North Hillsborough Aquifer Recharge Project Expands Saltwater Intrusion Barrier

Deborah Daigle and Michael Townsel

In 2009, the Hillsborough County Public Utilities Department (HCPUD) began evaluating the feasibility of using high-level disinfection public access-quality reclaimed water to provide environmental improvements, act as a barrier to saltwater intrusion, create a path to the restoration of water use caution area (WUCA) water levels, and support a long-term and sustainable solution to water management challenges in its service area.

The Southwest Florida Water Management District (SWFWMD) has established minimum aquifer levels to be met for prevention or reduction of saltwater intrusion along the Hillsborough County coast. The county's goal of 100 percent reuse capability is the driver behind the development of reclaimed water direct aquifer recharge pilot projects along the coastal county.

The county's South Hillsborough Aquifer Recharge Project (SHARP), located at the Port Redwing Outfall (near Apollo Beach), became the first reclaimed water direct aquifer recharge project in the region. The SHARP project targets saltwater intrusion in the most-impacted area (MIA) of the southern WUCA (SWUCA). The county has continued this program in the northwest service area by initiating a similar project, phase 1 of the North Hillsborough Aquifer Recharge Project (NHARP), which will also create a salinity barrier and improve water levels within the northern Tampa Bay Water WUCA.

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The NHARP recharge well (RW-1) is located at the Northwest Hillsborough County Dechlorination Facility (NHCDF) in Tampa. Public access reclaimed water is provided by the Northwest Hillsborough County Water Reclamation Facility (NHCWRF) in Odessa. The RW-1 will recharge up to 3 mil gal per day (mgd) of high-level disinfection public access-quality reclaimed water into the Avon Park Formation of the Upper Floridan aquifer (UFA) system. The HCPUD is now planning phase 2 of the NHARP expansion and installation of additional Class V recharge wells in the northwest county area. The HCPUD goal is to complete future wells farther inland from the coast in areas where the top of the Avon Park Formation is closer to 10,000 mg/L total dissolved solids (TDS).

Construction of the first NHARP recharge well and monitoring well began in August 2017. Since the position of the underground source of drinking water (USDW) was unknown at the NHCDF site, the recharge zone monitoring well (RZMW-1) was drilled first. The depth of the base of the USDW, defined as water with 10,000 mg/L TDS, was determined to be approximately 500 ft below land surface (bls) within the Ocala Limestone. The recharge zone for NHARP is the Avon Park Permeable Zone (APPZ) within the UFA system. The wells, pipelines, and electrical/supervisory control and data acquisition (SCADA) at the NHARP site were completed in March 2019, with operational testing completed in mid-2019.

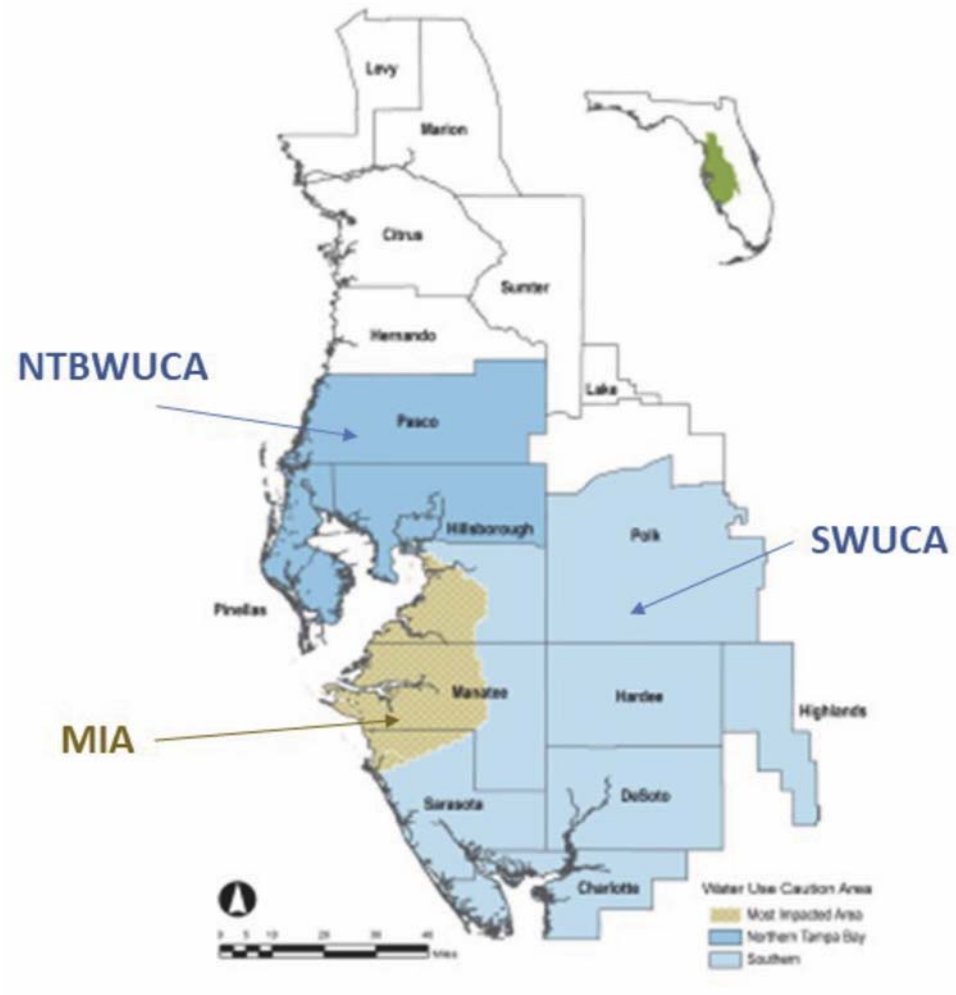

Figure 1. Water Use Caution Areas in Eastern Tampa Bay and Northern Tampa Bay

Operational data from SHARP indicates that the water levels have increased from approximately -5 ft National Geodetic Vertical Datum (NGVD) to 18.2 NGVD in the RZMW. The freshening of the Avon Park Formation has greatly improved water quality near the coast and the SHARP recharge well, thus creating a barrier to salt water intrusion. Operational challenges observed from SHARP include a loss of well capacity due to fouling. In response, the county has implemented a standard operating procedure to acidify the well when injectivity is reduced to 25 gal/pounds per sq in. (psi).

Background

In Florida, saltwater has intruded through a number of pathways, including the following (Prinos, 2013):

- Encroachment of seawater into aquifers in response to decreased fresh groundwater levels relative to sea level.
- The flow of saltwater inland through canals, rivers, boat basins, and coastal marshes, and subsequent leakage of this saltwater into aquifers.
- The movement of connate or relict saltwater in an aquifer.
- Leakage of saltwater between aquifers.

The reductions in fresh groundwater levels are caused by public and private water supply withdrawals from aquifers, excessive drainage, reductions in precipitation, or increases in sea level.

The HCPUD embarked on an innovative program that utilizes highly treated reclaimed water to recharge the UFA along its coastal areas to provide a saltwater intrusion barrier. The source water for the aquifer recharge program is excess reclaimed water from the county's wastewater treatment plants. In 2009, HCPUD began evaluating the feasibility of using highly treated wastewater from its existing advanced water reclamation facilities (WRFs) in support of a sustainable solution to water management challenges in the southern portion of its service area. The ultimate goal of HCPUD is 100 percent reuse capacity.

History of Groundwater Withdrawal Impacts in Hillsborough County

In the late 1980s it was noted that declines in groundwater levels had occurred in three regions. Declines in the Highlands Ridge, Northern Tampa Bay (NTB) and Eastern Tampa Bay (ETB) were primarily caused by regional groundwater withdrawals that resulted in lowered lake and wetland levels in the NTB and saltwater intrusion in the ETB. In response to the lowered groundwater and lake levels, the county's governing board declared each of the areas as WUCAs in 1989.

Out of concern for impacts to water resources in ETB, the governing board in 1992 established the SWUCA, encompassing both the ETB and Highlands Ridge WUCAs and all of the area in between. Specifically, the SWUCA encompasses an area of about 5,100 sq mi and covers the southern half of the district, including portions of the county. Historical increases in groundwater withdrawals have resulted in significant saltwater intrusion in coastal portions of the UFA, the principal source of public water supply in the region. In 1990, the district designated the coastal area of the ETB WUCA as the MIA (Figure 1). The SWFWMD has since established minimum aquifer levels to be met for prevention or reduction of saltwater intrusion within SWUCA.

In the NTB WUCA, most of the groundwater use is for public supply. As a result, most of the water resource impacts are in areas surrounding the major public supply wellfields, although models do confirm isolated areas of saltwater intrusion. In the NTB WUCA, the Tampa Bay Water central wellfields withdraw an annual average of 90 mgd of groundwater from the UFA. In 1988, Tampa Bay Water operated these wellfields at 192 mgd, but environmental impacts lead to the required reduction per the consolidated water use permit. Today, Tampa Bay Water operates the wellfields as an interconnected system at this lower pumping limit to promote environmental recovery. In addition, SWFWMD's goal is to continue evaluating the amount of environmental recovery that can be achieved while withdrawals remain at 90 mgd. Tampa Bay Water is preparing a recovery assessment report that will evaluate the status of the environmental recovery and will also identify any remaining adverse impacts that were not addressed with the pumping reduction.

Hillsborough County Implements Aquifer Recharge to Address Impacts in the Most-Impacted Areas and North Tampa Bay Water Use Caution Area

The SHARP is located at the Port Redwing Outfall near Apollo Beach and is the first reclaimed water direct aquifer recharge project in the region (Figure 2). The SHARP project targets saltwater intrusion in the MIA of the SWUCA. The SHARP recharge system began testing operations with injection of reclaimed water in July 2015. The system consists of one Class V aquifer recharge well, one recharge zone monitoring well, and two overlying monitoring wells. Expansion of the program is underway with the installation of two new Class V wells. The injectate water quality is advanced wastewater treatment high-level disinfection effluent from the county's south central public access reuse system.

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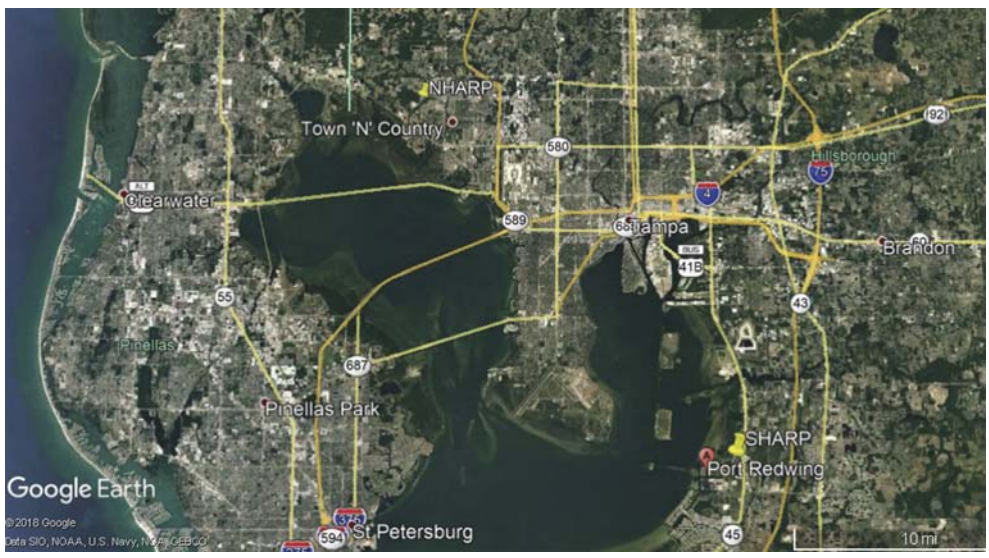

Figure 2. Location of the South Hillsborough Aquifer Recharge Project and North Hillsborough Aquifer Recharge Project Sites

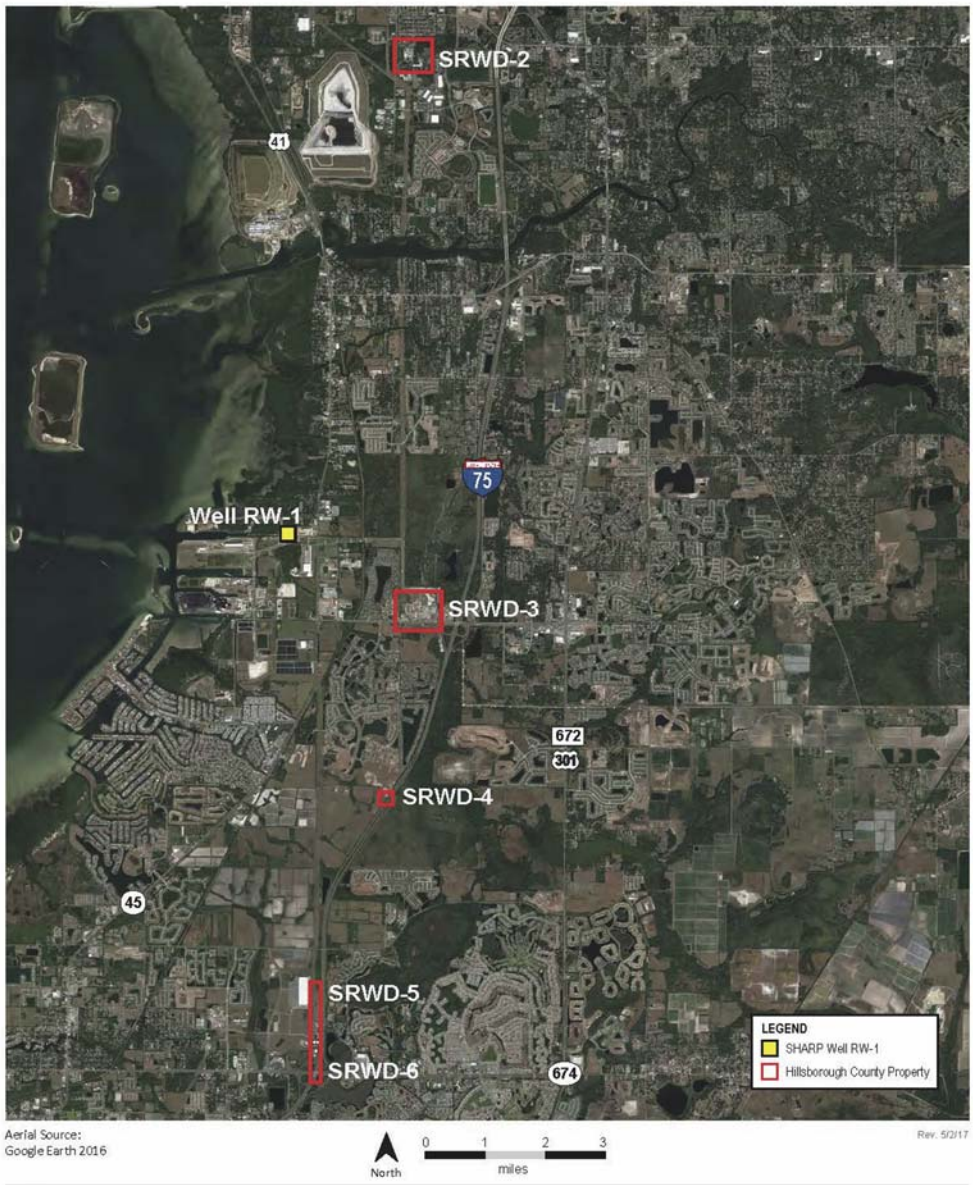

Figure 3. South Hillsborough Aquifer Recharge Project Expansion Locations

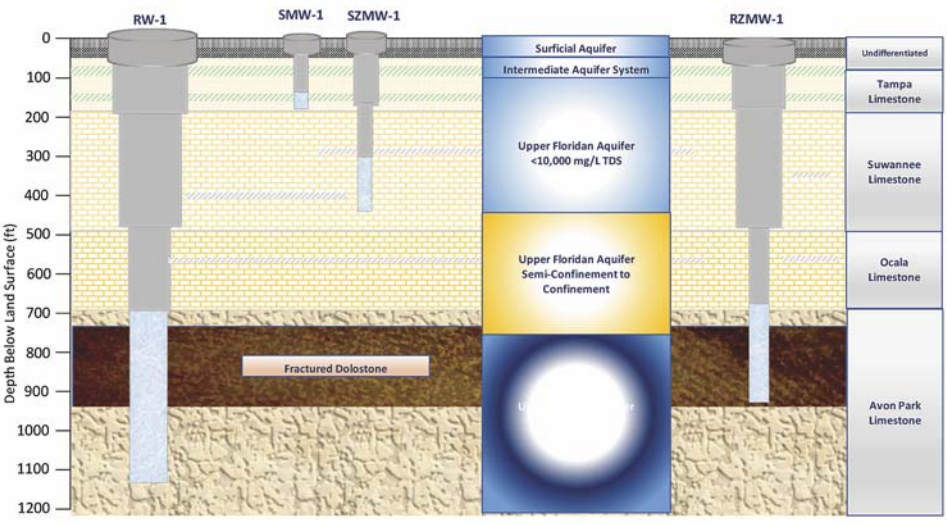

Figure 4. Site Geology and Hydrogeology, North Hillsborough Aquifer Recharge Project Well Completions

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The county has continued this program in the northwest service area by initiating a similar project (NHARP, phase 1), which will also create a salinity barrier and improve water levels within the NTB WUCA. The NHARP recharge well (NRW-1) is located at the NHCDF in Tampa (Figure 2). A north recharge zone monitoring well (NRZMW-1) was also installed at the facility approximately 1,200 ft northeast of NRW-1. Public access reclaimed water is provided by the NHCWRF. The RW-1 will recharge up to 3 mgd of high-level disinfection public access-quality reclaimed water into the Avon Park Formation of the UFA system. The wells, pipelines, and electrical/SCADA were completed in March 2019, with operational testing done later that year.

The HCPUD is planning phase 2 of the NHARP expansion and installation of additional Class V recharge wells in the northwest county. The county's aquifer recharge program includes a regional recharge system to provide a level of mitigation to the NTB WUCA and to allow for additional groundwater development in an area that has had historically adverse water level impacts to the aquifer. It's anticipated that at least seven aquifer recharge wells will be constructed as part of NHARP in several phases over the next 10 to15 years. Each well is anticipated to operate at 3 mgd annual average daily flow (AADF). Additionally, the construction of deep exploratory wells and associated monitoring wells will be initially required to characterize the aquifer in this project area. The total anticipated recharge quantity of the NHARP well program is 21 mgd AADF.

The location of future aquifer recharge wells will be adjusted inland per the SWFWMD to areas where the TDS of the top of Avon Park Formation is in the 10,000-mg/L TDS range. The top of the Avon Park at NHARP had a TDS range of approximately 15,000 to 18,000 TDS. The salinity profile into the Avon Park Formation at the SHARP and NHARP sites was unknown prior to drilling of the wells. As shown in Figure 3, future South Hillsborough Aquifer Recharge Expansion (SHARE) well locations are approximately 2 mi inland from the original SHARP location, which is also closer to HCPUD's reclaimed infrastructure. The NHARP expansion wells are also planned to be located farther inland from the NRW-1 site. The drilling of monitoring wells will be performed first at the new recharge sites to confirm the salinity profile.

North Hillsborough Aquifer Recharge Project Site Hydrostratigraphy and Recharge Zone

The target recharge zone for the NHARP recharge well is the APPZ of the UFA system (Figure 4). The lowermost permeable zone of the UFA is defined as occurring in the hard, fractured dolostone within the Avon Park Formation. The permeability of this zone is due primarily to fractures and interconnecting solution cavities and has been identified as the APPZ (Reese and Richardson, 2007). The APPZ usually lies between the UFA and the Lower Floridan aquifer and within the middle confining unit. This subaquifer is present over most of southern peninsular Florida and characteristically consists of thick units of dolostone with interbedded limestone in its upper part. Permeability in the APPZ is primarily associated with fracturing. The APPZ is the primary production zone in inland areas of Florida and the county.

Regional mapping shows the top of the APPZ at approximately 620 ft bls (600 ft below mean sea level NGVD) with a thickness of over 500 ft (Reese and Richardson, 2007) at the NHARP site. The actual top of the APPZ at the NHARP site is encountered much deeper, at approximately 740 ft bls (725 ft below mean sea level). Primary fracture zones within the APPZ were detected at both NHARP wells at depths of approximately 750, 820, and 900 ft bls during drilling, and geophysical logging indicates that most of the flow in the borehole is from these fracture zones. Below the fractured dolostone zones are dolomitic limestone and limestone. The APPZ contains adequate porosity and permeability (including significant fractures and voids) to accommodate an injection rate of 3 mgd. A specific capacity of 700 gpm (gal per minute)/ft was measured in well NRW-1 at the end of the constant rate pumping test at 2,500 gpm. The base of the APPZ was noted by the presence of evaporites at a depth of approximately 1,180 ft bls at the NHARP site.

Overlying the Avon Park Formation is the Ocala Limestone, a semiconfining unit that does not readily produce water and retards the upward movement of injectate. The Suwannee Limestone is found at the NHARP site above the Ocala Limestone between approximately 190 and 480 ft bls. The Suwannee Limestone aquifer is used extensively for fresh water supply and has been identified by SWFWMD as a critical aquifer needing water level increases to mitigate saltwater intrusion. At NHARP the Suwannee Limestone contains slightly brackish water (TDS ~850 mg/L). Above the Suwannee Limestone is the Tampa Member which is between approximately 100 and 190 ft bls at the NHARP site and contains fresh water (TDS ~350 mg/L).

To determine the confining characteristics of the stratigraphic units above the recharge zone, rock coring and packer testing was performed. Rock coring indicates low permeability strata between the depths of 464 to 677 ft bls, with vertical hydraulic conductivity ranging from 5.7 x 10-6 cm (centimeters)/sec to 7.2 x 10-11 cm/sec. The very low vertical hydraulic conductivities measured for the core samples collected confirm the confining characteristics of each of the cored intervals. Straddle packer tests were conducted at well NRW-1 at the following depths:

- Packer Test No. 1: 717 to 739 ft bls
- Packer Test No. 2: 688 to 710 ft bls

Calculated hydraulic conductivity for the test intervals was 22 ft/day for Test No. 1 and 16 ft/day for Test No. 2. The relatively low hydraulic conductivities measured during packer tests indicate that the tested intervals are confining. The packer tests generally estimate the hydraulic properties of the interval tested in the horizontal plane. The vertical hydraulic conductivity of the type of materials encountered in the tested intervals is a typical order of magnitude less than the horizontal hydraulic conductivity. In addition to the coring and packer tests, sonic porosity logs also indicate a continuous interval of comparably low sonic porosity located above the first fracture zone within the Avon Park Formation (low porosity interval extends from approximately 710 to 740 ft bls) at each well.

Table 1. North Hillsborough Aquifer Recharge Project Well Construction Details

Well Name	Total Depth (Ft BLS)	Casing Diameter (OD)	Casing Type	Casing Depth or Monitoring Interval
NRW-1	1140	44	Steel	52
		34	Steel	190
		24	Steel	470
		16	Steel	700
		16	Open Hole	700-1140
NRZMW-1	920	26	Steel	56
		20	Steel	190
		14	Steel	470
		6	FRP	700
		6	Open Hole	700-920
SZMW-1	415	18	Steel	48
		14	Steel	183
		6	steel	305
		6	Open Hole	305-415
SMW-1	170	12	Steel	40
		6	Steel	142
		6	Open Hole	142-170

North Hillsborough Aquifer Recharge Project Well Construction

Construction of the first NHARP recharge well and monitoring well began in August 2017 under a Class V, Group 2 construction and testing permit from the underground injection control (UIC) division of the Florida Department of Environmental Protection (FDEP). Since the position of the USDW was unknown at the NHCDF site, the NRZMW-1 was drilled first. The depth of the base of the USDW, defined as water with 10,000 mg/L TDS, was determined to be at a depth of approximately 500 ft bls within the Ocala Limestone portion of the geologic section. The TDS then increased to over 25,000 mg/L below a depth of approximately 800 ft bls in the Avon Park Formation during drilling.

The RZMW-1 was completed with 703 ft of a 6-in.-diameter fiberglass reinforced plastic (FRP) casing with an open hole back-plugged to 920 ft bls. The goal of FDEP was

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that the monitoring well be completed to isolate the main flow zones within the recharge interval (Figure 4). Two existing shallow monitoring wells (SMW-1 and SZMW-2) were also incorporated into the program at NHARP to monitor the Tampa Member and Suwannee Limestone within the USDW. The wells are completed to depths of 170 and 410 ft bls, respectively.

Operational Observations and Challenges for the Aquifer Recharge Systems

Although the NHARP recharge well is not yet operational, HCPUD has operated the SHARP recharge well since 2015. The RW-1 is located on the southern side of the Port Redwing Discharge Facility, is a 16-in.-diameter well, with a permitted annual average injection capacity of 3 mgd and a maximum daily injection capacity of 4.5 mgd. The RZMW-1 is located ~1200 ft to the east and monitors the injection zone. Monitor wells (TPW-1 and SMW-1) are utilized to monitor overlying intervals and aquifer zones above the injection interval and are located ~150 ft. north and ~65 ft. northeast of RW-1, respectively.

Injection of reclaimed water commenced in July 2015. During the initial discharge of reclaimed water into RW-1, injection rates were initially established at less than 0.5 mgd to condition the well and the Avon Park Formation, but subsequently increased to 1 mgd based on wellhead pressure. Recharge flow rate was increased to 2 mgd in March 2016, with an initial wellhead pressure of 25 psi. During November 2016, HCPUD increased the targeted recharge flow rate to 2.5 mgd, with an initial wellhead pressure of 73 psi.

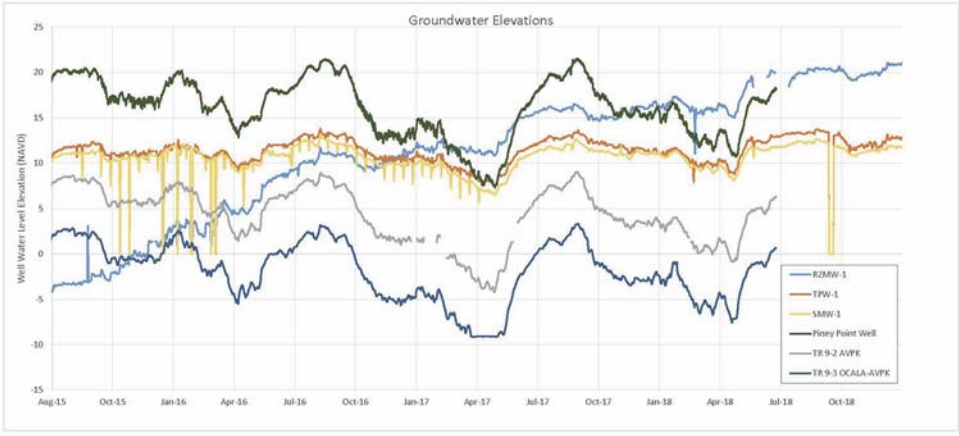

Figure 5. Water Levels at South Hillsborough Aquifer Recharge Project Monitoring Wells

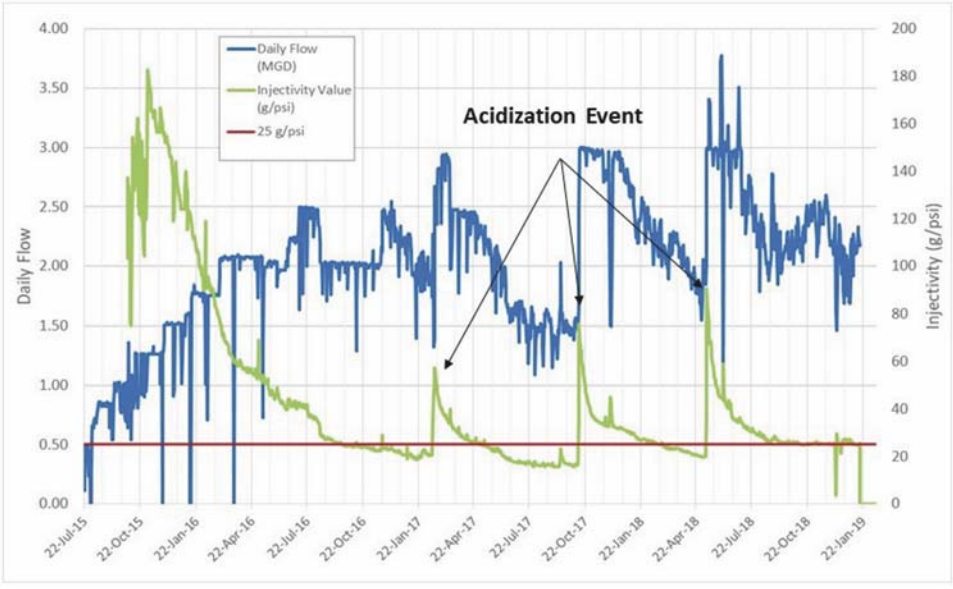

Figure 6. Injectivity Versus Daily Flow at South Hillsborough Aquifer Recharge Project

Figure 5 presents water levels in the SHARP monitoring wells and two regional monitoring wells. The regional wet season and dry season trends can be clearly observed in the overlying monitoring wells consistent with the offsite regional wells. While the seasonality is still visible at RZMW-1, the steady water level increase can be attributed to the injectate. The water levels in RZMW-1 clearly indicate an upward change in water levels in the Avon Park Formation. Water levels have increased from approximately -4 ft to 18.2 NGVD since operation began. Moderate seasonal variability between wet and dry seasons continues and this increase in water level elevation can be attributed to freshening in water quality at this well associated with the horizontal movement of reclaimed water from the recharge well. The increase in water level by an average of approximately 23.5 ft within the Avon Park Formation supports the SWFWMD SWUCA recovery strategy of mitigating saltwater intrusion.

The RZMW-1 has indicated a steady decrease in salinity due to the horizontal movement of the fresher reclaimed water within the saline recharge zone. From August 2015 through December 2016, the TDS concentration at RZMW-1 exhibited a decreasing trend from 35,000 to 3,700 mg/l. Water quality at RZMW-1 shows significant freshening, as there is ongoing mixing occurring between the reclaimed water and the saline water in the injection zone. This high degree of mixing is not unexpected due to the highly fractured nature of the injection zone. The release of arsenic at RZMW-1 has fluctuated following acidification events, but now appears stable. No significant metals mobilization has been observed at RZMW-1.

Operational Challenges

Operational challenges at SHARP, including declines in well performance associated with dissolved and suspended solids in the injectate, have been observed at RW-1. Using a total suspended solids value of 0.5 mg/l and a TDS value of 500 mg/l, there is potential to deposit ~1,500 lbs of solids per mil gal injected annually and an extensive amount of precipitation based on the measured oxidation reduction potential. The chemical precipitation of calcium carbonate in the formation fractures, combined with

suspended solids deposition, appears to be the primary cause of reduced injection capacity.

The HCPUD is utilizing the specific injectivity (SI) as an indicator parameter to declining well performance. The SI is calculated as the average daily injection rate divided by the average daily injection pressure and has been utilized in addition to the required parameters to evaluate injection capacity and system performance. Operational data to date indicate that an SI below 25 gal/psi results in reduced system control and wellhead performance. The HCPUD has developed a standard operating procedure to acidify the well when the SI is less than equal to 25 gal/psi. The SI plotted against the daily average injection rate with an SI threshold of 25 is shown in Figure 6 and clearly identifies reduced system performance prior to an acidification event and enhanced performance following an acidification event. The SI is being used to plan future acidification events.

These observations continue to support the position that acidizing is a successful procedure to properly maintain the recharge system for beneficial use in the SWUCA. The total volume injected at SHARP from July 2015 through Sept. 5, 2019, is approximately 3.105 bil gal.

Conclusions

In 2009, HCPUD began evaluating the feasibility of using highly treated wastewater from its existing advanced water reclamation facilities to provide environmental improvements, a barrier to saltwater intrusion, a path to the restoration of WUCA water levels, and support of a long-term and sustainable solution to water management challenges in its service area. Implementation of SHARP and NHARP will create a salinity barrier along two areas of the county coastline where impacts from groundwater withdrawals have been documented.

Operation of the SHARP project for approximately three years has shown an increase in water levels and the freshening of the Avon Park Formation, which has greatly improved water quality near the SHARP recharge well, thus creating a barrier to saltwater intrusion. Expansion of both the SHARP and NHARP along the coastal county will expand this barrier and potentially allow for new groundwater development inland in fresher portions of the aquifer.

The county is currently installing two additional recharge wells for the SHARP program and is planning future expansion of the NHARP program.

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