Aquifer Storage Recovery Wells: The Path Ahead

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Successful experience at 53 operating aquifer storage recovery (ASR) sites in Florida and 14 other states has demonstrated that this technology is proven, viable and cost-effective for storing large volumes of water deep underground in fresh and brackish aquifers. Most of the initial projects are storing treated drinking water, but several more- recent projects are planned, constructed or already storing water from other sources, including reclaimed water, untreated groundwater, and treated surface water.

Although many technical issues and uncertainties have been resolved and permitting of drinking-water ASR systems has become relatively routine in Florida, the regulatory framework governing recharge of water that does not meet all federal primary drinking-water standards at the wellhead prior to recharge is unnecessarily restrictive. These restrictions create a significant challenge for permitting such projects.

Substantial data has indicated the ability of natural physical, geochemical, and bacterial processes occurring in a small zone around an ASR well to reduce or remove microbiota and various chemical constituents. The 1974 Federal Safe Drinking Water Act appears to provide for such natural aquifer treatment, but Environmental Protection Agency (EPA) regulations promulgated after that law was enacted do not provide any allowance for these natural processes, except through an aquifer exemption process that appears unworkable. This difference in interpretation of the law is estimated to represent a potential unnecessary cost of at least $2 billion to Florida during the next 20 years.

Legislation is needed that would establish a Zone of Discharge for ASR wells in Florida. Leadership and support by Florida water interests is needed to pass this legislation, which would provide a logical, defensible, legal framework upon which state and federal regulations can be developed, consistent with the overriding need to protect groundwater quality from contamination.

Introduction

Since the initial project in Florida became operational in Manatee County in 1983 after five years of development, the ASR concept has evolved rapidly. It has been accepted as a proven, cost-effective technology for seasonal storage of water that meets all federal primary drinking-water standards. Water is stored in a suitable aquifer through one or more ASR wells at times when the water is available or of preferred quality. It is recovered from the same wells whenever it is needed, without the necessity for retreatment, except for disinfection.

ASR technology is proven. Fifty-three ASR systems are believed to be operational in the United States as of January 2002, with approximately 100 more in various stages of development, ranging from planning to operational startup. ASR systems are storing water in limestone, dolomite, sand, sandstone, clayey sand, basalt, and glacial aquifers, with native-water qualities ranging from fresh to brackish. One Florida site, not currently in operation, successfully stored drinking water in a seawater aquifer.

Most ASR sites store drinking water in an aquifer containing poor water quality, with at least one constituent of the native-water quality that would require treatment to meet potable-water standards. To date, such constituents have included iron, manganese, hydrogen sulfide, total dissolved solids, chloride, fluoride, radium, gross alpha radioactivity, nitrate, arsenic, boron, and other constituents. At each ASR site, a large "bubble" of stored water is created within the storage zone, displacing native groundwater around the well. Typically this bubble extends a radial distance of a few hundred feet, although pressure effects during recharge and recovery may be observed at greater distances.

Most ASR storage zones are in confined aquifers, but a few utilize unconfined aquifers, particularly where the depth to the water table is substantial. The shallowest depth to the top of a storage zone is about 200 feet, while the greatest depth to the base of an ASR storage zone is 2,600 feet. The thinnest storage zone is about 50 feet, while the thickest is about 1,300 feet.
Most ASR applications, particularly in Florida, are for seasonal water storage, but other applications include diurnal water storage; long-term water storage, or "water banking," from wet years to drought years; emergency water storage; restoring water levels in depleted aquifers; creating salinity intrusion barriers; controlling subsidence; maintaining pressures and flows in water distribution systems; improving water quality; reducing the cost of water system expansions; maintaining minimum flows and levels; and many other applications.

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The ASR technology has moved beyond the United States and is now operational in England (two sites), Australia (seven sites), Israel (two sites), and Canada (one site). ASR projects are being developed in Taiwan, Thailand, the Netherlands, South Africa, India, and possibly other countries.

The principal reason for the rapid development and acceptance of ASR technology has been its cost effectiveness compared to other alternatives for water supply and water storage. The national average capital cost for providing an additional 1 MGD of peaking capacity with an ASR well is about $400,000, plus or minus about $200,000. Single-well ASR systems that utilize new, deep wells tend to be toward the high end of this range. Multiple-well ASR systems that retrofit existing wells or construct new shallow wells tend to be toward the low end of the range. The most important consideration in determining unit costs is the individual well yield, since high-capacity wells such as those common in Florida tend to suppress unit costs. In other states where well yields may be relatively low, unit costs can extend above the normal range.

An important secondary reason for ASR implementation is its generally favorable acceptance by environmental groups. With a few exceptions, these interests have been pleased with the newfound ability to reduce the environmental impacts of surface storage reservoirs, or to eliminate the need for these reservoirs, by storing a small portion of peak flows that may otherwise be lost. The ability to maintain minimum

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flows and levels inexpensively by recovering water stored during floods is generally considered to be valuable to aquatic and terrestrial ecosystems.

With this ASR success has come a closer look at whether or not this technology may perhaps be utilized to store water from other sources, such as reclaimed water, untreated groundwater from other aquifers or other portions of the same aquifer where water quality is acceptable, and also treated surface water. As an indication of this level of interest, 14 reclaimed-water ASR projects are underway in Southwest Florida, one of which has already begun initial testing and operations. Three ASR sites are constructed to store untreated groundwater but are not yet fully operational, and several sites are being considered to store partially treated surface water. One of these sites, at West Palm Beach, is constructed, permitted, and about to begin operation.

The Zone of Discharge (ZOD)

ASR projects have raised several new issues for regulatory agencies. Each state typically has its own slate of issues, reflecting different hydrogeologic settings; water management opportunities and constraints; water laws, organization, regulations, policies, and responsibilities of state agencies; and related experience. For projects storing drinking water, however, it has generally been possible to resolve regulatory concerns in each state and thereby obtain necessary permits to build and operate ASR wells.

At each of these sites, drinking water is stored when available and is recovered when needed. Initial development and conditioning of the storage zone around an ASR well is usually required in order to develop a buffer zone separating the stored water from the surrounding native groundwater, which in Florida is usually brackish.

Once this initial development is completed, the quality of the recovered water is suitable for drinking following disinfection, and full recovery of subsequently stored water can be anticipated in most cases. Exceptions may occur whenever significant lateral movement of the stored water bubble may occur between the time of recharge and the time of recovery, or whenever density stratification occurs and distorts the shape of the storage bubble. These exceptions are uncommon.

Extensive monitoring of stored and native-water quality, both in the ASR well and also in one or more monitor wells during ASR system testing, has demonstrated that subtle changes in water quality can occur, most of which are beneficial. For example, although recovered-water quality meets all drinking-water standards, concentrations of disinfection byproducts present in the recharge water, such as trihalomethanes and haloacetic acids, tend to be reduced or eliminated in the recovered water.

While mixing and blending is certainly a factor, careful evaluation of the data has shown that non-conservative reaction processes are occurring underground, particularly geochemical and bacterial processes. These processes appear to occur close to the ASR well and may not extend to the edge of the storage bubble. From ASR experience combined with parallel experience with drainage wells, sinkholes, and deep-injection wells utilized for disposing reclaimed water into saline aquifers, it is evident that these same processes also reduce nitrate, nitrite, and phosphorus concentrations, along with attenuate bacteria, viruses, and protozoa.

These changes in water quality during ASR operations are highly significant. Most regulatory agencies give ample credit for water-quality changes that occur during storage within the surficial aquifer ("vadose zone") during surface recharge or land spreading operations, but no credit or allowance is usually provided for water-quality changes that occur once the stored water reaches a saturated aquifer from overlying surface recharge facilities or is recharged into that aquifer through a well. As a result, regulatory agencies have generally taken the position that the quality of recharge water has to meet all drinking-water standards at the wellhead prior to recharge.

This regulatory position is embodied in federal regulations promulgated by the Environmental Protection Agency (EPA) in 1981 pursuant to the 1974 Safe Drinking Water Act. The regulations established an Underground Injection Control (UIC) program, which in most cases is delegated to individual states for implementation, setting certain minimum criteria which each state has to meet and is welcome to exceed. The regulations are aimed at protecting aquifer water quality by controlling the disposal of waste materials into wells. They were not aimed at storing a high-quality water source for recovery and beneficial use, and they were promulgated before ASR became a widely implemented option for water management.

So long as the recharge water has been drinking water, this has not been a real issue for water utilities, but as ASR applications started to consider recharge of water from other sources, these regulations have proven to be a formidable stumbling block. Here are two examples:

Miami-Dade County ASR System

Plans by the Miami-Dade Water and Sewer Department to store seasonally available waters from the shallow Biscayne Aquifer in ASR wells penetrating the upper Floridan Aquifer have been stalled for over four years. Facilities have been constructed at the West Wellfield and were recently completed at the Southwest Wellfield, with a combined recovery capacity of 25 MGD. However, recharge cannot occur during wet-weather periods because total coliform bacteria concentrations in the recharge water from the Biscayne Aquifer have been known to reach as high as 22 mpn/100 ml during heavy rainfalls, compared to drinking-water standards of 4 mpn/100 ml. No fecal coliform concentrations in the recharge water have ever been detected, and monitoring has shown that total coliform concentrations return to "non-detect" within about one day of storage, reflecting natural geochemical and bacterial processes within the Zone of Discharge (ZOD) surrounding the ASR wells. The recovered water from the ASR wells is combined with water produced from the shallow Biscayne Aquifer wells and is then conveyed to the Alexander Orr Water Treatment Plant, where it is treated and disinfected before distribution.

The storage zone at these sites is a brackish aquifer with total dissolved-solids concentrations of 4,000 to 5,000 mg/l, or about 10 times the drinking-water standards. Under current law, we are in the somewhat strange position of protecting this aquifer as a future potential supply of drinking water, even though that would require desalination treatment, by preventing its recharge with freshwater, which would make it a more useful resource. Considering the demonstrated natural die-off of microbiota during ASR storage, this conservative position of protecting aquifer water quality against potential microbial contamination seems difficult to justify on technical grounds.

Since coliform bacteria are a federal primary drinking-water standard, an aquifer exemption has been needed from the Florida Department of Environmental Protection (FDEP) and the EPA in order to operate this system as designed. To date, this permitting process has required over four years. During the serious floods in Miami-Dade County in October 2000, no water was stored in the ASR wells. The following spring, drought conditions resulted in significant water-use restrictions being imposed on the county by the South Florida Water Management District. The county then had to recover the 1.4 billion gallons that were stored during the early part of 2000 before the heavy rains, but this relatively small amount was insufficient to sustain the need for very long. If the regulatory logjam could have been resolved in a timely manner, Miami-Dade County could have met a much larger portion of its drought water-supply needs with locally stored water, while reducing demands on its shallow-aquifer wellfields to comply with water-use restrictions. There are no other users of the brackish-water ASR storage zone in this area. Further treatment of the recharge water to eliminate microbiota is under consideration, but this would substantially increase the cost of water storage at this site.

West Palm Beach ASR System

The largest ASR well in the world was recently completed at the site of West Palm Beach's water treatment plant on Clear Lake. With a capacity of 8 MGD, this well will take filtered water from Clear Lake and store it in the upper Floridan Aquifer at depths of 1,000 to 1,300 feet. TDS concentrations in the aquifer at this site are around 4,000 mg/l.

As with Miami-Dade County, this ASR well has been sitting idle, waiting for regulatory approval to start testing. EPA officials indicated during December 2000 that they would accept this project for a proposed three-year demonstration test to confirm the fate of microbiota during ASR storage. However, the FDEP has subsequently indicated that a Chapter 120 Variance will be required because the recharge water contains low levels of total coliform bacteria, around 200 mpn/100 ml, thereby exceeding federal primary drinking-water standards. It currently appears unlikely that such a variance might be obtained, even though laboratory and field investigations regarding the fate of microbiota during ASR storage suggest that concentrations of coliform bacteria attenuate rapidly during ASR storage. The city has therefore equipped the well to provide disinfection prior to recharge, and is about ready to begin ASR operations.

Other Florida ASR Sites

Several other Florida ASR sites, either existing or potential, are monitoring the progress of these difficult ASR permitting issues. If they can be resolved in a satisfactory manner, it is likely that many more ASR systems storing seasonally available, treated surface water will be developed. If the requirement to treat to drinking-water standards can be moderated, then the cost of these systems will be low compared to other water-management solutions. Florida has seasonally abundant water resources but few good places to store the water. Evapotranspiration and seepage losses are high in surface reservoirs, while

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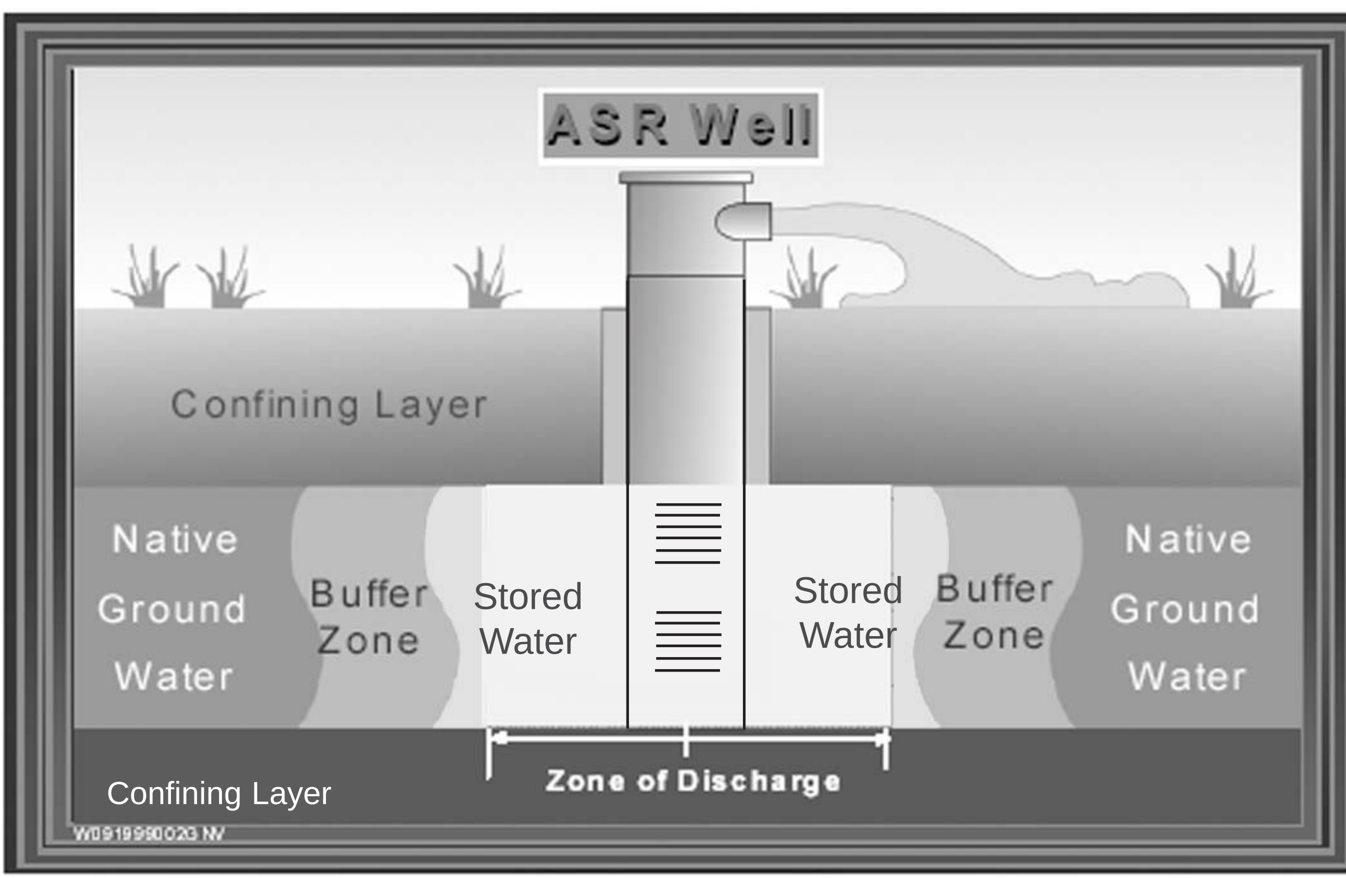

Figure 1 Zone of Discharge in an ASR Well

in ASR wells those two problems are insignificant.

At a few sites, simple filtration and disinfection of surface waters, without other chemical addition, may be enough to comply with federal primary drinking-water standards. This is similar to operations at the existing Marco Island ASR site operated by Florida Water Services, except that pH adjustment also occurs at that site. However, most ASR sites storing treated surface water will tend to be remote, and for these sites, the preference will be to try to avoid unnecessary capital investment and operating requirements for treatment facilities.

Proposed ASR Legislation

Primarily because of this impasse, the FDEP, the South Florida Water Management District, the Southwest Florida Water Management District, the St. Johns River Water Management District, various water utilities and others recently proposed a new approach to the permitting of ASR wells in Florida.

Under this approach, compliance with applicable water-quality standards would be evaluated at the edge of the Zone of Discharge instead of at the wellhead during recharge. The Zone of Discharge, or ZOD, has been defined as the radial distance around an ASR well, extending from the top to the bottom of the storage zone, within which water-quality changes may occur because of geochemical and bacterial processes. This is a legal term that has already been applied in Florida for ASR wells storing reclaimed water. The ZOD concept is also embodied in legislation in Utah, Arizona, and possibly other states, and is under consideration in Wisconsin under the name AMZ, or "ASR Management Zone."

Figure 1 shows a generic cross-section of an ASR well and the associated bubble of stored water available for recovery. This stored water, usually drinking water, is surrounded by a buffer zone that separates it from surrounding native groundwater, which in Florida is usually brackish water. The sum of the stored water volume and the buffer zone volume is referred to as the "Target Storage Volume," or TSV.

Once the TSV is reached for a particular well, it should be possible to fully recover subsequently stored volumes, so long as this volume remains relatively unchanged and so long as groundwater velocity is low enough that the stored water stays close to the well. Any increase in the volume to be recovered would entail a larger buffer zone. Also shown in Figure 1 is the Zone of Discharge, ZOD, which occurs close to the ASR well and within the stored water bubble, extending from the top to the bottom of the storage zone.

The ZOD is significant to Florida and other states because it provides a logical path forward to resolve the current regulatory problem relating to permitting ASR wells for storing water that does not meet all federal primary drinking-water standards. It is not a complete solution by itself, but it is a large and excellent step in the right direction. If this proposed legislation is passed, it will provide a pathway for ASR regulation that is better matched to Florida's needs and opportunities, rather than trying to fit within a "one size fits all" federal regulatory program that clearly is not working in this situation.

If a proposed ASR plan is deemed to comply with state ZOD legislation and associated regulatory requirements to be developed, the question may be raised as to whether this may contravene federal requirements that dictate compliance with drinking-water standards at the wellhead during recharge. Sooner or later we will have to face this issue, but passing the ZOD legislation will place Florida in a much stronger position to argue the merits of the case in any federal court or aquifer exemption proceeding.

The EPA and others are aware that current federal regulations have been deemed by some in the legal community to be inconsistent with the original intent of the 1974 Safe Drinking Water Act. That act provides for beneficial recharge practices through wells, so long as the practice does not cause an adjacent well owner or water user to have to provide a higher level of water treatment than would otherwise be necessary. In effect, this provided for a ZOD, but seven years later the EPA promulgated regulations that eliminated that option by requiring compliance with all federal primary drinking water standards prior to recharge. For Florida, a rough estimate of the difference in capital costs of facilities planned to meet 2020 water demands is at least $2 billion. Of this amount, approximately $1 billion is associated with the Everglades Restoration Program.

The Path Forward

First, water users and regulators need to get together and achieve passage of proposed ASR legislation, which would provide a ZOD for coliform bacteria and other microbiota. Certain requirements are established for situations in which the TDS of the storage zone exceeds 1,500 mg/l, and a few additional requirements occur for situations in which the TDS of the storage zone is below 1,500 mg/l.

Opposition to this legislation appears to be based on concerns about potential adverse impacts upon water quality in the storage zone, plus concerns regarding environmental justice. Opponents appear to be trying to link proposed ASR practices for storage and recovery of high-quality, treated surface water with deep-well injection disposal of wastewater effluent, on the incorrect presumption that the two practices are similar and have similar potential for contaminating water quality and the environment.

If this legislation is eventually passed, the next steps would include developing and promulgating ASR regulations. Such regulations would need to address a core issue of defining how the native groundwater quality is determined at each site, so that its regulatory exposure to the 1,500 mg/l TDS criterion can be established.

Currently the criterion applied by the FDEP mirrors federal criteria. Native water quality is established by pumping an initial three casing volumes from a well and then grabbing a sample for analysis. This is an overly conservative and inappropriate criterion for Florida, since many, if not most, of our wells in the coastal areas where ASR is most likely to be applied experience a decrease in water quality with extended pumping.

For practical reasons, the definition of native groundwater quality should be established as the concentration of any constituent of interest after the well has been pumped at a reasonable rate for a period of up to a month. Failure to make this adjustment will tend to drive many ASR systems into deeper aquifers and into locations closer to the coast, where salinity intrusion barrier formation would be inappropriately sited, pushing brackish water landward instead of seaward. There is no reason for Florida to repeat the Southern California experience in the 1950s, when the region's salinity intrusion barriers were located too close to the coast and have since been pushing brackish water inland from the barrier into coastal wellfields.

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Applications for construction and operating permits will then be made under the new law from several sites around Florida. If such permits are issued, then we will have solved the principal regulatory problem for many future ASR applications in the state. If they are legally challenged on the basis of non-compliance with federal (EPA) regulations, then it will be necessary to get the EPA to change the Underground Injection Control (UIC) regulations. This will require a congressional directive to the EPA, or possibly an amendment to the Safe Drinking Water Act that clarifies congressional intent and directs the EPA to either change its regulations and policies or to fully delegate the responsibility for regulation of ASR wells to the states. Such legal action would require a concerted effort by Florida and other water users and managers to change federal law and regulations.

With so much capital investment at stake, and so many potential water quality and environmental benefits, it appears reasonable to expect considerable statewide support for such an endeavor. At risk to the EPA is the potential for opening up the entire UIC program for other possible congressionally mandated changes extending beyond the resolution of Florida water management issues. At this point, however, no written confirmation of this policy change is evident.

Assuming that, one way or another, the regulatory issues associated with ASR storage of recharge water that fails to meet all federal primary drinking-water standards are satisfactorily resolved, subsequent steps will be appropriate. Among these will be the need to revisit rules and criteria for establishing minimum flows and levels in Florida surface water bodies. With ASR it may be possible to inexpensively meet these criteria, or perhaps to improve them, maintaining closer-to-natural variations in dry-weather flows and levels through recovery of flood flows stored during previous wet seasons.

It would also be appropriate to re-evaluate the water-quality constituents covered by proposed state legislation for inclusion in a ZOD. While coliform bacteria and other microbiota represent an area of immediate concern, the legislation could possibly be written to provide for other constituents failing to meet federal primary drinking-water standards that also do not represent a threat to groundwater quality, public health, or natural ecosystems. Among these could be constituents that have also been found to attenuate during ASR storage, such as disinfection byproducts and nutrients. Great care will be needed to ensure that constituents not amenable to subsurface natural treatment, and that are recognized as contaminants or otherwise threaten public health, are not stored in ASR wells.

An additional step in the path forward is to gain a better understanding of the physical, geochemical and bacterial processes by which changes in water quality occur during ASR storage. We know that these changes occur, but we have a limited understanding of why they occur. When we better understand these processes, we may be able to engineer them to achieve desired water-quality objectives in the recovered water and in the groundwater surrounding the ASR well. This will likely require extensive testing to determine microbial and geochemical processes, aquifer minerals, water quality, and other factors governing the rate, path, and end point of various subsurface reactions. Much work of this nature has been initiated and much remains to be completed. The outcome is unclear, but it is likely to be of great long-term value to Florida's water managers and water users.

Summary

Establishing in Florida law a Zone of Discharge for ASR wells is a logical step of great potential value. It will expedite storage of large water volumes during wet months, making them available for recovery during dry months to meet ecosystem, urban, agricultural, industrial, and other water needs. Rectifying this seasonal imbalance in Florida's water supply and demand will have a profound impact upon water management and sustaining Florida's natural environment. It can be done, and after many years of effort, we are closer to achieving success.

Once success is achieved, others will be able to adapt Florida law to meet their own needs. They may also be able to leverage the Florida experience to achieve a change in federal laws and regulations governing ASR, mirroring Florida law. Either ASR can be removed from the federal UIC program or the program can be amended to encourage beneficial injection well practices, such as Aquifer Storage Recovery.

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