Reclaimed Water Aquifer Storage and Recovery System: Update on a Groundbreaking System in Florida

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Barrier island and coastal communities often face greater water supply and wastewater management challenges than inland areas because of a combination of population growth, insufficient availability of affordable undeveloped land, and limited local freshwater resources that are vulnerable to contamination from saline-water intrusion. Using treated (reclaimed) wastewater for irrigation is increasingly being implemented as an environmentally sound means of putting wastewater flows to beneficial use and reducing demands on fresh groundwater and surface water resources.

Reuse systems, however, have constraints as the demand for irrigation water often has a strong seasonal variability; demand for reclaimed water decreases dramatically during wet periods when irrigation is not needed. Since wastewater is generated year-round, wastewater utilities need alternative disposal methods for low-demand periods. Developing alternative means of additional wastewater disposal is becoming increasingly challenging because property for land application systems may not be available (or is too expensive) and surface water outfalls may not be allowed or would face stiff public opposition.

Aquifer storage and recovery (ASR) is a logical means for managing reclaimed water supplies. Excess reclaimed water could be stored underground during periods of excess supply and recovered during dry or peak irrigation demand periods. The additional reclaimed water supply during high-demand periods provided by ASR systems can be instrumental in encouraging other users to commit to a reuse system. Reliability of supply is critical to potential reuse water customers. Prospective customers for reuse systems want to have the confidence that water will be available to them when it's needed; shallow aquifers in coastal areas that are not suitable for potable water supply due to poor water quality may be available for use as ASR storage zones.

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Figure 1. Site location map and site plan showing the locations of the aquifer storage and recovery wells, storage zone monitoring wells, and shallow monitoring wells.

The Destin Water Users Inc. (DWU) ASR system is a groundbreaking reclaimed water project. The City of Destin is located on a barrier island in the Gulf of Mexico, in the panhandle region of western Florida (Figure 1). The DWU faced the need for additional wet weather reclaimed water disposal capacity, with traditional options (e.g., additional land application, offshore disposal, deep well injection) either being too expensive, not permittable, or not technically feasible. The ASR was determined to be the most cost-effective option to provide additional wet weather disposal capacity, while at the same time conserving a valuable resource and increasing the reliability of the DWU reuse system. The ASR system was constructed at the DWU George W. French Wastewater Treatment Facility.

Destin Hydrogeology

Three main hydrogeologic units are present in northwestern Florida: the surficial aquifer system, the intermediate confining unit, and the Floridan aquifer system (Figure 2). The intermediate confining unit is also referred to as the Pensacola confining unit, intermediate aquifer system, and intermediate system. The upper Floridan aquifer is the primary potable water source in northwestern Florida and is the sole potable water source for the Destin area. The surficial aquifer system is used only for irrigation purposes in the vicinity of Destin.

The surficial aquifer system in northwestern Florida is defined as the "permeable hydrogeologic unit contiguous with land surface that is comprised principally of unconsolidated clastic deposits" (Southeastern Geological Society Ad Hoc Committee on Florida Hydrostratigraphic Unit Definition, 1986). The system consists of a single aquifer, the sand-and-gravel aquifer, which is made up of predominantly unconsolidated clastic deposits of Late Miocene to Holocene age. Stratigraphically, this aquifer in the Destin area contains undifferentiated Plio-Pleistocene sands, the Citronelle Formation, and Miocene coarse clastics (Clark and Schmidt, 1982; Pratt et al., 1996). All three units consist predominantly of quartz sand with varying amounts of gravel, silt, and clay.

The sand-and-gravel aquifer is divided into three hydraulic zones: the surficial zone, intermediate zone, and main-producing zone (Hayes and Barr, 1983). The surficial zone is composed of fine- to medium-grained quartz sands, and is approximately 40 ft thick at the ASR system site. The surficial zone is underlain by low-permeability clays, sandy clay, and clayey sand that constitute the intermediate zone. The surficial zone is widely used in Destin to supply small-diameter domestic (household) irrigation wells. The intermediate zone extends downward to the top of the main-producing zone, which is located at approximately 117 ft below land surface (bls) at the ASR system site. The main-producing zone is usually the most permeable part of the sand-and-gravel aquifer and consists mostly of medium- to very coarse-grained sand and gravel. The base of the main-producing zone occurs at about 166 ft bls.

Well cuttings and geophysical logs do not indicate the presence of particularly tight confining strata between the surficial zone and main-producing zone at the ASR site. Some zones of increased gamma ray activity are evident on borehole geophysical logs of the intermediate zone, which may be indicative of the presence of clay. Nevertheless, the static water levels measured during initial hydrogeological testing for the ASR system in 2002 revealed an approximately 10-ft difference in head (water level) between the surficial zone and main-producing zone, which is strong evidence for effective confinement. Heads in the main-producing zone are approximately 3 ft above sea level, whereas heads in the surficial zone are substantially higher and are related to land surface elevation. The data from an aquifer pumping test performed on the main-producing zone indicate a transmissivity of 4,800 to 5,100 ft^2/d, a storage coefficient of $3 X 10^{-4}$ to $3.8 X 10^{-4}$, and a leakance of $8 X 10^{-5}$ to $1.3 X 10^{-4} d^{-1}$.

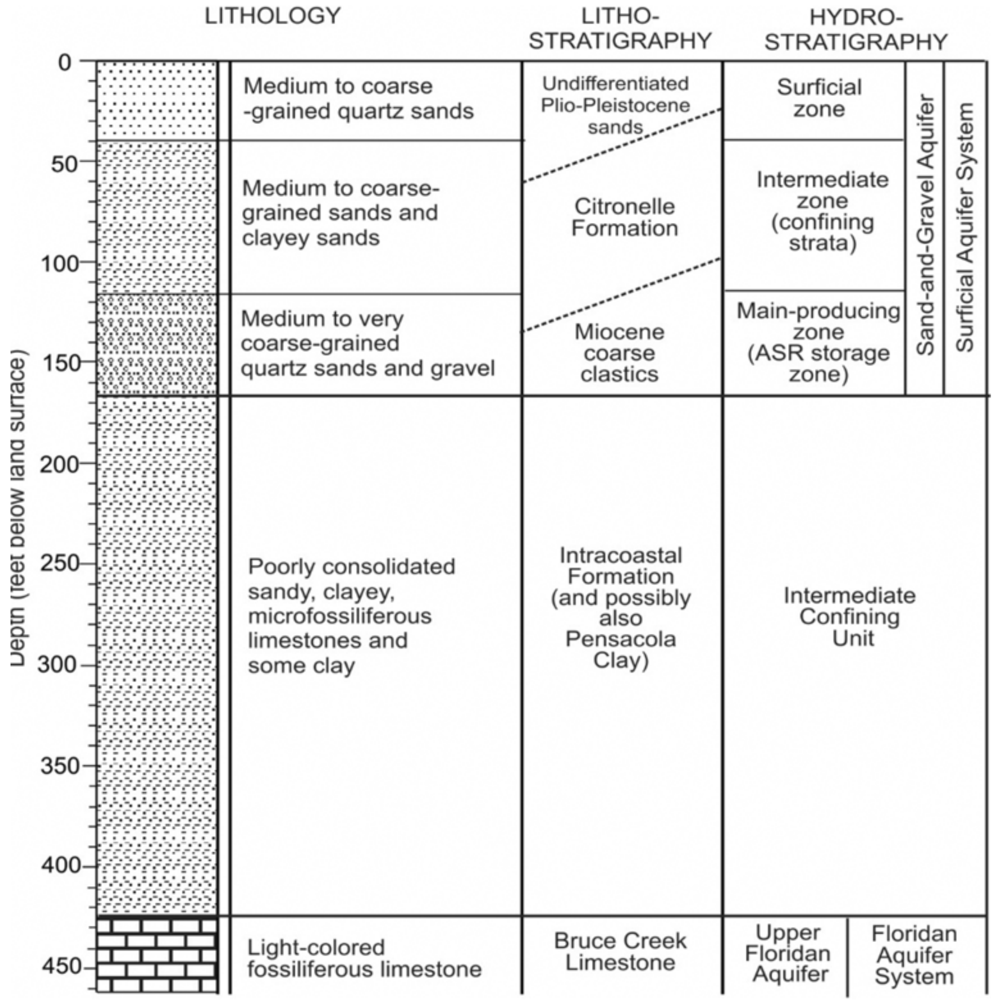

Figure 2. Hydrostratigraphic column for the aquifer storage and recovery system vicinity.

The intermediate confining unit is defined as including "all rocks that lie between and collectively retard the exchange of water between the overlying surficial aquifer system and the underlying Floridan aquifer system" (Southeastern Geological Society Ad Hoc Committee on Florida Hydrostratigraphic Unit Definition, 1986). The intermediate confining unit in the Destin area consists of the Intracoastal Formation and Pensacola Clay, which are generally composed of fine-grained clastic deposits with some locally interlayered carbonate rocks or coarser-grained clastic deposits. The base of the intermediate confining unit occurs at approximately 425 ft bls and is marked by a downward transition from predominantly low-permeability clastic rocks to the underlying more permeable carbonate strata of the Floridan aquifer system (Barr et al., 1985)

Project History and Regulatory Issues

The kickoff meeting for the DWU reclaimed water ASR project was held in May 2002. The initial primary goal of the project was to meet a wet weather disposal requirement of 3 mil gal per day (mgd) for three days. Recovery of injected fluids was recognized to be desirable, but not critical, to the project. The benefits of recovery as a supplemental water source were recognized. Two storage-zone monitor wells were installed and a 72-hour aquifer performance test was performed in June 2002, using an

Continued on page 54

Continued from page 53

existing production well as the pumped well, to obtain data on the hydraulic properties of the storage zone. The test data showed a high degree of hydraulic separation between the surficial and main-producing zone of the sand-and-gravel aquifer.

The ASR systems are categorized as Class V injection wells in the United States and are permitted in Florida by the Florida Department of Environmental Protection (FDEP). The ASR systems fall under the purview of the FDEP underground injection control (UIC) program of the aquifer protection program. Reclaimed water ASR systems are additionally regulated by the FDEP domestic wastewater program. The overriding requirement of federal and FDEP's UIC regulations is that underground injection shall not endanger underground sources of drinking water, which are defined as nonexempt aquifers containing less than 10,000 mg/L of total dissolved solids (TDS). Endangerment is defined as causing a violation of a primary (health-based) drinking water standard. The UIC regulations in Florida also require that injected water meets secondary (aesthetic-based) drinking water standards. Injection may cause violation of UIC regulations if the concentration of the parameter(s) in question in the injected water exceeds a drinking water standard, or if a standard is exceeded as a result of fluid-rock interactions (or other chemical processes) after injection. If the natural concentration of a parameter in an aquifer exceeds a drinking water standard, then the natural background concentration becomes the applicable standard for injection.

The domestic wastewater reuse rules (Chapter 62-610 of the Florida Administrative Code [FAC]) place another layer of regulations on ASR systems that store reclaimed water. If the native groundwater in the storage zone contains less than 1,000 mg/L of TDS, then an ASR system is required to meet the strict full treatment and disinfection requirements, which would have rendered the ASR project economically unviable. The full treatment and disinfection requirements basically assume that because of the low TDS concentration of an aquifer, indirect potable reuse may occur.

The pre-application report for an FDEP Class V injection well construction permit application (November 2002) identified that the requirement to meet the full treatment and disinfection requirements (FAC 62-610.563) was a fatal flaw. The treated wastewater cannot meet FAC 62-610 (reuse rules) total organic halides standards for injection in a G-II aquifer containing less than 1,000 mg/L of total dissolved solids. The full treatment and disinfection requirements are complex, onerous, and involve great costs that would render the project economically unfeasible. The stringent requirements include pilot testing of the treatment system (12-month minimum), mutagenicity testing, and that the water be free of pathogens and be of equal or better quality than current drinking water sources (which in Destin are of very high quality).

A variance from the full treatment and disinfection requirements was applied for on March 28, 2003. The basis for the proposed waiver request was that the requirements resulting from Rule 62-610.560 (2) FAC, are inappropriate for the proposed project because unique, site-specific conditions preclude the use of the sand-and-gravel aquifer in Destin as a potable source. Specifically, Section 10.05.05 (A) of the Destin city code states that shallow wells that draw water from the sand-and-gravel aquifer shall be used for irrigation purposes only. Despite its low TDS concentration, indirect potable reuse is not a possibility and "institutional controls" are in place to prevent indirect potable reuse.

It was proposed that the requirements of full treatment and disinfection, therefore, cannot be justified to protect public health and safety as there is little likelihood of public consumption of groundwater from the sand-and-gravel aquifer; furthermore, the proposed recharge of the sand-and-gravel aquifer that would be possible if the waiver were granted would enhance the use of the aquifer for its most beneficial purpose: a source of irrigation water. The FDEP proposed a denial on Sept. 2, 2004, and DWU filed for an administrative hearing. A settlement was reached and FDEP issued a variance on Oct. 20, 2006.

An FDEP Class V injection well construction permit application was submitted in December 2007 for the complete seven-well ASR system. The permit was issued on Jan. 29, 2009, with an administrative order to address arsenic leaching, should it occur. Phase I of the system consisted of a single ASR well (ASR-1) and associated monitor wells constructed in March 2009, and operational testing began in June 2009. The remaining six ASR wells and associated monitor wells were constructed from May to October 2011. An operation permit was issued on Jan, 7, 2014. The system is currently operational.

Aquifer Storage and Recovery System Design

The DWU reclaimed water ASR system uses the main-producing zone of the sand-and-gravel aquifer as a storage zone. The system currently consists of seven ASR wells (ASR-1 through ASR-7), six storage-zone monitor wells (SZMW-1 through SZMW-6), and two shallow monitor wells (SMW-1 and SWM-2; Figure 1). The system has a design capacity of 2.125 mgd. The ASR system was constructed in two phases. Phase I consists of one ASR well (ASR-1), two storage-zone monitoring wells, and one shallow monitoring well, which were constructed in March 2009. After successful completion of initial operational testing, the remaining ASR wells were constructed in late 2011.

The ASR wells are constructed with a 16-in.-diameter standard dimension ratio (SDR) 17 polyvinyl chloride injection casing set to 106 to 110 ft bls. The wells are completed with 50 ft of 8-in.-diameter (either 0.035-in. slot [ASR-1] or 0.050-in. slot [ASR-2 through ASR-7]) wire-wrapped 316 stainless steel screen with 5 ft of tail pipe. The annulus is filled with 8/16-grade sand filter pack. The wells are designed so that the screen and inner casing can be removed to rehabilitate the well, if necessary.

Samples of the water from the storage zone (well ASR-1), surficial zone (well SMW-1), and reclaimed water were collected in 2009, prior to the start of operational testing, and analyzed for the primary and secondary drinking water standards. The analytical results are summarized in Table 1. The main-producing zone has a very low salinity and high iron concentrations. The water chemistry of the surficial zone is impacted by reclaimed water from onsite infiltration basins.

Operational Issues

Recovery of Injected Reclaimed Water

The ASR storage zone contains native groundwater that can be used directly as a supplemental irrigation water source; however, large additional abstractions from the main-producing zone are likely not feasible due to saline-water intrusion concerns. The hydrologic benefit of the ASR system is that it will allow for sustainable use of the aquifer on a long-term basis by balancing recharge and abstractions.

A calibrated solute-transport model was developed for the ASR system using the MODFLOW (McDonald and Harbaugh, 1988) and MT3DMS (Zheng and Wang, 1999) codes. The objectives of the modeling were to develop a better understanding of the hydrogeology and mixing processes in the storage zone through the calibration process, and to develop a predictive tool that would assist in the design of ASR system expansion and development of operating protocols. The model was calibrated for the first three operational (cycle) tests (Table 2),

Continued on page 56

Table 1. Summary of Reclaimed Water and Pre-Injection Groundwater Chemistry

Parameter	ASR-1	SMW-1	Reclaimed
Chloride (mg/L)	9.6	88.4	139.7
Color (CU)	65	30	<5
Fluoride (mg/L)	<0.1	0.3	0.5
Foaming agents (mg/L)	<0.05	<0.05	<0.05
Ammonia N as N (mg/L)	<0.10	<0.10	<0.10
Total Kjeldahl N (mg/L)	<0.20	1.17	4.26
Total N (mg/L)	<0.20	1.17	3.56
Nitrate-N (mg/L)	<0.1	<0.1	3.56
Nitrite-N (mg/L)	<0.10	<0.10	<0.10
Odor (TON)	4	None	1
Total phosphorous as P (mg/L)	<0.20	0.36	3.80
Total orthophosphate as P (mg/L)	0.04	0.35	3.84
Total dissolved solids (TDS; mg/L	66	573	460
Sulfate (mg/L)	8	177	40
Uranium (mg/L)	0.32	0.47	0.04
Aluminum (mg/L) (µg/L)	4409*	<50	62
Cadmium (µg/L)	<0.1	<0.10	<1.0
Barium (µg/L)	11	110	11
Chromium (total) (µg/L)	9.1	<2.0	<2.0
Copper (µg/L)	<10.0	<10.0	11
Iron (µg/L)	575	359	<40
Manganese (µg/L)	7.3	149	<1.0
Nickel (µg/L)	<2.0	7.4	<2.0
Zinc (µg/L)	7.4	16	156
Antimony (µg/L)	<2	<2	<2
Arsenic (µg/L)	<2	3	<2
Beryllium (µg/L)	<0.1	<0.1	<0.1
Lead (µg/L)	2	<1	<1
Mercury (µg/L)	<0.2	<0.2	<0.2
Selenium (µg/L)	<2	<2	<2
Sliver (µg/L)	<0.4	<0.4	<0.4
Sodium (mg/L)	3	96	110
Thallium (µg/L)	<1	<1	<1

* High aluminum concentration is likely due to suspended drilling mud in sample.

Table 2. Summary of Operational (Cycle) Tests 1 Through 3

Phase	Volume (m^3)	Duration (days)	Average rate (m^3/day)
Cycle Test No. 1			
Injection	9,641.1	10	964.0
Storage	N/A	0	N/A
Recovery	9.569.5	12	797.5
Cycles Test No. 2			
Injection	8,085.6	9	898.3
Storage	N/A	10	N/A
Recovery	8,017.5	9	890.7
Cycle Test No. 3			
Injection	11,609.9	19	611.1
Storage	N/A	22	N/A
Recovery	11,079.9	15	738.6

Continued from page 54

against both water-level changes during injection and recovery and the percentage of reclaimed water in the recovered water, which was estimated using chloride, sodium, TDS, and fluoride as tracers (Figure 3). In order to obtain a reasonable match to the observed data, a very small grid size (1.25 ft in core area of model), small longitudinal dispersivity (0.3 ft), and highly effective porosity (0.35) were required. The model still slightly underestimates the fraction of reclaimed water in the late-stage recovered water due to numerical dispersion.

The monitoring data (reclaimed water was not detected in storage-zone monitoring wells during initial operational testing) and modeling results both indicate that the injected water is staying near the ASR well and there is a low degree of dispersive mixing. The combination of a highly effective porosity and low dispersivity of unconsolidated sand aquifers is particularly favorable for the high recovery of injected water in ASR systems.

Arsenic Leaching

The leaching of arsenic into stored water has been a widespread problem in ASR systems in Florida and elsewhere. The causes of arsenic leaching in Florida were reviewed by Maliva and Missimer (2010). Field observations and the results of bench-top experiments performed by the Florida Geological Survey (Arthur et al., 2005; Arthur et al., 2007) indicate that arsenic leaching is caused by oxidative dissolution of trace amounts of arsenic-bearing iron sulfide minerals (pyrite) present in the storage-zone rock or sediment. Pyrite is stable in the chemically reducing conditions that naturally occur in confined Florida aquifers and aquifer zones. Undersaturated conditions occur as the result of the introduction of water containing dissolved oxygen and nitrate.

Arsenic leaching became a more serious concern for ASR system operators in Florida in 2006 when the U. S. Environmental Protection Agency decreased the maximum contaminant level (MCL) for arsenic in drinking water from 50 to 10 micrograms per liter (µg/L); the drinking water MCL is the applicable groundwater quality standard. Systems in which stored water met the 50-µg/L arsenic MCL were in violation of the MCL when it was reduced to 10 µg/L. Although iron sulfide minerals are present in only minute quantities in Florida aquifers (often only detectable with thin section petrography or scanning electron microscopy), a very small amount of arsenic release is sufficient to exceed the 10-µg/L MCL.

It was hoped that the ASR system would not experience arsenic leaching because iron

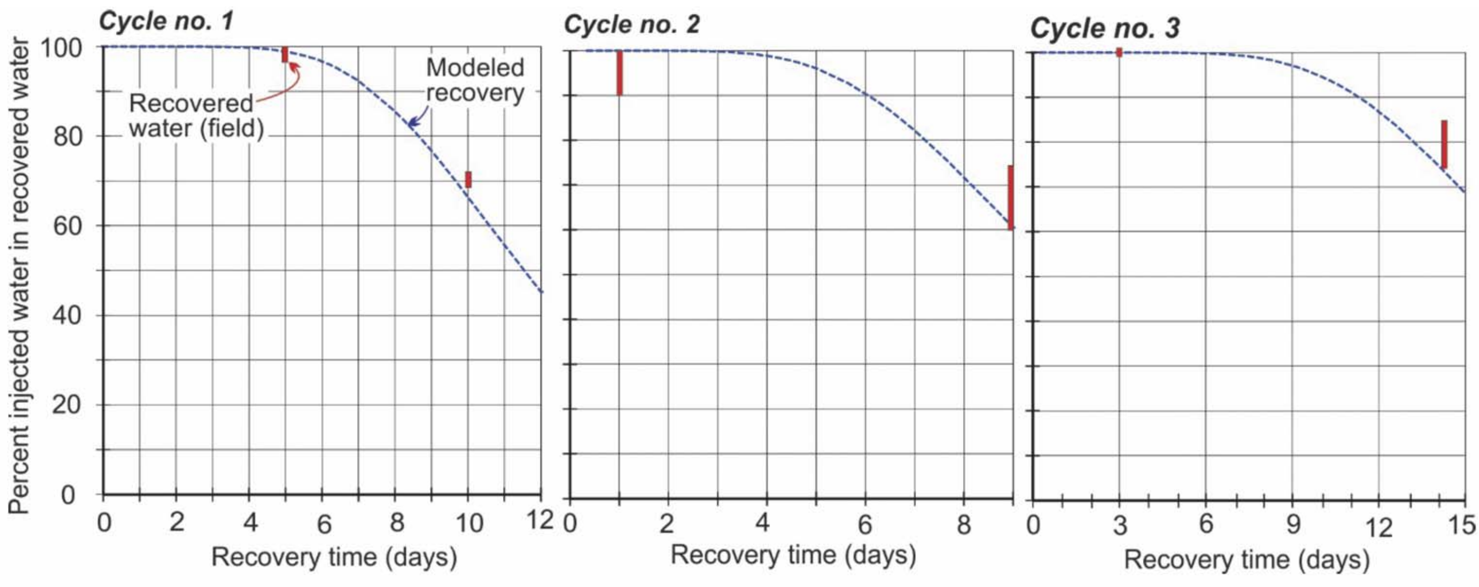

Figure 3. Modeled versus actual recovery of recharged reclaimed water.

sulfides did not appear to be present in the clean quartz sands of the storage zone. Nevertheless, arsenic leaching above the 50-µg/L groundwater standard occurred during the initial operational testing of well ASR-1.

Two main strategies have been employed in Florida to address arsenic leaching in ASR systems. Injected water may be pretreated to remove dissolved oxygen and reduce its oxidation reduction potential so that it is at or near chemical equilibrium with respect to iron sulfide minerals present in the aquifer. Pretreatment options for removing dissolved oxygen were reviewed by Maliva and Missimer (2010). Disadvantages of dissolved oxygen removal for management of arsenic leaching include additional capital and operational costs and that the injected water has to be pretreated in perpetuity.

An alternative approach, which was adopted for DWU's ASR system, is to allow arsenic concentrations to be reduced naturally over time (operational cycles), as the small, finite amount of leachable arsenic in the storage zone is progressively exhausted. Arsenic concentrations from the Phase I ASR well (ASR-1) and a Phase II well (ASR-4) are plotted versus time in Figure 4. Arsenic concentrations tend to increase as recovery progresses in each operational cycle. Cycle test 3 included an initial recovery period (3a) in which the injected volume was recovered. The decision was then made to recover additional water to remove arsenic-rich water still present in the aquifer (3b); the over-recovery results in much lower arsenic concentration in subsequent operational cycle 4. The later operational data for well ASR-1 and the Phase II wells (e.g., ASR-4) show a progressive reduction in arsenic concentrations over time to values eventually below 10 µg/L.

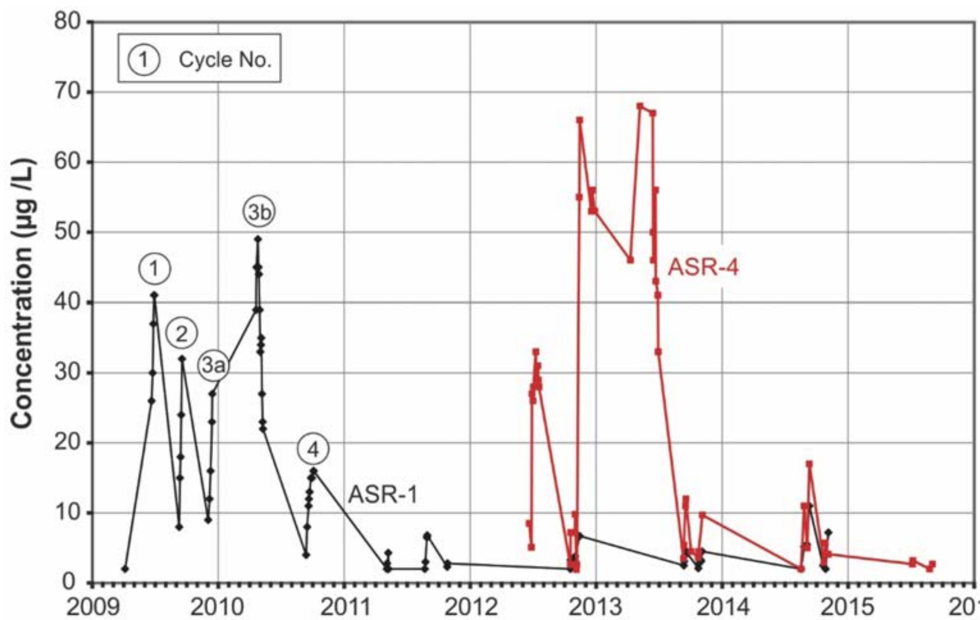

Figure 4. Arsenic concentrations of recovered water from wells ASR-1 and ASR-4.

Total Coliforms and Trihalomethanes in Injected Reclaimed Water

Injected water is required under FDEP's UIC rules to meet both the state groundwater total coliform bacteria standard of 4 cfu/100 mL and the total trihalomethanes (THMs) drinking water MCL of 80 µg/L. Where chlorination is used for disinfection, fine adjustments of the chlorine dose are required so that sufficient chlorine is added to ensure adequate disinfection (i.e., meeting the total coliform standard), while at the same time not adding too much chlorine so that the THM standard is exceeded. Simultaneously meeting both standards is often

Continued on page 58

Continued from page 57
a challenge for systems recharging treated wastewater or surface water because fluctuations in the organic concentration and composition of the water (e.g., seasonal and in response to storm events) may impact the required chlorine dose. Switching to ultraviolet light disinfection is not considered a viable option for DWU's ASR system (and other similar systems) because of its high costs and the need to maintain a chlorine residual in the injected water to control biological clogging.

The DWU wastewater facilities permit requires daily total coliform monitoring, with the requirement that total coliform samples shall have no more than one positive reading per month and that any one sample shall not exceed 4 cfu/100 mL. This requirement forces DWU to stop injecting for a month after a total coliform detection, which is particularly problematic because false positives with respect to total coliform bacteria are common, in general. Total coliform may be indigenous rather than of fecal origin (Mansuy, 1999) and coliform bacteria may be transported by the wind as dust particles (Rosas et al., 1997), so occasional detections due to contamination during sampling would be expected. The FDEP is currently considering changing the bacterial monitoring requirement from total coliform bacteria to E. coli, which is recognized to be a superior indicator of fecal contamination of water (Standridge, 2008).

Zone of Discharge

After the start of operation of the ASR system, FDEP adopted a zone of discharge (ZOD) policy, which sets the compliance point for primary (health-based) and secondary (aesthetic-based) drinking water standards at the boundary of ZOD, which for the ASR system is the wastewater treatment property boundary. Monitoring wells SZMW-5 and SZMW-6 were installed at the property boundary as ZOD compliance wells. The adoption of the ZOD concept is a very important step for the implementation of ASR in Florida, in general, as it formally allows for the natural attenuation of arsenic leaching over time, so long as the arsenic standard (and other groundwater standards) is met at the boundary of ZOD. The ZOD also allows for the natural attenuation of other parameters, such as coliform bacteria and THMs.

Clogging

The main operational challenge of the ASR project is the management of clogging, which is an endemic problem for injection wells, especially those with screened completions in unconsolidated sand-and-gravel aquifers. Huisman and Olsthoorn (1983) noted over four decades ago that "without any doubt, the most important drawback to the use of injection wells is the danger of clogging, primarily caused by an entrance rate into the aquifer, which is one to two orders of magnitude higher than that with spreading ditches." Well clogging in screened wells may occur even where the water is of very high quality, such as the predominantly reverse-osmosis-treated wastewater injected in the Orange County Water District (Calif.) Talbert Gap salinity barrier (Burris, 2015). The ASR wells are rehabilitated by periodic backflushing and occasional extensive well rehabilitation, which involves contracting a well driller to pull the submersible pump and to perform physical (jetting and surging) and chemical treatments.

The optimal well rehabilitation program for ASR sites is site-specific, in terms of the treatments used and the frequency of their application. The ASR system is in an adaptive management stage in which various rehabilitation options are being evaluated to find the strategy that will most cost-effectively maintain well performance.

Discussion

Although DWU's ASR system was implemented to address the specific needs of the utility, it has had further-reaching implications. The ASR system was an initial step toward recognizing the aquifer zoning concept in Florida and the use of institutional controls to protect public health (Missimer et al., 2014). Based on its salinity alone, the sand-and-gravel aquifer would normally be regulated as an aquifer in which indirect potable reuse was possible and water recharged using wells would have to be treated as if potable consumption of water could occur. Instead, an institutional control (the local ordinance restricting the aquifer to irrigation) was recognized as an alternative best local use of the aquifer.

There are numerous other coastal communities in Florida and elsewhere where a shallow aquifer is present that is not now and will not in the future be used as a potable water supply. A similar ordinance or other institution controls may facilitate putting these aquifers to their best use as ASR storage zones for irrigation.

A second institutional control applied to the ASR system is ZOD, which allows for natural attenuation of arsenic leaching, provided that groundwater with arsenic concentrations above the applicable groundwater standards remains on property owned by DWU. The ZOD also applies to other primary and secondary drinking water standards (e.g., coliform bacteria, THMs). The ZOD solution was workable for DWU because there is adequate room onsite to contain the arsenic-impacted groundwater; however, other existing and potential ASR system sites may either not have adequate property for an ownership-based ZOD or the ASR systems may have too-large storage capacities or aquifer heterogeneities (flow zones) to retain all injected water onsite.

The ASR system has particularly favorable conditions that are not present at all coastal locations. The very low storage-zone salinity allows for essentially 100 percent recovery of the injected water. The storage-zone geology of unconsolidated sand and gravel results in the aquifer having a highly effective porosity and low dispersivities, which favor a low degree of mixing with native groundwater. The recharged water tends to spread out less from the ASR wells.

The ASR of reclaimed water may still be feasible in coastal areas where the shallow aquifer is salinity-stratified and/or close to the saline-water interface. If the excess reclaimed water during wet periods would otherwise be discharged to tide, ASR, with even a low to moderate recovery efficiency, may still yield sufficient benefits to justify the investment in the system.

Conclusions

The DWU's ASR system experience illustrates the value of the aquifer zoning concept. Regulatory requirements for ASR systems, and injection wells in general, in the U.S. are based largely on the water quality in the storage or injection zone, rather than the actual existing or potential future uses of the aquifer. The sand-and-gravel aquifer in Destin is not suitable for use as a potable supply because of its poor quality and susceptibility to saline-water intrusion from prolonged pumping. Its best use is as a source of water for domestic irrigation and for storage of reclaimed water for irrigation use. Unconsolidated siliciclastic aquifers, such as the sand-and-gravel aquifer, have highly effective porosities and low dispersivities, which are favorable for recovery of reclaimed water in ASR systems; however, the required screened completions give them a greater susceptibility to clogging.

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