Prototype for a Reclaimed Water Aquifer Storage Recovery System: Benefits and Operational Experiences

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The reclaimed water aquifer storage and recovery (ASR) system of Destin Water Users Inc. (DWU), located on the northwest Florida Gulf Coast, is groundbreaking in several respects. It is the first ASR system in northwest Florida, and the first operational system in Florida, to successfully use a shallow sand aquifer (sand-and-gravel aquifer) as a storage zone. The system is also one of only three operational reclaimed water ASR systems in Florida and is the only one that uses an aquifer, considered to be an underground source of drinking water, as a storage zone. The storage zone of the system contains fresh water, but does not meet potable standards because of elevated iron and sulfide concentrations. The system also pioneered the use of institutional controls to address public health concerns and avoid the possibility of indirect potable reuse, namely an existing local prohibition against the use of the storage aquifer for potable supply purposes.

Groundwater modeling and monitoring results indicate that the stored water remains close to the ASR well with a relatively low degree of dispersive mixing. Despite the quartz sand mineralogy of the storage zone, arsenic leaching, at levels of regulatory concern, has occurred in the ASR system. However, concentrations have progressively decreased with each successive operational cycle. The strategy adopted is to allow leachable arsenic to be flushed out of the aquifer, rather than resort to much more expensive pretreatment of the stored water. Over-recovery (greater than 100 percent) was found to be effective in removing leached arsenic in solution in the groundwater, resulting in lower concentrations in the subsequent recovery cycle.

Operational testing is ongoing on the phase I ASR well (ASR-1), which now involves injection and recovery on demand under normal long-term operational conditions. Six additional ASR wells (ASR-2 through ASR-7) have been constructed and are operational. The completed system has a capacity of 2.125 million gallons per day (mgd). The system is a prototype for cost-effective use of ASR to optimize the reuse of reclaimed water, which has global applications. The system will allow more of the high-quality reclaimed water produced by the DWU's George F. French Water Reclamation Facility to be put to beneficial use, help ensure a reliable supply of reclaimed water to customers, and avoid potential environmental impacts associated with wastewater disposal.

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Background

Development of economical and environmentally sound supplies of water and means for wastewater disposal are a particular challenge for communities located on barrier islands and along the coast of Florida. Freshwater groundwater resources are locally limited, little undeveloped land may be available or is often expensive, and environmentally sensitive marine waters and coastal wetlands are often present. Offshore discharge of treated wastewater is a politically charged issue that will likely elicit strong public opposition because of concerns over impacts to the environment and beaches, and thus the economically important tourism industry. Offshore discharges of wastewater have also become very expensive to permit.

The City of Destin is located on a barrier island in Okaloosa County, in the state's panhandle. Water and wastewater services are provided by DWU, which faces challenges that are common in Florida's coastal areas. The DWU obtains its fresh water supply from the Upper Floridan Aquifer (Figure 1), which is now considered to be regionally utilized at its sustainable limits because of salt-water intrusion concerns. Additional withdrawals from the Upper Floridan Aquifer are not permittable.

The shallow aquifer in Destin, the sand-and-gravel aquifer, contains fresh water, but is not directly suitable for potable water use because of high iron and hydrogen sulfide concentrations. Use of the sand-and-gravel aquifer for potable use is prohibited in the City of Destin by a local ordinance, but it is widely used for residential irrigation.

The DWU reclaimed water flow is mostly reused for irrigation by residential and commercial users and some golf courses. Excess reclaimed water is disposed of by land application methods, and thus recharges the surficial zone of the sand-and-gravel aquifer.

The DWU needs additional wet weather wastewater disposal capacity. Expansion of the reuse system is constrained by the lack of a reliable additional supply during peak demand periods. Potential reclaimed water customers often will not commit to the reuse system unless they can be provided with a reliable year-around supply of water. The ASR system was determined to be a logical and highly cost-effective solution to DWU's wastewater management challenge. Excess reclaimed water could be stored in the ASR system during wet weather periods, which would address the need for additional peak disposal capacity. The stored reclaimed water could be recovered during high demand periods, which would increase the reliability of the water supply that is necessary to attract additional customers. Increased use of reclaimed water has the additional benefit of reducing demands on freshwater resources.

The Aquifer Storage Recovery System

The ASR system consists of seven ASR injection and recovery wells and six associated monitoring wells (Figure 2), and has a design injection and recovery capacity of 2.125 mgd. Reclaimed water is stored in the main-pro-

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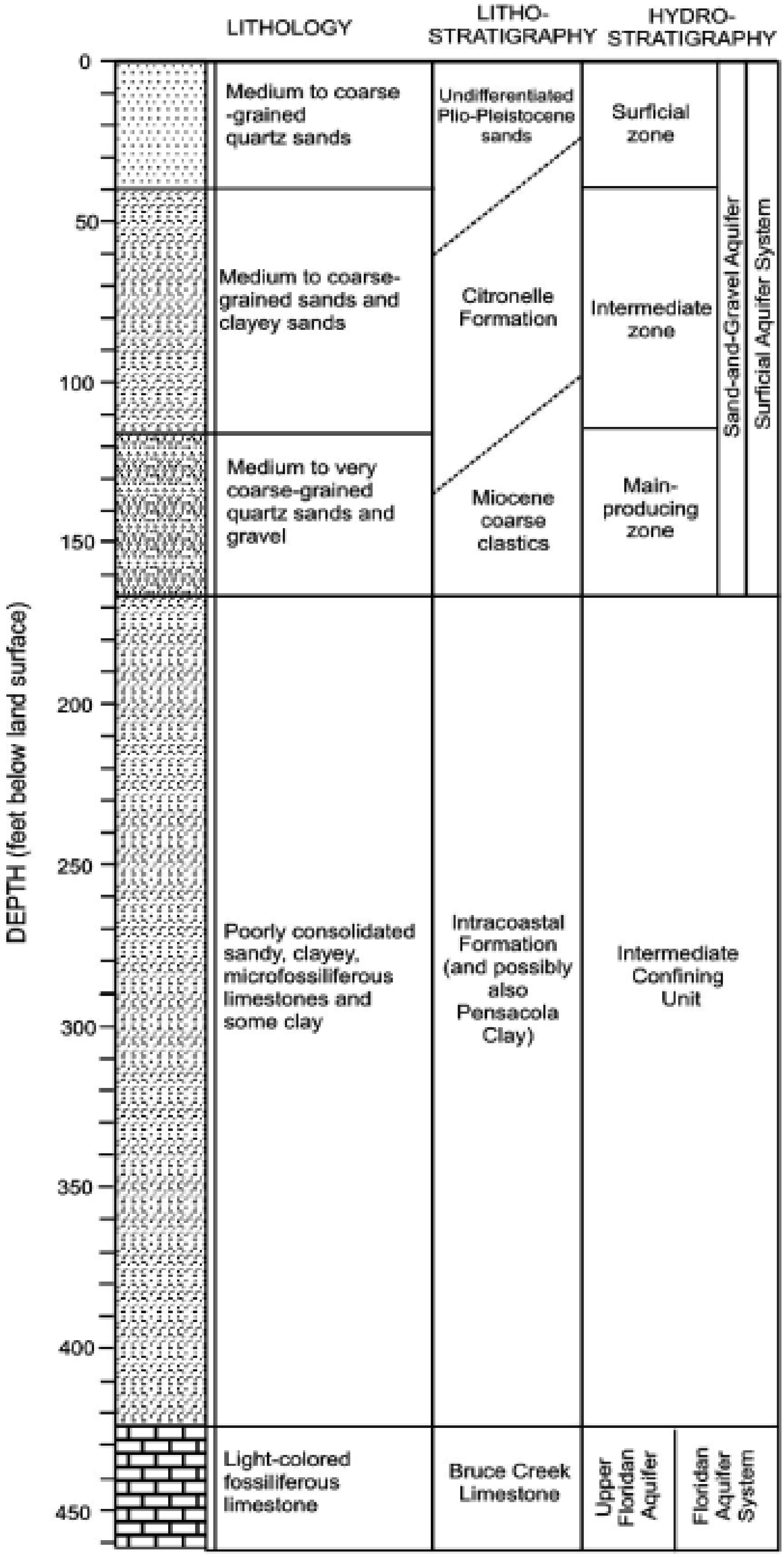

Figure 1. Hydrogeology of the Aquifer Storage Recovery System Site

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ducing zone of the sand-and-gravel aquifer of the surficial aquifer system. The ASR system was constructed in two phases. Phase I included the construction and testing of a pilot ASR system, which consists of a single ASR well (ASR-1) and three associated monitoring wells. Two of the monitoring wells are existing wells that were converted to storage-zone monitoring wells (SZMW-1 and SZMW-2) and a newly constructed shallow monitoring well (SMW-1). Phase II of the ASR project consisted of the construction of six additional ASR wells (ASR-2 through ASR-7), two additional storage-zone monitoring wells (SZMW-3 and SZMW-4), and an additional shallow monitoring well (SMW-2).

The ASR wells are constructed with a 16-in. diameter SDR-17 polyvinyl chloride (PVC) injection casing set to 106 to 110 ft below land surface (bls). The wells are completed with 50 ft of 8-in. diameter, and 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 could be removed to rehabilitate the well, if necessary.

Operational (cycle) testing for Phase I began on July 10, 2009, and five operational tests have been completed to date. Operational tests 1 through 4 consisted of discrete injection and recovery phases. An additional recovery was performed after the completion of operational test 3 as a measure to remove leached arsenic from the storage zone. Operational test 5 was an approximately nine-month period in which reclaimed water was injected as available and recovered as needed. The operational testing program is summarized in Table 1.

Regulatory Issues

This ASR system is unique in Florida in that reclaimed water is being stored in a freshwater aquifer. A key issue for making the system economically feasible was obtaining a variance from some of the requirements of the Florida Department of Environmental Protection (FDEP) reuse rules (FAC Chapter 62-610). Any ASR systems that use aquifers containing less than 1,000 mg/l of total dissolved solids (or in some cases less than 3,000 mg/L) are required to meet the full treatment and disinfection requirements, based under the assumption that indirect potable reuse will occur.

The main-producing zone in Destin contains fresh water that is not directly suitable for potable use because of high iron and hydrogen sulfide concentrations. Both the surficial zone and main-producing zone of the sand-and-gravel aquifer are used in Destin only for irrigation water supply. Section 10.05.05 (A) of the Destin city code specifically states that shallow wells that draw water from the sand-and-gravel aquifer shall be used for irrigation purposes only. The prohibition against potable use of the sand-and-gravel aquifer was instrumental in allowing DWU to obtain a variance from many of the full treatment and disinfection requirements, because it provided reasonable assurance that indirect potable reuse will not occur.

The permitting issues overcome in this ASR project illustrate some of the shortcomings of the federal and state underground injection control (UIC) rules. Groundwaters with a total dissolved solids concentration of less than 10,000 mg/L are uniformly treated as underground sources of drinking water, when in many instances, there is no likelihood that potable use will ever occur. Institutional controls, such as local prohibitions against the potable use of an aquifer and setbacks from potable supply wells, can be effective in meeting the ultimate goal of the UIC program of protection of potable water supplies.

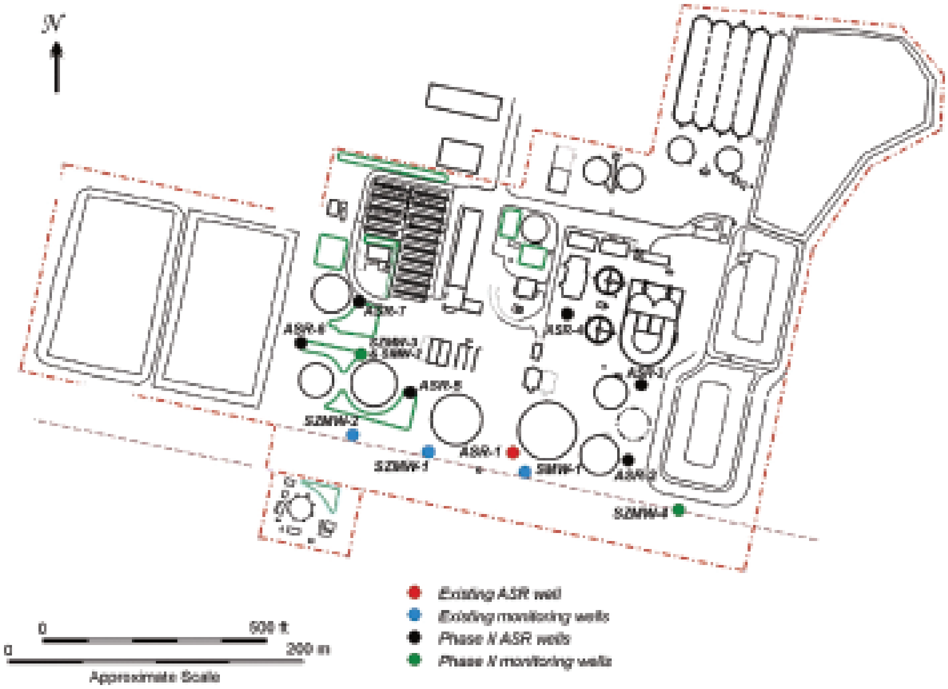

Figure 2. Site Plan of the George F. French Water Reclamation Facility With Locations of Aquifer Storage Recovery System Wells

Table 1. Summary of Operational Tests 1 Through 5

Operational Test	Start of test	Injected Volume (MG)	Recovered Volume (MG)
1	July 10, 2009	2.547	2.528
2	Aug. 21,2009	2.136	2.118
3	Oct. 21, 2009	3.067	2.927
3 Additional recovery	April 20, 2010	0	4.360
4	May 12, 2010	5.701	4.299
5	Feb. 8, 2011	5.122	3.465
Total		**18.573**	**19.697**

Solute-Transport Modeling

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.
- Develop a predictive tool that would assist in the design of ASR system expansion and development of operating protocols.

The model was successfully calibrated against head buildups during injection and drawdown during recovery. A comparison of the predicted recovery data, expressed as the percentage of injected water in the recovered water sample and the measured values, is provided in 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 high effective porosity (0.35) were required. The model still slightly underestimates the fraction of injected water in the late-stage recovered water due to the numerical dispersion inherent in numerical codes such as MT3DMS.

Injected water was not detected in either the storage-zone monitoring wells or the shallow monitoring well during the operational data conducted using well ASR-1. The combination of the modeling results and monitoring data was instrumental in evaluating the mixing and movement of the injected water, and demonstrating that the injected water was staying near the ASR well and remaining on site. The recovery data also indicated that a relatively low degree of dispersive mixing occurs during injection and recovery. These results are as expected in an unconsolidated sand aquifer that is dominated by intergranular matrix flow (i.e., flow between sand grains). Much greater degrees of mixing and migration of injected water occur in carbonate aquifers in which flow is often highly influenced by secondary porosity.

Arsenic Leaching

The leaching of arsenic into stored water has been a common phenomenon in Florida ASR systems and has become a major constraint on implementation of the technology in the state. Arsenic is present in trace quantities in iron sulfide minerals such as pyrite. The available evidence from field observation and bench-top experiments performed by the Florida Geological Survey ((Arthur et al., 2001,

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2002, 2007; Mirecki, 2004, 2006a, 2006b) indicates the injection of fresh water with a high dissolved oxygen concentration causes the dissolution of sulfide minerals and the release of arsenic to solution. It was expected that the ASR system would have a low susceptibility to arsenic leaching because of the apparent paucity of arsenic-containing mineral phases in the clean quartz sands of the storage zone. Nevertheless, the water recovered from the ASR system had arsenic concentrations that exceeded the Florida groundwater standard and drinking water maximum contaminant level of 10 µg/L.

The arsenic concentration data from the recovered water are plotted in Figure 4. The arsenic concentration in the recovered water decreased during each cycle test. A key result is that the arsenic concentration in the recovered water progressively increased during the additional recovery performed at the end of the operational/cycle test 3, and then decreased sharply.

The data suggest that over-recovery may be an effective strategy in removing arsenic from the ASR system and expediting the conditioning of the system so that arsenic concentrations meet regulatory standards (i.e, concentrations of 10 µg/L or less). The operational testing results are consistent with there being a limited amount of leachable arsenic in the storage-zone sands, which is being progressively removed. Most of the arsenic apparently has already been removed from the sand next to well ASR-1, as the last-injected and first-recovered water, which necessarily has remained near the well and had minimal enrichment in arsenic in cycle tests 2 through 5.Arsenic concentrations during operational/cycle test 4 leveled off at 16 µg/L. The arsenic concentrations of all samples tested during operational test 5 were below 10 µg/L. The DWU experience demonstrates that arsenic leaching can be managed by progressively removing leachable arsenic from the formation during system testing and operation, which is a much less expensive option than pretreating the injected water to remove dissolved oxygen.

Lessons From The Aquifer Storage Recovery System

This ASR system is a forerunner in Florida in several ways, and provides a prototype for similar systems elsewhere. Shallow aquifers are present on many barrier islands and onshore in coastal areas that are not suitable for potable water supply, often because the freshwater resources are limited and may have been impacted by saline-water intrusion. The optimal use of these aquifers may be as storage zones for reclaimed water, or perhaps stormwater ASR systems for later irrigation use. The ASR system demonstrated that reclaimed water using shallow sand-and-gravel aquifers is feasible. The system also pioneered the use of institutional controls to ensure that public health is protected. There is a clear need for underground injection rules and policies to be modified so that permitting and monitoring requirements are based on actual public health risks, rather than unrealistically assumed potable use. For example, there is no rational reason why the drinking water arsenic and total trihalomethane maximum contaminant levels should be applied to the DWU and similar ASR systems.

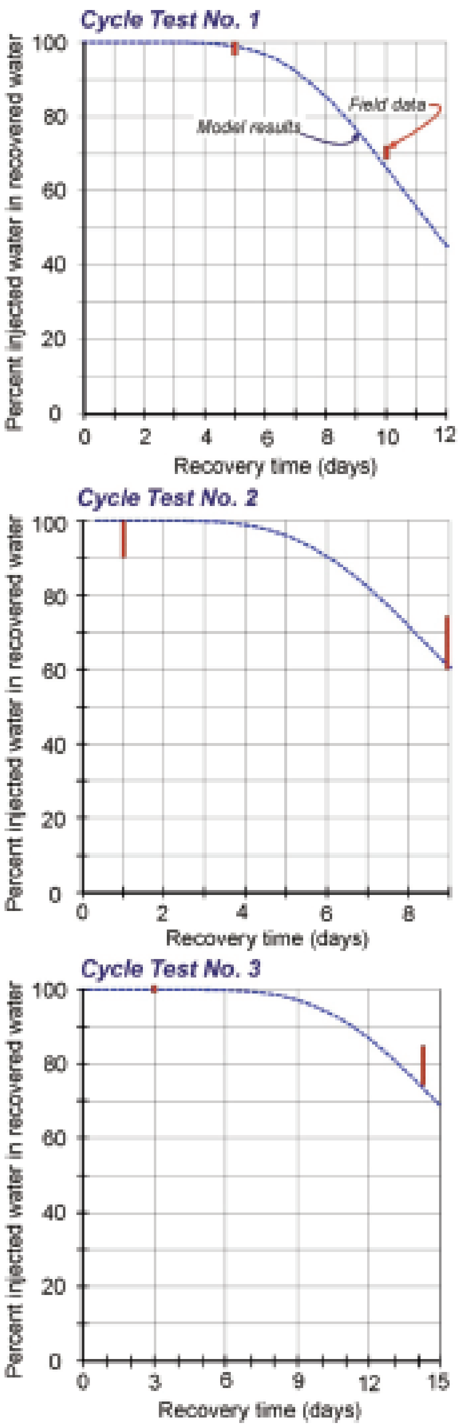

Figure 3. Aquifer Storage Recovery System Modeling Results

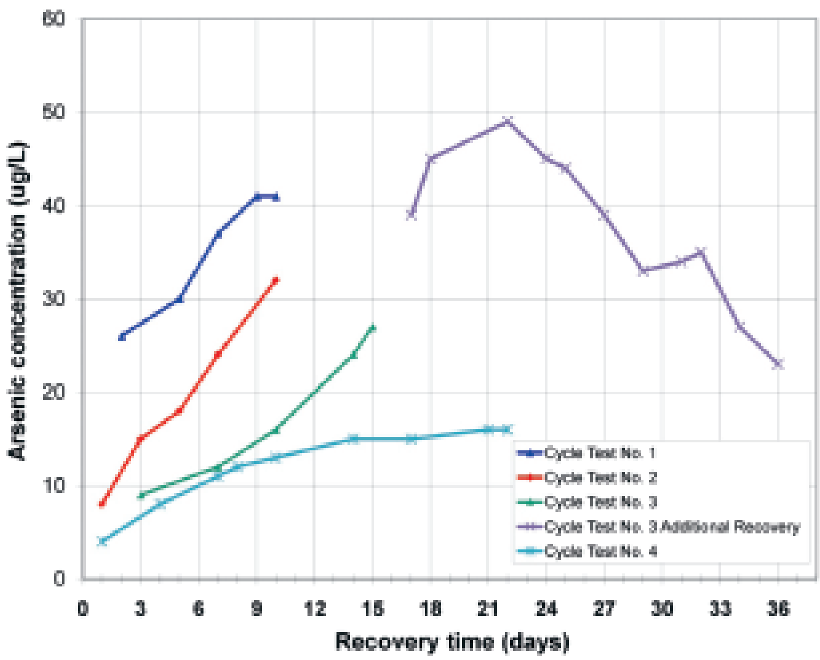

Figure 4. Arsenic Concentrations in Recovered Water

The ASR systems also provides some insight into the management of arsenic leaching; they have usually been initially operated by leaving some of the injected water in the formation of each operation cycle in order to develop a buffer zone between the injected and native groundwater. This strategy may have the adverse impact of leaving dissolved arsenic in the storage zone. Where arsenic leaching is a concern, the most effective strategy may be to over-recover in order to remove as much dissolved arsenic from the storage zone as possible. Over-recovery may expedite conditioning the aquifer so that arsenic leaching is no longer a regulatory concern. However, it is recognized that over-recovery may not be practical in ASR systems that use brackish aquifers for storage zones, and there is no economic means for disposing of the produced water in an environmentally sound manner.

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