storage.
- Recovery took place by allowing the ASR well to flow freely under artesian pressure back to the Hillsboro Canal. The recovery flow rate was approximately 1,400 gpm (equivalent to 2 mgd).
- Recovery ended after 89 days, when the specific conductivity of the recovered water reached 1,275 µmhos/cm. Approximately 178 million gallons of water were recovered from the ASR well.
- The recovery efficiency for Cycle 4 was approximately 60 percent, representing a continued increase in recovery efficiency from the previous cycles. Further improvement in the recovery efficiency is anticipated during subsequent operation of the system, as a target storage volume is developed.
- A net volume of 122 million gallons (equivalent to 374 acre-feet) of Hillsboro Canal water remained in the aquifer after recovery was terminated, which will locally recharge and freshen the FAS until the next cycle can be conducted.
- Equipment testing and monitoring indicated the facility operated as designed, although there were brief periods of noncompliance during recharge.
- The system was monitored remotely and during weekly site visits for routine operation and maintenance.
- During recharge, the ASR wellhead pressure increased from approximately 50 psi to more than 60 psi. To maintain optimal wellhead pressure, the well was back-flushed for a few hours on March 17, 2017.
- Water quality data from the storage zone monitor wells indicated canal recharge water mixed and diffused with UFA groundwater at distances of 330 and 1,010 feet away from the ASR well.

- Water recovered water from the ASR well exhibited an initial arsenic concentration of 25 ppb, which decreased to less than 10 ppb after 3 weeks. Arsenic was not detected in water collected from the site's monitor wells during the recovery period.

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APPENDIX

Table A-1. Cycle 1 water quality data.

Sample Date	Mode	Apparent Color (PCU)	Chloride (mg/L)	Dissolved Oxygen (mg/L)	F Coliforms (cfu/100 mL)	Oxidation Reduction Potential (mV)	pH	Specific Conductance (µS/cm)	T Coliforms (cfu/100 mL)	Temperature (°C)	Total Dissolved Solids (mg/L)	Turbidity (NTU)	Arsenic (µg/L)
ASR Well													
1/4/2010	Recharge	50	68.7	10.55	*	*	7.63	585	*	*	361	1.22	1.1
1/11/2010	Recharge	60	102	8.94	*	*	8.08	679	5	9.71	387	1.31	1.1
1/19/2010	Recharge	60	82.4	8.11	52	103.6	7.64	674	10	16.47	383	1.4	1.3
1/27/2010	Recharge	50	70.3	6.83	*	-59	7.98	631	3	18.91	352	1.3	1
2/2/2010	Recharge	60	82.8	7.83	*	24.7	7.64	678	6	21.83	379	1.62	1.8
2/10/2010	Storage	*	*	*	*	*	*	*	*	*	*	*	*
2/16/2010	Storage	*	*	*	*	*	*	*	*	*	*	*	*
2/23/2010	Storage	*	*	*	*	*	*	*	*	*	*	*	*
3/2/2010	Storage	*	*	*	*	*	*	*	*	*	*	*	*
3/8/2010	Recovery	40	81.2	8.34	*	-77.7	7.44	621	*	21.21	343	17	102
3/16/2010	Recovery	15	233	8.12	*	-60.5	7.06	1388	*	20.63	714	0.31	34.4
3/22/2010	Recovery	*	*	7.23	*	-83.4	7.55	2075	*	20.6	*	0.26	*
3/23/2010	Recovery	20	456	7.98	*	-119.1	7.37	2249	*	20.67	1050	0.31	31.8
4/7/2010	Recovery	*	*	6.76	*	-133.2	7.5	3988	*	21.66	*	0.22	6.7
PBF-10R													
1/5/2010	Recharge	5	1920	1.36	*	*	7.12	8611	6	21.4	5170	7.13	*
1/11/2010	Recharge	5	2010	1.98	*	*	7.75	8240	1	21.04	5470	7.7	*
1/20/2010	Recharge	5	1880	0.68	*	-169.4	7.8	7661	*	23.26	4230	6.39	*
1/27/2010	Recharge	5	1610	3.06	*	-132.3	7.56	7171	*	22.73	4260	2.25	*
2/2/2010	Recharge	5	1850	0.17	*	-264.2	7.65	7269	*	24.27	4250	5.41	*
2/10/2010	Storage	5	1800	0.55	*	-242.2	7.5	6525	*	22.82	3320	1.25	0.53
2/16/2010	Storage	5	1850	1.13	*	-249.5	7.64	6178	*	23.13	3270	0.26	0.9
2/23/2010	Storage	5	1630	0.95	*	-228	7.5	5878	*	23.24	3350	0.15	0.86
3/2/2010	Storage	5	1470	0.95	*	-235.9	7.51	5908	*	23.41	2910	0.45	0.85
3/9/2010	Recovery	5	1600	0.23	*	-265.1	7.46	6015	*	23.21	2940	0.91	0.61
3/16/2010	Recovery	5	1950	0.38	*	-260.1	7.57	7244	*	23.25	3430	0.17	0.82
3/23/2010	Recovery	30	2050	0.16	*	-252.2	7.64	7777	*	23.41	4490	0.16	0.98
3/30/2010	Recovery	5	2170	0.38	*	-267.8	7.66	7948	*	22.78	5400	0.11	0.52
4/7/2010	Recovery	*	*	*	*	*	*	*	*	*	*	*	*

Table A-1. Cycle 1 water quality data (continued).

Sample Date	Mode	Apparent Color (PCU)	Chloride (mg/L)	Dissolved Oxygen (mg/L)	F Coliforms (cfu/100 mL)	Oxidation Reduction Potential (mV)	pH	Specific Conductance (µS/cm)	T Coliforms (cfu/100 mL)	Temperature (°C)	Total Dissolved Solids (mg/L)	Turbidity (NTU)	Arsenic (µg/L)
PBF-14													
1/5/2010	Recharge	5	1490	1.03	*	*	7.63	6024	*	22.24	3380	11.9	*
1/11/2010	Recharge	5	1560	0.57	*	*	7.83	6197	*	21.29	3150	16.2	*
1/20/2010	Recharge	5	1330	1	*	-178.4	7.83	5000	*	23.05	2840	19.9	*
1/26/2010	Recharge	5	1070	2.24	*	-145.7	7.8	5122	*	22.35	2860	8.26	*
2/2/2010	Recharge	5	1040	0.3	*	-268.4	7.6	4317	*	24.47	2320	14.3	*
2/10/2010	Storage	5	966	0.57	*	-208.6	7.61	3648	*	23.15	2140	2.24	0.66
2/16/2010	Storage	5	837	0.33	*	-230.7	7.65	3243	*	23.12	1860	1.32	1.1
2/23/2010	Storage	5	691	0.32	*	-185.1	7.56	3015	*	24.71	1790	1.86	1
3/2/2010	Storage	5	681	0.4	*	-218.1	7.52	2981	*	23.81	1590	1.38	1
3/9/2010	Recovery	5	713	0.21	*	-220.9	7.64	3045	*	23.42	1630	0.81	0.75
3/16/2010	Recovery	5	865	0.27	*	-229.3	7.56	4125	*	23.52	2040	0.38	1.2
3/23/2010	Recovery	5	1040	0.16	*	-240	7.57	4626	*	23.88	2200	0.38	1.3
3/30/2010	Recovery	5	1190	0.26	*	-233.6	7.58	4859	*	24.04	2810	0.19	0.52
PBS-11													
1/5/2010	Recharge	10	1170	1.4	*	*	6.95	4640	*	22.44	2660	8.44	*
1/11/2010	Recharge	5	1000	0.83	*	*	7.18	4604	*	22.22	2590	10.8	*
1/20/2010	Recharge	15	1060	3.1	*	-126	6.91	4651	*	22.7	2630	0.23	*
1/26/2010	Recharge	15	1070	2.09	*	-143.3	7.21	4767	*	23.4	2540	0.39	*
2/2/2010	Recharge	15	1020	0.66	*	-259.9	7.09	4681	*	24.49	2330	0.43	1.4
2/10/2010	Storage	15	1060	3.44	*	-234.8	7.07	4602	*	23.38	2560	0.18	*
2/16/2010	Storage	15	971	1.88	*	-245.6	7.08	4550	*	24.08	2530	0.38	*
2/23/2010	Storage	20	1090	2.12	*	-219.7	6.97	4607	*	24.64	2620	0.26	1.4
3/2/2010	Storage	20	1010	1.79	*	-243.7	7.05	4582	*	23.61	2560	0.22	*
3/9/2010	Recovery	5	1040	1.71	*	-239.3	7.47	4541	*	23.8	2390	0.66	0.82
3/16/2010	Recovery	10	1020	1.19	*	-237.6	6.99	4615	*	24.17	2290	0.5	1.3
3/23/2010	Recovery	20	1020	0.52	*	-214.2	6.96	4659	*	24.05	2380	0.39	1.4
3/30/2010	Recovery	10	1020	0.65	*	-238	6.95	4601	*	23.93	2600	0.37	0.5

* Data not collected.

Table A-2. Cycle 2 water quality data.

Sample Date	Mode	Apparent Color (PCU)	Chloride (mg/L)	Dissolved Oxygen (mg/L)	F Coliforms (cfu/100 mL)	Oxidation Reduction Potential (mV)	pH	Specific Conductance (µS/cm)	T Coliforms (cfu/100 mL)	Temperature (°C)	Total Dissolved Solids (mg/L)	Turbidity (NTU)	Arsenic (µg/L)
ASR Well													
4/27/2010	Recharge	35	46.9	7.71	*	-2.6	8.07	509	19	25.02	323	6.22	1.6
5/4/2010	Recharge	70	45.8	7.87	*	12.3	7.75	427	22	28.98	262	1.88	1.1
5/11/2010	Recharge	40	45.5	8.33	*	21.1	7.76	429	3	28.66	239	3.38	1.2
5/18/2010	Recharge	40	67	7.28	*	12.1	7.67	616	2	27.95	353	1.7	1.6
5/25/2010	Recharge	70	62.6	4.69	8	8.7	7.38	542	20	29.69	340	1.81	0.95
6/2/2010	Recharge	60	64.7	6.71	10	-14	7.99	541	100	30.25	329	1.76	1.1
6/9/2010	Recharge	70	72.5	6.81	*	-13.2	7.86	543	60	30.32	335	4.15	1.8
6/15/2010	Recharge	100	55.9	6.02	*	-8.5	7.45	384	50	31	250	1.69	0.92
6/22/2010	Recharge	60	63.4	6.73	*	-17.1	7.93	478	8	30.78	346	2.34	1.3
6/29/2010	Recharge	50	67.4	6.29	*	-10.4	7.68	482	20	31.77	320	1.52	0.91
7/6/2010	Recharge	90	79.3	6.65	4	-25.9	8.21	532	18	28.61	358	2.07	1.4
7/14/2010	Recharge	100	79.1	6.9	4	7.7	7.51	490	190	30.94	316	1.34	1.2
7/20/2010	Recharge	70	73.1	7.76	38	-14.5	8.16	538	110	30.55	356	2.16	1.3
7/26/2010	Recharge	80	69.1	7.47	10	-5.8	7.96	538	14	31.02	339	2.48	1.3
7/28/2010	Recovery	50	82.6	1.96	*	-104.3	7.64	579	*	31.5	352	0.82	2.7
8/2/2010	Recovery	50	94.9	1.79	30	-113.3	7.81	625	430	30.78	402	3.18	0.9
8/11/2010	Recovery	30	196	2.03	*	-96.2	7.72	979	*	29.63	602	0.33	1.2
8/17/2010	Recovery	25	259	5.89	*	-9.8	7.62	1225	*	29.02	750	0.35	0.96
PBF-10R													
4/27/2010	Recharge	5	2260	0.32	*	-246.4	7.42	8199	*	23.96	6020	2.83	0.55
5/4/2010	Recharge	5	2000	0.22	*	-262.4	7.5	7410	*	23.82	6380	15.9	0.62
5/11/2010	Recharge	5	1920	0.14	*	-268.7	7.63	6868	*	23.79	4160	9.89	0.61
5/18/2010	Recharge	5	1790	0.15	*	-266.4	7.66	6611	*	24.22	3950	13.2	0.64
5/25/2010	Recharge	5	1920	0.18	*	-256.3	7.61	6255	*	23.84	5230	31.6	0.5
6/2/2010	Recharge	5	1700	0.15	*	-269.2	7.53	5934	*	24.02	3760	28	5.1
6/9/2010	Recharge	5	1740	0.09	*	-249.1	7.68	5751	*	23.92	3590	1000	18.8
6/15/2010	Recharge	250	1530	0.12	*	-252.3	7.59	5533	*	23.91	3350	1000	19
6/22/2010	Recharge	5	90.8	0.15	120	-223.5	7.63	6003	190	23.86	4130	157	2.2

Table A-2. Cycle 2 water quality data (continued).

Sample Date	Mode	Apparent Color (PCU)	Chloride (mg/L)	Dissolved Oxygen (mg/L)	F Coliforms (cfu/100 mL)	Oxidation Reduction Potential (mV)	pH	Specific Conductance (µS/cm)	T Coliforms (cfu/100 mL)	Temperature (°C)	Total Dissolved Solids (mg/L)	Turbidity (NTU)	Arsenic (µg/L)
6/29/2010	Recharge	5	1810	0.26	*	-249.1	7.62	6059	110	24.25	4040	1000	11.4
7/6/2010	Recharge	10	1610	0.27	10	-277.6	7.62	6310	20	23.65	3940	184	7.2
7/13/2010	Recharge	5	1830	0.32	*	-227.9	7.67	6464	10	24.04	9690	73.5	1.8
7/20/2010	Recharge	50	1820	0.41	*	-231.4	7.93	6088	*	23.92	4060	746	9.6
7/26/2010	Recharge	10	1880	0.44	*	-220.5	7.62	6505	*	24.41	4060	86.9	1.9
7/28/2010	Recovery	5	1930	0.13	*	-217.3	7.73	6669	*	24.55	4480	21.4	0.9
8/2/2010	Recovery	5	2050	0.18	*	-174	7.83	7075	*	24.01	4690	7.69	0.65
8/11/2010	Recovery	5	2670	0.12	*	-166.6	7.71	7478	*	24.02	4790	0.67	0.5
8/13/2010	Recovery	*	*	0.14	*	-124.6	7.58	7198	*	24.09	*	2.32	*
PBF-14													
4/27/2010	Recharge	5	1280	0.15	*	-274.5	7.57	4657	*	23.99	3130	14.3	0.67
5/4/2010	Recharge	5	1120	0.95	*	-188.7	7.4	4208	*	24.96	2580	11.7	0.96
5/11/2010	Recharge	5	871	0.11	*	-200.7	7.45	3410	*	25.91	2310	30.4	1
5/18/2010	Recharge	5	683	0.18	*	-189.2	7.42	2846	*	24.72	1560	28.6	1.3
5/25/2010	Recharge	5	613	0.16	*	-174.1	7.2	2488	*	24.78	1640	18.7	1.3
6/2/2010	Recharge	5	507	0.08	*	-208	7.35	2402	*	24.78	1490	16.9	1
6/9/2010	Recharge	5	663	0.15	*	-136.6	7.28	2297	*	24.49	1380	11	1.6
6/15/2010	Recharge	5	487	0.1	*	-147.1	7.21	2082	*	24.94	1250	15.4	1.1
6/22/2010	Recharge	5	495	0.15	*	-148.6	7.22	1926	*	24.61	1160	7.9	1.1
6/29/2010	Recharge	5	328	0.29	*	-154.1	7.43	1927	*	25.22	1120	14.3	1.2
7/6/2010	Recharge	10	452	0.14	*	-154.8	7.33	1835	*	24.95	1060	9.75	0.79
7/13/2010	Recharge	10	435	0.18	*	-129.3	7.07	1823	*	25.72	1040	7.59	0.98
7/20/2010	Recharge	10	415	0.17	*	-150.9	7.52	1730	*	25.67	1030	11.6	1
7/26/2010	Recharge	5	388	0.2	*	-133.9	7.19	1710	*	25.92	1000	5.23	0.97
7/28/2010	Recovery	5	337	0.14	*	-125	7.11	1430	*	25.64	848	1.22	1
8/2/2010	Recovery	5	327	0.15	*	-86.3	7.43	1481	*	25.59	934	1.98	1.8
8/11/2010	Recovery	5	396	0.42	*	-74.5	7.41	1728	*	25.24	1030	0.3	0.66
8/13/2010	Recovery	*	*	0.23	*	-56.4	7.35	1756	*	25.06	*	2.91	*

Table A-2. Cycle 2 water quality data (continued).

Sample Date	Mode	Apparent Color (PCU)	Chloride (mg/L)	Dissolved Oxygen (mg/L)	F Coliforms (cfu/100 mL)	Oxidation Reduction Potential (mV)	pH	Specific Conductance (µS/cm)	T Coliforms (cfu/100 mL)	Temperature (°C)	Total Dissolved Solids (mg/L)	Turbidity (NTU)	Arsenic (µg/L)
PBS-11													
4/27/2010	Recharge	15	1100	0.27	*	-237.9	7	4499	*	24.87	3120	0.19	*
5/4/2010	Recharge	15	1150	0.38	*	-214.1	6.83	4464	*	25.36	2990	0.77	*
5/11/2010	Recharge	10	1130	0.26	*	-218.9	6.9	4443	*	24.78	2560	0.28	*
5/18/2010	Recharge	15	1170	0.19	*	-217.7	6.83	4442	*	25.36	2580	1.01	*
5/25/2010	Recharge	20	1160	0.27	*	-216.4	6.89	4386	*	25.15	2730	0.35	*
6/2/2010	Recharge	15	952	0.25	*	-242.4	6.97	4414	*	24.94	3120	6.64	*
6/9/2010	Recharge	5	1000	0.23	*	-182	6.91	4395	*	24.93	2690	2.71	*
6/15/2010	Recharge	15	*	0.2	*	-205	6.93	4347	*	26.05	10500	1.86	*
6/22/2010	Recharge	20	894	0.28	*	-195.1	6.97	4215	*	25.39	2720	4.84	*
6/29/2010	Recharge	15	1180	0.18	*	-169	6.74	4324	*	25.36	2660	4.75	0.68
7/6/2010	Recharge	20	954	1.05	*	-211.8	7.06	4320	1	25.15	1070	1.4	*
7/13/2010	Recharge	35	1200	0.65	*	-177.3	6.86	4364	*	26.05	2590	0.79	*
7/20/2010	Recharge	15	998	0.83	*	-196.6	7.14	4287	*	25.57	2660	0.35	*
7/26/2010	Recharge	25	951	0.51	*	-183.3	6.95	4344	*	25.65	2700	0.23	0.77
7/28/2010	Recovery	15	945	0.4	*	-184.8	6.95	4256	*	24.85	2710	0.62	*
8/2/2010	Recovery	20	904	0.28	*	-142.8	7.21	4276	*	25.36	2780	1.45	*
8/11/2010	Recovery	15	907	1.29	*	-110.8	6.93	4346	*	25.28	2730	0.52	*
8/13/2010	Recovery	*	*	0.66	*	-97.7	6.95	4234	*	25.19	*	1.32	0.5

* Data not collected.

Table A-3. Cycle 3 water quality data.

Sample Date	Mode	Apparent Color (PCU)	Chloride (mg/L)	Dissolved Oxygen (mg/L)	F Coliforms (cfu/100 mL)	Oxidation Reduction Potential (mV)	pH	Specific Conductance (µS/cm)	T Coliforms (cfu/100 mL)	Temperature (°C)	Total Dissolved Solids (mg/L)	Turbidity (NTU)	Arsenic (µg/L)
ASR Well													
10/31/2011	Recharge	30	40.8	5.2	2	61.7	7.7	448	17	25.3	272	2.39	1.33
11/15/2011	Recharge	55	86.4	2.72	2	52.3	7.54	717	129	24	420	1.65	1.6
11/21/2011	Recharge	55	69.6	0.66	8	-109	6.95	692.1	200	25.4	422	4.7	1.55
11/29/2011	Recharge	60	77.6	1.82	2	-24	7.33	718	21	23.51	444	2.3	1.89
12/6/2011	Recharge	55	89	2.56	79	16.1	7.45	772	200	23.9	476	1.37	1.32
12/13/2011	Recharge	130	96.4	*	11	-142.1	6.86	798	200	23.4	472	0.89	2.46
1/26/2012	Recharge	55	104	5.41	8	96.7	7.61	779	35	22.7	450	1.08	1.05
2/1/2012	Recharge	55	102	5.97	2	48.9	7.89	766	15	22.3	446	0.9	1.42
2/7/2012	Recharge	20	93	3.71	49	45.4	7.54	745	200	23.7	408	2.05	1.5
2/14/2012	Recharge	70	92	4.52	17	46.7	7.63	856	200	18.8	498	1.66	1.42
2/22/2012	Recharge	70	100	5.29	2	97	7.62	816	84	23.9	482	2.46	1.46
2/29/2012	Recharge	60	99.5	5.24	7	32	7.68	699	187	25.5	396	1.05	1.1
3/7/2012	Recharge	*	*	5.62	2	119.4	7.67	695	19	21.6	416	1.23	1.27
5/30/2012	Recovery	50	86	5.74	70	-87.8	7.44	595	200	26.2	370	1.81	5.05
6/5/2012	Recovery	1	1030	4.54	49	-43.9	7.17	522	200	27.3	282	1.44	1.15
6/12/2012	Recovery	80	67.5	4.66	2	-78.3	7.03	441	5	28.3	270	0.84	0.79
6/20/2012	Recovery	40	95.8	5.28	2	-166.2	7.44	709	71	27	404	3	1.18
6/25/2012	Recovery	40	131	5.19	2	-56.6	7.46	822	5	26.2	484	0.98	1.37
PBF-10R													
10/31/2011	Recharge	5	1800	0.17	2	-331.6	7.58	6697	1	23.8	3960	5.66	0.88
11/17/2011	Recharge	25	1860	0.17	2	-118	7.29	7605	1	23.9	4000	*	4.82
11/22/2011	Recharge	5	1320	0.13	2	-134	7.21	5790	1	23.8	3580	3.56	4.02
12/1/2011	Recharge	5	1520	0.08	2	-286.9	7.52	5574	1	23.9	3600	21.3	4.05
12/6/2011	Recharge	10	1580	0.08	2	-282.7	7.52	6902	1	23.9	3760	41.7	1.6
12/14/2011	Recharge	5	1230	0.03	2	-243.5	7.48	5032	1	23.8	2980	2.76	3.33
1/25/2012	Recharge	5	1090	0.14	2	-235.5	7.47	4992	1	23.8	2540	1.75	2.2
2/1/2012	Recharge	5	1190	0.09	2	-226.1	7.5	4726	1	23.9	2620	1.24	2.25
2/6/2012	Recharge	1	1220	0.03	2	-300.2	7.48	5318	1	24	2990	0.75	3.65

Table A-3. Cycle 3 water quality data (continued).

Sample Date	Mode	Apparent Color (PCU)	Chloride (mg/L)	Dissolved Oxygen (mg/L)	F Coliforms (cfu/100 mL)	Oxidation Reduction Potential (mV)	pH	Specific Conductance (µS/cm)	T Coliforms (cfu/100 mL)	Temperature (°C)	Total Dissolved Solids (mg/L)	Turbidity (NTU)	Arsenic (µg/L)
2/14/2012	Recharge	1	1360	0.04	2	-260.5	7.47	5277	1	24.1	1680	0.37	3.95
2/21/2012	Recharge	5	1210	0.1	2	-275	7.53	4790	1	24.2	2880	7.32	4.3
2/29/2012	Recharge	5	1310	0.02	2	-292.8	7.59	4982	1	24.3	2650	23.1	3.09
3/8/2012	Recharge	5	1100	0.06	2	-298.1	7.55	4444	1	24.1	2650	5.94	2.37
3/14/2012	Storage	1	1770	0.03	2	-323.1	7.46	6445	1	24.1	3760	3.37	*
3/21/2012	Storage	5	1440	0.11	2	-285.5	7.51	5172	1	24	2980	1.8	*
3/28/2012	Storage	10	1180	0.11	2	-268.9	7.49	4547	1	24.1	2520	0.41	*
4/3/2012	Storage	10	1010	0.12	2	-269.3	7.53	4342	1	24	2480	1.54	0.8
4/9/2012	Storage	5	1120	0.11	2	-251.2	7.51	4341	1	24.5	2500	0.38	*
4/18/2012	Storage	5	1080	0.12	2	-293	7.56	4139	1	24	2310	0.29	*
4/24/2012	Storage	1	1150	0.24	2	-226	7.49	4073	1	23.8	2370	0.46	*
5/1/2012	Storage	5	1020	0.06	2	-299	7.42	4021	1	24.1	2200	2.86	0.8
5/9/2012	Storage	1	1030	0.2	2	-224	7.45	4035	1	24.17	2300	0.36	*
5/17/2012	Storage	5	1030	0.17	2	-268.9	7.48	4005	1	24.1	2300	0.82	*
5/22/2012	Storage	20	824	0.07	*	-293.8	7.56	3997	*	24.1	2330	0.66	*
5/23/2012	Storage	*	*	*	2	*	*	*	1	*	*	*	*
5/30/2012	Recovery	5	1110	0.06	2	-267.6	7.44	4486	2	24.1	2510	0.43	0.8
6/6/2012	Recovery	5	1200	0.05	2	-300.2	7.47	4883	1	24.2	2840	0.27	0.9
6/12/2012	Recovery	1	1270	0.13	2	-258.8	7.42	5211	1	24	2990	0.27	0.85
6/19/2012	Recovery	5	1430	0.08	2	-242.1	7.43	5601	1	24.1	3280	0.16	1.05
6/27/2012	Recovery	10	1650	0.17	2	-269.5	7.46	6129	1	24	3610	0.66	5.1
PBF-14													
11/1/2011	Recharge	8	377	0.06	2	-259.9	7.61	1742	1	24	1040	3.99	0.54
11/16/2011	Recharge	15	664	0.12	2	*	7.48	2810	1	24.1	1680	0.22	0.7
11/22/2011	Recharge	5	190	0.09	2	-180	7.36	2038	1	24.2	1220	0.8	1.99
11/30/2011	Recharge	8	376	0.12	2	-292.1	7.57	1930	1	24.2	1090	0.52	1.35
12/6/2011	Recharge	5	405	0.15	2	-242	7.52	1786	1	24.1	1090	0.17	0.64
12/13/2011	Recharge	15	336	*	2	-175.7	7.55	1612	1	24.2	924	0.33	1.23
1/26/2012	Recharge	1	379	0.14	2	-244.2	7.46	1867	1	24.2	1000	0.25	1.48
2/1/2012	Recharge	5	378	0.1	2	-230.2	7.49	1902	1	24.5	1000	3.76	1.45
2/7/2012	Recharge	12	363	0.05	2	-206.3	7.51	1762	1	24.3	948	0.19	1.5

Table A-3. Cycle 3 water quality data (continued).

Sample Date	Mode	Apparent Color (PCU)	Chloride (mg/L)	Dissolved Oxygen (mg/L)	F Coliforms (cfu/100 mL)	Oxidation Reduction Potential (mV)	pH	Specific Conductance (µS/cm)	T Coliforms (cfu/100 mL)	Temperature (°C)	Total Dissolved Solids (mg/L)	Turbidity (NTU)	Arsenic (µg/L)
2/15/2012	Recharge	5	394	0.06	2	-246.8	7.5	1832	1	24.3	1000	2.09	1.72
2/20/2012	Recharge	15	361	0.14	2	-236.8	7.48	1872	1	24.3	2690	3.12	1.7
2/28/2012	Recharge	5	354	0.1	2	-227.8	7.46	1851	1	24	1000	1.4	2.1
3/7/2012	Recharge	5	370	0.14	2	-226.8	7.45	1843	1	24.4	1030	1.62	1.34
3/13/2012	Storage	10	290	0.15	2	-205.1	7.46	1579	1	24.1	828	0.47	*
3/20/2012	Storage	1	284	0.11	2	-220.5	7.46	1493	1	24.1	824	0.5	*
3/27/2012	Storage	5	298	0.17	2	-171.6	7.46	1455	1	24	820	0.46	*
4/2/2012	Storage	10	296	0.12	2	-222	7.45	1458	1	24.2	820	0.29	0.92
4/11/2012	Storage	10	254	0.09	2	-239.9	7.49	1401	1	24.2	772	0.19	*
4/17/2012	Storage	20	252	0.14	2	-230.6	7.44	1426	1	24.1	760	0.25	*
4/24/2012	Storage	5	253	0.14	2	-184.7	7.45	1335	1	23.9	768	0.71	*
4/30/2012	Storage	5	272	0.09	2	-217.4	7.37	1436	1	23.8	784	0.35	5.08
5/9/2012	Storage	10	247	0.02	2	-216.2	7.42	1386	1	24.14	776	0.24	*
5/15/2012	Storage	5	296	0.03	2	-212.8	7.46	1437	1	24.5	792	0.23	*
5/23/2012	Storage	5	204	0.11	2	-230.3	7.47	1402	1	24.3	808	0.33	*
5/30/2012	Recovery	5	199	0.13	2	-223.2	7.42	1177	2	24.1	688	0.14	0.7
6/7/2012	Recovery	10	562	0.16	2	-228.3	7.43	2536	1	24.2	1420	0.22	0.72
6/12/2012	Recovery	1	466	0.1	2	-255.8	7.45	2232	1	24.2	1180	0.16	0.69
6/18/2012	Recovery	1	460	0.1	2	105	7.51	2187	1	24.65	1200	0.16	0.6
6/26/2012	Recovery	5	418	0.25	2	-222.3	7.47	2037	1	24.3	1150	0.22	1.78
PBS-11													
11/1/2011	Recharge	13	1090	0.05	2	-294.6	6.98	4558	1	24.2	2600	0.23	0.7
11/16/2011	Recharge	23	1130	0.1	2	*	6.84	4385	1	24.8	2480	0.26	*
11/21/2011	Recharge	18	1160	0.08	2	-214	6.62	4566	1	24.8	2600	0.26	*
11/29/2011	Recharge	15	1080	0.05	2	-289.1	6.92	4555	83	24.6	2590	0.16	*
12/5/2011	Recharge	20	1040	0.05	2	-268.2	6.96	4515	17	24.8	2630	0.11	*
12/12/2011	Recharge	10	1030	0.08	2	-268.1	6.96	4567	1	24.6	2640	0.16	2.12
1/25/2012	Recharge	15	1020	0.07	2	-289.6	6.92	4621	1	25.1	2500	0.24	*
1/31/2012	Recharge	15	1020	0.07	2	-270	6.9	4574	1	24.6	2450	0.16	*
2/7/2012	Recharge	10	1040	0.05	2	-275	6.96	4517	1	24.7	2470	0.19	2.2
2/15/2012	Recharge	10	1160	0.09	2	-284.5	6.96	4481	1	24.8	2470	0.11	*

Table A-3. Cycle 3 water quality data (continued).

Sample Date	Mode	Apparent Color (PCU)	Chloride (mg/L)	Dissolved Oxygen (mg/L)	F Coliforms (cfu/100 mL)	Oxidation Reduction Potential (mV)	pH	Specific Conductance (µS/cm)	T Coliforms (cfu/100 mL)	Temperature (°C)	Total Dissolved Solids (mg/L)	Turbidity (NTU)	Arsenic (µg/L)
2/22/2012	Recharge	10	1250	0.09	2	-294.7	6.97	4567	6	24.6	2550	0.31	*
2/28/2012	Recharge	10	1210	0.08	2	-287.5	6.96	4600	1	25.1	2520	0.26	*
3/7/2012	Recharge	10	1180	0.04	2	-313	6.97	4548	1	24.7	2550	0.25	1.69
3/13/2012	Storage	15	1130	0.07	2	-279.7	6.93	4515	1	25.1	2480	0.38	*
3/20/2012	Storage	10	1150	0.07	2	-300.1	6.91	4534	1	25.2	2510	0.64	*
3/27/2012	Storage	15	1140	0.08	2	-278.8	6.93	4582	1	24.8	2570	0.24	*
4/2/2012	Storage	15	1110	0.08	2	-250.3	6.92	4575	1	25.2	2520	0.24	0.75
4/11/2012	Storage	15	1180	0.07	2	-280.1	6.98	4567	1	24.9	2590	0.13	*
4/17/2012	Storage	10	1170	0.07	2	-280.5	6.92	4563	1	24.8	2440	0.29	*
4/24/2012	Storage	10	1150	0.06	2	-281.8	6.92	4530	1	24.7	2490	0.19	*
4/30/2012	Storage	10	1180	0.1	2	-277.3	6.83	4568	1	24.4	2560	0.1	0.81
5/9/2012	Storage	10	1120	0.02	2	-291.5	6.9	4547	1	24.55	2580	0.2	*
5/15/2012	Storage	10	1330	0.03	2	-287.7	6.91	4442	1	24.55	2560	0.19	*
5/22/2012	Storage	10	954	0.04	2	-278.6	6.85	4530	1	24.6	2570	0.19	*
5/30/2012	Recovery	5	1160	0.05	2	-298.3	6.91	4680	2	24.8	2580	0.28	*
6/5/2012	Recovery	1	1030	0.04	2	-264.6	6.88	4553	2	24.6	2570	0.19	*
6/11/2012	Recovery	20	1050	0.05	2	-268.3	6.93	4554	1	24.8	2520	0.27	*
6/19/2012	Recovery	5	1060	0.04	2	-252.5	6.89	4591	1	24.7	2580	0.4	*
6/26/2012	Recovery	20	1070	0.25	2	-245.3	6.91	4545	1	24.7	2570	0.33	*

* Data not collected.

Table A-4. Cycle 4 water quality data.

Sample Date	Mode	Apparent Color (PCU)	Chloride (mg/L)	Dissolved Oxygen (mg/L)	F Coliforms (cfu/100 mL)	Oxidation Reduction Potential (mV)	pH	Specific Conductance (µS/cm)	T Coliforms (cfu/100 mL)	Temperature (°C)	Total Dissolved Solids (mg/L)	Turbidity (NTU)	Arsenic (µg/L)
ASR Well													
4/26/2016	*	15	206	0.05	*	-242.2	7.45	1144	*	24	548	0.91	1.7
5/25/2016	*	15	192	0.03	*	-289.7	7.41	1107	*	24.3	604	0.72	0.5
6/1/2016	*	*	*	*	*	*	*	*	*	*	*	*	*
6/29/2016	*	90	75.5	4.83	1	121.5	7.42	538	*	29.8	307	1.01	1
7/6/2016	*	*	*	*	*	*	*	*	*	*	*	*	*
7/13/2016	*	*	*	*	*	*	*	*	*	*	*	*	*
7/20/2016	*	*	*	*	*	*	*	*	*	*	*	*	*
7/27/2016	*	*	*	*	*	*	*	*	*	*	*	*	*
1/19/2017	*	50	101	0.05	*	-276.4	7.34	778	*	26.5	454	0.67	0.5
1/26/2017	*	35	95.6	0.02	*	-259.1	7.38	781	*	26.9	472	0.5	0.5
2/20/2017	*	40	101	0.03	*	-233.8	7.39	801	*	26.7	472	1.02	0.5
2/23/2017	Recharge	70	118	4.82	*	-59.4	7.66	789	*	21.9	496	0.71	0.5
3/1/2017	Recharge	70	*	6.49	*	33	7.79	724	*	24.9	464	0.72	0.5
3/9/2017	Recharge	120	109	7.51	*	30.4	8.13	703	*	23	415	0.49	0.5
3/16/2017	Recharge	60	123	6.33	*	17.6	7.82	744	*	21.2	468	2.31	0.5
3/23/2017	Recharge	125	106	7.01	*	32.9	7.92	677	*	23.1	430	0.18	0.5
3/29/2017	Recharge	60	122	3.7	*	33.2	7.56	839	*	25.9	545	2.54	0.5
4/6/2017	Recharge	60	101	5.91	*	76.2	8.21	601	*	26.4	329	1.86	0.5
4/13/2017	Recharge	60	84.5	7.19	*	77.7	8.23	533	*	24.5	295	1.75	0.5
4/20/2017	Recharge	60	79.8	6.47	*	82.9	8.15	507.3	*	24.1	289	1.63	0.5
4/24/2017	Recharge	60	92.8	5.03	141	92.6	7.67	573	*	24.1	353	1.52	0.5
4/27/2017	Storage	*	*	*	*	*	*	*	*	*	*	*	*
5/4/2017	Storage	*	*	*	*	*	*	*	*	*	*	*	*
5/11/2017	Storage	*	*	*	*	*	*	*	*	*	*	*	*
5/18/2017	Storage	*	*	*	*	*	*	*	*	*	*	*	*
5/25/2017	Initial Recovery	120	85.1	0.06	*	-193.7	7.62	614	*	24.1	*	1.3	26
5/30/2017	Recovery	60	93.6	0.04	*	-174.5	7.77	645	*	25.5	378	0.46	18
6/2/2017	Recovery	50	96.7	0.1	*	-189.1	7.77	643	*	25.3	384	0.04	16

Table A-4. Cycle 4 water quality data (continued).

Sample Date	Mode	Apparent Color (PCU)	Chloride (mg/L)	Dissolved Oxygen (mg/L)	F Coliforms (cfu/100 mL)	Oxidation Reduction Potential (mV)	pH	Specific Conductance (µS/cm)	T Coliforms (cfu/100 mL)	Temperature (°C)	Total Dissolved Solids (mg/L)	Turbidity (NTU)	Arsenic (µg/L)
6/8/2017	Recovery	50	101	0.05	*	-178.6	7.72	693	*	24.4	391	0.45	13
6/15/2017	Recovery	50	120	0.34	*	-194.7	7.67	740	*	24.3	330	0.15	*
6/22/2017	Recovery	35	125	0.04	*	-203.6	7.68	773	*	25.1	459	0.11	5.6
6/29/2017	Recovery	35	149	0.03	*	-201.9	7.65	833	*	25.4	492	0.26	3.5
7/6/2017	Recovery	25	150	0.06	*	-170.6	7.61	891	*	23.9	494	0.31	2.6
7/13/2017	Recovery	30	155	0.04	*	-211.1	7.61	933	*	25.1	524	0.28	2
7/20/2017	Recovery	30	176	0.04	*	-180.5	7.62	984	*	25.1	517	0.35	1.4
7/27/2017	Recovery	30	193	0.03	*	-194.8	7.58	1034	*	24.8	569	0.52	1.2
8/3/2017	Recovery	30	190	0.03	0	-184.2	7.56	1087	*	25.1	626	0.77	1.2
8/10/2017	Recovery	25	215	0.04	*	-227.5	7.61	1150	*	24.7	640	0.17	0.5
8/17/2017	Recovery	20	229	0.1	*	-192.7	7.6	1210	*	25.1	696	0.28	0.5
8/24/2017	Recovery	25	255	0.03	33	-211.7	7.55	1283	1	24.5	762	0.24	0.5
PBF-10R													
4/26/2016	*	*	*	*	*	*	*	*	*	*	*	*	*
5/25/2016	*	*	1540	0.07	*	-298.2	7.56	6159	*	23.6	3320	1.09	*
6/1/2016	*	*	1640	0.07	*	-242.3	7.54	6156	*	23.7	2560	0.73	*
6/29/2016	*	5	1330	0.07	*	-196.9	7.55	5636	*	23.8	3050	3.51	*
7/6/2016	*	5	1230	0.1	*	-239.2	7.49	5490	*	23.8	2810	0.73	*
7/13/2016	*	5	1220	0.1	*	-217.8	7.47	5400	*	23.6	2740	1.07	*
7/20/2016	*	5	1360	0.07	*	-230.6	7.48	5287	*	23.7	2970	0.79	*
7/27/2016	*	*	1360	0.03	*	-263.9	7.54	5245	*	24.1	3020	0.99	*
1/19/2017	*	5	1110	0.06	*	-288.1	7.48	5047	*	24	3020	0.85	*
1/26/2017	*	5	1130	0.06	*	-286.9	7.5	5405	*	24	3150	2.24	*
2/20/2017	*	5	1150	0.1	*	-255.1	7.49	5358	*	24.1	3170	0.3	*
2/23/2017	Recharge	5	1010	0.15	*	-325.2	7.53	4805	*	23.3	2890	7.77	*
3/1/2017	Recharge	5	952	0.22	*	-228	7.53	4428	*	24.4	2800	9.49	*
3/9/2017	Recharge	5	945	0.16	*	-221.7	7.57	4155	*	24.2	2390	8.99	*
3/16/2017	Recharge	5	944	0.13	*	-235.2	7.2	3972	*	24.1	2420	11.2	*
3/23/2017	Recharge	*	950	0.16	*	-247	7.56	4039	*	24.4	2410	1.84	*
3/29/2017	Recharge	5	977	0.08	*	-230.1	7.54	4036	*	24.7	2460	3.76	*
4/6/2017	Recharge	5	906	0.1	*	-224	7.88	4080	*	24	2220	3.04	*

Table A-4. Cycle 4 water quality data (continued).

Sample Date	Mode	Apparent Color (PCU)	Chloride (mg/L)	Dissolved Oxygen (mg/L)	F Coliforms (cfu/100 mL)	Oxidation Reduction Potential (mV)	pH	Specific Conductance (µS/cm)	T Coliforms (cfu/100 mL)	Temperature (°C)	Total Dissolved Solids (mg/L)	Turbidity (NTU)	Arsenic (µg/L)
4/13/2017	Recharge	*	886	0.14	*	-215.2	7.57	4495	*	23.6	2430	5	0.5
4/20/2017	Recharge	5	961	0.1	*	-192.8	7.34	4353	*	23.6	2540	2.64	*
4/24/2017	Recharge	5	1190	0.08	*	-191.8	7.3	4630	*	23.9	2600	2.46	*
4/27/2017	Storage	5	1080	0.08	*	-254.8	7.56	4907	*	24.5	2930	2.41	*
5/4/2017	Storage	5	897	0.1	*	-241.9	7.58	4413	*	24.7	2410	1.9	*
5/11/2017	Storage	5	827	0.13	*	-199.7	7.59	3772	*	23.5	*	1.23	*
5/18/2017	Storage	5	820	0.06	*	-265.9	7.63	3666	*	24.8	2100	0.67	*
5/25/2017	Storage	5	842	0.08	*	-244.5	7.6	3653	*	24.6	1960	1.06	*
5/30/2017	Recovery	*	*	*	*	*	*	*	*	*	*	*	*
6/2/2017	Recovery	*	1080	0.06	*	-233.2	7.56	4301	*	24.6	2500	0.6	*
6/8/2017	Recovery	5	1080	0.07	*	-200.7	7.57	4393	*	23.7	2570	0.67	*
6/15/2017	Recovery	5	1120	0.1	*	-223.6	7.58	4377	*	23.5	2380	0.88	*
6/22/2017	Recovery	5	1120	0.07	*	-240.9	7.58	4291	*	24.9	2520	0.05	*
6/29/2017	Recovery	*	1020	0.09	14	-262.4	7.56	4321	*	24.2	2530	0.44	*
7/6/2017	Recovery	5	967	0.14	*	-214.2	7.56	4423	*	23.9	2620	0.37	*
7/13/2017	Recovery	5	182	0.06	1	-254.8	7.57	4424	*	24.3	2640	0.43	*
7/20/2017	Recovery	5	1030	0.1	*	-218.2	7.6	4471	*	24.5	2540	0.67	*
7/27/2017	Recovery	*	1150	0.06	*	-202.5	7.59	4501	*	24.5	2690	0.54	*
8/3/2017	Recovery	5	1080	0.06	0	-204	7.57	4591	*	24.8	2700	0.29	*
8/10/2017	Recovery	*	1130	0.05	*	-239.3	7.62	4682	*	24.1	2720	0.34	*
8/17/2017	Recovery	5	1210	0.12	*	-220	7.62	4763	*	24.5	2880	0.49	*
8/24/2017	Recovery	5	1290	0.08	*	-250.3	7.56	4963	*	24	2940	0.6	*
PBF-14													
4/26/2016	*	*	*	*	*	*	*	*	*	*	*	*	*
5/25/2016	*	*	356	0.06	*	-278.9	7.56	1784	*	23.6	946	1.01	*
6/1/2016	*	*	407	0.07	*	-224	7.51	1893	*	23.7	960	0.4	*
6/29/2016	*	10	433	0.11	*	-188.7	7.49	1951	*	23.6	1190	0.46	*
7/6/2016	*	*	478	0.09	*	-208.3	7.46	2101	*	24	1130	0.38	*
7/13/2016	*	5	381	0.07	*	-211.4	7.45	1841	*	23.6	1090	0.46	*
7/20/2016	*	5	370	0.09	*	-215.5	7.44	1718	*	23.6	1140	0.27	*
7/27/2016	*	5	337	0.04	*	-242.3	7.53	1661	*	24.3	1040	0.86	*

Table A-4. Cycle 4 water quality data (continued).

Sample Date	Mode	Apparent Color (PCU)	Chloride (mg/L)	Dissolved Oxygen (mg/L)	F Coliforms (cfu/100 mL)	Oxidation Reduction Potential (mV)	pH	Specific Conductance (µS/cm)	T Coliforms (cfu/100 mL)	Temperature (°C)	Total Dissolved Solids (mg/L)	Turbidity (NTU)	Arsenic (µg/L)
1/19/2017	*	10	274	0.06	*	-195.9	7.47	1475	*	24.2	928	0.58	*
1/26/2017	*	10	253	0.05	*	-262.7	7.52	1451	*	24	886	0.56	*
2/20/2017	*	*	*	*	*	*	*	*	*	*	*	*	*
2/23/2017	Recharge	10	422	0.39	*	-305.7	7.54	2081	*	23	1370	0.1	*
3/1/2017	Recharge	10	430	0.1	*	-241.9	7.53	2015	*	23.9	1200	0.33	*
3/9/2017	Recharge	5	414	0.07	*	-136.4	7.68	1933	*	24.1	1180	0.3	*
3/16/2017	Recharge	5	412	0.25	*	-141.5	7.53	1886	*	23.8	1170	1.28	0.5
3/23/2017	Recharge	10	377	0.28	*	-111.6	7.58	1902	*	24.5	1240	0.29	0.5
3/29/2017	Recharge	10	391	0.12	*	-218.2	7.59	1876	*	24.2	1240	2.84	0.5
4/6/2017	Recharge	*	408	0.09	*	-202.8	7.9	1822	*	23.6	1020	1.44	0.5
4/13/2017	Recharge	5	359	0.11	*	-197.3	7.61	1762	*	23.5	1060	1.31	1.4
4/20/2017	Recharge	10	353	0.09	*	-163.2	7.44	1710	*	23.1	990	2.72	1.3
4/24/2017	Recharge	10	368	0.1	*	-176.1	7.62	1686	*	23.2	1030	1.31	*
4/27/2017	Storage	10	347	0.1	*	-232.7	7.65	1658	*	24.4	1030	0.28	1.1
5/4/2017	Storage	10	275	0.08	*	-208.8	7.67	1403	*	24.5	918	0.29	1.1
5/11/2017	Storage	5	248	0.11	*	-166.1	7.66	1272	*	23.4	*	0.3	1
5/18/2017	Storage	5	258	0.09	*	-232.5	7.69	1336	*	24.1	*	0.05	0.5
5/25/2017	Storage	10	238	0.15	*	-136.8	7.65	1313	*	23.4	770	0.3	0.5
5/30/2017	Recovery	5	254	0.1	*	-205	7.65	1369	*	24.8	878	0.28	0.5
6/2/2017	Recovery	5	278	0.07	*	-196	7.65	1392	*	24.6	948	0.68	0.5
6/8/2017	Recovery	*	309	0.1	*	-141.9	7.63	1554	1	23.7	998	0.38	0.5
6/15/2017	Recovery	*	356	0.13	*	-193.2	7.61	1641	*	23.2	856	0.09	0.5
6/22/2017	Recovery	5	378	0.07	*	-206.7	7.63	1749	*	24.8	1090	0.07	0.5
6/29/2017	Recovery	5	444	0.06	*	-232	7.6	1877	*	24.1	1270	0.28	*
7/6/2017	Recovery	5	483	0.07	*	-174.3	7.59	2044	*	23.7	1270	0.2	0.5
7/13/2017	Recovery	5	377	0.09	*	-230.2	7.6	2157	*	24.3	1230	0.26	*
7/20/2017	Recovery	5	492	0.43	*	-126.6	7.52	2300	*	24.4	1230	0.57	*
7/27/2017	Recovery	*	526	0.08	*	-202.6	7.6	2455	*	24.4	1410	0.33	0.5
8/3/2017	Recovery	10	588	0.09	0	-197.5	7.58	2604	*	24.7	1480	1.05	*
8/10/2017	Recovery	*	584	0.05	*	-220.4	7.63	2764	*	23.8	1530	0.17	*
8/17/2017	Recovery	*	700	0.25	*	-209.1	7.61	2923	*	24.5	1580	0.2	*

Table A-4. Cycle 4 water quality data (continued).

Sample Date	Mode	Apparent Color (PCU)	Chloride (mg/L)	Dissolved Oxygen (mg/L)	F Coliforms (cfu/100 mL)	Oxidation Reduction Potential (mV)	pH	Specific Conductance (µS/cm)	T Coliforms (cfu/100 mL)	Temperature (°C)	Total Dissolved Solids (mg/L)	Turbidity (NTU)	Arsenic (µg/L)
8/24/2017	Recovery	10	696	0.08	*	240	7.57	3078	*	23.8	1780	0.22	*
PBS-11													
4/26/2016	*	5	1110	0.07	*	-272.7	6.99	4567	*	25.2	2380	0.39	4.5
5/25/2016	*	15	1070	0.09	*	-202.7	7	4525	*	25.1	2390	1.06	*
6/1/2016	*	10	1040	0.09	*	-240.2	6.99	4526	*	27.2	2160	0.4	*
6/29/2016	*	*	*	*	*	*	*	*	*	*	*	*	*
7/6/2016	*	*	*	*	*	*	*	*	*	*	*	*	*
7/13/2016	*	*	*	*	*	*	*	*	*	*	*	*	*
7/20/2016	*	*	*	*	*	*	*	*	*	*	*	*	*
7/27/2016	*	*	*	*	*	*	*	*	*	*	*	*	*
1/19/2017	*	20	1010	0.06	*	-298.7	6.9	4665	*	24.6	2740	0.58	*
1/26/2017	*	15	981	0.1	*	-253	6.95	4846	*	24.9	2720	0.55	*
2/20/2017	*	*	*	*	*	*	*	*	*	*	*	*	*
2/23/2017	Recharge	15	998	0.15	*	-297.9	6.93	4768	*	23.4	2810	0.33	*
3/1/2017	Recharge	15	1010	0.08	*	-251.3	6.98	4649	*	24.8	2800	0.39	*
3/9/2017	Recharge	20	1020	0.08	*	-252	7.24	4639	*	24.5	2660	0.22	*
3/16/2017	Recharge	20	1100	0.1	*	-229.2	6.63	4671	*	22.6	2760	1.61	*
3/23/2017	Recharge	20	1090	0.14	*	-244.5	7.02	4725	*	25	2780	0.62	*
3/29/2017	Recharge	20	1100	0.12	*	-179.9	5.97	4680	*	24.8	2790	1.59	*
4/6/2017	Recharge	20	1170	0.13	*	-225.7	7.31	4683	*	24.7	2470	1.1	*
4/13/2017	Recharge	15	1010	0.2	*	-246.4	7.04	4768	*	24.1	2740	1.03	*
4/20/2017	Recharge	20	1010	0.16	*	-224.7	6.95	4705	*	23.8	2680	1.13	*
4/24/2017	Recharge	20	1190	0.22	*	-227.8	6.99	4681	*	23.5	2750	0.83	*
4/27/2017	Storage	*	*	*	*	*	*	*	*	*	*	*	*
5/4/2017	Storage	*	*	*	*	*	*	*	*	*	*	*	*
5/11/2017	Storage	*	*	*	*	*	*	*	*	*	*	*	*
5/18/2017	Storage	*	*	*	*	*	*	*	*	*	*	*	*
5/25/2017	Storage	*	*	*	*	*	*	*	*	*	*	*	*
5/30/2017	Recovery	*	*	*	*	*	*	*	*	*	*	*	*
6/2/2017	Recovery	*	*	*	*	*	*	*	*	*	*	*	*
6/8/2017	Recovery	*	*	*	*	*	*	*	*	*	*	*	*

Table A-4. Cycle 4 water quality data (continued).

Sample Date	Mode	Apparent Color (PCU)	Chloride (mg/L)	Dissolved Oxygen (mg/L)	F Coliforms (cfu/100 mL)	Oxidation Reduction Potential (mV)	pH	Specific Conductance (µS/cm)	T Coliforms (cfu/100 mL)	Temperature (°C)	Total Dissolved Solids (mg/L)	Turbidity (NTU)	Arsenic (µg/L)
6/15/2017	Recovery	*	*	*	*	*	*	*	*	*	*	*	*
6/22/2017	Recovery	*	*	*	*	*	*	*	*	*	*	*	*
6/29/2017	Recovery	*	*	*	*	*	*	*	*	*	*	*	*
7/6/2017	Recovery	*	*	*	*	*	*	*	*	*	*	*	*
7/13/2017	Recovery	*	*	*	*	*	*	*	*	*	*	*	*
7/20/2017	Recovery	*	*	*	*	*	*	*	*	*	*	*	*
7/27/2017	Recovery	*	*	*	*	*	*	*	*	*	*	*	*
8/3/2017	Recovery	*	*	*	*	*	*	*	*	*	*	*	*
8/10/2017	Recovery	*	*	*	*	*	*	*	*	*	*	*	*
8/17/2017	Recovery	*	*	*	*	*	*	*	*	*	*	*	*
8/24/2017	Recovery	20	1220	0.11	*	-235.9	6.98	4844	*	26.5	2810	0.29	*

* Data not collected.